Ecological risk assessment of stocking Murray cod in South Australia

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Executive Summary

Native species are widely stocked in the Murray-Darling Basin including in Queensland, New South Wales, Australian Capital Territory, and Victoria. They have not to date been regularly stocked in South Australia (SA).

The ecological risks of stocking Murray cod fingerlings into habitat associated with the South Australian section of the River Murray under flow (>20,000 ML.day^{-1}) and reduced flow (<20,000 ML.day^{-1}) scenarios were assessed. These two flow scenarios were chosen to distinguish between flows when successful recruitment of Murray cod in the lower River Murray was likely (>20,000 ML.day^{-1}) versus when recruitment was likely to be minimal (<20,000 ML.day^{-1}). Stocking of Murray cod fingerlings into reservoirs and farm dams in the South Australian Gulf Drainage Division (western Mount Lofty Ranges), and into dams linked with tributaries in the eastern Mount Lofty Ranges, which are outside the natural distribution of Murray cod, but hydrologically connected to the lower River Murray was also assessed.

An updated review of literature on potential impacts of stocking native fish was provided, such that appropriate impact categories could be used in an environmental risk assessment. A one day workshop with local and interstate experts was held to assess likelihood (probability of an impact occurring) and consequences (measure of ecological effect), along with confidence (amount of supporting information and agreement on consequence score), of potential impacts. Potential ecological benefits were also considered. Depending on the likelihood and consequence a level of risk (low, medium, high, extreme) was provided.

The risk tables should be considered along with the fish/biota of the potential receiving environment. For example, stocking of Murray cod into areas where there are endangered species is likely to entail a higher risk than indicated. Similarly, stocking where there are only exotic species may be associated with a lower risk.

A number of high risks were identified for stocking Murray cod into the River Murray including those related to broodstock exploitation, predation on some groups of organisms (e.g. common small-bodied native fish, rare/endangered small-bodied native fish and other organisms), and displacement of rare/endangered small-bodied native fish. High risks were associated with both flow and reduced flow scenarios.

An increased number of high/extreme level risks were associated with stocking Murray cod into reservoirs and farm dams in the South Australian Gulf Drainage division or farm dams linked to tributaries in the eastern Mount Lofty Ranges largely because Murray cod do not occur naturally in these regions.

Potential high level benefits associated with stocking Murray cod included stock enhancement where there were years of recruitment failure. This was considered a moderate benefit under the high flow scenario and a high benefit under the reduced flow scenario in the River Murray.

Prior to any stocking occurring in South Australian waters we recommend research to determine baseline genetic structure across the extant range in SA and whether the lower River Murray population has any unique genes. Such information will ensure that appropriate wild broodstock are used. It would also be prudent to determine environmental factors that may be leading to recruitment failure in Murray cod since these factors may also limit survival of stocked fish.

Should stocking proceed significant resources will be required for monitoring and assessment. We recommend higher levels of surveillance for pathogens than that which currently occurs in NSW since virtually nothing is known of wild fish pathogens in SA. Maximising genetic diversity is also important and appropriate genetic sampling and monitoring will be required. If threatened species are present, then ideally stocking should not occur, however if it is to occur then additional caution and monitoring may be required to ensure that there are no negative impacts. Referrals to other Acts may also be required for stocking into some areas. We recommend that all stocked fish are marked such that effectiveness of stocking can be ascertained.

Our risk assessment focused on ecological risks (and benefits) of stocked fish and only considered the progeny of any stocked fish in terms of genetic risks. We have not considered ecological risks associated with recreational fishing that might result from stocking of Murray cod, but acknowledge that the National Recovery Plan for Murray Cod lists a number of threats associated with fishing (e.g. size limit may not allow fish to breed prior to capture, Murray cod are sensitive to handling and susceptible to fungal disease, survival and subsequent breeding of released fish is unknown) among other things. We also did not consider any potential socio-economic benefits of stocking, such as benefits to the recreational fishery. A socio-economic risk assessment also needs to be undertaken.

Our risk assessment focused on a component of the risk assessment process. Prior to stocking of Murray cod in South Australian waters we recommend that the full risk assessment process including communicating and consulting more widely (e.g. with conservation groups, recreational fishers) be undertaken. Such a process would also incorporate social and economic aspects. Should stocking proceed it is also recommended that monitoring and review occurs.

Introduction

Hatchery stocking of native species has been carried out throughout the Murray-Darling Basin either to enhance recreational angling or to aid conservation of a species. In most cases, however, the impacts of stocking on non-target species are not well understood or considered (Pearsons & Hopley 1999). Despite this, interactions between hatchery stocked fish and wild non target taxa may be different than between wild and non target taxa. For example, hatchery reared fish are generally released in large numbers and may behave differently to wild conspecifics. A range of ecological interactions (e.g. competition, predation, behaviour and pathogens) both positive and negative are possible (Pearsons & Hopley 1999).

Risk assessment is generally used to estimate the likelihood and consequences of undesired events and can be qualitative or quantitative in nature (Hayes 1997). While ecological risk assessments have been carried out in the aquatic environment, they generally cover risks associated with contaminants and aquatic animal health (Hayes 1997, Crawford 2003, Bartley et al. 2006), but have also been used for fisheries management (e.g. Astles et al. 2006). The process requires establishing the context, identifying, analysing and evaluating the risks (see Figure 1).

Pearsons and Hopley (1999) provided a practical approach for assessing risks associated with fish stocking programs. While their approach was focused on anadromous salmonids, they suggested that the general principles of the approach could be used for any stocking program. Their focus was on non target taxa with two types of overlap recognised (namely between non target taxa and stocked fish, and between non target taxa and the progeny of hatchery fish). Five tasks were required to perform their ecological risk assessment, namely (1) determine the non target taxa (NTT) of concern, and their status; (2) determine the life stages of NTT that may overlap with the target taxon (spatial and temporal component); (3) determine what ecological interactions may occur (taken from the literature review) and their likely strength; (4) assess the ecological risk, or probability of failing to meet the NTT objectives, of stocking the target taxon; and (5) calculate the scientific uncertainty of the risk assessment. Such an approach would be difficult to quantify in the current situation since it would be difficult to identify acceptable impact levels in a quantitative manner. Several papers, however, address responsible approaches to fish stocking in freshwater, estuarine and marine environments (e.g. Blankenship & Leber 1995, Lorenzen 2005, Taylor et al. 2005).

A qualitative approach based on the Australian/New Zealand Standard for Risk Management was used to assess the effects of shellfish farming on the environment in Tasmania (Crawford 2003), as well as stocking of freshwater fish in NSW (NSW Fisheries 2003). A more recent approach in SA used a similar methodology to assess the risks of proposed management scenarios for Lake Alexandrina on the resident fish community (Bice & Ye 2009). The current project uses a similar methodology to evaluate the risks (and benefits) of stocking Murray cod in the River Murray and in reservoirs and farm dams in the Mount Lofty Ranges, SA (Figure 2). We recognise that other quantitative approaches are possible, but such approaches require considerable data, expertise and resources (e.g. Bayesian networks - relocation of cheetahs, Johnson et al. 2010).

Murray cod is an iconic species of the River Murray, which supported a valuable commercial fishery and still supports an important recreational fishery in South Australian waters. In South Australia, the commercial catch of Murray cod declined dramatically from a peak of more than 140 tonnes yr^{-1} in 1957/58 to less than 10 tonnes yr^{-1} in the mid 1970s. Annual landings remained at this level until a moratorium on the catch of Murray cod was instituted in January 1990. The moratorium was lifted in January 1994 and the catch increased in the following years to a maximum of ~ 29 tonnes yr^{-1} before the closure of the native fish fishery in the SA River Murray in July 2003 (Ye & Zampatti 2007). In the Murray-Darling Basin, the distribution and abundance of Murray cod has declined significantly since European settlement, primarily attributed to flow regulation, habitat loss and degradation, barriers to fish passage, cold water releases and fishing (MDBC 2005). However, the ecological mechanisms behind these threats are complex and require further study. Murray cod is now considered nationally vulnerable to extinction under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

River flows play a crucial role in facilitating the recruitment of Murray cod. Although Murray cod spawn annually during spring/early summer (Lake 1967, Cadwallader 1977, Rowland 1983, 1985, Koehn & Harrington 2006), strongest recruitment occurs when the breeding season coincides with high river flows, both within-channel and overbank (Rowland 1998, Ye et al. 2000). In SA, the strong year classes associated with significant floods in 1989 and early 1990s helped the Murray cod population to rebuild in the lower River Murray (Ye et al. 2000). Nevertheless, there has been little recruitment success in the main channel since 1994 despite some low level recruitment occurring in the lotic environments of the Chowilla Anabranch system (Ye & Zampatti 2007, Zampatti et al. 2010). The current Murray cod population in the SA River Murray is dominated by fish in the large size range (>800 mm) (Ye & Zampatti 2007) and older year classes (prior to 1994) (Ye unpublished data). Given the extensive drought in the Murray-Darling Basin and lack of flow conditions over the last decade, a moratorium on recreational fishing for Murray cod was instituted in January 2009 in SA. Following a recent review that involved engagement with the recreational fishing sector, alternative arrangements were introduced that included allowing for recreational catch and release fishing during 2011 and 2012. The 2010-2011 overbank floods provided hydrological connectivity along 1000s of kilometres of the River Murray and returned hydraulic complexity to the weir pools of the lower River Murray. Such conditions are hypothesised to be important in facilitating the recruitment of some key native fish species including Murray cod, which is currently being investigated.

With concerns over lack of strong recruitment of Murray cod in the SA River Murray, questions were raised whether there was a need for stock enhancement to improve recreational fishing or for conservation purposes. A feasiblity study was proposed including the current ecological risk assessment before policy recommendations be made to the SA Government in relation to the release of cultured or translocated Murray cod into wild populations in the River Murray or into impoundments. Stocking of Murray cod currently occurs in rivers and impoundments in Queensland, New South Wales, Australian Capital Territory and Victoria (see Gillanders et al. 2006).

The present study assessed the ecological risks of stocking Murray cod fingerlings into habitat associated with the South Australian section of the River Murray under flow (>20,000 ML.day^{-1}) and reduced flow (<20,000 ML.day^{-1}) scenarios. These two flow scenarios were chosen to distinguish between flows when successful recruitment of Murray cod in the lower River Murray was likely versus when minimal recruitment was found respectively (Ye & Zampatti 2007). In addition, two other scenarios were also assessed – stocking of Murray cod fingerlings into reservoirs and farm dams in the South Australian Gulf Drainage Division (western Mount Lofty Ranges), and into dams linked with tributaries in the eastern Mount Lofty Ranges which are outside the natural distribution of Murray cod, but hydrologically connected to the lower River Murray (Figure 2). Further information on the context of stocking and the assumptions made in the risk assessment is provided in the methods, but it should be noted that the full risk assessment process described in Figure 1 was not undertaken, as it was outside the scope of the project. For example, consultation with all stakeholders did not occur. It should be noted that the risk assessment focused on environmental/ecological risks and does not consider socio-economic risks or benefits associated with stocking.

PIRSA Context – taken from terms of reference for a review of SA policy

Fisheries resources in South Australia are managed consistent with the objectives of the *Fisheries Management Act 2007*. Fisheries management is focussed on the sustainable use of South Australia's aquatic resources and the allocation of access to resources equitably to achieve optimum utilisation. However, fish stocks have been impacted by factors that are outside the control of the *Fisheries Management Act 2007*, including pollution, habitat destruction and environmental changes.

Various applications have been made to release cultured or translocated fish species into wild populations in fresh and marine waters. The common goal of these applications has been to enhance stocks with the argument that an increase in the numbers of a target species will result in increased catches, and higher economic and or social gains. However, significant difficulty exists in predicting the success of stock release and the many risks involved.

Any future stock enhancement exercises should be performed under the principles of ecologically sustainable development (ESD). Achieving ESD requires the integration of short and long-term economic, social and environmental effects in all decision-making.

The *Fisheries Management Act 2007* provides that ESD comprises the use, conservation, development and enhancement of the aquatic resources of the State in a way, and at a rate, that will enable people and communities to provide for their economic, social and physical well-being while—

(a) sustaining the potential of aquatic resources of the State to meet the reasonably foreseeable needs of future generations; and
(b) safeguarding the life-supporting capacity of the aquatic resources of the State; and
(c) avoiding, remedying or mitigating adverse effects of activities on the aquatic resources of the State,

(taking into account the principle that if there are threats of serious or irreversible damage to the aquatic resources of the State, lack of full scientific certainty should not be used as a reason for postponing measures to prevent such damage).

The current baseline of viability for stock enhancement must be investigated to construct an appropriate policy with scope to incorporate future developments. Improvements in techniques and technology will increase the viability and potential applications for stock enhancement in the future. The purpose of this review is to recommend a policy for the South Australian Government in relation to the release of cultured or translocated Murray cod into wild populations in the River Murray or into impoundments.

In South Australia, there is a very limited range of examples where stocking programs have been implemented. The Director of Fisheries has granted a small number of authorities under the *Fisheries Management Act 2007*. An example of these is for the South Australian Fly Fishers' Association to stock hatchery reared trout in designated waterways. Other examples in this state include closed system reservoirs for ecological and environmental purposes. The South Australian Government has not previously permitted the stocking of freshwater impoundments or marine waters for recreational or commercial fishing benefit. PIRSA has the legislative responsibility for granting permits to release freshwater fish in state waters, incorporating advice from other relevant government departments.

It should be noted that current pressure to undertake stocking in South Australia is growng, and this pressure may increase as use and interaction with natural resources increases over time. As this occurs, the potential social benefit of stocking programs will also increase. Additionally, our scientific knowledge of stocking will increase over time, enhancing the potential for successful outcomes.

Methods

A literature review on the impacts of stocking native fish was used to inform the ecological risk assessment. In particular, four key areas related to ecological interactions (e.g. competition and/or predation), genetic-related impacts, the unintentional introduction of pathogens or other organisms, and ecosystem level effects were identified as important mechanisms by which stocking of native fish may affect the ecology of the system. A workshop involving a multi-disciplinary group of experts (Appendix A), was then run to identify any other potential risks, to analyse the risks in terms of their probable consequences, the likelihood of these consequences occurring, and to produce an estimated level of risk (see Table 1, 2). A similar exercise was undertaken to assess the benefits.

The risk assessment focused on the stocked fish and only considered the progeny of any stocked fish in terms of genetic risks. Little consideration was given to collection of broodstock (but see below). All discussion assumed that any stocking of Murray cod would be based on use of local wild broodstock and that requirements of the NSW Hatchery Quality Assurance Program (HQAP) would be met (further details on the NSW HQAP can be found at: http://www.dpi.nsw.gov.au/fisheries/aquaculture/publications/species-

freshwater/collecting-finshish-broodstock/info-sheet). Murray cod are nationally listed as *vulnerable* under the *EPBC Act* (Environment Protection and Biodiversity Conservation Act 1999) and subsequently, there is a requirement to ensure that the number of fish that pass on genetic information (Ne) is maximised; a minimum of 100 broodstock is required.

It was also assumed that prior to stocking, fish would be tested to at least World Organisation for Animal Health (OIE) standards for known pathogens and that processes would be in place to identify and prevent the release of emerging diseases. Whilst all pathogens were considered together, it is acknowledged that the risks vary across groups of pathogens. For example, the likelihood of parasites being translocated with fish is high, but their establishment generally has low or moderate consequences, while viral diseases are less likely to be translocated, but on average have medium to high consequence where they establish in wild populations. These are averaged scenarios, and exceptional consequences are recorded in association with all pathogen groups. The efficacy of biosecurity measures in fish for stocking depends heavily on the Quality Management systems in place and the level to which this is adhered to and/or audited and compliance checked.

Examination of the NSW Department of Industry and Innovation data for Murray cod stocking from 2000 onwards showed that the majority of fish were stocked in batches of less than 10,000 fish. The risk assessment therefore assumed that stocking would generally comprise less than this number of fish and be made into large areas of a system.

Six groups of fish were considered in the ecological risk assessment (Table 3), namely:

(1) Native Murray cod already in the system;
(2) Large-bodied native freshwater species (e.g. golden perch, bony herring);
(3) Common small-bodied native freshwater species (e.g. flat-headed gudgeon, carp gudgeon);
(4) Rare and endangered small-bodied native freshwater species (e.g. Murray hardyhead, southern purple-spotted gudgeon);
(5) Exotic freshwater species (e.g. common carp, redfin perch);
(6) Diadromous species (e.g. common galaxias, congolli)

Estuarine fish species were not considered. Other threatened fauna [e.g. southern bell frog (*EPBC Act 1999*, vulnerable), broadshell turtle (*National Parks and Wildlife Act*, rare), Murray crayfish (Protected under the *Fisheries Management Act 2007*) were also considered (referred to as other in Appendix B, C).

Results

Between 37 and 58 potential impacts were identified for the different scenarios. From the consequence and likelihood scores determined at the workshop for each impact a level of risk was assigned and reviewed by workshop participants. High and extreme risk scores are summarised for the four major impact types (genetics, disease, abundance/behaviour, ecosystem level) in Table 4a. The likelihood, consequence and confidence, and subsequent risk of each impact and scenario are provided in Appendix B. Note that to properly assess the

risk tables the fish/biota in the potential receiving environment should also be considered/known. For example, stocking of Murray cod into areas where there are endangered species is likely to entail a higher risk than indicated. Similarly, stocking where there are only exotic species may be associated with a lower risk.

The risk of broodstock exploitation, where more fish are removed from the wild than can be replaced by natural reproduction or through recruitment of adults of hatchery origin, was considered high for both Murray River stocking scenarios. There has been minimal recruitment of Murray cod in South Australian waters, particularly in the lower River Murray since 2000 (National Murray Cod Recovery Team 2010), although recent flow events may have facilitated some recruitment.

Potential for high risks were also associated with predation on some groups, where stocked fish prey on wild biota (e.g. common small-bodied native fish, rare/endangered small-bodied native fish and other organisms). Murray cod are an apex predator feeding mainly on fish and crustaceans (Ebner 2006, National Murray Cod Recovery Team 2010). High risks were associated with both flow and reduced flow scenarios in the River Murray. Displacement of rare/endangered small-bodied native fish was also considered high risk under both flow scenarios for the River Murray, as was competition between stocked Murray cod and rare/endangered small-bodied native fish under a reduced flow scenario in the River Murray.

A greater number of high and extreme risks were associated with stocking Murray cod into reservoirs and farm dams in the South Australian Gulf Drainage division (65%) or the farm dams linked to tributaries in the eastern Mount Lofty Ranges (77%) largely because Murray cod do not naturally occur in these regions (Table 4a). The risk here is of Murray cod invading non-native catchments from farm dams etc if farm dams overflow during high rainfall events. High risks were associated with unintentional introduction of non-pathogenic organisms, behavioural impacts, displacement of wild fish, predation of stocked fish on wild fish and some ecosystem level effects (e.g. localised extirpation of a species) (Appendix B). Stocking Murray cod into farm dams in the eastern Mount Lofty Ranges (scenario 4) was also considered high or extreme risk in terms of competition between stocked and wild fish for space and habitat, and in the case of large-bodied natives for food.

Stocking Murray cod under Scenario 3 and 4 was not assessed as part of the ecological benefits table because these areas were outside of the natural range of the species. The only high level benefit was potential stock enhancement of Murray cod when there were years of recruitment failure, but this was only considered a high level benefit under reduced flow scenarios when natural recruitment was not likely to occur (Table 4b, Appendix C). It should be noted that the moderate level ecological benefits ascribed to hybridisation/genetic rescue assume that genetic rescue is necessary, which is not currently known for the lower River Murray.

Discussion

This study investigated ecological risks, but has not considered social and economic risks (or benefits), which will need considering prior to stocking of fish. In addition, if stocking is to proceed, then a management and evaluation plan is needed to ensure not only the effectiveness of stocking, but also to ascertain whether negative impacts have occurred. If negative impacts have occurred, then it will be necessary to ascertain whether they are within the bounds that are considered acceptable. Monitoring and periodic review is also recommended. Future research may also consider a more quantitative assessment where impact levels are identified (e.g. as a percentage), although such assessment generally requires more detailed environmental information, which is not always available.

The status of Murray cod in SA currently provides some level of concern. Abundances are likely low, and the population is dominated by larger sized individuals in the lower River Murray. While Murray cod do spawn annually the bottleneck seems to be with recruitment, which appeared to be low for the past 16 years (Ye & Zampatti 2007, Ye unpublished data). It is important to recognise that stocking of Murray cod may mask what is causing recruitment failure, and there is no assurity that stocked fish will survive as the low level of recruitment in the past years and the current low abundance of the population may be indicative of environmental stress limiting the survival in the early life stages and population size. Further research is required to determine the environmental factors and/or mechanisms that are leading to recruitment failure in Murray cod.

Further research is required to properly assess the genetics of Murray cod in the lower River Murray. Whilst Rourke (2007) had some samples from SA for her population structure research, they came from 2-3 locations near the SA border. It is important to determine the genetic diversity of the SA Murray cod population across its extant range and whether the lower River Murray population has any unique genes. This is vital information to obtain prior to stocking to ensure that the appropriate wild broodstock (location and number) are used. Depending on the genetic diversity of the SA fish, it may be advantageous to bring in fish from other areas, but within the population boundaries of the SA population. Thorough baseline data and ongoing genetic testing would be required.

It is also recommended that the level of surveillance for pathogens be higher than that in NSW (currently examine 5 fish) since virtually nothing is known of wild fish pathogens in SA. It was acknowledged that Murray cod and silver perch (Protected under the *Fisheries Management Act 2007*) share similar pathogens. Fish under environmental stress (e.g. low flow, extreme temperatures, breeding condition) may have increased susceptibility to disease. If stocking occurs during times of environmental stress, then additional monitoring may be required.

To minimise impacts particularly on threatened species, it is important to avoid stocking Murray cod into areas known to have threatened species. For example, Murray cod should not be stocked into catchments where river blackfish (and other small-bodied threatened species) occur. South Australia also has other listed entities (e.g. Ramsar wetlands).

Consideration of stocking in these listed entities may trigger referrals through the EPBC Act, River Murray Act and National Parks and Wildlife Act.

The risk assessment focused around release of fingerlings and their potential impacts. It does not consider potential impacts associated with angler take should stocking proceed. Indeed, an expanding recreational fishery was thought to contribute to a decline in Murray cod numbers in some NSW rivers (National Murray Cod Recovery Team 2010). In addition, the National Recovery Plan for Murray cod also notes that stocking is not generally considered a long-term conservation solution (National Murray Cod Recovery Team 2010). Management should also consider addressing other threats that may allow population levels to rebuild without artificial enhancement.

Although large numbers of native fish are stocked throughout the Murray-Darling Basin, little is known about the fate of stocked fish or their impacts on wild populations (Crook et al. 2010). Stocking is generally considered most effective in impoundments, although it is river populations of Murray cod that are under threat (National Murray Cod Recovery Team 2010). Until recently, following the fate of stocked individuals has been difficult due to a lack of effective methods for marking small individuals (but see Crook et al. 2007, Crook et al. 2009, Woodcock et al. 2011). We recommend that should stocking proceed all stocked fish are marked such that success can be evaluated. Stocking of golden perch in three Murray-Darling Basin rivers showed that a proportion of stocked fish survived to reach the legal minimum size, but that the impacts of stocking on population structure varied considerably among rivers (Crook et al. 2010). Management and monitoring of any stocking activities would therefore be essential to determine the effectiveness and potential risks/benefits.

Management Recommendations

Prior to stocking of Murray cod it is recommended that further research includes:

- Determining the environmental factors and/or mechanisms that may be leading to recruitment failure in Murray cod;
- Properly assessing the baseline genetics of Murray cod across their extant range in the lower River Murray;
- Assessing potential impacts associated with recreational fishing (angler take plus catch and release) in terms of risks and benefits;
- Undertaking the full risk assessment process including assessing socio-economic risks and benefits and consulting with all potential stakeholders.

Should Murray cod stocking proceed, it is recommended that:

- Clear goals and objectives for stocking are identified as part of the management plan;
- Quantitative measures of success or otherwise are defined;
- Monitoring, assessment and periodic review is undertaken;
- Ongoing genetic sampling and monitoring is undertaken for wild stocks and hatchery fish;

- Surveillance of pathogens should be higher than that currently undertaken in NSW;
- The fish/biota of the receiving environment are assessed to ensure that areas where threatened species occur are not stocked;
- All hatchery-reared fish should be marked such that the effectiveness of stocking can be evaluated;
- An adaptive management approach is utilised.

Table 1. Qualitative measures of (a) consequence, and (b) likelihood of stocking Murray cod in rivers and impoundments (adapted from Crawford 2003). An indication of confidence is also included.

Level	Descriptor	Detailed description
(a)	***Consequence***	
1	Insignificant	Changes to the environment are not readily detectable; any changes occur over small spatial and temporal scales
2	Minor	Minor environmental effects around local stocking site
3	Moderate	Medium environmental impact
4	Major	Large and widespread environmental impact
(b)	***Likelihood***	
A	Almost certain	Is expected to occur in most circumstances
B	Likely	Will probably occur in most circumstances
C	Possible	Might occur at some time
D	Unlikely	Could occur at some time
E	Rare	May only occur in exceptional circumstances
(c)	***Confidence***	
1	High	Local or regional information available, documented process, experts generally agree
2	Medium	Limited information, documented process elsewhere in region or similar region, experts differ
3	Low	Perception based on limited information that is not local or regional or no supporting information

Table 2. Risk analysis matrix incorporating consequence and likelihood scores as one of four categories: low (L), moderate (M), high (H) or extreme (E).

	Consequence			
	Insignificant	Minor	Moderate	Major
Likelihood	1	2	3	4
A (almost certain)	Low	Moderate	High	Extreme
B (likely)	Low	Moderate	High	Extreme
C (moderate)	Low	Low	Moderate	High
D (unlikely)	Low	Low	Moderate	Moderate
E (rare)	Low	Low	Low	Moderate

Table 3. Species list for the River Murray (natural range of Murray cod), eastern Mount Lofty Ranges (outside the natural range of Murray cod) and the South Australian Gulf Drainage Division indicating life history, grouping for risk assessment, EPBC, SA Fisheries Act and 2009 Action Plan for South Australian Freshwater Fishes ratings. Fish are 'grouped' as: L – Large-bodied native freshwater species, SC – Common small-bodied native freshwater species, SR – Rare or endangered small-bodied native freshwater species, EX – Exotic freshwater species, D – Diadromous species. EPBC ratings are: EN – endangered, VU – vulnerable; SA Fisheries column indicates if a protected species in SA; and the 2009 Action plan ratings are: EN – endangered, RA – rare, VU – vulnerable, EX – presumed extinct, CREN – critically endangered.

Common name	Scientific name	Family	Authority date	Life history	Grouping	EPBC rating	SAFisheries	2009 ActionPlan	River Murray - natural range of Murray cod	Eastern Mount Lofty Ranges (outside range)	South Australian Gulf Division
Pouched lamprey	*Geotria australis*	Petromyzontidae	Grey, 1851	Diadromous	D			EN	Yes		Yes
Shortheaded lamprey	*Mordacia mordax*	Petromyzontidae	(Richardson, 1846)	Diadromous	D			EN	Yes		Yes
Shortfinned eel	*Anguilla australis australis*	Anguillidae	Richardson, 1841	Diadromous	D			RA	Yes		Yes
Bony herring	*Nematalosa erebi*	Clupeidae	(Günther, 1868)	Obligate freshwater	L				Yes		
Freshwater catfish	*Tandanus tandanus*	Plotosidae	(Mitchell, 1838)	Obligate freshwater	L		P	EN	Yes		Introduced
Australian smelt	*Retropinna semoni*	Retropinnidae	(Weber, 1895)	Obligate freshwater	SC				Yes		
Climbing galaxias	*Galaxias brevipinnis*	Galaxiidae	Günther, 1866	Diadromous	D			RA		Single record	Yes
Common galaxias	*Galaxias maculatus*	Galaxiidae	(Jenyns, 1842)	Diadromous	D				Yes	Yes	Yes
Mountain galaxias	*Galaxias olidus*	Galaxiidae	Günther, 1866	Obligate freshwater	SR			VU	Yes	Yes	Yes
Flathead galaxias	*Galaxias rostratus*	Galaxiidae	Klunzinger, 1872	Obligate freshwater				EX	Presumed extinct		
Smallmouthed hardyhead	*Atherinosoma microstoma*	Atherinidae	(Günther, 1861)	Estuarine					Yes		Yes
Lake Eyre hardyhead	*Craterocephalus eyresii*	Atherinidae	(Steindachner, 1883)	Obligate freshwater							Yes (Lake Torrens)
Murray hardyhead	*Craterocephalus fluviatilis*	Atherinidae	McCulloch, 1912	Obligate freshwater	SR	VU		CREN	Yes		
Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*	Atherinidae	Ivanstoff, Crowley & Allen, 1987	Obligate freshwater	SC				Yes		
Murray rainbowfish	*Melanotaenia fluviatilis*	Melanotaeniidae	(Castelnau, 1878)	Obligate freshwater	SR				Yes		Introduced
Agassizi's glassfish	*Ambassis agassizii*	Ambassidae	Steindachner, 1867	Obligate freshwater			P	CREN	Presumed extinct		
River blackfish	*Gadopsis marmoratus*	Percichthyidae	Richardson, 1848	Obligate freshwater	L		P	EN	Yes (lower tribs.)	Yes	?
Trout cod	*Maccullochella macquariensis*	Percichthyidae	(Cuvier, 1829)	Obligate freshwater	L	EN	P	EX	Presumed extinct		
Murray cod	*Maccullochella peelii*	Percichthyidae	(Mitchell, 1838)	Obligate freshwater	L	VU		EN	Yes		Introduced
Murray-Darling golden perch	*Macquaria ambigua ambigua*	Percichthyidae	(Richardson, 1845)	Obligate freshwater	L				Yes		Introduced
Macquarie perch	*Macquaria australasica*	Percichthyidae	Cuvier, 1830	Obligate freshwater	L	EN		EX	Presumed extinct		
Estuary perch	*Macquaria colonorum*	Percichthyidae	(Günther, 1863)	Diadromous	D			EN	Yes		
Southern pygmy perch	*Nannoperca australis*	Percichthyidae	Günther, 1861	Obligate freshwater	SR		P	EN	Yes	Yes	Yes (Fleurieu)
Yarra pygmy perch	*Nannoperca obscura*	Percichthyidae	(Klunzinger, 1872)	Obligate freshwater	SR	VU	P	CREN	Yes		
Silver perch	*Bidyanus bidyanus*	Terapontidae	(Mitchell, 1838)	Obligate freshwater	L		P	EN	Yes		Introduced
Spangled grunter	*Leiopotherapon unicolor*	Terapontidae	(Günther, 1859)	Obligate freshwater	L				Yes		
Congolli	*Pseudaphritis urvillii*	Pseudaphritidae	(Valenciennes, 1832)	Diadromous	D			VU	Yes	Yes	Yes
Carp gudgeons	*Hypseleotris spp.*	Eleotridae	Species complex	Obligate freshwater	SC				Yes	Yes	Yes (Fleurieu)
Southern purple-spotted gudgeon	*Mogurnda adspersa*	Eleotridae	(Castelnau, 1878)	Obligate freshwater	SR		P	CREN	Yes		Presumed extinct
Flathead gudgeon	*Philypnodon grandiceps*	Eleotridae	(Krefft, 1864)	Obligate freshwater	SC				Yes	Yes	Yes
Dwarf flathead gudgeon	*Philypnodon macrostomus*	Eleotridae	Hoese and Reader, 2006	Obligate freshwater	SC				Yes	Yes	Yes (Fleurieu)
Western bluespot goby	*Pseudogobius olorum*	Gobiidae	(Sauvage, 1880)	Estuarine					Yes		Yes
Lagoon goby	*Tasmanogobius lasti*	Gobiidae	Hoese, 1991	Estuarine					Yes		Yes (KI)
Brown trout	*Salmo trutta*	Salmonide	Linnaeus, 1758	Obligate freshwater	EX				Introduced	Introduced	Introduced
Rainbow trout	*Oncorhynchus mykiss*	Salmonide	Walbaum, 1792	Obligate freshwater	EX				Introduced	Introduced	Introduced
Common carp	*Cyprinus carpio*	Cyprinidae	Linnaeus, 1758	Obligate freshwater	EX				Introduced	Introduced	Introduced
Goldfish	*Carassius auratus*	Cyprinidae	Linnaeus, 1758	Obligate freshwater	EX				Introduced	Introduced	Introduced
Tench	*Tinca tinca*	Cyprinidae	Linnaeus, 1758	Obligate freshwater	EX				Introduced	Introduced	Introduced
Eastern Gambusia	*Gambusia holbrooki*	Poecilidae	(Girard, 1859)	Obligate freshwater	EX				Introduced	Introduced	Introduced
Redfin perch	*Perca fluviatilis*	Percidae	Linnaeus, 1758	Obligate freshwater	EX				Introduced	Introduced	Introduced

Table 4. Summary of high and extreme risk or benefits of stocking Murray cod fingerlings under four scenarios (Scenario 1, stocking River Murray under flow conditions (>20,000 $ML.day^{-1}$), Scenario 2, stocking River Murray under reduced flow conditions (<20,000 $ML.day^{-1}$), Scenario 3, stocking reservoirs and farm dams in the SA Gulf drainage division and Scenario 4, stocking farm dams linked to tributaries in the eastern Mount Lofty Ranges). Shown are numbers of high or extreme (a) risks and (b) benefits, as well as the total number of potential impacts possible. Also shown is the percent of total responses that were high or extreme risk/benefit.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
(a) Risk				
Genetics	1/5	1/5	N/A	N/A
Disease	0/9	0/9	3/7	3/8
Abundance/Behaviour				
Competition	0/12	4/12	0/8	5/10
Behaviour	0/12	0/12	8/8	10/10
Displacement	1/6	2/6	4/4	5/5
Predation	3/6	3/6	4/4	5/5
Total	4/36	9/36	16/24	25/30
Ecosystem	0/7	0/8	5/6	6/7
Total Risk	5/57	10/58	24/37	34/45
Percent of total	9	17	65	77
(b) Benefit				
Genetics	0/1	0/1		
Abundance/behaviour	0/3	1/3		
Ecosystem	0/2	0/2		
Total Benefit	0/6	1/6		
Percent of Total	0	17		

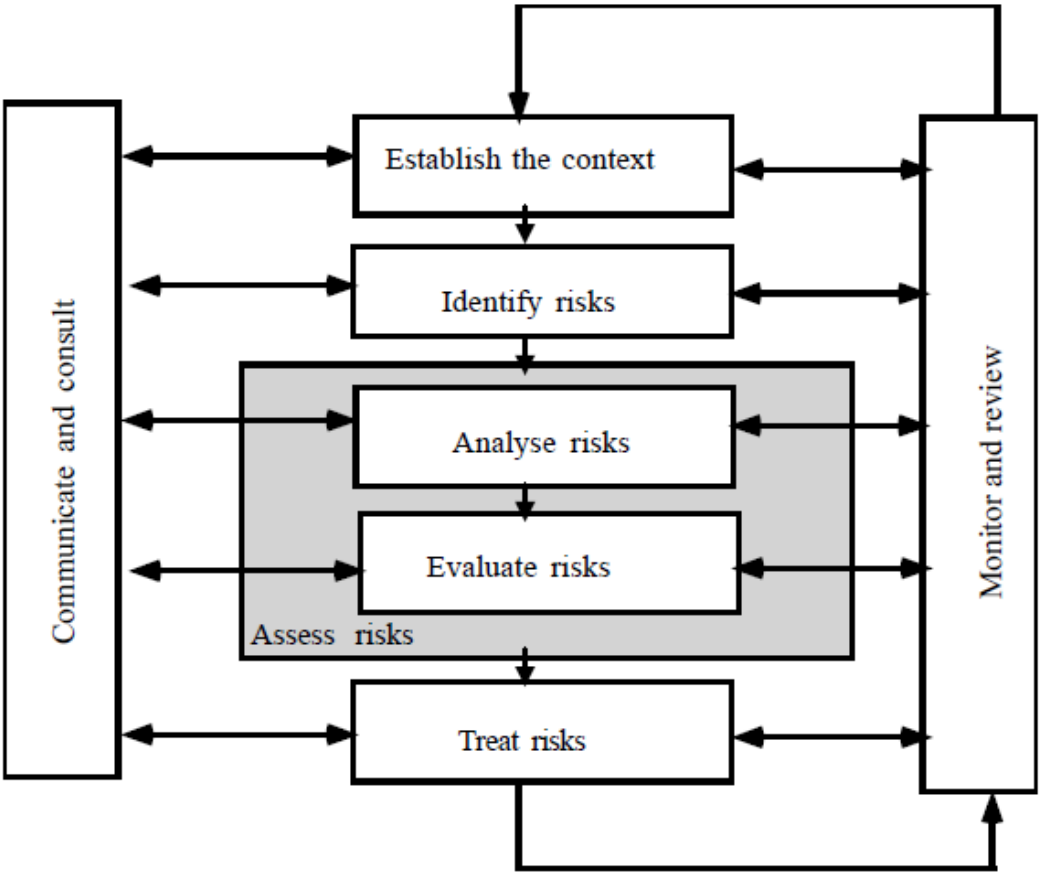

Figure 1. Overview of the risk management process (from Joint Australia/New Zealand Risk Management Standards).

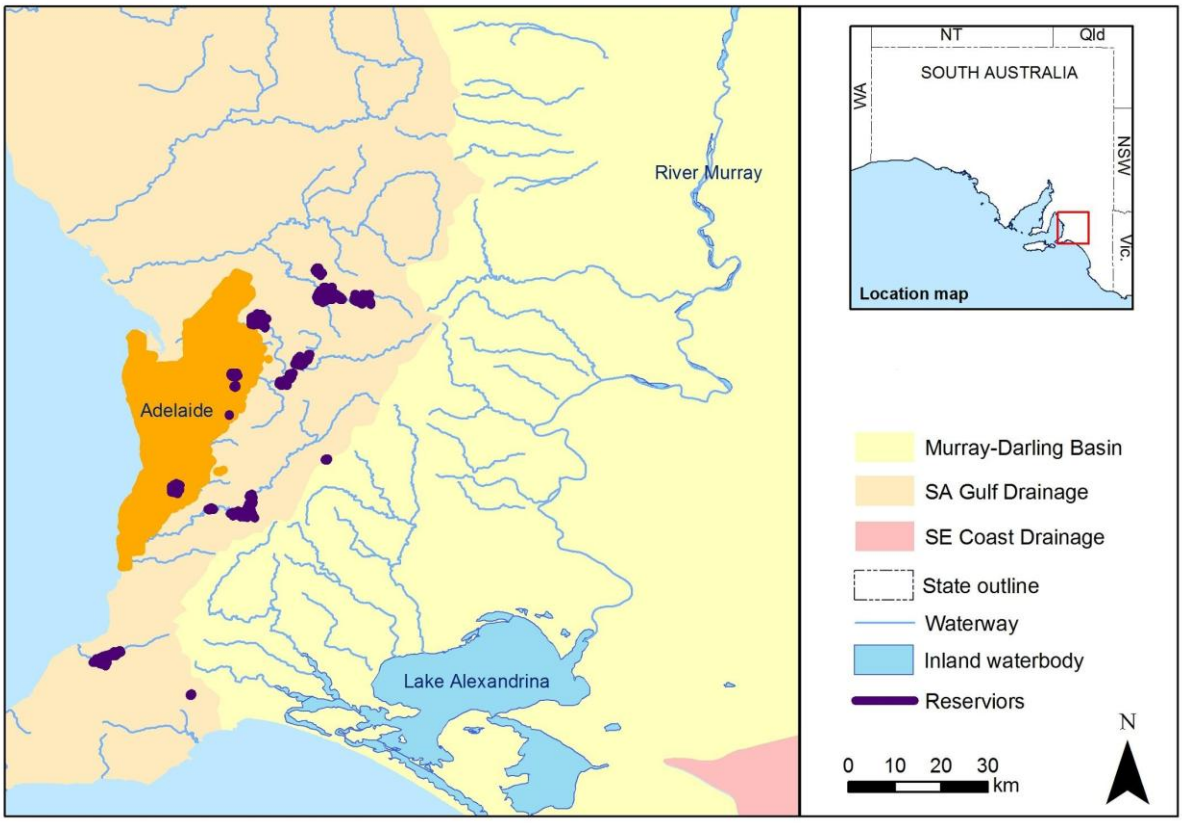

Figure 2. Map of South Australian section of the Murray-Darling basin and South Australian Gulf drainage division showing reservoirs.

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Appendices

Appendix A

List of workshop participants

Name	Position	Organisation
Chris Bice	Research Officer, Fish Ecology	SARDI Aquatic Sciences
Peter Copley	Senior Ecologist, Threatened Species & Ecological Communities	Department of Environment and Natural Resources
Marty Deveney	Senior Research Scientist, Marine Biosecurity	SARDI Aquatic Sciences
Sue Gehrig	Senior Research Officer, Plant Ecology	SARDI Aquatic Sciences
Bronwyn Gillanders	Professor, School of Earth and Environmental Sciences	University of Adelaide
Michael Hammer	Research Scientist	Native Fish Australia (SA)
Peter Jackson	Murray Darling Basin Authority Native Fish Strategy independent scientist	Independent Consultant
Dale McNeil	Acting Sub-program Leader, Climate & Catchment	SARDI Aquatic Sciences
Jonathan McPhail	Inland Fisheries Management Officer/Native Fish Strategy Coordinator	PIRSA Fisheries and Aquaculture
Andy Moore	Scientist, Fisheries and Marine Sciences	Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry
Stuart Rowland	Principal Research Scientist, Aquatic Ecosystems and Aquaculture	NSW Department of Industry and Innovation
Michael Sierp	Manager, Marine Biosecurity	Biosecurity SA
Nicholas Whiterod	Ecologist	Department of Environment and Natural Resources
Skye Woodcock	PhD student	University of Adelaide
Qifeng Ye	Principal Scientist, Inland Waters & Catchment Ecology	SARDI Aquatic Sciences
Brenton Zampatti	Sub-program leader, Fish Ecology	SARDI Aquatic Sciences

Appendix B

Table of environmental risk assessment for stocking Murray cod in South Australia. Shown is the broad impact type, more detailed impact, and aspect considered for four stocking scenarios (Scenario 1, stocking River Murray under flow conditions (>20,000 ML.day^{-1}), Scenario 2, stocking River Murray under reduced flow conditions (<20,000 ML.day^{-1}), Scenario 3, stocking reservoirs and farm dams in the SA Gulf drainage division and Scenario 4, stocking farm dams linked to tributaries in the eastern Mount Lofty Ranges). For each scenario the consequence (C1), likelihood (L), risk and confidence (C2) is provided (see Table 1 and 2 for details). Shaded grey areas were considered not applicable to the respective scenario.

Impact Type	Impact	Aspect	Scenario 1				Scenario 2				Scenario 3				Scenario 4				Notes
			Stocking River Murray (Flow)				Stocking RM (reduced flow)				Reservoirs and farm dams				Farm dams linked to tributaries				
			>20,000 ML/day				<20,000 ML/day				SA Gulf Drainage Division				Eastern Mt Lofty Ranges				
			C1	L	Risk	C2	C1	L	Risk	C2	C1	L	Risk	C2	C1	L	Risk	C2	
Genetic	Hybridisation & introgression with wild population (is homogenisation of genetic variation among populations likely)	Wild Murray cod	3	C	Moderate	2	2	B	Moderate	2	N/A				N/A				
	Genetic swamping (replacement of indigenous gene pool with genetic material from a stocked fish that are offspring of few parents)	Wild Murray cod	4	D	Moderate	1	4	D	Moderate	1									
	Oubreeding depression (erosion of population fitness following hybridisation, e.g. reduced fertility or viability)	Wild Murray cod	4	E	Moderate	1	4	E	Moderate	1									
	Broodstock exploitation (when more fish are removed from wild than can be replaced by natural reproduction or through recruitment of adults of hatchery origin)	Wild Murray cod	4	C	High	3	4	C	High	3									
	Hybridisation & introgression with wild population (is this likely to reduce fitness of population)	Trout cod	4	E	Moderate	1	4	E	Moderate	1									
Disease	Unintentional introduction of diseases, parasites and other pathogenic organisms via stocking	Wild Murray cod	3	C	Moderate	2	3	C	Moderate	2									
		Large bodied native	3	D	Moderate	2	3	D	Moderate	2					4	D		3	
		Common small-bodied native	3	D	Moderate	2	3	D	Moderate	2	3	D	Moderate	3	3	D	Moderate	3	
		Rare/endangered small bodied native	4	D	Moderate	2	4	D	Moderate	2	4	D	Moderate	3	4	D	Moderate	3	
		Diadromous	3	D	Moderate	2	3	D	Moderate	2	3	D	Moderate	3	3	D	Moderate	3	
		Other	3	E	Low	2	3	E	Low	2	3	E	Low	3	3	E	Low	3	
	Unintentional introduction of non-pathogenic organisms (e.g. carp, redfin perch, mosquitofish) via stocking contaminants		3	C	Moderate	1	3	C	Moderate	1	3	B	High	1	3	B	High	1	
	Introduction Native Fish and other biota (within natural range)		2	B	Moderate	2	2	B	Moderate	2	3	B	High	2	3	B	High	2	
	Introduction Native Fish and other biota (outside natural range)		3	C	Moderate	2	3	C	Moderate	2	3	B	High	2	3	B	High	2	
Abundance/behaviour responses	Competition between stocked & wild fish for food (may be density & resource dependent & age)	Wild Murray cod	2	C	Low	3	2	B	Moderate	3									Depends on carrying capacity, stocking density
		Large bodied native	2	C	Low	3	2	B	Moderate	3					3	B	High	2	
		Common small-bodied native	2	C	Low	3	2	B	Moderate	3	2	C	Low	3	2	B	Moderate	3	
		Rare/endangered small bodied native	3	C	Moderate	3	3	B	High	3	3	C	Moderate	3	3	B	Moderate	3	
		Diadromous	3	C	Moderate	3	3	B	High	3	3	C	Moderate	3	3	B	Moderate	3	
		Other	3	C	Moderate	3	3	B	High	3	3	C	Moderate	3	3	B	Moderate	3	
	Competition between stocked & wild fish for space & habitat	Wild Murray cod	2	C	Low	3	2	B	Moderate	3									
		Large bodied native	2	C	Low	3	2	B	Moderate	3					3	B	Moderate	3	
		Common small-bodied native	2	B	Moderate	3	2	A	Moderate	3	2	B	Moderate	3	3	A	High	3	
		Rare/endangered small bodied native	3	C	Moderate	3	3	B	High	3	3	C	Moderate	3	4	B	Extreme	3	
		Diadromous	2	B	Moderate	3	2	A	Moderate	3	2	B	Moderate	3	3	A	High	3	
		Other	2	C	Low	3	2	B	Moderate	3	2	C	Low	3	3	B	High	3	
	Behavioural changes: Stocked fish have behaviours that cause competition with wild fish (e.g. aggression)	Wild Murray cod	3	E	Low	1	3	E	Low	1									
		Large bodied native	3	E	Low	2	3	E	Low	2					4	A	Extreme	2	
		Common small-bodied native	3	E	Low	2	3	E	Low	2	3	B	High	2	3	B	High	2	
		Rare/endangered small bodied native	3	E	Low	2	3	E	Low	2	4	A	Extreme	2	4	A	Extreme	2	
		Diadromous	3	E	Low	2	3	E	Low	2	3	B	High	2	3	B	High	2	
		Other	3	E	Low	2	3	E	Low	2	3	B	High	2	3	B	High	2	
	Behavioural changes: Stocked fish alter behaviour of wild fish (e.g. activity patterns)	Wild Murray cod	3	D	Moderate	2	3	D	Moderate	2									
		Large bodied native	3	D	Moderate	2	3	D	Moderate	2					4	A	Extreme	2	
		Common small-bodied native	3	D	Moderate	2	3	D	Moderate	2	3	B	High	2	3	B	High	2	
		Rare/endangered small bodied native	3	D	Moderate	2	3	D	Moderate	2	4	A	Extreme	2	4	A	Extreme	2	
		Diadromous	3	D	Moderate	2	3	D	Moderate	2	3	B	High	2	3	B	High	2	
		Other	3	D	Moderate	2	3	D	Moderate	2	3	B	High	2	3	B	High	2	
	Displacement of wild fish (e.g. where resources are limited or where numbers of stocked fish exceed wild recruitment rates)	Wild Murray cod	3	C	Moderate	2	4	B	Extreme	2									
		Large bodied native	3	E	Low	2	3	E	Low	2					4	B	Extreme	2	
		Common small-bodied native	3	E	Low	2	3	E	Low	2	4	B	Extreme	2	4	B	Extreme	2	
		Rare/endangered small bodied native	4	C	High	2	4	C	High	2	4	B	Extreme	2	4	B	Extreme	2	
		Diadromous	3	E	Low	2	3	E	Low	2	4	B	Extreme	2	4	B	Extreme	2	
		Other	3	E	Low	2	3	E	Low	2	4	B	Extreme	2	4	B	Extreme	2	
	Predation – Stocked fish prey on wild fish	Wild Murray cod	3	D	Moderate	2	3	D	Moderate	2									
		Large bodied native	3	C	Moderate	2	3	C	Moderate	2					4	C	High	2	
		Common small-bodied native	3	B	High	2	3	B	High	2	4	B	Extreme	2	4	B	Extreme	2	
		Rare/endangered small bodied native	4	C	High	2	4	C	High	2	4	A	Extreme	2	4	B	Extreme	2	
		Diadromous	3	C	Moderate	2	3	C	Moderate	2	4	C	High	2	4	C	High	2	
		Other	3	B	High	2	3	B	High	2	4	B	Extreme	2	4	B	Extreme	2	
Ecosystem level	Water quality						2	D	Low	1									
	Habitat alteration from stocking native fish																		
	Trophic cascades/ecosystem shifts (e.g. piscivores prey on planktivores leading to increased abundance of herbivores, & reduced phytoplankton biomass)		2	D	Low	3	2	D	Low	3	2	C	Low	3	2	C	Low	3	
	Localised extirpation of a species	Wild Murray cod																	
		Large bodied native	4	E	Moderate	2	4	E	Moderate	2					4	B	Extreme	1	
		Common small-bodied native	4	E	Moderate	2	4	E	Moderate	2	4	C	High	2	4	C	High	2	
		Rare/endangered small bodied native	4	E	Moderate	2	4	E	Moderate	2	4	B	Extreme	2	4	B	Extreme	2	
		Diadromous	4	E	Moderate	2	4	E	Moderate	2	4	C	High	2	4	C	High	2	
		Other	4	E	Moderate	2	4	E	Moderate	2	4	C	High	2	4	C	High	2	
	Exceeding carry capacity		3	D	Moderate	2	3	C	Moderate	2	4	A	Extreme	2	4	A	Extreme	2	
Number assessed			57				58				37				45				

Appendix C

Table of environmental benefits associated with stocking Murray cod in South Australia. Shown is the broad impact type (where impact is positive), more detailed impact, and aspect considered for four stocking scenarios (Scenario 1, stocking River Murray under flow conditions (>20,000 ML.day^{-1}), Scenario 2, stocking River Murray under reduced flow conditions (<20,000 ML.day^{-1})). For each scenario the consequence (C1), likelihood (L), benefit and confidence (C2) is provided (see Table 1 and 2 for details). Shaded grey areas were considered not applicable to the respective scenario. Stocking outside the natural range of Murray cod (scenario 3 and 4) was not considered beneficial therefore was not considered further.

Benefit Type	**Benefit**	**Aspect**	**Scenario 1**				**Scenario 2**			
			Stocking River Murray (Flow)				***Stocking RM (No/low flow)***			
			>20,000 ML/day				***<20,000 ML/day***			
			C1	*L*	*Benefit*	*C2*	*C1*	*L*	*Risk*	*C2*
Genetics	Is hybridisation beneficial (e.g. introduces variation upon which natural selection can act) / genetic rescue	Murray cod	3	C	Moderate	3	3	C	Moderate	3
Abundance/behaviour responses	Stock enhancment for Murray cod when there is recruitment failure for multiple years	Murray cod	3	C	Moderate	2	3	B	High	2
	Expansion of species range	Murray cod	2	C	Low	2	2	C	Low	2
	Predation – Stocked fish prey on wild fish	Exotic	3	C	Moderate	1	3	C	Moderate	1
Ecosystem level	Water quality		4	D	Moderate	1	4	D	Moderate	1
	Localised extirpation of a species	Exotic	4	E	Moderate	2	4	E	Moderate	2