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Assessment of priority species in the Murray Darling Basin for the potential development of population models:

Final report for project MD1179

Charles R. Todd, David J. Sharley, John D. Koehn and Ivor Stuart.

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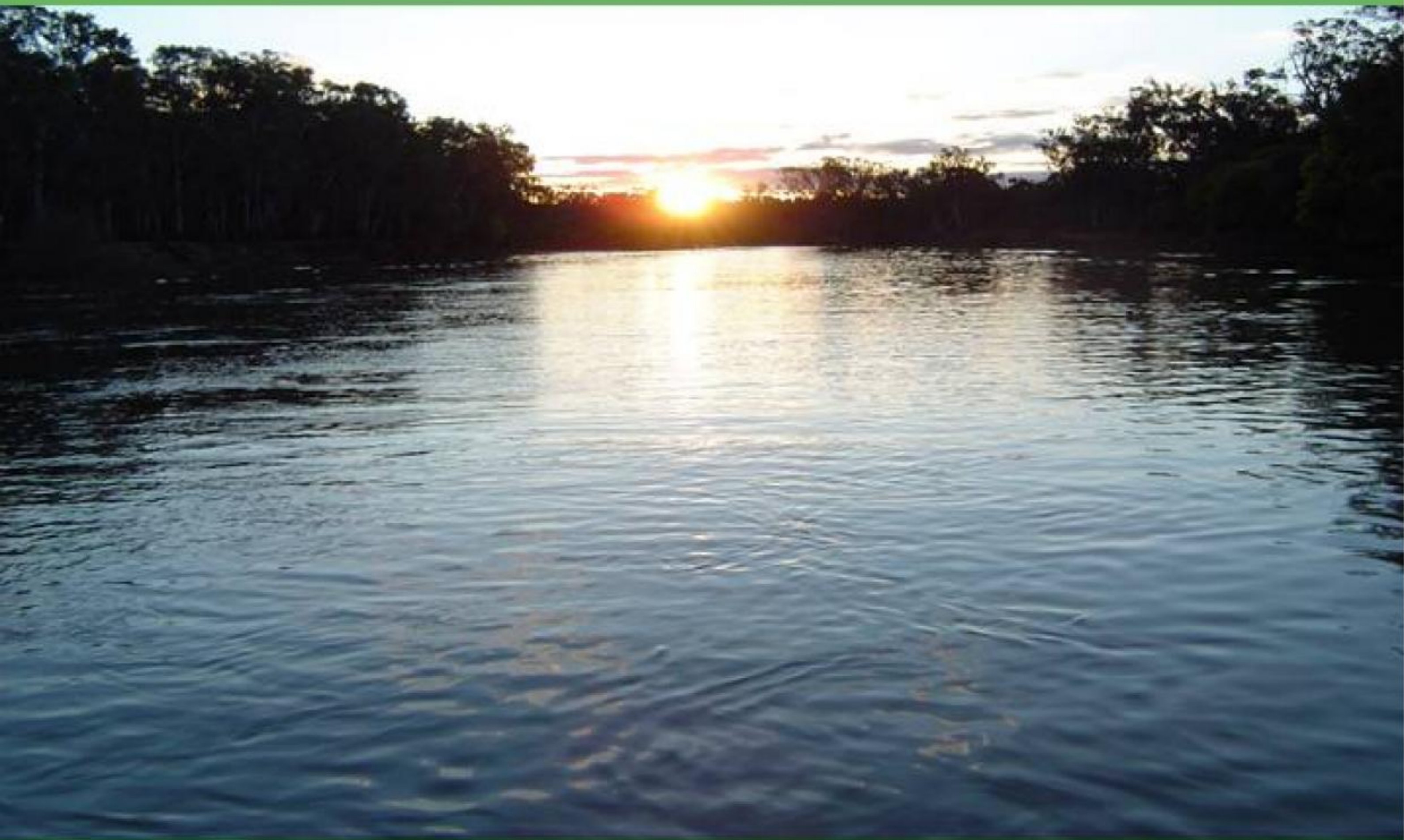

Arthur Rylah Institute for environmental research

State Government Victoria

Assessment of priority species in the MDB for the potential development of population models:

Final report for project MD1179

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Summary

Australia's native fishes have experienced severe contractions over the past 200 years with substantial changes to population structures and species diversity. Gaining greater insight into the population dynamics of native fishes is critical for species conservation over the longer term. The *Native Fish Strategy*, implemented by the Murray-Darling Basin Commission (MDBC) in 2004 provided a plan to rehabilitate native fish communities in the Murray-Darling basin back to 60% of their estimated pre-European settlement levels by 2054. To help achieve this, the Murray-Darling Basin Authority commissioned the development of a population model for Murray cod (Todd and Koehn 2009a), an iconic freshwater fish, to assess impacts of threats and recovery options. This project indicated that the adoption of appropriate management actions, such as changes to the size limits on angler-take could have a major impact on species persistence.

Mathematical models such as the Murray Cod Management Model (Todd and Koehn 2009a) play an important role in identifying underlying factors that may affect population structure and hence the persistence of the species. Population models can provide a tool to address gaps in understanding, whilst facilitating decision making in situations where there is inherent uncertainty. It follows that the development of robust models can also guide future investment and monitoring strategies that will underpin management and policy directions. This study examines whether a similar approach, to that adopted in the development of the Murray cod population model, could be applied to other species of interest in the Murray-Darling Basin. This "Assessment of priority species in the MDB for the potential development of population models (MD1179)" draws upon the need to understand more fully the role population models play in the development of conservation policy and management strategies in Australia, prior to instigating the development of models for other species.

A review of population models in natural resource management raised a number of concerns in relation to the ability to source appropriate information from the primary literature. Although the literature contains a number of peer-reviewed articles discussing the development of population models for addressing management issues or decision-making, it was more difficult to locate references that discussed how those models were being adopted. One reason for this could be the disconnection some environmental managers, policy makers and stakeholders have with the science literature and the peer-review process (see Koehn 2004a), often relying on scientists to inform through stakeholder reports and other media. Although important, limited opportunities exist for stakeholder inputs back into the science literature. This limitation is often due to time constraints and the reality that environmental management is multifaceted, leaving little scope to focus on any one system component. Sourcing information from the secondary or 'grey' literature, often the medium by which stakeholders disseminate their own findings was useful in obtaining some information on population model adoption. Some models were also possibly designed for a narrow stakeholder group, namely the scientists themselves, and were never intended for use

beyond answering a specific question. It could be argued that once such research was completed, the model was not used for any further purpose, and although it may have influenced external stakeholders decisions, it is at times unclear whether external stakeholders actually used the model or not. Alternatively, some models may not be user friendly or accessible to allow stakeholder use. To facilitate model adoption Todd and Koehn (2009b) developed a user manual for the software package Murray Cod Management Model (Todd 2009) to allow a broad range of use from a variety of stakeholders. In light of such assessments being open to interpretation, we decided that for a model to have been considered used by stakeholders, those stakeholders had to be different users to those who created the model.

The review did find important and instructive examples of where population models have integrated into management strategy and policy. The development of adaptive management strategies, particularly for fisheries, often exploits the utility of population models for the continual assessment of management actions. The adoption of mathematical models for decision-making and development of strategic responses to the contraction of native fish in the Murray Darling Basin is still developing and explored in more detail within the review. There are some examples where models have influenced management and policy development in freshwater research such as the trout cod model developed by Todd et al. (2004). Although the review found there was strong interest in the development of models, there needs to be a concerted effort from all interested parties to ensure models are used to influence policy and management outcomes and utilised by the intended stakeholders.

The review highlighted the benefits of a well-structured management plan that considers adaptive management approaches coupled with strategies that combine population models, evaluation procedures and continued exploration of outcomes over time. In order to ensure that population models do influence management and policy, it is recommended that models be integrated into natural resource management in a more formal manner, for example explicitly stated in species' recovery plans.

Management strategies need to be developed as structured learning environments, akin to an active adaptive management framework. Prior to implementing any management action, it is recommended that population models be used to assess potential outcomes of alternative management strategies. If the model represents the best knowledge available on the life cycle of a species, then the optimal management strategy assessed by the model should be the action adopted for implementation. Once a suitable management action (or multiple actions) is identified, the development and implementation of an effective monitoring program will permit continual adjustment of the model as new data is received. For this to happen, it is also essential that there be continuous communication between the developers of models and resource managers. Such an approach will ensure model uptake by stakeholders.

This study also surveyed a number of fish and fishery managers in the Murray-Darling Basin to establish a list of fish species of most concern. Twenty five species were recorded as of most concern and these were scored for priority. A further survey of scientists and managers was conducted to assess data availability that could be used in an age structured population model similar to that developed for Murray cod. Of the twenty five species reviewed, there was sufficient life cycle information, to construct an age population model and data that could be used to estimate the parameters required for an age structured model for eight species (in order of concern with rank number): silver perch (*Bidyanus bidyanus*) (1st); Macquarie perch (*Macquaria australasica*) (2nd); trout cod/bluenose cod (*Maccullochella macquariensis*) (4th); Murray hardyhead (*Craterocephalus fluviatilis*) (6th); golden perch (*Macquaria ambigua ambigua*) (7th); two-spined blackfish (*Gadopsis bispinosus*) (14th); carp (*Cyprinus carpio*) (17th); brown trout (*Salmo trutta*) (23th); and while no data was held in Australia for rainbow trout (*Oncorhynchus mykiss*) (12th), sufficient data is available in the international literature to estimate the required parameters for an age based population model.

Given the available information on the nine species listed above, it is recommended that population models be developed for these species. Additionally it is recommended, to identify optimal management actions (including the assessment of alternate management actions), to identify critical knowledge gaps, and to address key questions detailed in the species management strategies. As a priority, it is recommended that models be developed for the five species ranked in the top 10 of species of most concern (Table 2): silver perch (*Bidyanus bidyanus*) (ranked 1st); Macquarie perch (*Macquaria australasica*) (2nd); trout cod/bluenose cod (*Maccullochella macquariensis*) (4th); Murray hardyhead (*Craterocephalus fluviatilis*) (6th); and golden perch (*Macquaria ambigua ambigua*) (7th). It is also recommended that research be undertaken on the five other species of concern in the top 10, for which there is insufficient information to construct a model, to improve knowledge and/or data to the model development level and consider model development for these species: barred galaxias (*Galaxias fuscus*) (3rd); freshwater catfish (*Tandanus tandanus*) (5th); oriental weatherloach (*Misgurnus anguillicaudatus*) (8th); mountain galaxias (*Galaxias olidus*) (9th); and southern purple-spotted gudgeon (*Mogurnda adspersa*) (10th).

Project Brief

The Native Fish Strategy provides a response to the key threats to native fish populations in the Murray- Darling Basin. These include flow regulation; habitat degradation; lowered water quality; man made barriers to fish movement; the introduction of alien fish species; fisheries exploitation; the spread of diseases and translocation and stocking of fish. Native fish populations in the Basin's rivers have declined under these threats with experts estimating that current levels are about 10 per cent compared to pre-European settlement. The vision of the Native Fish Strategy is to ensure that the Basin sustains viable fish populations and communities throughout its rivers (MDBC 2004).

Management actions must be underpinned with good science to reduce uncertainties and increase the likelihood of success. In turn, research must be directed at answering key management questions if best use is to be made of limited knowledge and resources. Modelling is potentially an efficient way of formally articulating the interaction between management, the ecology of fish species and available data. Uncertainty in management, ecology and data can be included in the modelling process, thereby allowing the risk of particular management scenarios or ecological ignorance to be examined.

A recently completed project funded by the Commission (MD 745 "Murray cod modelling to address key management actions": Todd and Koehn 2009a) has developed a population model for Murray cod to assess impacts of threats and recovery actions. The development of similar models for other fish species in the Murray-Darling Basin would greatly assist in the formulation of appropriate management actions for these species, as well as highlighting key data deficiencies and hence strategic direction of future research.

Before investing significantly in development of population models for other fishes in the Basin there is a need to review models developed for Australian freshwater fishes, and assess the degree to which they have been adopted to inform decision making by managers and to guide data collection and research directions. This process will help maximise the value of subsequent investment, through refining project outputs, and developing appropriate extension channels.

There is also a need to assess the quality and accessibility of data to be used in model development. Ideally the\is scoping study will concentrate on high social and/or conservation value species such as Golden perch, Silver perch, Eel-tailed catfish and Macquarie perch and widespread alien species such as Redfin perch, however the final list of species will be driven by data availability and it is expected that at least six species for which sufficient data are available to develop Basin-wide models be recommended.

1 Introduction

A number of native species in the Murray Darling Basin are considered iconic. One example is Murray cod with an MDBC workshop (MDBC, 3-4 June 2004) being dedicated to the management of this species (Lintermans and Phillips 2005). Native fish populations have declined substantially and several species are now listed under the Environment Protection and Biodiversity Conservation Act 1999 and under state legislation (Lintermans 2007). The reasons for decline include: flow regulation; habitat degradation; lowered water quality; man-made barriers to fish movement; the introduction of alien fish species; fisheries exploitation; the spread of diseases; translocation; and stocking of fish. Some fish species sustain important inland recreational fisheries, both native (e.g. golden perch) and alien species (e.g. redfin). Additionally, a number of protected species are prone to recreational fishing regardless of whether they are the target species or not, e.g. the protected species trout cod in waters that also contain Murray cod and golden perch. Therefore the management of the species of interest requires a balance between actions for a threatened species (i.e. rehabilitate populations) and those to sustain a recreational fishery. This may include circumstances where the species is not the focus of the recreational fishery or the threat occurs from other activities such as water extraction.

In the population model developed for Murray cod (MD 745 "Murray cod modelling to address key management actions": Todd and Koehn 2009a) to examine impacts of threats and recovery actions, the life cycle of Murray cod was used to inform the model development. In order to manage the variety of threatening processes confronting native species it is important to understand the impact that these threatening process have on the life cycle of the species of interest. In general, individual organisms are born, grow, mature, reproduce and ultimately die. The likelihood that any one of these events occurs depends upon the environment that the individual inhabits and the evolutionary adaptation of the individual to its environment. Life cycle analysis of a species translates the individual to the population level (Saila et al. 1991, Caswell 2001). As well, these likelihoods determine the rates of birth, growth, maturation, fertility and mortality, which are collectively described as the vital rates. The dynamics of a population are determined by the vital rates. Population models provide a quantitative link between the individual and the population, built around a simple description of the life cycle.

Some of the information about Murray-Darling species life cycle vital rates has been documented in the literature (for example Koehn and O'Connor 1990), other information such as mortality or survival can be estimated from age frequency data, and age frequency data can be obtained from ageing otoliths.

This study will provide the context for developing population models to assess freshwater fish management actions in the Murray-Darling Basin and provide detail on the role of population modelling within the field of natural resource management. This study will also provide a general overview of the data requirements for a number of species of concern within the Murray-Darling Basin.

2 Methodology

As part of this project, a literature review of population models in Australia and overseas over the last 10 years was undertaken to assess the degree to which populations models developed for Australian freshwater fishes have been adopted to inform decision making by managers or guide data collection and research directions. To focus the review on model adoption, four questions were asked:

1. Does the model have a management/policy focus (i.e. did the model address a management policy question or need)?
2. Did the model meet the purpose for which it was designed (i.e. did the model answer the question)?
3. Did the model influence management/policy?
4. Was the model used by the intended stakeholders (i.e. for whom it was designed for)?

A survey was undertaken of fish and fishery managers to identify species of interest. A further survey of managers and researchers provided information on data availability for these species. For each species of interest, a life cycle model was developed to help identify the data required to develop a population model. This process, in conjunction with the information gathered from mangers and researchers and information already available in the literature, identified key knowledge gaps to help guide future research and data acquisition for developing a deeper understanding of population dynamics.

Population models are a valuable tool for addressing gaps in biological understanding, whilst facilitating decision making under uncertainty and guiding future investment in knowledge acquisition and allowing the development of an understanding of the species' population dynamics. Additionally, population models allow the influence of management actions and the impact of threatening processes to be examined. In order to establish whether population models can be developed, it is necessary to develop conceptual life cycle (or ecological) models for each species and then determine the availability of data to quantify the relationships in the models. Such models take into account the needs and locations of different life stages, movement patterns and potential differences that may occur across the species' geographic range. Once this is completed, a more formal mathematical representation as well as the inclusion of threatening processes and management actions can be developed.

3 Literature review

In 2004, the Murray-Darling Basin Commission (MDBC) released The *Native Fish Strategy* (MDBC 2004) in response to the effect of threatening processes on native fish populations in the Murray-Darling basin. Key threatening processes include flow regulation (Gehrke and Harris 2001, Bunn and Arthington 2002), habitat degradation (Nicol et al. 2002; Howson et al. 2009, Rayner et al. 2009), water quality (CSIRO 1992, Koehn 2005), barriers (Saddlier and O'Connor 2005), alien species (Koehn 2004b) and over-exploitation (Rowland 1989). According to expert opinion, since European settlement, native fish populations within the Murray-Darling Basin have declined to around 10% of original levels in response to these key threats (MDBC 2004). The goal of the *Native Fish Strategy* is to rehabilitate native fish communities in the Basin back to 60 per cent of their estimated pre-European settlement levels after 50 years of implementation. For this to occur, a fuller understanding of how these key threatening processes effect native fish needs is imperative. Equally important is the next step: taking the outcomes of research projects and programs and formulating adaptive management strategies as outlined below. Gaining greater insight into the population dynamics of native fish is critical if these species are to be conserved and populations recovered over the longer term.

Adaptive management (AM) (Holling 1978, Walters 1986, Walters 1987), is a structured, iterative process of optimal decision making in the face of uncertainty, which aims to reduce uncertainty over time. There are two distinct forms of AM; passive and active (Walters 1986). Passive adaptive management begins by using predictive modelling based on present knowledge to inform management decisions. Best practice is usually assumed and as new knowledge is gained, the models are updated and management decisions adapted accordingly. Active adaptive management can best be described as the implementation of two or more experimental approaches to see which one will best meet management objectives. When attempting to adopt adaptive management strategies for species conservation and management of key threats, it is often necessary to predict and model the ecological responses of species. There are however, many ecological, biological and physical drivers that need to be considered, and amongst all these drivers, one common element emerges, that of prevailing uncertainty (Clark 2002). As uncertainty increases, decision-making becomes more difficult. Coupled with species variability, it becomes essential that any AM tool developed is able to minimise this inherent uncertainty. For example, in fisheries, unpredictable environmental fluctuations are a major problem, and are greatest in the form of temporal variations in population structure and species cohorts through over-exploitation and random fluctuations. To mitigate this uncertainty, fisheries have used harvest refugia to shield a proportion of exploited populations through the establishment of marine reserves (Botsford et al. 1997), effectively reducing the uncertainty surrounding harvest rates, as a proportion of the population would remain intact (Clark 1996). Marine reserves also allowed the possibility of testing responses to experimental harvesting and the development of active adaptive management approaches to fisheries issues (Ludwig et al. 1993, Grafton and Kompas 2004). One approach to adopting an adaptive management strategy for the conservation of threatened and rare species is the development of population models for the organism(s) of interest.

This study builds on a previous review of approaches for testing alternate management options that was undertaken by Todd and Koehn (2009a), which stated that population modelling can be a valuable tool in species conservation or invasive species control when detailed information is lacking and attaining such information may take years or decades (Christensen and Walters 2004). Appropriately constructed models explore the impacts of disturbance or change to a species life cycle such as migratory behaviour (Jager 2006a, b), growth rate (Bearlin et al. 2002), environmental variability (Brown and Walker 2004; Todd et al. 2004) or anthropogenic disturbance on population persistence. This information can be used to choose between management options when they are explicitly tested and can also indicate new management options not previously considered. In addition, sensitivity analysis can identify the life cycle stages critical for population persistence and can guide conservation actions which concentrate on these stages (Kareiva et al. 2000).

3.1 Utility of Population models

A fundamental goal of natural resource managers is the sustainable use of those resources. Management plans assist in identifying risks associated with a particular issue or problem and provide strategies to mitigate those risks. For example, the Murray-Darling Basin Plan is a single consistent and integrated approach to managing the water resources of the Murray–Darling Basin (MDB). One of the central objectives of the Basin Plan is the sustainable management of the Basin's water resources in a way that promotes the objects of the Water Act 2007. A requirement of the Water Act 2007 stipulates that any assessment of environmental water needs must encompass key environmental assets, including the water dependant ecosystem and sites with important ecosystem services and functions. The Basin plan recognises this and has identified an objective set of 18 indicator assets designed to protect the Basin's natural resource base. The fish fauna of the MDB form an important component of the Basin's ecology, and will be one of the key indicators measured, and the one by which the public will judge the success of the Basin plan. The specific water requirements of fish in the MDB remains uncertain, therefore, it is important to be able to predict, then measure the outcomes of environmental water allocations (EWAs) on the Basin's fish populations over time. Population processes such as survival, reproduction, migration and dispersal are of critical importance to the maintenance of fish populations and ecosystem. These processes are important components of individual species population models, and the use of such models is one of the few ways that outcomes from watering events can be predicted and then tested through the collection of data. For example, individual-based and spatially explicit models have been used to evaluate the effects of water releases on Chinook salmon (Jager et al. 1997) and brown and rainbow trout (Van Winkle et al. 1998). By linking individual population models to hydraulic and habitat models, both these studies were able to give water managers an instrument to assess and evaluate the effects of instream flows. Fish population models, such as the models above, provide a key tool to guide proof of concept assessment for the evaluation of fish responses to EWA's.

In addition to managing EWA's, there are a suite of key threats to native fish populations that would benefit from the use of predictive models; such as the management of habitat loss and degradation, pollution, barriers to fish passage, flow regulation, cold water releases, fishing and the introduction of alien species such as carp. There is abundant evidence to suggest that each of the aforementioned impacts can independently increase the risk of extinction faced by freshwater fishes (Dudgeon et al. 2006). In addition to single threats, the risk of extinction is further increased when these threats interact with each other (Omerod et al. 2010), and in particular Cottingham et al. (2001) states that reductions in native fish populations result from the interactions between inadequate flows, poor water quality, poor habitat and predation. Indeed, the development of population models that are able to incorporate multiple threatening processes will lead to more informed evaluation strategies and help manage risk and ecological outcomes. The Murray cod for example, is a threatened species which needs immediate management actions in order to rehabilitate populations. Like many other fish species it is subject to habitat changes and multiple other threats such as angling pressure. All of these impacts may increase the risk of population reductions or extinction and need to be monitored regularly so that appropriate changes to management actions can be quickly adapted if needed. The Murray Cod Management Model (Todd 2009), was developed to form the basis for the assessment and prioritisation of management options for Murray cod to minimise the risk to populations. By highlighting data gaps and monitoring requirements, once operational, it will become an integral part of the conservation and fishery management process and will provide a tool for exploring the outcomes of management scenarios at both the regional and local scale.

When information on a species of interest is lacking, or attaining such information is prohibitive, population modelling can be a robust and cost-effective tool in evaluating management strategies before they are implemented, as well as defining monitoring objectives (Christensen and Walters 2004). To understand how the development of a workable ecological model can influence the management of some ecological process, it is important to understand that a mathematical model is neither a hypothesis nor a theory. It is a tool to formalise ecological processes and provide a framework for generating testable hypotheses relevant to the problem or an issue being investigated under different scenarios (Hilborn and Mangel 1997). For instance, (Todd et al. 2008) showed that the construction of a simulation model of the dynamic interaction between koala populations and their food supply (Manna Gums: *Eucalyptus viminalis*), allowed managers to fully explore the cost of imposing alternative management strategies. This enabled management to proceed with a course of action, in this case hormone implants to reduce koala numbers, and reduce the risk of population collapse while returning the forest to good health. It was able to identify important time-lags between implementing fertility control, reducing the abundance of a herbivore with high survival rates and subsequent changes in the abundance of its food supply.

3.2 Population processes

3.2.1 Life-cycle

Population models are dependent on knowing something about the life cycle of the species under investigation. Individual organisms are born, grow, mature, reproduce and ultimately die. The likelihood that any one of these events occurs within a particular time period depends upon the environment that the individual inhabits and the evolutionary adaptation of the individual to its environment. Life cycle analysis descriptively translates the individual to the population level. The likelihoods that determine the population-level rates of birth, growth, maturation, fertility and mortality, are collectively described as the vital rates, and it is these vital rates that determine the dynamics of a population. Structured population models provide a quantitative link between the individual and the population, built around a simple description of the life cycle (Todd et al. 2004, Todd and Koehn 2009a). Using life cycle information, it is possible to construct models to explore the impacts of change to a species life cycle as well as the impacts of environmental perturbation on population persistence.

Models can investigate the impacts of disturbance or change to a species life cycle such as migratory behaviour (Jager 2006a), growth rate (Bearlin et al. 2002), environmental variability (Brown and Walker 2004, Todd et al. 2004) or anthropogenic disturbance on population persistence. For example, Sherman et al. (2007), used a stochastic fish population model coupled with a hydrodynamic model to examine the impacts of cold water pollution (CWP) on Murray cod downstream of Hume dam. The study showed that introducing selective withdrawal capabilities at Hume dam would reduce the risk to Murray cod populations downstream of the dam considerably, with substantial increases in the threshold population size under all spawning scenarios predicted if the impacts of CWP were mitigated. This study provides a rational basis for the assessment and prioritisation of remedial works to assist Murray cod and could be applied to other fish species.

Information generated from modelling population processes can be used to choose management options to be tested and can assist in the development of new management options not previously considered. In addition, sensitivity and perturbation analysis of population models can be useful in setting research priorities by highlighting those parameters that have the most influence on population growth rate (Burgman et al. 1993, Cariboni et al. 2007). For instance, Yearsley et al. (2003) showed how sensitivities helped set research priorities for the management of Short-tailed Shearwaters (*Puffinus tenuirostris*) on Fisher Island, in the Bass Strait, Australia under a density-dependent population model.

3.2.2 Density dependence

Population processes such as survival, growth, reproduction, and movement may be density dependent if their rates change as a function of population abundance. Lower survival, slower growth, and increased emigration are examples of processes that limit population growth at high abundances, whereas higher survival, faster growth, and increased immigration are examples of processes that may increase population growth when population abundance is low. Both are examples of direct density dependence, or compensation, and tend to stabilise population abundance. If processes such as survival and growth decrease at low population abundances or increase at high abundances are examples of depensation. This usually has a destabilising effect on, population abundance. Competition for resources is an important process that can drive density dependence in populations caused by the limited availability of a necessary commodity, usually a resource, or space (habitat or niche). When a new source of mortality or a change in the mortality rate occurs in a population, the population may respond by offsetting the change in mortality through compensation or depensation (Guckenheimer et al. 1976). Anthropogenic disturbance can initiate a density dependent response in a population. For example, entrainment of fish populations through the diversion of water for irrigation or power plant cooling, often remove large numbers of young fish from a population (Lorda et al 2000). The issue of entrainment at power plants and the role compensation plays in maintaining fish populations has received particular attention (Van Winkle 2000). Rose and Cowen Jnr (2000) showed that incorporating site-specific information and life-history theory into an individual-based modelling approach is critical in understanding the population dynamics of fish when they are entrained. By focusing on the effects of power plant cooling systems on fish populations, their study showed that individual-based modelling can assist in understanding the role compensation plays in maintaining fish populations under stress, and the need to incorporate site-specific conditions into regulations and guidelines. It was found that the models were also useful in determining the numbers of fish entrained that constitute an adverse environmental impact, thus directly influenced regulators decision making. Although power companies are obligated to minimise the risk of entrainment to aquatic life through various mitigation strategies, population dynamic models have often been applied to assess whether an action is warranted at specific sites. For example, Lorda et al (2000) used simulation modelling to assess the impact of entrainment and impingement of a cooling system at a power plant in the U.S. The study investigated the effects on winter flounder, with the model projecting annual population sizes resulting from different fishing rates, larval entrainment losses, impingement of juvenile and adult fish, and included a compensation function. The approach identified fishing mortality as the driving force in shaping the future size and viability of the local flounder population, and suggested that larval entrainment mitigation measures, costing hundreds of millions of dollars, would be ineffective in reversing currently declining trends of that population. These conclusions were later accepted by the state regulators which deemed that mitigation measures at this particular power plant were not warranted.

3.3 Conservation harvesting

The management of wildlife and species that come under pressure from harvesting requires knowledge of population size over long periods of time, life cycle and vital rates, habitat requirements, key threats and resilience to environmental variation and change

(Ramsey et al. 2010). To facilitate this knowledge, monitoring programmes are required to gather data over time that provides estimates of the species population parameters. However, it is often the case that species-specific information is lacking and managers and policy makers are reliant on simulated information. To specify models that can predict population responses to harvesting under uncontrolled environmental variation requires developing alternative models that can account for the uncertainty around these effects. In response to concerns raised by hunting organisations and community groups in regards to waterfowl hunting in Victoria, a sustainable harvest model was developed (Ramsey et al. 2010). It aimed to place the decision-making process used to manage duck harvesting in Victoria on an objective scientific basis, allowing managers to make informed decisions in regards to hunting management. It is anticipated that the harvest model will reduce conflict between decision makers and other stakeholders, and provide assurance that harvest limits will not impinge on the sustainability of waterfowl populations in Victoria. Already the model has increased knowledge of the factors driving waterfowl dynamics, especially the link between wetland area and waterfowl sustainability, and determined the most appropriate monitoring regime to successfully manage waterfowl populations over the longer term.

Models can also assist in determining harvesting quotas and limits for practically any harvestable commodity. For instance, Freckleton et al. (2003) used a structured population model to investigate the impacts of harvesting on the tropical palm *Euterpe edulis* Mart. By incorporating density dependence and timing of harvesting into the model, the authors showed that the form and intensity of harvesting was important to the sustainability of *E. edulis* populations. Investigating the timing of harvest in relation to the point in the life cycle at which populations were censused, it was shown that the threshold level (minimum number of seed trees for the maintenance of the population) is sensitive to harvesting that affects individuals growing from pre-reproductive to reproductive size classes. Thus, much larger thresholds are required than if harvesting affects only mature plants. Moreover, thresholds required to maintain population persistence will be much lower than thresholds that maximize yields. Information attained through this study reaffirmed that high intensities of harvesting at frequent intervals are sustainable if a threshold level for harvesting is implemented, as stipulated in the *E. edulis* sustainable management programme (Reis et al. 2000).

3.4 Fisheries

3.4.1 Single-species models

Marine fisheries have long history of developing trophic and population models to find solutions to the problem of over-exploitation and commercial sustainability (Quinn II 2003). The utilisation of population models to set planning direction or management objectives is best illustrated in fisheries management. In particular, this occurs through models that are designed to investigate the consequences of alternative fishery policy. For example, the development of standard reference points have been used by many countries to determine allowable harvests (Caddy and Mahon 1995), and have in effect become the *de facto* management procedure in the United States and Canada. Reference points provide the primary mechanism for applying the 'precautionary approach' to fisheries management (FAO 1995), and are computed from mathematical models that relate the observed data to the assumed population dynamics (Richards and Maguire 1998). The models used to determine reference points are species-specific and vary according to the fishery in question. For example, to determine the optimal harvest rates and escapement goals for Coho salmon (*Oncorhynchus kisutch*), (Bradford et al. 2000) used a piecewise linear (hockey stick) model to devise provisional reference points for the management of coho salmon aggregates. Whereas, Schueller and Hansen (2008) used a stochastic age-structure model to determine reference points and sustainability of walleye (*Sander vitreus*) fisheries in north Wisconsin. Uncertainty surrounding the model was evaluated using local sensitivity analysis, with results indicating that the current management would maintain self-sustaining walleye populations. By building simple population models to simulate the effects of overfishing and exploitation of species, allows decision makers, managers and industry the opportunity to provide management solutions to problems before they are exasperated. As an example, up until the late 1900s the eel industry in New Zealand was always considered sustainable, however, Hoyle and Jellyman (2002), showed that *Anguilla dieffenbachii* was under considerable threat of over-fishing. Their model predicted that continued fishing of adult *A. dieffenbachii* would eventually lead to populations that were unsustainable and that a portion of the stock must be protected through the use of no-take reserves. The utilisation of population models for eel management has the marked advantage of being able to work at the long time scales required to assess the success of changing eel management. Recent management developments have included the use of no-take reserves for the protection of *A. dieffenbachii*, although it is predicted that this alone will not prevent populations of *A. dieffenbachii* falling below sustainable levels (Jellyman 2007).

3.4.2 Ecosystem approaches

The incorporation of population models and ecosystem models provides an opportunity to investigate the trophic interactions that exist within a system. Ecopath and Ecosim software packages, which use mass-balance and food-web models to quantify the impact of ecosystems on fisheries, have made a major contribution to fisheries management and policy across the world (Pauly et al. 2000). To date, there are over 7800 users of the 'Ecopath with Ecosim' software from over 170 countries, and it continues to be used in fishery management plans. For instance, the development of the Chesapeake Bay fishery management plan in the United Sates used a dynamic mass balance model (Ecopath) to quantify trophic relationships at all levels of the ecosystem (Giordano 2005). The incorporation of an 'optimal policy search module' within EcoSim (Christensen and Walters 2004), allows different policy and management objectives to be analysed, resulting in positive policy outcomes and management of marine ecosystems world-wide (Usumaila 2007). Although, Christensen and Walters (2004) warn that Ecosim can produce misleading predictions of the impacts of policy proposals, primarily due to the result of bad estimates or lack of information pertaining to predator-prey relationships, thus it is essential that caution should be considered before applying Ecosim predictions in driving policy reform. These models were evaluated for their applicability to Murray cod (*Maccullochella peelii*) in Australia, but were found to be too difficult to implement due to the lack of supporting ecological data (Todd and Koehn 2009a). Assessing the impact of management scenarios on multi-species and multi-fleet fisheries requires spatially and seasonally explicit simulation tools. To evaluate the impact of management measures on the dynamics of a complex fishery Mahevas and Pettellier (2004) developed Spatial Information and Simulation of FISHeries management (ISIS-Fish), a simulation tool based on a spatially explicit model of fisheries dynamics, aimed at evaluating the impact of a variety of policies on the dynamics of a mixed fishery. As the primary goal of ISIS-Fish is to evaluate and compare the consequences of policy strategies, particular attention is paid to policy parameterization, so that a wide range of policies may be considered, from conventional options like catch quotas (TAC), direct effort, control (licences, trip limitations) and gear restrictions to marine protected areas assessment. For a comprehensive review of the utility of ISIS-Fish in setting management and policy agendas see (Pelletier and Mahevas 2005).

3.4.3 GIS and Habitat Modelling

Coupling population models into Global Information System (GIS) and habitat models, permits spatially explicit species information to be gathered. Spatially explicit models allow for the interaction of ecological processes through space, including species specific variables. As spatially explicit models are geographically referenced, they can be linked to Geographical Information Systems (GIS). Understanding the dispersal ability of species and how those species respond to constantly changing habitats and environments is crucial for NRM. For instance, this approach has been used to assess the spread of invasive species (Feehan et al. 2005, Brown and Waker 2004), determine the effects of altered fire regimes and climate change on fire dependent species (Lawson et al. 2010) and assess the effectiveness of translocations as a conservation strategy for endangered species (Akçakaya 2001). Akçakaya et al. (1995) linked landscape data using GIS and a metapopulation model for the Helmeted Honeyeater *Lichenoistomus melanops cassidix*, culminating in an extinction risk assessment and analysis of translocation strategies. In 2008, the helmeted Honeyeater species recovery team initiated a program of bi-annual population simulations to predict the impact of a range of management scenarios (Menkhorst 2008), stating that without a specific program for applying modelling tools, their value is unlikely to be fully realised. This is especially true for the European carp *Cyprinus carpio* L., an invasive pest species that has been implicated in degradation of Australian aquatic ecosystems (Koehn et al. 2000). It has been recognised that the development of CARPSIM, an age-based model to simulate the effects of a range of management scenarios (Brown and Walker 2004) has been important for selection of control measures most likely to succeed in different parts of the catchment (www.invasiveanimals.com/research/goals/goal-4/4f11/). The model predicts that faster growing populations may be better controlled through forced shifts that induce male-dominance, while slower growing populations may respond better to removal type approaches (Brown and Walker 2004).

This approach can also be utilised in predicting the effects of climate change on fisheries management. Linking changes to environmental conditions to productivity allows assessment of alternative management strategies. Estuarine fisheries are particularly susceptible to anthropogenic induced climate change, with one of the main concerns being the effect of changes to river discharges and water resources. Ives et al. (2009) developed a simulation model to analyse the dynamics of Australian prawn fishery for 10 years under alternative river discharge scenarios, and examined the effectiveness of a series of management strategies. The model indicated that both growth and movement of prawns were affected by the rates of river discharge, with lower discharges generally reducing prawn abundance, suggesting that drought or increased water extraction could impact upon prawn sustainability. The study concluded that there was little reason to change from the current management strategy, even under a wide range of river discharge scenarios, giving confidence in the current estuary prawn trawl management strategy (NSWF 2003).

3.5 Conservation modelling

Unlike, fisheries, where the focus is on maintaining self-sustaining populations for anthropogenic reasons such as commercial or recreational harvesting, species conservation is more concerned with how anthropogenic and natural disturbance may influence species viability. A popular method for assessing species resilience over time is population viability analysis (PVA) (Boyce 1992), and has been used to simulate future viability of numerous species under different management regimes, including white sturgeon (Jager 2006a, 2006b), the giant panda (Wei et al. 1997; Zhou and Pan 1997), Chinook Salmon (Richard et al. 2006), trout cod (Todd et al. 2004), Murray cod (Todd and Koehn 2009a) and the mountain pygmy-possum (McCarthy and Broome 2000). PVA predicts species persistence, and is closely related to minimum viable population (MVP) analysis (Shaffer 1981). When sufficient biological data is available to build quantitative population models, PVA is reasonably accurate in assessing a species vulnerability to threats (Brook et al. 2000). Species recovery plans[*] would therefore seem an obvious conduit for applying PVA. It has been argued that PVA may not be appropriate for all recovery plans and indeed superfluous for critically endangered species due to the inherent lack of data, and the need to take immediate action (Morris et al. 2002). Nevertheless, for critically endangered species for which there is sufficient data, PVA can indicate how urgently recovery efforts may be needed, act as a mechanism for data synthesis and identify critical life stages for management action (Morris et al. 2002). There are some good examples of where species recovery plans have integrated population models and (PVA) into management strategies, including the Southern emu-wren (*Stipiturus malachurus intermedius*) (Littlely and Cutten 1996), the Southern corroboree frog (*Pseudophryne corroboree*) (Anon 2001), the Victorian rock lobster (*Jasus*

[*] Species recovery plans set out the research and management actions necessary to stop the decline of, and support the recovery of, listed threatened species or threatened ecological communities. The aim of a recovery plan is to maximise the long term survival in the wild of a threatened species or ecological community.

edwardsii) (Hobday and Punt 2001; DPI 2009), the Baw Baw frog (*Philoria frosti*) (Hollis 1997), and multi-species plans such as that for Australian marine turtles (Environment Australia 2003).

One particular example, that of the trout cod, highlights the value of integrating population models into species recovery programs. In this example, (largely undocumented) the integration of information from the stochastic population model developed by (Todd et al. 2004), played a valuable role in the implementation of the national recovery program for the trout cod (Trout Cod Recovery Team 2008). In particular, it was used to assess the viability of the only truly natural population in the Murray River system and whether additional protective measures were needed for this population. The model was used to evaluate stocking strategies, providing insight into site selection and stocking rates and predicted probabilities for population establishment. A key finding from the trout cod model was the strategy of on-growing fish to 1 year old before reintroduction. Trials are currently underway in the Ovens River to assess the efficacy of this approach (Trout Cod Recovery Team 2008). Given the model also identified anthropogenic disturbance as a key factor regulating viable trout cod populations, this information was used to identify and prioritise new stocking sites, leading to success in establishing viable populations of trout cod in the Goulburn and Ovens Rivers. Although not well documented, it is understood that authorities responsible for the continuation of trout cod conservation restocking programs are now utilising information from the model in determining the optimal approach to the reintroduction of trout cod populations and for the establishment of long-term monitoring programs. The model continues to be used as a tool to assist the management of these populations. Although this population model was mainly used by the National Recovery team and conservation agency staff, its 'ownership' by wider interest groups (e.g. Fisheries Victoria and Native Fish Australia), provided confidence in the modelled outcomes.

The spotted tree frog *Litoria spenceri* was recognised as a critically endangered species of frog in 1996 in a report to the spotted tree frog recovery team (Robertson and Gillespie 1996). As part of the recovery plan (Robertson and Gillespie 1998), numerous objectives were proposed to ensure viability of the 13 known remaining populations, including regular monitoring and integration of PVA modelling to form the basis of the recovery plan. The model used known life cycle and demographic data that indicated that the level of recruitment from the larval phase was a particularly important determinant of population size and probability of extinction. The model assisted in the identification of threats and suggested measures for threat amelioration, including focussing on survivorship of the larval stage to maximise outcomes (DSE 2004). In 2010, the national conservation status of *L. spenceri* was revised to endangered, and with populations remaining relatively stable since monitoring began in 1994 (Gillespie and Hines 1999), there is suggestion that threat abatement and recovery strategies could be having an influence on the survival of this species.

The species recovery plan for mountain pygmy possum (*Burramys parvus*) provides a further example of the importance of integrating population models into the management of endangered species. The greatest threat to the continued viability of the mountain pygmy possum is habitat loss and marginalisation, which is expected to increase with the predicted effects of climate change (Anon 2002). A population model was developed which provided greater understanding of the population dynamics of the mountain pygmy possum (McCarthy and Broome 2000). However due to the migratory behaviour of this species, a meta-population model (Hanski and Simberloff 1997) was proposed. This meta-population model was used to inform on relative influence of habitat quality and isolation on mountain pygmy possum persistence, assist in the prediction of climate change impacts, aid the design of monitoring programs, assess the impact of further development in key habitat areas, and measure the efficacy of potential management strategies to mitigate adverse impacts (Anon 2002). van der Ree et al (2009) used population viability analysis to assess the implementation of tunnels to mitigate the effects of roads on *B. parvus* populations. Analysis showed that the adoption of tunnels under roads in key habitat areas decreased, but did not completely remove the effects of roads, nevertheless increased the viability of *B. parvus* populations. They conclude that in assessing the effectiveness of mitigation measures, the extent to which the risk of extinction decreases should be adopted, and argue that that the use of population modelling become routine in these evaluations. In relation to a genetically isolated population of 350 *B. parvus* individuals at Mt Buller, which declined by 90% in the 10 years to 2006 due to habitat fragmentation, the authors argue that if population modelling had been used at the impact-assessment stage, the population decline may have been avoided.

We have shown that population modelling is important for many aspects of natural resource management and that once developed, single-species models can be adapted for many different situations. To be truly useful, models that can be incorporated into adaptive management frameworks and form part of a structured learning process will be effective in setting strategies that can be modified or adapted as new knowledge comes to hand.

3.6 Modelling for adaptive management of riverine species

Population modelling is a versatile tool for initial evaluation of NRM programs. By examining the different options that a strategy might adopt is a cost effective and robust approach. This allows managers to test and manipulate outcomes without actually implementing long-term and expensive programs. The active adaptive management approach is beginning to be recognised as an integral part of natural resource and water management strategies (Allan 2007). This is especially true for complex riverine ecosystems which are often integrated into larger more diverse ecosystems (Clark 2002), and particularly important in a conservation context. Freshwater aquatic ecosystems remain sensitive to changes in water regime (Bunn and Arthington 2002), habitat changes (Nicol et al. 2002), climate variation (Poff et al. 2002) and the effects of anthropogenic changes (CSIRO 1992). When species conservation management plans are designed and executed, it is important that these factors are taken into account. Models that reduce uncertainty and test different management scenarios become valuable tools in undertaking such management.

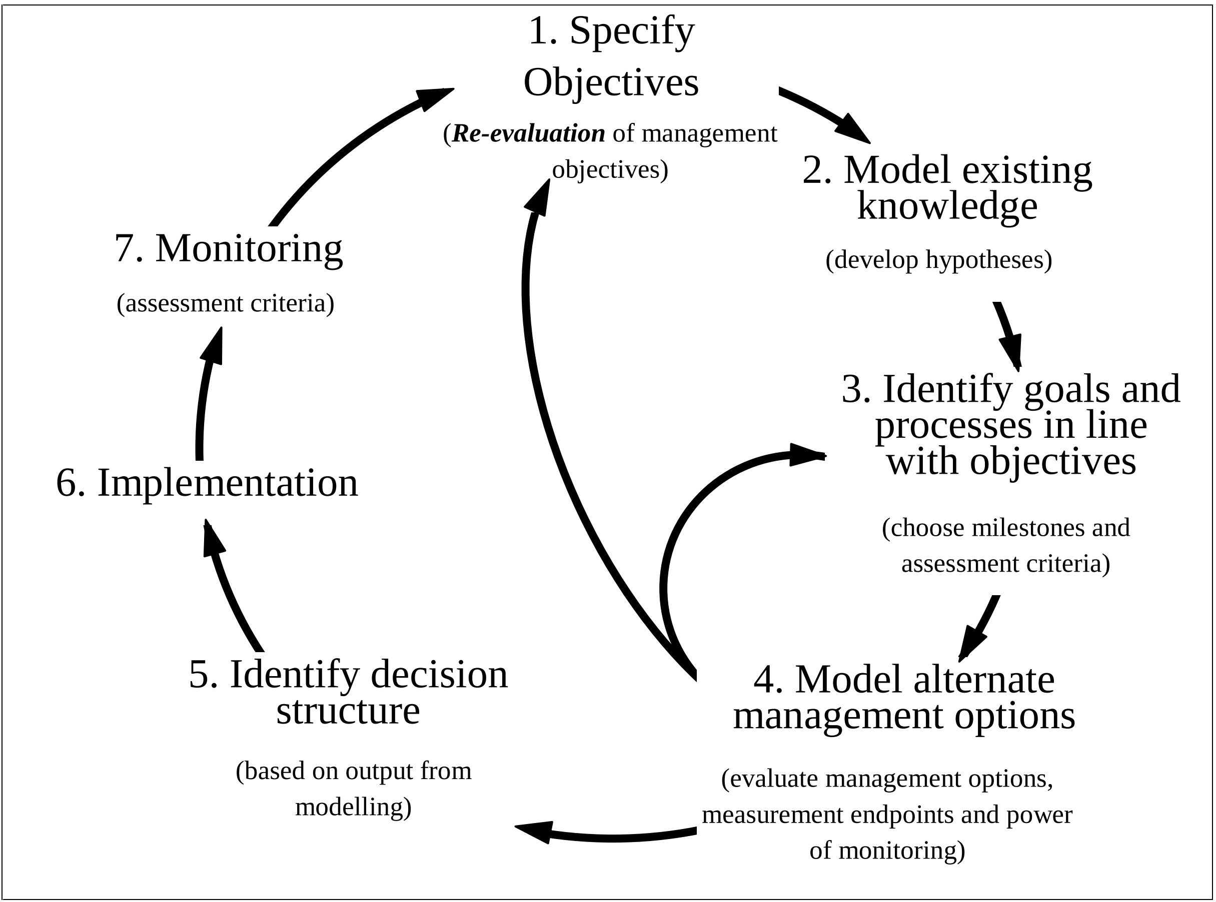

Figure 1. The adaptive management cycle highlights the integral role of modelling in the process of structured learning..

Managing threatened freshwater fish is challenging as many species are in serious decline due to a wide range of factors. Historically, a common management action has been the use of reintroductions through stocking hatchery produced fish into an area that was historically part of the species range but from which it has become extinct (IUCN 1996). In such situations, simulation modelling can be used to test different options to determine optimal reintroduction strategies. Bearlin et al. (2002) used a discrete time stochastic population model to simulate different stocking rates and alternative growth rates to predict the success of such reintroductions over time. They showed, for the endangered freshwater species trout cod (*Maccullochella macquariensis)*, the importance of simulating the whole adaptive management cycle when prioritising management actions, monitoring strategies and system states' that lead to management intervention. Management intervention can be a costly exercise and it is not always clear that the intervention was successful. Bearlin et al. (2002) also demonstrated the importance of finding the right metric or measure to assess the outcomes from management intervention to determine the success of management action. To assess reintroduction management practices, Bearlin et al. (2002) and Todd et al. (2004) presented examples of the value of using a stochastic population model to explore conservation strategies.

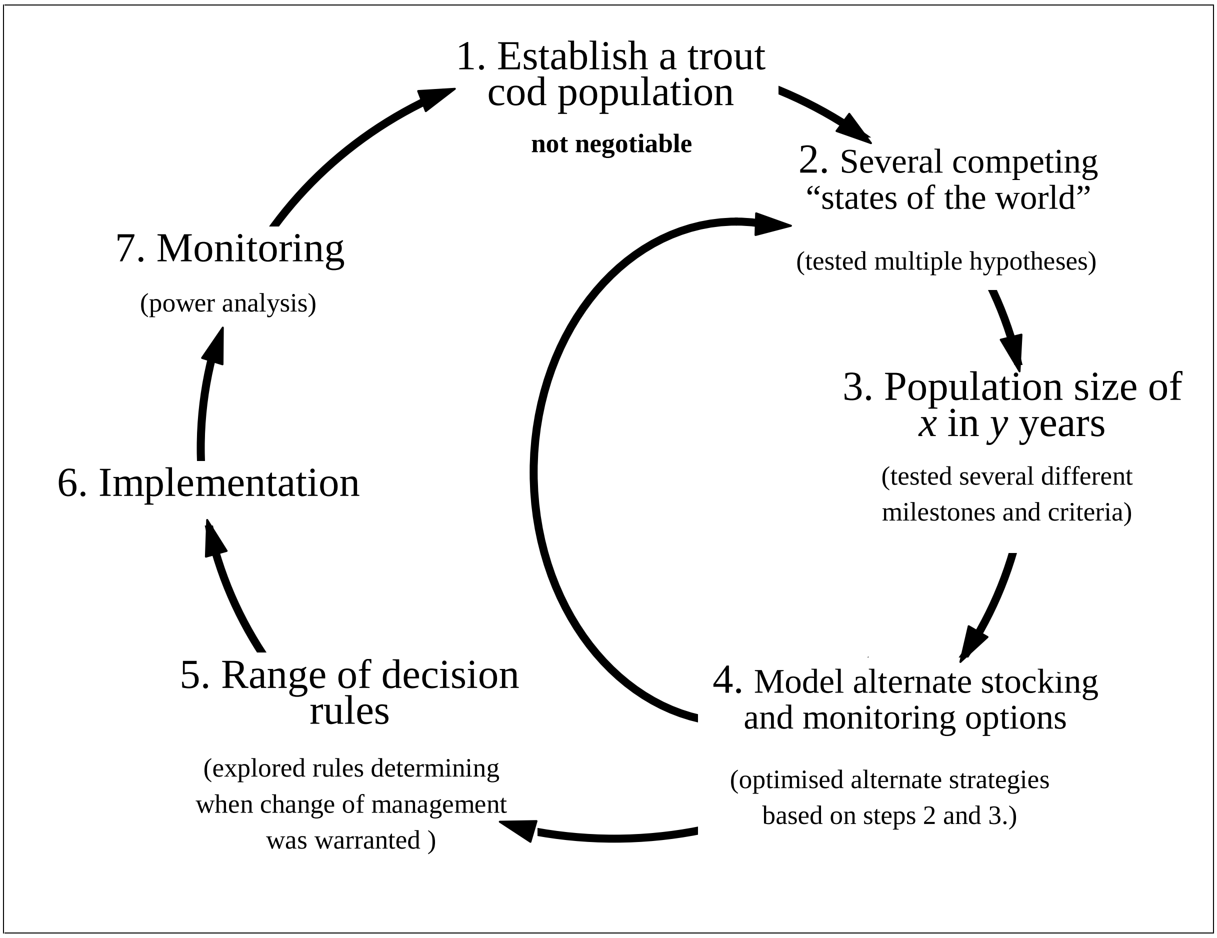

Figure 2. The adaptive management cycle modelled by Bearlin et al. (2002), again highlights the important role of modelling in the adaptive management process.

3.7 Adoption of mathematical models for natural resource management

This review set out to: assess the level of adoption of models developed for freshwater fish in Australia; assess the outputs of these models in regards to policy/management strategy; advise on approaches to maximise model adoption. As information on models relating to freshwater fish in Australia was scarce, the review was then broadened to terrestrial species in Australia. Again, as information on models relating to terrestrial species in Australia was also scarce, the review was then broadened to commercial fish species in Australia as well as looking at models and approaches adopted elsewhere in the international literature. To assist in the assessment of model adoption, four questions were devised:

1 Does the model have a management/policy focus (i.e. did the model address a management policy question or need)?

2 Did the model meet the purpose for which it was designed (i.e. did the model answer the question)?
3 Did the model influence management/policy?
4 Was the model used by the intended stakeholders (i.e. for whom it was designed for)?

The review revealed only 22 studies that met the first criteria (Table A2). Of these 22 studies 15 met criteria 2 with a further 3 partially fulfilling criteria 2; 10 studies met criteria 3 with a further study partially fulfilling criteria 3; and 7 studies met all four criteria (Table A2). Of the 4 studies on freshwater species only 1 study met all 4 criteria. Surprisingly few studies that report on model development have a strictly management or policy focus. This highlights the difficulty of undertaking the assessment on adoption as many published studies do not necessarily report on the management outcomes or policy assessment. Approximately half the studies reported a management influence or it is known that the studies influenced management. While the numbers are small this outcome does suggest that recommendations from the modelling process are being adopted.

The outcomes from reviewing published material raised a number of questions. Where do the results or information contained in those studies end up? How are they utilised? It is almost impossible to fully assess adoption of population models in NRM. This is primarily due to the lack of information in the literature pertaining to management decisions that were based on results stemming from models. Using species recovery plans of NSW as an example, of the 915 species actions statements in NSW, only 0.87% presented information on, or discussed the use of population modelling as a key requirement Table A1). A review of the role that PVA plays in recovery planning and management of rare species in the United States found 14% of 181 randomly selected recovery plans from 1991-1998 presented information on modelling, while a further 7% stated modelling information did not exist, and 25% of plans state that model information would be beneficial (Hoekstra et al. 2002; Morris et al. 2002). This suggests a number of things: either species managers are not aware of the usefulness of population modelling in setting management goals; monitoring and data collection; or simply modelling has been overlooked in recovery plan development. It is not in the scope of this review to tease out these questions, but to highlight the insufficient use of models in the management of endangered species. This should not be seen as a negative, but rather an opportunity to enhance population model utilisation in conservation strategy and policy setting.

The requirement for funding agencies and resource managers to justify their spending is greater than ever. As the cost of implementing NRM programs increases, so does the accountability. Where possible, the incorporation of population models into active adaptive management strategies makes justification of NRM programs more rigorous and defensible. Models provide a synthesis of available knowledge and understanding and help generate testable hypotheses for which experiments can be implemented to examine or produce further fundamental data. This process provides the clear context for the collection of information that links in to the management of the resource.

3.8 Policy settings with modelling as a guide

Environmental management is always complex and characterised by multiple and conflicting objectives, often involving numerous stakeholders with differing interests and ideas (Mitchell 1986; Cairns and Crawford 1991). Over the past few decades, there has been a substantial shift in how decision makers approach environmental management; from ad hoc, often disjointed approaches to a more integrated and 'whole of ecosystem' approach that considers the diversity of ecosystem constituents and functions (Margerum and Born 1995). For instance, the recognition of multiple co-occurring threats on fish populations that were once rarely considered when designing management strategies, has led to a greater understanding of impacts on population dynamics (Todd and Koehn 2009a). Conflict between recreational fishing and threatened species conservation requirements; coupled with problems associated with multiple stakeholder involvement, divergent interests and high levels of uncertainty surrounding resource dynamics can often stifle the on-going management of vulnerable and endangered species (Smith et al. 1999; Pressey et al. 2007). However, this is not always the case. For example, during the 1980s all five species of turtles in the USA were listed as endangered. In particular, conservation management of loggerhead turtles (*Caretta caretta*) had come under increased scrutiny. At the time, nearly all of the conservation efforts focused on a single life stage: eggs on the nesting-beach. However there was growing concern that incidental capture and drowning in shrimp trawls may account for a large proportion of loggerhead turtle deaths (Mager 1985). Using a stage-class matrix model, (Crouse et al. 1987) showed that for loggerhead turtles, the juvenile stage was the most important for maintaining population viability and that protecting this vulnerable stage would improve population persistence. Later studies by the National Research Council (NRC 1990) also affirmed findings by (Crouse et al. 1987) that the use of turtle excluder devices (TED) in shrimp fishing nets would significantly reduce juvenile mortality. It is now a requirement by law for all shrimp nets to be is equipped with (TEDs). This example highlights that, through model building, the importance of identifying life stages that are contributing most to population contraction, and how well designed studies can influence policy decision making across jurisdictions.

Understanding the impact of multiple threats on species is also complex. Murray cod face multiple threats and impacts, yet up until recently there was no formalised approach to Murray cod management, making it difficult to assess vulnerable populations. Recent development of the Murray cod modelling tool (Todd and Koehn 2009a) offers an example of how using an appropriate modelling approach can form the basis of a dynamic management strategy while presenting a system to assess and prioritise management options to minimise risk to populations. This approach utilised principles developed in management-strategy-evaluations (MSE), a process used in commercial fisheries to assess the consequences of a range of management options and trade-offs (Smith et al. 1999). MSE rely on simulation testing of management processes using performance measures derived from operational objectives (Sainsbury et al. 2000.), and deals explicitly with uncertainty through a process of identification and analysis of critical aspects of management. For the continual protection of endangered fish species in

Australia, it is essential integration of MSE and AM strategies occur before new goals are set and policies governing species management are applied.

Natural resource managers can learn a lot from fisheries approach to sustainable harvesting. It is generally well accepted that in fisheries management mathematical models play an important role in identifying underlying factors that may affect the population structure and even the survivorship of species (Hilborn and Mangel 1997). By applying a similar approach to conservation and natural resource management to that of fisheries, will in essence allow managers to collect baseline data, develop monitoring strategies and investigate alternative management options, before the implementation of economically and temporally expensive plans. Single-species population models, although non-accountable to some ecosystem effects, remain critical to the further development of complex ecosystem, GIS and spatially explicit models that NRM now requires. Knowing and understanding single-species requirements are also needed before multi-species models can be developed, thus opening up more options to managers and policy makers as they decide on the most appropriate management strategy. Although not reviewed here, it is possible that modelling the population dynamics and trophic requirements of keystone species such as the Murray Cod will ultimately encompass other species, allowing one or two models to predict large-scale ecological effects that ultimately affect a multitude of species. Thus, the integration of models into NRM is critical for accurate assessment of long-term management goals.

3.9 Recommendations

This review raises a number of concerns in relation to the ability to source appropriate information from the primary literature. Although the literature contains a number of peer-reviewed articles discussing the development of population models for addressing management issues or decision-making, it was more difficult to locate references that discussed how those models were being adopted. One reason for this could be the disconnection some environmental managers, policy makers and stakeholders have with the science literature and the peer-review process (see Koehn, 2004a), often relying on scientists to inform through stakeholder reports and other media. Although important, limited opportunities exist for stakeholder inputs back into the science literature. This limitation, mostly forced upon the end users of science is due to a number of reasons, but mainly time constraints and the reality that environmental management is multifaceted which often leaves no scope to focus on any one system component. Sourcing information from the secondary or 'grey' literature, often the medium by which stakeholders disseminate their own findings, was useful in obtaining some information on population model adoption. Another possibility is that the models were designed for a narrow stakeholder group, namely the scientists themselves, and were never intended for use beyond answering a specific question. It could be argued that once the research was completed, the model was not used for any further purpose, and although may have influenced external stakeholders decisions, it is at times unclear whether external stakeholders actually used the model or not. Alternatively, some models may not be user friendly or accessible to allow stakeholder use. To facilitate model adoption Todd and Koehn

(2009b) developed a user manual for the software package Murray Cod Management Model (Todd 2009) to allow a broad range of use from a variety of stakeholders. In light of the results being open to interpretation we decided that for a model used by stakeholders those stakeholders had to be different users to those who created the model.

The review did find important and instructive examples of where population models have integrated into management strategy and policy. The development of adaptive management strategies, particularly for fisheries, often exploits the utility of population models for the continual assessment of management actions. The adoption of mathematical models for decision-making and development of strategic responses to the contraction of native fish in the Murray Darling Basin is still developing and explored in more detail within the review. There are some examples where models have influenced management and policy development in freshwater research such as the trout cod model developed by Todd et al. (2004). Although the review found there was strong interest in the development of models, there needs to be a concerted effort from all interested parties to ensure models are used to influence policy and management outcomes and utilised by the intended stakeholders.

The review highlighted the benefits of a well-structured management plan that considers adaptive management approaches coupled with strategies that combine population models, evaluation procedures and continued exploration of outcomes over time. In order to ensure that population models do influence management and policy, it is recommended that models be integrated into natural resource management in a more formal manner, for example explicitly stated in species' recovery plans.

Management strategies need to be developed as structured learning environments, akin to an active adaptive management framework. Prior to implementing any management action, it is recommended that population models be used to assess potential outcomes of alternative management strategies. If the model represents the best knowledge available on the life cycle of a species, then the optimal management strategy assessed by the model should be the action adopted for implementation. Once a suitable management action (or multiple actions) is identified, the development and implementation of an effective monitoring program will permit continual adjustment of the model as new data is received. For this to happen, it is also essential that there be continuous communication between the developers of models and resource managers. Such an approach will ensure model uptake by stakeholders.

This scoping study demonstrates that the documentation of adoption of population models for natural resource management is currently inadequate, probably contributing to the lack of adoption of population models into management plans and policy frameworks. It is recommended that this be addressed through increased liaison between interested parties at all levels – researcher, recovery manager, decision maker and community with clear mandates put in place to guard against plans being developed in haste, with state and national guidelines employed to ensure effective adaptive management and management-strategy-evaluation.

4 Priority fish species and data availability

4.1 Species survey

As part of the objective to provide advice on at least six species for which models could be developed, it was planned to hold a workshop to achieve a consensus on species of interest from managers around the basin. However due to an inability to co-ordinate a satisfactory date to hold the workshop it was decided instead to individually survey the managers to elicit information on species of most interest to fisheries and fish conservation managers. The managers contacted were:

Peter Kind Queensland Fisheries
Peter Gallagher NSW Fisheries
Matt Beitzel Environment ACT
Kelly Crosthwaite PIRSA, SA
Travis Dowling Fisheries Victoria
Gary Backhouse DSE, Vic

Table 1 was sent to the above managers requesting them to respond with a 10 – 1 ranking where 10 was species of highest priority for model development.

Table 1. Species of the Murray-Darling Basin rank from 10 to 1, 10 being highest concern/interest

Family	Scientific name	Common name	Rank
Clupeidae	*Nematalosa erebi*	Bony herring	
Galaxiidae	*Galaxias fuscus*	Barred galaxias	
Galaxiidae	*Galaxias olidus*	Mountain galaxias	
Galaxiidae	*Galaxias rostratus*	Flat-headed galaxias	
Retropinnidae	*Retropinna semoni*	Australian smelt	
Plotosidae	*Porochilus rendahli*	Rendahl's tandan	
Plotosidae	*Neosilurus hyrtlii*	Hyrtl's tandan	
Plotosidae	*Tandanus tandanus*	Freshwater catfish	
Atherinidae	*Craterocephalus amniculus*	Darling River hardyhead	
Atherinidae	*Craterocephalus fluviatilis*	Murray hardyhead	
Atherinidae	*Craterocephalus stercusmuscarum fulvus*	Un-specked hardyhead	
Atherinidae	*Atherinosoma microstoma*	Small-mouthed hardyhead	
Melanotaeniidae	*Melanotaenia fluviatilis*	Murray-Darling rainbowfish	

Melanotaeniidae	*Melanotaenia splendida tatei*	Desert rainbowfish	
Ambassidae	*Ambassis agassizii*	Olive perchlet	
Percichthyidae	*Macquaria ambigua ambigua*	Golden perch	
Percichthyidae	*Macquaria australasica*	Macquarie perch	
Percichthyidae	*Macquaria colonorum*	Estuary perch	
Percichthyidae	*Maccullochella macquariensis*	Trout cod/Bluenose cod	
Terapontidae	*Bidyanus bidyanus*	Silver perch	
Terapontidae	*Leiopotherapon unicolor*	Spangled perch	
Nannopercidae	*Nannoperca australis*	Southern pygmy perch	
Nannopercidae	*Nannoperca obscura*	Yarra pygmy perch	
Gadopsidae	*Gadopsis bispinosus*	Two-spined blackfish	
Gadopsidae	*Gadopsis marmoratus*	Northern River blackfish	
Bovichtidae	*Pseudaphritis urvillii*	Congolli	
Eleotridae	*Philypnodon grandiceps*	Flat-headed gudgeon	
Eleotridae	*Philypnodon macrostomus*	Dwarf flat-headed gudgeon	
Eleotridae	*Mogurnda adspersa*	Southern purple-spotted gudgeon	
Eleotridae	*Hypseleotris klunzingeri*	Western carp gudgeon	
Gobiidae	*Pseudogobius olorum*	Western blue-spot goby	
Gobiidae	*Afurcagobius tamarensis*	Tamar goby	
Gobiidae	*Tasmanogobius lasti*	Lagoon goby	
Salmonidae	*Salmo trutta*	Brown trout	
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	
Cyprinidae	*Cyprinus carpio*	Carp	
Cyprinidae	*Carassius auratus*	Goldfish	
Cyprinidae	*Tinca tinca*	Tench	
Cyprinidae	*Rutilus rutilus*	Roach	
Cobitidae	*Misgurnus anguillicaudatus*	Oriental weatherloach	
Poecilidae	*Gambusia holbrooki*	Eastern gambusia	
Percidae	*Perca fluviatilis*	Redfin perch	

There were only five responses received from managers: Peter Kind; Peter Gallagher; Matt Beitzel; Gary Backhouse; and Anthony Forster (delegated by T. Dowling). Brenton Zampatti (SARDI) provided a South Australian perspective. The results are summarised in Table 2.

Table 2. Priority fish species of the Murray-Darling Basin for population model development as ranked from survey of managers

Rank	Family	Scientific name	Common name	Score
1	Terapontidae	*Bidyanus bidyanus*	Silver perch	32
2	Percichthyidae	*Macquaria australasica*	Macquarie perch	24
3	Galaxiidae	*Galaxias fuscus*	Barred galaxias	23
4	Percichthyidae	*Maccullochella macquariensis*	Trout cod/Bluenose cod	22
5	Plotosidae	*Tandanus tandanus*	Freshwater catfish	21
6	Atherinidae	*Craterocephalus fluviatilis*	Murray hardyhead	20
7	Percichthyidae	*Macquaria ambigua ambigua*	Golden perch	20
8	Cobitidae	*Misgurnus anguillicaudatus*	Oriental weatherloach	17
9	Galaxiidae	*Galaxias olidus*	Mountain galaxias	16
10	Eleotridae	*Mogurnda adspersa*	Southern purple-spotted gudgeon	15
11	Ambassidae	*Ambassis agassizii*	Olive perchlet	14
12	Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	13
13	Gadopsidae	*Gadopsis marmoratus*	Northern River blackfish	11
14	Gadopsidae	*Gadopsis bispinosus*	Two-spined blackfish	11
15	Melanotaeniidae	*Melanotaenia fluviatilis*	Murray-Darling rainbowfish	10
16	Galaxiidae	*Galaxias rostratus*	Flat-headed galaxias	9
17	Cyprinidae	*Cyprinus carpio*	Carp	8
18	Nannopercidae	*Nannoperca australis*	Southern pygmy perch	8
19	Percidae	*Perca fluviatilis*	Redfin perch	8
20	Atherinidae	*Craterocephalus stercusmuscarum fulvus*	Un-specked hardyhead	5
21	Gobiidae	*Pseudogobius olorum*	Western blue-spot goby	4
22	Plotosidae	*Neosilurus hyrtlii*	Hyrtl's tandan	3
23	Salmonidae	*Salmo trutta*	Brown trout	2
24	Poecilidae	*Gambusia holbrooki*	Eastern gambusia	2
25	Plotosidae	*Porochilus rendahli*	Rendahl's tandan	1

4.2 Data identification

A survey of researchers and managers in the Murray Darling basin was conducted to establish what data were available for the priority fish species identified in Table 2, the results are in Table A3 in the Appendix and summarised in Table 3.

Table 3. Summary of data held by researchers and managers across the MDB.

Species	Estimated no. otoliths	Basin Coverage	Otoliths to be cut
Golden perch	7000+	south, north, west, east	Yes
Murray cod	2500+	South, north	Yes
Congolli	500	Estuary/lower lakes	No
Carp	500+	Murray	Some
Silver perch	500+	Mid Murray, NSW dams	No
Redfin	500+	NSW dams	No
Macquarie perch	100+	Cataract Dam, Cotter R.	Yes
Bony herring*	300+	Mid Murray	Yes
Trout cod	100+	Ovens and mid Murray	No
Australian smelt	hundreds	South, north	No
Murray hardyhead	50+	Mildura area	Yes
Olive perchlet	<20	Lachlan River	No

*samples to be located

5 Life cycles and recommendations for fish species in the Murray Darling Basin

As stated previously, individual organisms are born, grow, mature, reproduce and ultimately die. The likelihood that any one of these events occurs within a particular time period depends upon the environment that the individual inhabits and the evolutionary adaptation of the individual to its environment. Life cycle analysis descriptively translates the individual to the population level. The likelihoods that determine the population-level rates of birth, growth, maturation, fertility and mortality, are collectively described as the vital rates, and it is these vital rates that determine the dynamics of a population. Structured population models provide a quantitative link between the individual and the population, built around a simple description of the life cycle.

The model developed for Murray cod, described in Todd and Koehn (2009a), adopted an age structure as the underlying structure for the model, and also included estimates of growth based on age so that length based harvesting rules could be applied. Stage structured models (i.e. models that only consider developmental stages such as juvenile and adults) do not lend themselves to easily including other aspects of a species life cycle that may be considered important when constructing a model for a set of specific questions. Age structure is the fundamental structure from which other aspects of the life cycle of a species can be added if required. The other advantage of an age structured model is that the intrinsic time step is one year. Although for some species with very short life spans, a shorter time step may be required.

The potential to develop a population model for each species in Table 2 was assessed. Firstly, the potential model structure was assessed, such as the age at sexual maturity and longevity. These life cycle characteristics allow a suitable structure for an age structured population model to be identified. Once a structure was identified, the available data was reviewed as to whether the analysis of the data would yield estimates of the vital rates required as parameters of the model. For example, female Murray cod mature at around 5 years old and known to live as long as 48 years. Todd and Koehn (2009a) describe the development of a 25 age class model in which estimates of survival for 25 ages and fecundity for 20 ages were provided. It is not the purpose of this study to estimate the necessary parameters for a given model structure, only to identify whether the data exists that would yield estimates of the appropriate parameters (survival and fecundity rates - vital rates) if analysed.

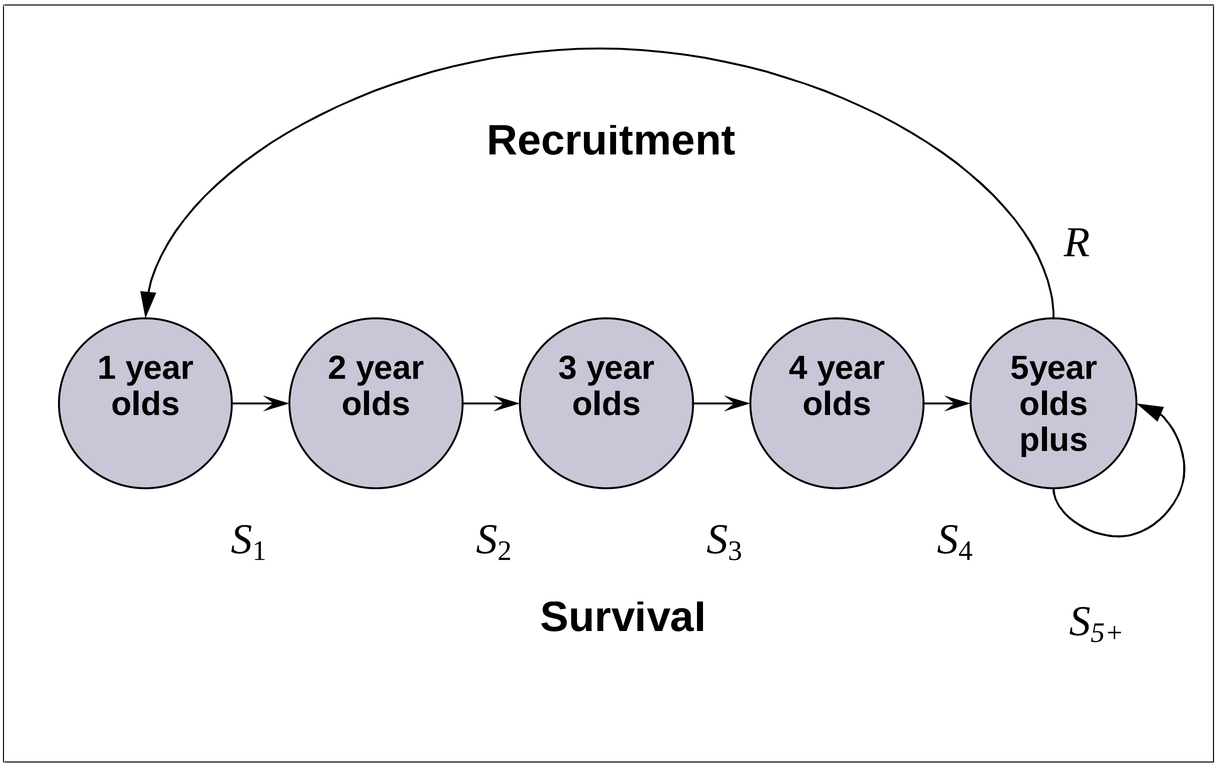

Figure 3. Simple life cycle graph for Murray cod, where Todd and Koehn (2009a) expanded the 5 year old plus group to include ages 5 to 25 plus.

5.1 Bidyanus bidyanus, Silver perch

Silver perch are a long lived species and is known to live up to 26 years (Mallen-Cooper and Stuart, 2003) and can grow to eight kilograms, although less than 16 years and 1-1.5 kilograms is more common in the southern Murray-Darling Basin (Morris et al. 2001). Males mature at approximately three years, while females take up to five years to mature (Lake 1967a).

Most eggs were released at the one spawning. Lake (1967b) considered silver perch to have a high fecundity. Merrick (1996) indicates a female can produce over 300 000 eggs. A 1.8 kg female has been recorded producing 500 000 pelagic eggs (Merrick and Schmida 1984).

A considerable number of sectioned otoliths exist which can be analysed to estimate age survival. Some GSI information is available and can be analysed to estimate fecundity.

- **Recommendation**: There is sufficient data to construct an age structured model with 30 age classes, with sexual maturity occurring at age 5. Aged otoliths can be used to estimate age specific survival rates, age-fecundity relationship may be estimated.

5.2 Macquaria australasica, Macquarie perch

Males reach sexual maturity at two years of age and 210 mm total length, and females at three years and 300 mm total length (Harris and Rowland 1996). However fish may mature at smaller lengths: 140–150 mm in the Cotter River in the ACT (Lintermans and Osborne 2002); 140 mm in the Mitta Mitta River (Douglas 2002); 117 mm in Lake Dartmouth, Victoria (Douglas et al. 2002) and 134 mm in Hughes Creek, Victoria (Appleford et al. 1998). Fecundity is approximately 31,000 eggs per kilogram of fish weight (Cadwallader and Rogan 1977: N=14 females 305-404 mm length), with females carrying up to 110,000 eggs (Battaglene, 1988).

While a number of otoliths are yet to be sectioned, a sufficient number of sectioned otoliths exist to estimate age survival (M. Lintermans pers. comm.). There is sufficient fecundity data to estimate an age-fecundity relationship.

- **Recommendation**: There is sufficient data to construct an age structured model with 30 age classes, with female sexual maturity occurring at age 3. Aged otoliths can be used to estimate age specific survival rates, age-fecundity relationship can be established.

5.3 Galaxias fuscus, Barred galaxias

Very limited work has been conducted on aspects of the ecology and life cycle of this species (Raadik 1995). Only recently has the specific species status been recognised and because of prior taxonomic uncertainty, most population studies have focused on the more abundant Mountain Galaxias *Galaxias olidus*. Shirley (1991) estimated that there were five age classes, with the smallest fish sampled (36 mm total length, TL) being less than one year old (0+) and the oldest being 4+ years old (Raadik 1995). This species is probably slow growing when young and longevity is estimated to be 4-6 years (Raadik 1995).

Fecundity ranges up to 1000 eggs (mature ova) for a 140 mm TL fish (Raadik 1995), but the average egg number of all populations sampled was around 500 (Shirley and Raadik 1997). By mid-May, 90% of the population is in a ripe stage, but the fish appear to wait through most of the winter before spawning (Shirley and Raadik 1997).

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 6 ages to capture the dynamics of the species. However age at sexual maturity is unknown and there is insufficient data to estimate age specific vital rates, survival and fecundity.

5.4 Maccullochella macquariensis, Trout cod/Bluenose cod

Trout cod is a relatively low fecund, benthic egg laying species that is thought to have a life span of 20–25 years and grow to around 800 mm (Todd et al. 2004). Trout cod reach sexual maturity at 3-5 years of age at a weight of 0.75-1.5 kg (Douglas et al. 1994). The fecundity of Trout cod is not known, but 1,188-11,338 eggs have been stripped from individual broodfish (Ingram and Rimmer 1992; Douglas et al. 1994).

Numerous sectioned otoliths are available for analysis as well as fecundity estimates from 80 trout cod sampled from the Ovens River, Victoria (J. Lyon pers. comm.).

Todd et al. (2004) developed a 7 age/stage population model for trout cod to examine density-dependence uncertainty and its influence on the management of trout cod. This model does not have any size structure and can not examine any size based harvesting. While trout cod are a protected species, there are impacts on trout cod from angling of Murray cod as well as a desire to create a trout cod fishery in an isolated lake (Anthony Forster pers. comm.). It is advisable that the previous model be updated, to include size structure and the latest knowledge and data to address management question(s).

- **Recommendation**: There is sufficient data to construct an age structured model with 25 age classes, with female sexual maturity occurring at age 5. Aged otoliths can be used to estimate survival rates, age-fecundity relationship can be established.

5.5 Tandanus tandanus, Freshwater catfish

Adults pair and build a nest in coarse sediments (Davis 1977a). Freshwater catfish may grow to about 915 mm in length and weigh 6.8 kg, although the majority caught weigh between about 0.9 kg and 1.8 kg (Lake 1959). In his study of freshwater catfish in the Gwydir River, Davis (1977b) indicated the largest fish of 666 captured measured 574 mm and weighed 2.7 kg. Clunie and Koehn (2001) documented catfish aged up to 12 years with a range of fecundities 18 000-26 000 eggs (1.25-2kg fish) and fish 0.675 kg to 2.275 kg, 2,000 to 20,600 eggs (Davis 1977c). Catfish mature between 3 and 5 at a weight around 1.2kg (Davis 1977a). Llewellyn and Pollard (1980) documented a few mature at 2 years and all mature by 5 years and some females matured at an earlier age and lower weight than males (Davis 1977c)

No documentation of otoliths being held and little available fecundity data.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 15 ages to capture the dynamics of the species, with female sexual maturity occurring at age 4. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.6 Craterocephalus fluviatilis, Murray hardyhead

Murray hardyhead are a short lived annual species (Ellis 2005, 2006), and are not highly fecund, Ellis (2005) documented females producing eggs from 30-87.

Otoliths for Murray hardyhead are available and the study by Ellis (2005) provides some insight in to fecundity.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 1 age to capture the dynamics of the species (a single age structured model), with female sexual maturity occurring at age 1. Aged otoliths can be used to estimate survival rates, age-fecundity relationship can be established. However this may be uninformative for management. As the species is effectively an annual species a seasonal model (i.e. 4 times steps per year) may provide greater insight for management.

5.7 Macquaria ambigua ambigua, Golden perch

Golden perch mature at 3 years for males and four for females (Lake 1967a, b) with fish of 2.2 to 2.4 kg producing approximately 500,000 eggs (Lake, 1959, 1967c) female of 4.3 kg had 650,910 eggs (Cadwallader 1977) fish of 2.5 kg produce well over 500,000 eggs (Harris and Rowland 1996) for 1.0 to 2.1 kg fish, N = 1000 x (249.16 – 39.02 W) where N = no. of eggs and W = weight of fish in kg (Rowland 1983).

Golden perch are likely to be a relatively long lived fish, and there are a substantial number of sectioned otoliths that can be used to estimate age specific survival.

- **Recommendation**: : There is sufficient data to construct an age structured model, with female sexual maturity occurring at age 4. Aged otoliths can be used to estimate survival rates, age-fecundity relationship can be established. The number of age classes specified in the model requires further research such as analysing the age data to estimate the oldest appropriate age for a model.

5.8 Misgurnus anguillicaudatus, Oriental weatherloach

Oriental weatherloach reach sexual maturity at 100 mm in length and are multiple spawners which lay between 4,000 and 8,000 red adhesive eggs in each event. Weatherloach are relatively long lived and can live in captivity for 13+ years (Lintermans and Burchmore 1996). They can reach a maximum length of 25 cm but in Australia usually grow to only around 20 cm (Lintermans and Burchmore 1996).

No data is held and little information was found in the literature. Very little information was found in the international literature that would help quantify life cycle vital rates.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 13 ages to capture the dynamics of the species. However age at sexual maturity is unknown and there is insufficient data to estimate age specific vital rates, survival and fecundity.

5.9 Galaxias olidus, Mountain galaxias

Moutain galaxias live for four years (Moffat and Voller 2002), with females producing few eggs (50 to 350) (Marshall 1989, Allen et al. 2002). Juvenile fish grow rapidly, attaining a length of around 30 mm in just 8 weeks.

This species complex has recently been split in to several distinct taxa (T. Raadik pers. comm.).

No data is held and little information was found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 4 ages to capture the dynamics of the species. Age at sexual maturity is unknown and there is insufficient data to estimate age specific vital rates, survival and fecundity.

5.10 Mogurnda adspersa, Southern purple-spotted gudgeon

This is a small fish (up to 12 centimetres maximum) that lives up to four years of age. It is mature at 12 months (Moffatt and Voller 2002) and spawns during the wet season from November to April (Allen et al. 2002). It is a serial spawner, and, although spawning cues are unknown, they are speculated to be rising temperature (more than 20°C) and photoperiod (Hansen 1988). Males are territorial, and establish a nesting site. Adults pair off and the female lays between 100 to 1300 (Larson and Hoese 1996), small adhesive eggs onto the hard substrate (rocks, woody debris, broad-leafed aquatic vegetation). The male will fan and defend the nest until hatching three to nine days later (temperature dependant).

No data is held and little information was found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 4 ages to capture the dynamics of the species. Age at sexual maturity is unknown and there is insufficient data to estimate age specific vital rates, survival and fecundity.

5.11 Ambassis agassizii, Olive perchlet

Ambassis agassizii spawns between November and December, or when the water temperature reaches 23oC. The adhesive eggs are about 0.7mm in diameter and are scattered amongst aquatic vegetation. Females 49mm long contain around 2350 eggs (Allen, 1996). This species has a lifespan of approximately four years, but are sexually mature after 12 months (Moffatt and Voller, 2002).

No data is held and little information was found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 4 ages to capture the dynamics of the species. Age at sexual maturity is unknown and there is insufficient data to estimate age specific vital rates, survival and fecundity.

5.12 Oncorhynchus mykiss, Rainbow trout

Rainbow Trout mature at about 3 years of age, with a. maximum age of 8 (Rutz 1993). About 1,500 eggs are produced per kilo of body weight and are laid in gravel substrate of flowing, highly oxygenated water (Davies and McDowall 1996). Hatching takes between 3-12 weeks. Schill et al. (2010) estimated fecundity based on length, F = 0.0002TL^2.5989

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 10 ages to capture the dynamics of the species, with female sexual maturity occurring at age 3. There is insufficient data to estimate age specific vital rates, survival and fecundity, however international studies exist in which these rates have been estimated.

5.13 Gadopsis marmoratus, Northern River blackfish

The northern form of this species has a life span of roughly 5 years while the southern form attains an age of at least 10 years at low altitudes (Cadwallader and Backhouse, 1983). In the northern Murray-Darling Basin, *G. marmoratus* has a reported lifespan of over six years, but is reproductively mature at two years (Moffatt and Voller 2002). Fecundity is low and thought to be proportional to the size of the fish (Cadwallader and Backhouse, 1983), with females producing around 500 eggs in one spawning (Lake, 1971), although some larger females (the southern form) may produce up to 2500 eggs (Jackson et al. 1996).

No data is held and little information was found in the literature. A search of grey literature may find more information on life cycle vital rates.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 10 ages to capture the dynamics of the species, with female sexual maturity occurring at age 2. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.14 Gadopsis bispinosus, Two-spined blackfish

Two-spined blackfish has a shorter lifespan than the northern river blackfish, living for at most 8 years (O'Connor et al. 2001, O'Connor and Zampatti 2006, M. Lintermans pers. comm.). Two-spined blackfish mature at age 2. They are not very fecund and have been recorded to produce between 10 and 396 eggs (Sanger 1990, O'Connor and Zampatti 2006). Sanger (1990) recorded 2 length fecundity relationships ,either: Fecundity = 2.5 x Total Length – 205; (rsq = 0.74); or log10Fecundity = 2.16 Log10 TL – 2.5 (rsq = 0.72).

Some age data is held (M. Lintermans pers. comm.) and the fecundity data in the 3 studies cited allow life cycle vital rates to be estimated.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 8 ages to capture the dynamics of the species, with female sexual maturity occurring at age 2. Aged otoliths can be used to estimate survival rates, age-fecundity relationship can be established.

5.15 Melanotaenia fluviatilis, Murray-Darling rainbowfish

This species lives for three years, attaining sexual maturity after 12 months. They breed between October and January cued by rising water temperatures. Females can spawn up to three to four times per day over several days. Adults pair for a single spawning of up to 10 demersal eggs.

No data is held and little information was found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 3 ages to capture the dynamics of the species, with female sexual maturity occurring at age 1. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.16 Galaxias rostratus, Flat-headed galaxias

Commonly found from 100-140 mm and up to 150 mm, achieving 25 g (McDowall and Frankenberg, 1981) and producing 3000 to 7000 eggs (Llewellyn 1971, McDowall and Fulton 1996).

No data is held and little information was found in the literature.

- **Recommendation**: There is insufficient information to determine a suitable model structure. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.17 Cyprinus carpio, Carp

Most carp are mature by 350mm which approximates to an age of 2 years (Sivakumaran et al. 2003, Smith 2005) and have a maximum age of 32, although most carp are in the range 3 – 11 (Brown et al. 2003). Estimates of instantaneous fecundity (the average number of stripped eggs per kilogram of fish) range from 114, 000 to 163, 000.kg-1 (Szabo et al. 2000, Sivakumaran et al. 2003), some carp have been recorded producing around 1,500,000 eggs (Brown et al. 2003).

Models have already been developed for carp (Todd and Stuart 2001, Brown and Walker 2004). However if the management concern can not be adequately addressed with the previous models then it is advisable to construct a model to address management question(s).

Carp are long lived fish, and there are a number of sectioned otoliths that can be used to estimate age specific survival as well GSI data for estimating fecundity.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 30 ages to capture the dynamics of the species, with female sexual maturity occurring at age 2. Aged otoliths can be used to estimate survival rates, age-fecundity relationship can be established.

5.18 Nannoperca australis, Southern pygmy perch

Most populations are predominantly 1 to 2 year old individuals; however, this species can live up to 5 years (Kuiter et al. 1996) . Fish in natural populations, however, release all of their eggs at once, with fecundity varying from 500 to 4000 eggs per female. Newly hatched larvae 3-4mm long emerge 2-4 days after fertilisation. Nannoperca australis reaches sexual maturity in its second year, when males are about 36mm and females 33mm long (Cadwallader and Backhouse, 1983).

No data held, however there is a reasonable amount of information available from international studies to quantify life cycle vital rates.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 5 ages to capture the dynamics of the species, with female sexual maturity occurring at age 1. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.19 Perca fluviatilis, Redfin perch

Redfin generally mature after two to three years, but males may mature at the end of the first year. Spawning occurs in spring when water temperature reaches 12°C, with thousands of two to three millimetre diameter eggs laid as gelatinous ribbons amongst freshwater plants. Eggs hatch in one to two weeks and juveniles will often form large schools (McDowall 1996).

Redfin have a lifespan of around 16 years but most do not live this long, and are highly fecund a redfin 35cm long may produce up to 100,000 eggs (Heibo and Vøllestad 2002).

No data held, however there is information available from international studies to quantify life cycle vital rates.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 16 ages to capture the dynamics of the species, with female sexual maturity occurring at age 3. There is insufficient data to estimate age specific vital rates, survival and fecundity, however there is information available from international studies to quantify age specific vital rates.

5.20 Craterocephalus stercusmuscarum fulvus, Un-specked hardyhead

Un-specked hardyhead become sexually mature after 150 days (Semple 1985). They live up to three years, and have an extended spawning season from late winter through to summer, but a peak occurs in late winter to early spring (Pusey et al. 2004).

No data held and little information was found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 3 ages to capture the dynamics of the species, with female sexual maturity occurring before age 1. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.21 Pseudogobius olorum, Western blue-spot goby

Cadwallader and backhouse (1983) report up to 150 eggs per female.

No data held and no data found in the literature.

- **Recommendation**: There is insufficient information to determine a suitable model structure. There is insufficient data to estimate age specific vital rates, survival and fecundity.

5.22 Neosilurus hyrtlii, Hyrtl's tandan

No information on age structure was found in the literature for Hyrtl's tandan, although length at first maturity was 135 mm TL for both male and female (Bishop et al. 2001). Fecundity is little known, however, a 205 mm female had 3,630 eggs of ~1.3 mm diameter (Pollard et al. 1996). Orr and Milward (1984) estimated fecundities of Hyrtl's tandan to range from 1600 to 15 300 for individuals 267 mm standard length taken from the Ross River, northern Queensland.

No data held and no data found in the literature.

- **Recommendation**: There is insufficient information to determine a suitable model structure. There is insufficient data to estimate age specific vital rates, survival and fecundity.

It was from a 205 mm TL fish (weighing 63 g) with a GSI of 10.13. The estimated number of eggs was 3630

5.23 Salmo trutta, Brown trout

The number by eggs produced by a female stream-dwelling brown trout was highly exponentially correlated with fork length, providing the most typical fecundity curve of all species/ecotypes (y= 0.00003x^2.99, R2 = 0.88). Using this regression equation, a 200mm brown trout would produce ~228 eggs and a 300mm brown trout would produce ~765 eggs (Halfyard et al. 2008).

Male Brown trout become sexually mature at 2 years of age, female at 3 years. Brown trout may live to 20 years however in Australia rarely live longer than 10 years (Davies et al. 1996, Douglas 2008).

No data held, however Douglas (2008) has age data which can be used to estimate survival as well as a body of international literature that includes information on life cycle traits.

- **Recommendation** There is sufficient knowledge to construct an age structured model with 12 ages to capture the dynamics of the species, with female sexual maturity occurring before age 3. There is sufficient data to estimate age specific survival rates, and information is available from international studies to quantify age specific vital rates, survival and fecundity.

5.24 Gambusia holbrooki, Eastern gambusia

Eastern gambusia mature at about 20 millimetres long, with the fertilised eggs developing inside the female and live-born young being a few millimetres long at birth.

Maturity can be reached in one to two months and individuals can breed several times a year (Pen and Potter 1991, Pyke 2005). Eastern gambusia can have up to nine broods per mating season (Milton and Arthington 1983), with the average clutch sizes ranging from 5 to 100 (Pyke 2005) and is considered to have a high reproductive rate, producing an average of 50 young per brood although up to 300 have been recorded. The clutch size of each brood is highly variable, and dependant on age, time of season, food availability, female size, and geographic location (Pyke 2005). Fertilized eggs develop for 3 to 4 weeks inside the female then larvae of a few millimetres in length are born. The usual life span is a few months, where most fish live and die in the same season in which they mature (McKay et al. 2001). Females maturing towards the end of the season have been recorded living up to 15 months (Cadwallader and Backhouse 1983, McKay et al. 2001) although a lifespan of up to three years has been reported (Karolack 2006). A population growth rate was estimated by Tonkin et al. (2009) indicating the potential for rapid increases in population size.

No data held and little found in the literature.

- **Recommendation**: There is sufficient knowledge to construct an age structured model with 2 ages to capture the dynamics of the species, with female sexual maturity occurring before age 1. There is insufficient data to estimate age specific vital rates, survival and fecundity. A model with an annual time step may be uninformative for management and a model with 2 month time steps may be more appropriate and in line with the life cycle of the species.

5.25 Porochilus rendahli, Rendahl's tandan

Male and female *Porochilus rendahli* matured at approximately the same length: 100 mm for males and 110 mm TL for females (Bishop et al. 2001). The ovaries of eight fish were examined. Egg numbers ranged from 240 (fish length 100 mm TL, weight 6.3 g, GSI 3.62) to 3465 (fish length 209 mm TL, weight 80 g, GSI 7.25), with an average egg count of 900 eggs (Bishop et al. 2001).

No data held and no data found in the literature.

- **Recommendation**: There is insufficient information to determine a suitable model structure. There is insufficient data to estimate age specific vital rates, survival and fecundity.

6 Conclusions

Of the 25 Murray-Darling Basin species reviewed in this study, eight species were identified as having sufficient life cycle information to develop age structured models and sufficient data that, if analysed, would yield the parameter estimates required for the identified model structures:

- silver perch (*Bidyanus bidyanus*);
- Macquarie perch (*Macquaria australasica*);
- trout cod/bluenose cod (*Maccullochella macquariensis*);
- Murray hardyhead (*Craterocephalus fluviatilis*);
- golden perch (*Macquaria ambigua ambigua*);
- two-spined blackfish (*Gadopsis bispinosus*);
- carp (*Cyprinus carpio*);
- brown trout (*Salmo trutta*);

and while no data was held in Australia for rainbow trout (*Oncorhynchus mykiss*) sufficient data is available in the international literature to estimate the required parameters for a population model. While all species, except brown and rainbow trout, have sectioned otoliths, these otoliths may require ageing prior to the estimation of survival rates being undertaken. Also additional analysis of GSI data may be required to estimate fecundity.

Given the available information on the nine species listed above, it is recommended that population models be developed for these species, to identify optimal management actions (including the assessment of alternate management actions) and identify critical knowledge gaps, to address key questions detailed in the species management strategies. As a priority, it is recommended that models be developed for the five species ranked in the top 10 of species of most concern (Table 2): silver perch (*Bidyanus bidyanus*) (ranked 1st); Macquarie perch (*Macquaria australasica*) (2nd); trout cod/bluenose cod (*Maccullochella macquariensis*) (4th); Murray hardyhead (*Craterocephalus fluviatilis*) (6th); and golden perch (*Macquaria ambigua ambigua*) (7th). It is also recommended that research be undertaken on the five other species of concern in the top 10, for which there is insufficient information to construct a model, to improve knowledge and/or data to the model development level and consider model development for these species: barred galaxias (*Galaxias fuscus*) (3rd); freshwater catfish (*Tandanus tandanus*) (5th); oriental weatherloach (*Misgurnus anguillicaudatus*) (8th); mountain galaxias (*Galaxias olidus*) (9th); and southern purple-spotted gudgeon (*Mogurnda adspersa*) (10th).

The review of population models in natural resource management raised a number of concerns in relation to the ability to source appropriate information from the primary literature. Although the literature contains a number of peer-reviewed articles discussing the development of population models for addressing management issues or decision-making, it was more difficult to locate references that discussed how those models were being adopted. Sourcing information from the secondary or 'grey' literature, often the medium by which stakeholders disseminate their own findings, was useful in obtaining some information on population model adoption. The review did, however, find important and instructive examples of where population models have integrated into management strategy and policy. The development of adaptive management strategies, particularly for fisheries, often exploits the utility of population models for the continual assessment of management actions. The adoption of mathematical models for decision-making and development of strategic responses to the contraction of native fish in the Murray Darling Basin is still developing and explored in more detail within the review. There are examples where models have influenced management and policy development in freshwater research, such as the trout cod model developed by Todd et al. (2004). Although the review found there was strong interest in development of models, it concludes that there needs to be a concerted effort from all interested parties to ensure models are used to influence policy and management outcomes and utilised by the intended stakeholders.

The review highlighted the benefits of a well-structured management plan that considers adaptive management approaches coupled with strategies that combine population models, evaluation procedures and continued exploration of outcomes over time. In order to ensure that population models do influence management and policy, it is recommended that models be integrated into natural resource management in a more formal manner, for example explicitly stated in species' recovery plans.

Management strategies need to be developed as structured learning environments, akin to an active adaptive management framework. Prior to implementing any management action, it is recommended that population models be used to assess potential outcomes of alternative management strategies. If the model represents the best knowledge available on the life cycle of a species, then the optimal management strategy assessed by the model should be the action adopted for implementation. Once a suitable management action (or multiple actions) is identified, the development and implementation of an effective monitoring program will permit continual adjustment of the model as new data is received. For this to happen, it is also essential that there be continuous communication between the developers of models and resource managers. Such an approach will ensure model uptake by stakeholders.

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Appendices

Table A1. Models used in NSW species recovery plans (www.threatenedspecies.environment.nsw.gov.au)

Taxa and number of species recovery plans	PVA	Population
Reptiles (38)	*Hoplocephalus bungaroides*	
Amphibians (28)		*Pseudophyne corroboree*
Bats (21)		
Birds (122)	*Ptilinopus superbus*	
Endangered populations (17)	*Phascolarctos cinereus* *Petaurus norfolcensis*	
Invertebrates (15)		
Marine mammals (7)		*Eubalaena australis* *Physeter macrocephalus*
Marsupials (25)	*Dasyurus maculatus*	*Burramys parvus*
Rodents (13)	*Pseudo fumeus*	Mastocomys

Plants (629)	*Grevillea caleyi* *Boronia granitica*	

Table A2. Details of models developed to investigate management scenarios and the adoption of those models for management and policy.

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Murray Cod model/ stochastic population model	Yes	Yes	Yes	NA	Assessment of adoption is not yet practical as model has only recently been developed as has not been published as yet.. However, given the large degree of interest in this model and the extensive stakeholder involvement and testing, it is expected to be widely used. It has already been used to support changes to regulations and explore additional potential regulation changes.	(Todd and Koehn 2009a)
Koala-forest interactive management model	Yes	Yes	Yes	Yes	Helped set targets for the number of koalas to receive hormonal implants. Identified the likely cost requirements to achieve desired outcomes and a crucial time lag in response from forest to reduced koala numbers. Parks Victoria initiated a large scale hormone implant program with a comprehensive mark-recapture monitoring program based on recommendations from this study. The program is on-going	(Todd et al. 2008)

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Trout cod model / density dependence	Yes	Yes	Yes	Yes	Adoption has been inferred indirectly from other publications	(Todd et al. 2004)
Logger-head turtles - Lefkovitch seven-stage class matrix model and a five-stage model	Yes	Yes	Yes	Yes	After release of this paper, the US National research Council concluded that the results of this study showing that protecting juvenile loggerhead turtles from accidental drowning in nets was the most important factor affecting the viability of this species. This led to legislative action for all shrimp trawlers to be fitted with turtle exclusion devices (TEDs).	(Crouse et al. 1987), (Crowder et al. 1994)
Mountain pygmy – possum Population viability analysis	Yes	Yes	Yes	Yes	A decrease in carrying capacity (1%) and loss of habitat would increase probability of extinction. results suggest ski-slope development should account for this.	(Mansergh et al. 1990) in (Clark et al. 1991)
Mountain pygmy possum / population model	Yes	Yes -limited	Limited	No	The model was inadequate in assessing population structure due to biological constraints	(McCarthy and Broome 2000)
Brown headed snake / population viability analysis	Yes	NA	NA	NA	No information pertaining to the outcomes of the PVA available in the literature	NA[1*]

[1*] Information is only contained in the species recovery plan – see www.threatenedspecies.environment.nsw.gov.au

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Southern corroboree frog / population model	Yes	NA	NA	NA	No information pertaining to the outcomes of the model available in the literature	NA*
Superb fruit dove / population viability analysis	Yes	NA	NA	NA	No information pertaining to the outcomes of the model available in the literature	NA*
Koala populations in Pittwater Local Government Area / Population viability analysis	Yes	NA	NA	NA	No information pertaining to the outcomes of the model available in the literature	NA*
Spotted-tailed Quoll / Viability models	Yes	NA	NA	NA	No information pertaining to the outcomes of the model available in the literature	NA*
Abalone/ Matrix models – elasticity analysis	Yes	Yes	Yes	Yes	Models from this work assisted in the drafting of the white abalone recovery plan and contributed to the including the introduction of a catch size limit of 7 inches.	(Rogers-Bennett 2008); (Rogers-Bennett and Leaf 2006)
Mountain pygmy possum / metapopulation model	Yes	NA	NA	NA	No information pertaining to the outcomes of the model available in the literature	NA*

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Murray Cod / age structured simulation model	Yes	Yes - limited	NA	NA	Assessed the impact of different stock-enhancement scenarios – as yet findings from this study have not been adopted	(Rogers-Bennett and Leaf 2006)
Murray Cod / age structured simulation model	Yes	Yes - Limited	NA	NA	Assessed the influence of minimum length limits for Murray cod. Model Adoption by fisheries managers is reliant upon obtaining further fishing mortality rates for this species	(Allen et al. 2009)
Chinook Salmon / PVA Simulation modelling	Yes	Yes	NA	NA	Modelled climate variability and juvenile recruitment. Results suggested that increasing juvenile carrying capacity was important for population recovery – no information on adoption of results for management	(Zabel et al. 2006)
Chinook Salmon / modified Leslie matrix model	Yes	Yes	Yes	Yes	This study modelled the effect of habitat degradation on population viability of Chinook salmon. This influenced subsequent habitat management plans and led to a focus on habitat rehabilitation.	(Ratner et al. 1997)

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Chinook salmon / age-structured matrix model	Yes	Yes	NA	NA	This model investigated the influence of dams along the Snake River U.S.A. of viability of Chinook salmon. Findings from this study will probably increased debate on dam removal along the Snake river, for increased salmon survivorship	(Kareiva and Marvier 2000)
Tilapia species / growth models - linear, power, Gompertz, von Bertalanffy, and logistic	Yes	NA	NA	NA	Modelled juvenile growth in Tilapia species under hyper-saline conditions. May assist in understanding how climate induced changes in estuarine habitats will affect juvenile fish survival	(Diouf et al. 2009)
Trout cod - Discrete time stochastic population model	Yes	Yes	NA	NA	Simulated the entire adaptive management cycle for trout cod. Should have major influence on management strategies for this species	(Bearlin et al. 2002)
White sturgeon - PVA	Yes	Yes	NA	NA	Investigated numerous scenarios affecting movement of translocated fish. Emigration affected translocation success. may not influence long-term adaptive management strategies	(Jager 2006a)
White sturgeon - PVA	Yes	Yes	NA	NA	This study investigated screening size at fish passages, although may not influence long-term adaptive management strategies	(Jager 2006b)

species/model	management/policy focus	answer the question	influence management/policy	used by stakeholders	comments	reference
Eastern barred bandicoot - PVA	Yes	Yes	Yes	Yes	Long term captive management plan was suggested and highlighted that a combination of management actions were needed than just a single management action	(Patrick and Myroniuk 1990) in (Clark et al. 1991)
Spotted tree frog - PVA	Yes	Yes	Yes	Yes	PVA The model was able to inform on the identification of threats and suggest measures for threat amelioration. It also suggested that the larval life stage should be the focus on conservation efforts	(Robertson and Gillespie 1996)
Orange-bellied parrot – PVA	Yes	Yes	Yes	Yes	Re-enforced the use of a captive management program to supplement natural population growth. Also showed that juvenile mortality is the biggest threat for extinction of this species	(Brown et al. 1990) in (Clark et al. 1991)

Table A3. Researchers and managers around the MDB with data that that can contribute to the estimation of life cycle vital rates.

Name	Org	Phone and E-mail	Will supply data	Species	Site	Unprocessed otoliths	Sectioned otoliths	Gonad data
Clayton Sharpe	MDFRC	0350514062 C.Sharpe@latrobe.edu.au	Yes	Golden perch	Frenchmans Ck (Lake Vic.)	100s	100s	GSI
			Yes	Golden perch	Darling River d/s Menindee		400 adults 100s of YOY	GSI
			Yes	Golden perch	Murray River (Hume to Yarra)		80	GSI
			Yes	Murray cod	Murray R. (Mildura)	Mark/recap data only		
Iain Ellis	MDFRC	0350514061 I.Ellis@latrobe.edu.au	Yes	Murray hardyhead	Mildura area	50 or more	A few	GSI and other life cycle
Lee Baumgartner	NSW I&I	0269588215 lee.baumgartner@industry.nsw.gov.au	To be contacted	Golden perch, Murray cod, Redfin, Silver perch	Burrinjuck Dam		100s 10s 100s 100s	GSI
				Golden perch,	Blowering Dam		100s	GSI

				Murray cod, Redfin, Silver perch			10s 100s 100s	
				Golden perch, Murray cod, Redfin, Silver perch	Copeton Dam		100s 10s 100s 100s	GSI
				Murray cod	Murray River (Tocumwal)		30	GSI
				Murray cod	Murrumbidgee River (Narrandera area)		50	GSI
Stuart Rowland	NSW I&I	(02) 6640 1691 Stuart.Rowland@industry.nsw.gov.au	Yes (GB)	Murray cod	Murray near Yarrawonga		00s	
Gavin Butler	NSW I&I	0266401671 Gavin.butler@industry.nsw.gov.au	Yes	Murray cod	Dumeresq R. Macintyre R. Gwydir R.	To be collected	100 100 100	GSI
			Yes	Murray cod Golden perch Silver perch	Random collection from across basin from Stu Rowland	Approx. 500 mostly MC		
Dean Gilligan	NSW	0244789111		Macquarie perch				

	I&I	dean.gilligan@industry.nsw.gov.au						
Andrew Bruce	NSW I&I	Andrew.bruce@industry.nsw.gov.au		Macquarie perch	Eastern spp			
David Moffatt	Qld NRM	0422572211 David.moffatt@nrm.qld.gov.au	Yes	Golden perch Murray cod	Warrego R. Paroo R. Cooper Ck. Condamine R.	Hundreds of GP few MC	Few sections	Sex data
David Roberts	Qld NRM	(07) 3035 5515 dtroberts@seqwater.com.au		Golden perch	Eastern spp			
David Crook	ARI	0394508600 David.crook@dse.vic.gov.au	Yes	Golden perch	Billabong/Edwards/Murray/ Murrumbidgee		100s	Some sex data

Jarod Lyon	ARI	0394508678 jarod.lyon@dse.vic.gov.au	Yes	Trout cod	Murray River and Ovens River		300	GSI for 150 TC
			Yes	Murray cod	Murray R.		200	No
			Yes	Golden perch	Murray R.		80	No
			Yes	Silver perch	Murray R.		60	No
				Macquarie perch	Dartmouth, Yarra R. King Parrot Ck.		60	gonads for 10 MP
Zeb Tonkin	ARI	0394508660 Zeb.tonkin@dse.vic.gov.au	To be contacted	Australian smelt				
Brenton Zampatti	SARDI	08 8207 5491 brenton.zampatti@sa.gov.au	Yes	Golden perch Murray cod Congolli	Lower Murray and off-channel habitats Lower lakes		100s 10s 100s	GSI no GSI
			Yes	Common galaxids	Lower Murray		100s	GSI
			Yes	Australian smelt	SA Murray		100s	GSI
			Yes	Southern pygmy perch and Yarra pygmy perch	SA Murray		10s	GSI
			Yes	Carp	SA Murray		10s	
Dale McNeil	SARDI	08 820 75342 dale.mcneili@sa.gov.au	To be contacted	Olive perchlet	Lachlan River		17	Sex data

Chris Bice	SARDI	08 8207 5491 chris.bice@sa.gov.au	Yes	Golden perch Redfin	Lower lakes		46 GP 76 RF	
Mike Hammer	Consultant	michael.hammer@student.adelaide.edu.au	To be contacted	Might have some small fish data				
Martin Mallen-Cooper	Consultant	0294499638 mallencooper@optusnet.com.au	Yes	Golden perch Silver perch Bony herring*	Murray River (Torrumbarry and tribs and dams) (archived)	00s	100s 100s	GSI GSI GSI
Anthony Conallin	Murray CMA	0358801400 Anthony.Conallin@cma.nsw.gov.au	Yes	Murray cod Golden perch	Wakool system (fish kills)	100 MC 25 GP		Sex info for 33%
Paul Brown	DPI	03 57708013 Paul.Brown@dpi.vic.gov.au	To be contacted	Carp	Murray system		720	Sex
John Douglas	DPI	John.douglas@dpi.vic.gov.au	To be contacted	Macquarie perch	Dartmouth	10s		Sex
Ivor Stuart	Consultant	0394384864 Ivor.stuart@gmail.com	Yes	Carp Murray cod	Murray system Murray and tribs	100	95	GSI No
Harry Balcombe	Griffith Uni	0737357308	Yes	Golden perch	Moonie River	To be collected		Sex

Mark Lintermans	UCan	02 6201 2853 mark.lintermans@canberra.edu.au	Yes	Golden perch Macquarie perch Two-spined blackfish	ACT dams Cataract Cotter R.	00s 40 100	1000	sex sex sex
Matt Beitzal	ACT	0262056755		Golden perch Murray cod Silver perch Macquarie perch Trout cod	ACT dams and some rivers		1000s GP 100s others	sex
Janet Pritchard	MDBA	0262790580 Janet.Pritchard@mdba.gov.au		Golden perch			100s	sex
John Anderson			Yes	Murray cod Golden perch	Murray system + tribs		290 889	Sex
Geoff Gooley			Yes	Murray cod	Lake Charlegrark		231	Sex
Brendan Ebner	Griffith Uni	0740925768 b.ebner@griffith.edu.au		Nil				
Glen Wilson	Griffith Uni	026773308	To be contacted	Murray cod Small species	Goondiwindi and border rivers area		100s	
Tariq Khan	Griffith Uni		To be contacted	Golden perch	Northern MDB	Larvae and early stages	10s	

Andrew Berghuis	QDPI	0741315757 Andrew.Berghuis@deedi.qld.gov.au		Nil – suggested Adam Butcher				
Ivor Growns	UNE	0267735282 Ivor.Growns@dnr.nsw.gov.au		Australian smelt		Larvae and early life stages	100s	

*samples to be located