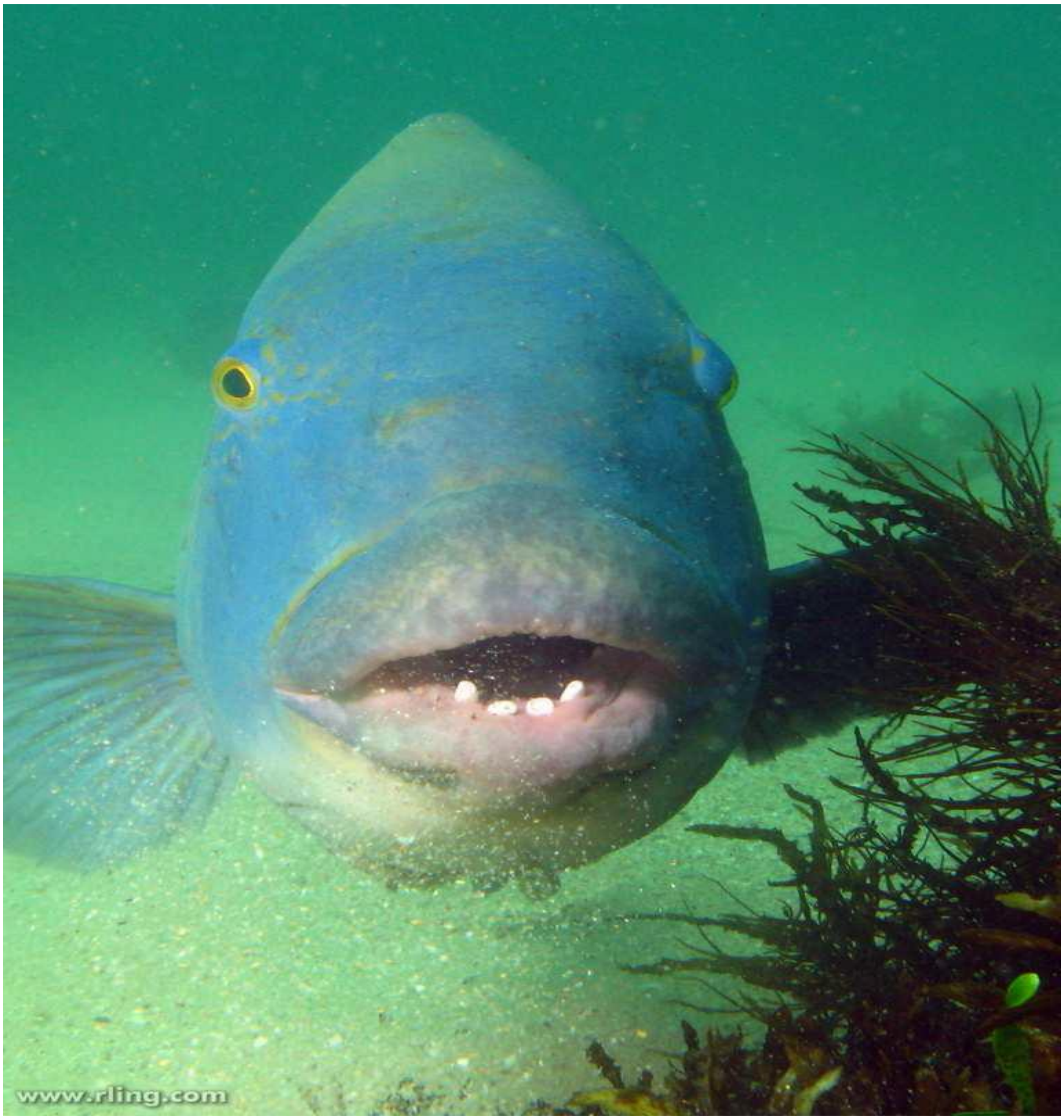
Preadapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species

Nicholas Bax, Neville Barrett, Alistair Hobday, Ruth Casper

Project No. 2010/564
February 2013



IMAS INSTITUTE FOR MARINE AND ANTARCTIC STUDIES
UTAS
National Research FLAGSHIPS Climate Adaptation
CSIRO
FRDC FISHERIES RESEARCH & DEVELOPMENT CORPORATION
Australian Government Department of Climate Change and Energy Efficiency

The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

National Library of Australia Cataloguing-in-Publication entry:

Author:	Bax, Nicholas J., author.
Title:	Preadapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species / by Nicholas Bax, Neville Barrett, Alistair Hobday and Ruth Casper.
ISBN (paperback):	978-1-922173-55-3
ISBN (ebook):	978-1-922173-56-0
Notes:	Includes index.
Subjects:	Fishes--Reintroduction--Tasmania. Wildlife reintroduction--Tasmania. Aquaculture--Environmental aspects--Tasmania. Fishery management--Tasmania.
Other Authors/Contributors:	Barrett, Neville, author. Hobday, Alistair J., author. Casper, Ruth author. CSIRO
Dewey Number:	639.309946

Suggested citation

Bax, N. J., Barrett, N. Hobday, A. J., Casper, R. (2013). Preadapting a Tasmanian coastal ecosystem to ongoing climate change through reintroduction of a locally extinct species. FRDC report 2010/564.

Table of Contents

1 Non-technical Summary

2010/564	**Preadapting a Tasmanian coastal ecosystem to ongoing climate change through reintrododuction of a locally extinct species.**

PRINCIPAL INVESTIGATOR: Dr Nicholas Bax
ADDRESS: CSIRO Marine and Atmospheric Research
Castray Esplanade
Hobart, Tasmania, 7001
Telephone: 03 6232 5341
Email: Nic.Bax@csiro.au

OBJECTIVES:

1. Develop and promote a national framework to evaluate potential translocations of native marine species.
2. Determine the feasibility of reintroducing blue groper as a test case.
3. Design a monitoring and evaluation program to determine the effects of a trial re-introduction.
4. Reach the critical decision point on whether to re-establish blue groper in Tasmania, or take an alternative approach indicated by the research. Develop a proposal to support this outcome.

OUTCOMES ACHIEVED TO DATE

Conservation translocations are increasingly being considered as a climate adaptation strategy. It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on CT proposals. This project developed a framework to assist those decisions and evaluated the framework with particular reference to the Eastern blue groper (EBG) in Tasmania.

Contrary to the recent published literature, our research showed that it is unlikely that EBG was present in Tasmania in the 1800's and if present was certainly not common. Therefore it was not fished to extinction as suggested by Last et al. (2010).

EBG has recently been observed in north-eastern Tasmania which is considered to be a range extension from NSW waters. In NSW, adult EBG are commonly seen in association with urchin grazed barrens and are thought to be a key predator of *C. rodgersii*. Based on evidence from NSW, populations of EBG in Tasmania may have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This suggests that any proposed translocation of EBG for this purpose would need to be part of a larger integrated management plan.

The need for a comprehensive decision framework with which to assess CT proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. A decision framework was designed in collaboration with the Tasmanian and Victorian governments to assist decision-makers evaluate proposals for managed translocation (Fig. 1). Our model for assessing CT proposals systematically considers relevant socio-economic, governance and scientific issues and is based on the Common Assessment and Reporting Framework model (MACC 2010) designed to facilitate implementation across the science/policy interface. It is structured around an adaptive management framework.

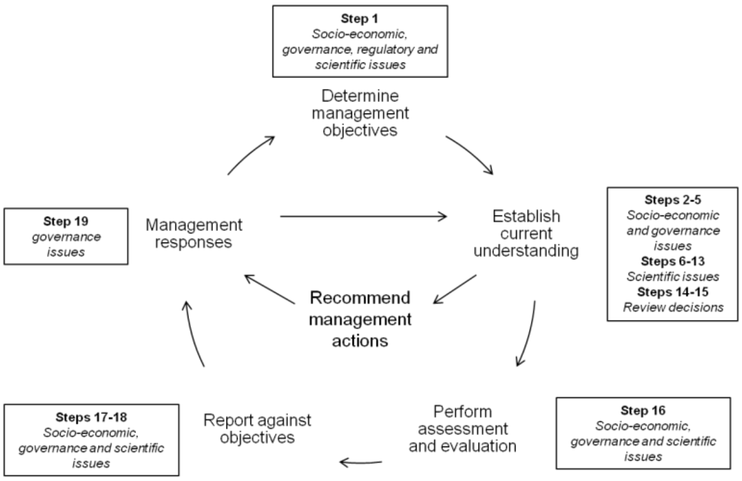


Figure 1. The Conservation Translocation decision framework

Management objectives are articulated at step 1. Risk analyses of socio-economic and governance issues (steps 2-5), and scientific issues (steps 6-13) are then carried out. Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section (steps 14-15) where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. If a CT project is implemented, appropriate performance indicators should be monitored and then evaluated at step 16. Findings and recommendations are then reported to management (steps 17-18), who then determine and implement appropriate responses (step 19).

Our framework suggests that a CT project should not be implemented for EBG at this stage as the aims are inadequately supported by available scientific evidence. The framework was also tested against 3 other CT examples described in the published literature. Although this decision framework was developed to assess CT proposals as an ecosystem-level climate change adaptation strategy, we demonstrated that this model can also successfully test CT proposals with other ecosystem oriented goals from a range of ecological contexts. This decision framework is a flexible and utilitarian model for assessing CT proposals, which can be modified where necessary and used effectively across a variety of situations. Above all, this framework is intended as a tool to facilitate progressive and constructive discussion, as well as assessment and implementation of conservation translocation proposals as a climate change adaptation strategy.

The framework was developed in consultation with the Tasmanian and Victorian governments. Discussions are ongoing with Tony Roberts who chairs the Biodiversity Thematic Oversight Group (Bio TOG) that reports to SCEW (via the Senior Officials Group), and Dr Subho Banerje, chair of the Select Council on Climate Change (SCCC) Adaptation Working Group (AWG), to determine how or whether this framework can be considered to support decision making by all Australian governments.

KEYWORDS

WRASSE, Labridae spp, marine species, climate change, adaptation, East Australian Current, managed translocation, conservation translocation, decision framework.

2 Acknowledgments

We thank Jo Klemke, Grant Pullen and Greg Johannes for their expert advice on socio-economic, regulatory and governance issues. This paper is an output for FRDC-DCCEE Project 2010/564, supported by CSIRO and UTAS.

3 Background

Over the last 10 years, concern has been mounting over the increased incidence of mainland marine species moving south and establishing residence in Tasmania. This is widely interpreted as an early result of climate change, in particular because the increased southerly penetration of the eddy field of the East Australian Current has caused the waters off Eastern Tasmania to warm more rapidly than any marine area in the southern hemisphere over the last 50 years. While this southerly extension of mainland fish has been often discussed, it was only in 2010 that a scientific study went back to the earliest reliable records of fish present in Tasmania to provide evidence that a change has indeed occurred (Last et al. 2010. Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography. DOI 10.1111/j.146608238.2010.00575.x.). An unexpected outcome of this analysis was to identify three species that had been present locally in the 'late 1800s', one of which was the blue groper. The authors concluded: "Some of the region's largest predatory reef fishes have become extinct in Tasmanian seas since the 'late 1800s', most likely as a result of poor fishing practices."

At the same time, long-term monitoring of temperate Australian marine reserves in particular the Maria Island marine reserve off Eastern Tasmania have shown the effects that removing fishing pressure can have on the invertebrate (Barret et al. 2009; Changes in invertebrate and macroalgal populations in Tasmanian marine reserves in the decade following protection. J. Exp. Mar. Bio. Ecol. 370: 104-119) and fish populations (Edgar and Stuart-Smith 2009. Ecological effects of marine protected areas on rocky reef communities – a continental-scale analysis. Mar. Ecol. Prog. Ser. 388: 51-62). These studies indicated how the presence of larger (in)vertebrate predators can change the structure of the temperate rocky reef ecosystems through trophic cascades. An extreme example of this would be the local extinction of possibly Tasmania's largest fish reef predator.

Other changes have been occurring on Tasmania's rock reefs. The sea urchin (*Centrostephanus rodgersii*) has undergone a poleward expansion creating urchin barrens off Eastern Tasmania and negatively impacting biodiversity (Ling. 2008. Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. Oecologia 156: 883-894). The lack of large predators has been suggested as one reason for its successful establishment and a project is underway to test the potential of translocating larger individuals of the southern rock lobster to shallower waters where they can prey on the urchins.

In the face of all this change, the adaptation options may appear to be limited. One prospect however is enhancing autonomous adaptation by translocation. Assisted translocation has been proposed as an approach to conserve species threatened by climate change (eg. Hoegh-Guldberg et al. 2008. Assisted colonization and rapid climate change. Science 321: 345-346) and also condemned as foolhardy by scientists familiar with the failures of non-specific biological control (Ricciardi and Simberloff 2009. Assisted colonization is not a viable conservation strategy. TREE 24: 248-251). Here we propose to ask whether assisted translocation could be used to improve resilience (or pre-adapt) the Tasmania's temperate reefs to climate-related threats including range expansion of invasive species. Reintroducing the blue groper provides an ideal opportunity to test this concept in a risk-averse manner, but while this project will have a focus on this fish, we will also be asking more generally, under what conditions should society consider reintroduction, local enhancement or assisted translocation to "pre-adapt" temperate rocky reefs to climate change, and what safeguards need to be in place before this occurs. We will build on aquaculture guidelines (eg. Lorenzen et al. in press. Responsible approach to marine stock enhancement: an update. Reviews in Fisheries Science), the extensive literature on the success and failure of biological control (eg. Bax et al. 2001. The control of biological invasions in the world's oceans. Conservation Biology 15: 1234-1246), and the national protocols developed for species translocation through MACC.

Once the opportunity for this research was identified we held a meeting with Rebekah Burton and Greg Johannes (both Deputy Secretaries of the State Department of Premier and Cabinet) to gauge the interest of the Tasmanian Government in pursuing this idea. They supported developing these ideas further and recognized the long-term potential of the research for Tasmania.

4 Need

Changing marine climate is driving species south, impacting recreational and commercial fishers and biodiversity and conservation values. At the same time, the local environment is changing the capacity of ecosystems to respond to an increasing array of environmental pressures. Is adapting our social and economic systems the only option for conservation managers and planners, or can we increase the resilience of the local environment to the increasing pressures? Can we gain time, or could we even influence the trajectory of change?

Assisted translocation (within the historic range) may preserve isolated populations of terrestrial animals. Is this appropriate in marine environments? Translocation typically emphasizes individual species. Would a more influential approach be to translocate species that would benefit the receiving ecosystem? We propose to develop the protocols and safeguards to reintroduce a key temperate reef predator – the blue groper – that became locally extinct in Tasmania over a century ago. The blue groper is a temperate wrasse that grows to over 50kg. It is a charismatic component of the NSW fish fauna interacting with snorkelers, divers and recreational fishers. Its diet includes the long-spined sea urchin currently establishing in Tasmania. Rearing and transporting similar species is well understood and the sequential hermaphroditism potentially provides the opportunity to introduce only larger male fish.

This will be a test case to determine whether translocating marine species is a viable option to improve resilience to climate change and what processes, knowledge and changes in policy are required before attempting this. Our application is regional but the implications are national (and global). While we are using the blue groper as the focus for our work, we will be exploring more generally the opportunities for assisted translocation, local enhancement to increase the resilience of temperate reefs, and the protocols and safeguards that would be required.

5 Objectives

1. Develop and promote a national framework to evaluate potential translocations of native marine species.
2. Determine the feasibility of reintroducing blue groper as a test case.
3. Design a monitoring and evaluation program to determine the effects of a trial re-introduction.
4. Reach the critical decision point on whether to re-establish blue groper in Tasmania, or to take an alternative approach indicated by the research. Develop a proposal to support this outcome.

6 Methods

Methods are extracted from 3 published or submitted manuscripts presented in full in the appendices to this document.

In this project, we are investigating the scientific, legal and social feasibilities of the managed translocation of locally extinct top predator species or likely future climate migrants, where this would benefit the receiving ecosystem.

As a test case, we are considering the managed translocation of the Eastern Blue Groper as a means of pre-adapting coastal reefs to ongoing warming of waters off eastern Tasmania (Casper et al. 2011).

As part of this process, the purpose of this report is to:

- review the history of EBG in Tasmania
- review the known ecology of EBG
- assess the potential for EBG to benefit Tasmanian coastal reefs, and
- identify important knowledge gaps

It is beyond the scope of this report to carry out a risk assessment or investigate the logistics of translocating EBG into Tasmania. Other components of this project will develop generic protocols for these elements and the EBG/Tasmanian test case will be assessed within those frameworks.

6.1 A review of the history of EBG in Tasmania and its known ecology

According to Last et al. (2011), the EBG was present in Tasmanian waters in the late 1800s and disappeared in the early 1900s. Within this period, the EBG was referred to by multiple scientific and common names and these names did not necessarily refer exclusively to the EBG. Therefore, an extensive search of historical records was carried out to confirm the presence of EBG populations in Tasmania, to determine where they existed and when and why they disappeared.

Electronic searches for potential references to the EBG in Tasmania were conducted using:

- Web of Knowledge scientific database (http://www.isiwebofknowledge.com)
- search for biological and archaeological records dating back to 1864
- TROVE digital newspaper database (http://trove.nla.gov.au/newspaper)
- Search of 22 Tasmanian newspaper and magazine titles from 1816-1954
- Manual searches were also conducted on the following hard copies:
- Royal Society of Tasmania papers and proceedings (1849-1970)
- Royal Commission on the Fisheries of Tasmania (1883)
- Superintendent and Inspector of Fisheries reports (1885-1887)
- Fisheries Board general report (1889)
- Commissioners of Fisheries reports (1911-1923)

The life history characteristics, distribution and abundance of the EBG were compiled using a combination of peer-reviewed literature, technical reports and unpublished data. The latter include Reef Life Survey (RLS) data (http://reeflifesurvey.com/; Edgar and Stuart-Smith), Marine Biodiversity (MB) data (Edgar, Barrett and Stuart-Smith), Victorian Subtidal Reef Monitoring Program (SRMP) data, post-graduate reports and theses, and expert opinion. The SRMP data are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment.

6.2 The decision framework design

A decision framework was designed to be used to assess proposals to translocate species as a management strategy for ecosystem level problems that are linked to climate change impacts. The framework was designed to include consideration of scientific, social, economic and governance issues. Adaptive management was incorporated as an integral component to promote ongoing learning with consequent appropriate and timely responses by management (Holling 1978). The design of the framework was based on a Common Assessment and Reporting Framework model (MACC 2010) to facilitate implementation across the science/policy interface.

Based on potential concerns associated with CT proposals identified in the scientific literature, we also incorporated a series of risk assessments of relevant socio-economic, governance and scientific issues. In consultation with three experts with socio-economic and governance knowledge at the level of Australian state government, we developed and refined the framework iteratively using a proposed CT of the eastern blue groper (EBG; *Achoerodus viridus*) from NSW to Tasmanian coastal reefs in Australia (Casper et al. 2011).

6.3 Testing the decision framework

Following development of the decision framework, we searched the scientific literature for examples with which to test it. Very few ecosystem oriented CTs have been proposed or carried out (Polak and Saltz 2011). Of these, even fewer have sufficient published information available to enable adequate testing of the decision framework. Here, we tested four suitable proposed or implemented CT projects (Table 1). The EBG was the only example where the project was an ecosystem-level climate change adaptation strategy (Casper et al. 2011). Although the other projects tested have alternate ecosystem benefits as their primary goals, all acknowledge that ecosystem-level mitigation of climate change impacts is a likely additional benefit [dingo (*Canis lupus dingo*; Ritchie et al. 2012); European beaver (*Castor fiber*; Hood and Bayley 2008); large and giant tortoises (Testudinidae; Hansen et al. 2010)].

For the EBG example, decisions at each step within the framework were based on our own research (Casper et al. 2011) and expert advice. For the other examples, decisions at each step and any recommended and implemented management actions were based on the available literature.

Table 1. Summary characteristics of taxa used to test decision framework for conservation translocation projects.

Taxa	*Habitat*	*Climatic zone*	*Ecological niche*
eastern blue groper	Marine	temperate	large predator
Beaver	semi-aquatic riparian	temperate	keystone herbivore
Dingo	Terrestrial	semi-arid	keystone predator
giant tortoise	Terrestrial	tropical	keystone fructivore

7 Results/Discussion

Results and Discussion are extracted from 3 published or submitted manuscripts presented in full in the appendices to this document.

7.1 A review of the history of EBG in Tasmania and its known ecology

Close examination of the historical evidence, together with a review of the ecology of the EBG, has led us to conclude that it is unlikely that the EBG was present in Tasmania in the 1800s, and if present, was certainly not common (Figure 1). However, EBG are currently present in very small numbers in north-eastern Tasmanian waters. It is likely that this reflects a southward range expansion of EBG as a result of the southerly movement of the East Australian Current. The EBG is a fish species adapted to warm temperate coastal reef environments. The EBG present in Tasmania are currently at the southern edge of their range. In addition, EBG are protogynous hermaphrodites which change sex from female to male at around 10 years of age. Consequently, it is expected that it would take many years for a reproductively viable population of EBG to establish naturally in Tasmania. This process could be speeded up by managed translocation of EBG into Tasmanian waters, following demonstration of a clear environmental benefits and jurisdictional agreement.

In NSW, adult EBG are commonly seen in association with urchin grazed barrens and are thought to be a key predator of *C. rodgersii*. Based on evidence from NSW, populations of EBG in Tasmania may have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This suggests that any proposed translocation of EBG for this purpose would need to be part of a larger integrated management plan.

Although adult EBG in mainland waters appear to tolerate a range of habitats that vary in depth and degree of shelter, the requirements of larval and juvenile EBG are more specific. Establishing ecologically viable populations of EBG in Tasmania would depend on the availability of suitable juvenile habitat in shallow, sheltered seagrass or kelp. It is not known where EBG spawn, how larvae move from the continental shelf to seagrass beds, or how juveniles move from inner estuarine reefs to adult habitat on open coastal reefs. Linkages between estuaries and rocky reefs are important for sustaining populations of EBG, but the specific connectivity required, such as distances, movement corridors, stepping stones of natural habitat, are not known. EBG are particularly susceptible to spearfishing and gillnetting. It is therefore unlikely that EBG populations will become ecologically significant in Tasmanian coastal reefs, either naturally or through managed translocation, unless they are protected from fishing.

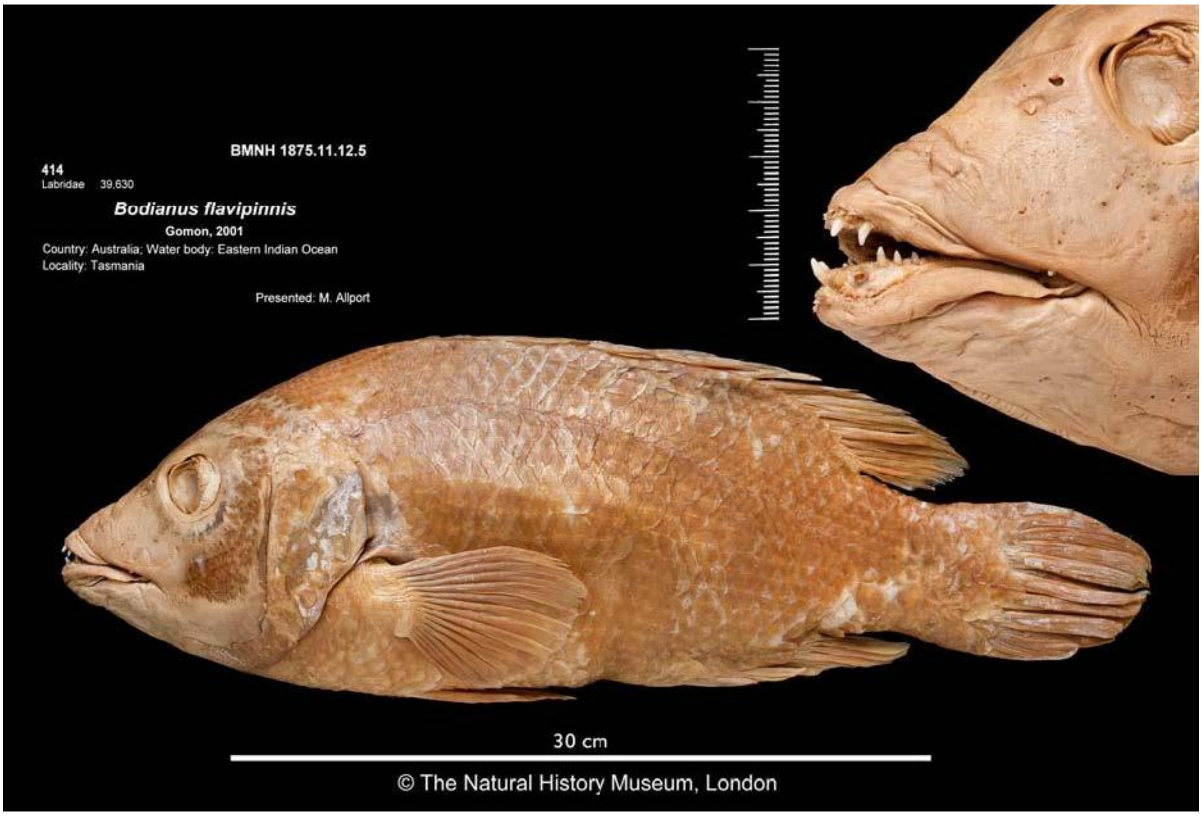


Figure 1. Photograph of Mr Allport's specimen No. 2 identified in 1875 by Dr Gunther as *Cossyphus gouldii* (Record 3 in Results). This specimen was subsequently identified in 2011 by Dr Gomon as *Bodianus flavipinnis*. Image: H. Taylor, © Natural History Museum, London.

7.2 The decision framework design

The framework consists of a series of decision steps (Appendix 5: WebPanel 1; Figure 2) which are guided by a set of principles (Appendix 5: WebPanel 2). Depending on the response at each step, the decision maker is guided to the next step or to one or more recommended management actions (Appendix 5: WebTable 1). For the most comprehensive assessment of a proposal, however, as much information as possible should be completed at all steps.

Management objectives are articulated at step 1. Risk analyses of socio-economic and governance issues (steps 2-5), and scientific issues (steps 6-13) are then carried out. Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section (steps 14-15) where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. If a CT project is implemented, appropriate performance indicators should be monitored and then evaluated at step 16. Findings and recommendations are then reported to management (steps 17-18), who then determine and implement appropriate responses (step 19).

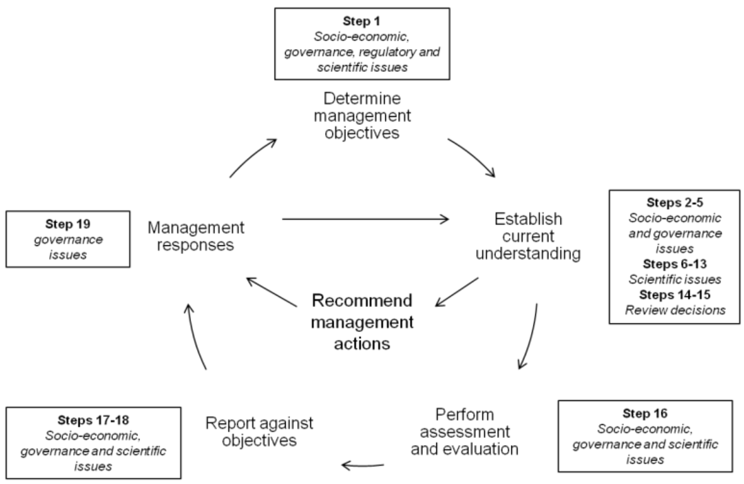


Figure 2. Decision steps.

The decisions at each step should be informed by people with appropriate expertise and authority (I.U.C.N. 2012). For example, decisions at step 1 ('Determine management objectives'), would involve individuals who are able to provide relevant advice on scientific, social, economic, governance and regulatory issues. Steps 6-13 deal with scientific issues, so need to be informed by scientists. Any decisions and actions, however, are a governance issue. This recognises that while recommendations can be made by social, economic and scientific experts as a result of this decision process, management responses (step 19) are also influenced by other considerations.

The framework consists of a series of steps (Part A) which are guided by a set of principles (Part B). Roman numerals refer to relevant guiding principles in Part B. Part A is divided into consecutive sections, each consisting of one or more decision steps. At each step, the decision results in either progression to the next decision step or in recommendation of one or more management actions (Table 2). Each section in Part A deals with decisions pertaining to one or more issues categories (i.e. scientific, social, economic, governance). The decisions made in each section should therefore be made by people with appropriate expertise and authority.

For example, decisions in the first section, 'Agree on objectives', should involve collaboration between individuals who, as a group, are able to provide relevant advice on scientific, social, economic and governance issues. The section 'Establish current understanding' deals with scientific issues, so decisions here should be made by scientists. Any actions taken, however, are a governance issue. This recognises that while recommendations can be made by scientific, social and economic experts as a result of this decision process, management responses are also influenced by considerations external to this process.

Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. Finally, this decision framework is not intended to be prescriptive. Rather, it is presented as a generic model which can be modified to suit individual situations as required.

Table 2. Recommended management actions referred to in Part A of decision framework.

A.	Investigate alternate management strategies, including managed translocation of alternate species and a 'do-nothing' option
B.	Fill data gaps and return to the appropriate level/s of the decision framework
C.	Investigate complementary management strategies to address non-climate change effects
D.	Implement a reversible pilot managed translocation project with adaptive management procedures
E.	Implement a more extensive managed translocation project with adaptive management procedures
F.	Implement management strategies to reverse any undesired effects of the MT project

Definitions

Ecosystem: a dynamic complex of plant, animal and micro-organism communities and the non-living environment interacting as a functional unit. A well defined ecosystem has strong interactions among its components and weak interactions across its boundaries (MilleniumAssessment 2003)

MT: the proposed managed translocation of Species X

MT project: the implemented managed translocation of Species X

Risk: the function of the likelihood of an event and the consequence of the event should it occur (Anon 2004)

7.3 Testing the decision framework

Conservation translocations (CT) are increasingly being considered as a climate change adaptation strategy. This has mostly been as a means of conserving populations or species (Perez et al. 2012), but there is also growing recognition of the potential for this strategy to provide profound benefits at an ecosystem-level, for example through restoration of seagrass beds (Irving et al. 2011), oyster reefs (Beck et al. 2011), plant-animal mutualisms (Kaiser-Bunbury et al. 2010) and predator-prey relationships (Ripple and Beschta 2012). It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on CT proposals.

Although still low, the number of peer-reviewed articles on species reintroductions that are ecosystem oriented has increased rapidly in recent years (n=0 before 1990, n=18 from 1991 to 1999, n=45 from 2000 to 2009; Polak and Saltz 2011). In most cases, however, there is a lack of clear description of the process. In addition, it is often uncertain how or indeed if, socio-economic and governance issues were considered. The need for a comprehensive decision framework with which to assess CT proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. Our model for assessing CT proposals systematically considers relevant socio-economic, governance and scientific issues.

In doing so, the strengths and risks associated with different proposals are clearly highlighted. For example, for both the EBG and dingo proposals, our framework suggests that a CT project should not be implemented at this stage, but for different reasons. The aims of the EBG proposal are inadequately supported by the available scientific evidence. By contrast, the aims of the dingo proposal are supported by good scientific evidence, but the associated socio-economic and governance risks are high. The value of the decision framework in identifying strengths and risks is realised by completing all steps as much as possible. For example, even though alternate strategies to CT were recommended early on in the assessment of the EBG proposal (step 6), completing subsequent steps provided a more complete evaluation of all the issues associated with this proposal. This allowed more comprehensive recommendations to management (Table 3).

Importantly, this process also facilitates prioritising areas for future research. For example, what data would be most useful to overcome the obstacles identified in the assessment of the proposal? In addition, the research questions identified in this way are not biased towards scientific issues. Socio-economic and governance impediments to achieving the aims of a proposal are highlighted in the same manner. This allows informed decisions on the most constructive research directions to be made in any particular case.

The decision framework also incorporates an adaptive management facility which allows for ongoing assessment and management of scientific, social, economic and governance issues once a pilot CT has been implemented. The European beaver and giant tortoise test cases illustrate this. In the case of the beaver, it is too soon to determine any positive or negative effects arising from the CT, which is therefore currently being monitored closely as a limited pilot project. The tortoise CT pilot project has been going for longer. Ongoing monitoring and evaluation indicate associated ecological and economic benefits and no threats. In response to these findings, the tortoise CT project has been expanded (Table 3).

Although this decision framework was developed to assess CT proposals as an ecosystem-level climate change adaptation strategy, we have demonstrated that this model can also successfully test CT proposals with other ecosystem oriented goals from a range of ecological contexts (Table 3). This decision framework is a flexible and utilitarian model for assessing CT proposals, which can be modified where necessary and used effectively across a variety of situations. Above all, this framework is intended as a tool to facilitate progressive and constructive discussion, as well as assessment and implementation of conservation translocation proposals as a climate change adaptation strategy.

Table 3. Summary outcomes of conservation translocation (CT) proposals used to test the decision framework For detail, see Appendix 5: WebTable2.

	CT of eastern blue groper (*Achoerodus viridis*) from NSW to Tasmania, Australia	**CT of European beaver (*Castor fiber*) to Scotland**	**CT of dingo to rangelands in semi-arid western NSW**	**CT of large and giant tortoises to Round Island, Mauritius**
Aim	To improve resilience of kelp dominated Tasmanian coastal reefs at risk of shifting to climate change mediated urchin barrens (*Centrostephanus rodgersii*; CR) dominated ecosystems.	To benefit Scotland's wider biodiversity through the effects of beaver foraging and engineering activities on woodland and aquatic habitats.	To increase biodiversity of small and medium sized native vertebrates through suppression of invasive mesopredator populations and increase plant biomass and biodiversity through suppression of irrupting herbivore populations.	To restore extinct keystone frugivore seed dispersal and herbivory functions of *Cylindraspis* spp. (Testudinidae) through taxon substitution with captive sourced *Aldabrachelys gigantea* and *Astrochelys radiata* (Testudinidae).
Outcome	It was assessed that significant effort is required to provide reasonable scientific evidence to support this aim. Effort is also needed to mitigate social and governance risks. Investigation of alternate management strategies is therefore recommended. This could include data gathering to assess the feasibility of mitigating these risks to acceptable levels, or increasing the abundance of an existing CR predator in this region, the southern rock lobster (*Jasus edwardsii*). .	Significant scientific and economic evidence supports the aim of this proposal. Following necessary mitigation of social and related governance risks, a reversible pilot CT project was implemented. Ongoing monitoring is being carried out, but it is too early to determine if the aim of this CT project is being achieved or if there are any associated ecological, social, economic or governance benefits or threats. The adaptive management program is continuing and there are currently no published plans to expand the project.	Although there is good scientific evidence supporting the aim of this proposal, significant mitigation effort is required to reduce the social, economic and governance risks to a level compatible with its likely success. Investigation of alternate management strategies is therefore recommended. This could include data gathering to assess the feasibility and usefulness of implementing a reversible pilot experiment using radio-collared dingos within a fenced protected area	The aim of this proposal is supported by scientific evidence. Following mitigation of some risks associated with ecological issues, a reversible pilot CT project was implemented. Ongoing monitoring and evaluation has provided evidence of ecological and economic benefits arising from this CT project. It has been assessed that the aim of the CT project is being achieved. The initial project has subsequently been expanded.

8 Benefits and Adoption

The decision framework was designed in consultation with the governments of Tasmania and Victoria, and is available to those governments and others to assist their decision making.

The literature survey corrected the scientific literature that had indicated the EBG to have been fished to extinction in Tasmanian waters.

The decision framework and its value in four test cases have been documented and presented to the scientific community through a formal scientific publication.

Formal adoption of the translocation framework was hindered by the dissolution of MACC since the project conception. We have explored another avenue, as detailed below.

On advice of Tony Roberts (Deputy Director-General, Environmental Policy and Planning, Department of Environment and Heritage Protection, Queensland Government) who chairs the Biodiversity Thematic Oversight Grooup (Bio TOG) that reports to SCEW (via the Senior Officials Group), the frameworks was discussed with Dr Subho Banerjee, Deputy Secretary of the Adaptation, International and Corporate Group of Department of Climate Change and Energy Efficiency and chair of the Select Council on Climate Change (SCCC) Adaptation Working Group (AWG).

Dr Bannerjee previously wrote to various organisations seeking advice on current climate change adaptation work being undertaken and where gaps may exist in this field. Tony Roberts suggested that given the relevance of managed translocation to climate change adaptation, that we raise the matter with Dr Banerjee so that it can be properly considered as the AWG refine potential work plans for the seven national priorities for collaborative action. Although the SCCC is set to conclude in March next year, the climate adaptation component is expected to transition to another Standing Council.

Dr Bannerjee is considering whether this research fits under the current AWG work plan areas, and if not will provide an alternative suggestion of where it might sit.

9 Further Development

This project was initially targeted at evaluating the potential for translocation of one species, based on the presumption that restoring this species to eastern Tasmania may result in ecosystem benefits. While Eastern Blue Groper remains a candidate species, one of the next steps should be to consider which other marine species may also be candidates for providing ecosystem, services, and evaluate these prior to any field trials for any species. At the same time, the expected benefit from translocation should be evaluated relative to the expected cost, benefit and risk of implementing other non-translocation options, including some traditional fishery management tools such as maximum size limits for southern rock lobster (an alternative urchin predator), or fishery closures to protect all sizes of lobster. This evaluation could be done using an ecosystem model, or via bioeconomic modelling.

With regard to the focal species, eastern blue groper, we also identified using the framework, where additional data should be collected (see Appendix and Table 3). Experiments to determine trophic impact of blue groper could be established in aquaria, or in part of the historical range.

10 Planned outcomes

Both Tasmanian and Victorian governments were formally involved in this process and are therefore now in a better position with respect to their capacity to develop policies to deal with climate change when ecosystem function is threatened. Results were to be presented to the MACC Biodiversity Working Group to extend these results to other Australian governments through MACC, however as detailed above this was not possible so other official avenues are being sought.

The work has been presented to local and national groups. Talks and media articles were used to raise awareness in local communities. The scientific community was and is being kept informed through conference presentations and journal papers.

11 Conclusion

1. Conservation translocations are increasingly being considered as a climate adaptation strategy. It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on CT proposals. This project developed a framework to assist those decisions and evaluated the framework with particular reference to the Eastern blue groper (EBG) in Tasmania.
2. Contrary to the recent published literature, our research showed that it is unlikely that EBG was present in Tasmania in the 1800's and if present was certainly not common. Therefore it was not fished to extinction as suggested by Last et al. (2010).
3. EBG has recently been observed in north-eastern Tasmania which is considered to be a range extension from NSW waters. EBG has been observed to eat *Centrostephanus rodgersii* in NSW waters suggesting that it might have an important ecological role to play in Tasmania temperate reef areas.
4. EBG are protogynous hermaphrodites and it is expected that it would take many years for a reproductively viable population to establish in Tasmania. Managed translocation could speed this process
5. A decision framework was designed in collaboration with the Tasmanian and Victorian governments to assist decision-makers evaluate proposals for managed translocation.
6. The need for a comprehensive decision framework with which to assess CT proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. Our model for assessing CT proposals systematically considers relevant socio-economic, governance and scientific issues.
7. Our framework suggests that a CT project should not be implemented for EBG at this stage as the aims are inadequately supported by available scientific evidence.
8. Despite EBG currently being rare in Tasmanian waters, future anticipated warming and increasing influence of the EAC could see EBG increasing in numbers and importance as a Centrostephanus predator in this region through time. As this species is particularly vulnerable to capture in recreational gillnets and to spearfishing, a precautionary approach to allowing EBG numbers to become established may be to give this species full protection under fishery legislation in a similar manner adopted recently in Victoria. Facilitating a "natural" establishment of EBG in NE Tasmania would be an ideal first step towards gathering the necessary scientific evidence to evaluate future CT options involving this species in NE Tasmania and eastern Victoria.

12 References

Beck MW, Brumbaugh RD, Airoldi L, *et al.* 2011. Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *Bioscience* **61**: 107-16

Casper RM, Barrett NS, Bax N, *et al.* 2011. Review of the eastern blue groper. Hobart: Institute of Marine and Antarctic Studies. http://eprints.utas.edu.au/11977.

Hansen DM, Donlan CJ, Griffiths CJ, *et al*. 2010. Ecological history and latent conservation potential: large and giant tortoises as a model for taxon substitutions. *Ecography* **33**: 272-84.

Holling CS (ed.). 1978. Adaptive environmental assessment and management.

Hood GA and Bayley SE. 2008. Beaver (*Castor Canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. *Biological Conservation* **141**: 556-67.

Irving AD, Connell SD and Russell BD. 2011. Restoring Coastal Plants to Improve Global Carbon Storage: Reaping What We Sow. *Plos One* **6**:

Kaiser-Bunbury CN, Traveset A and Hansen DM. 2010. Conservation and restoration of plant-animal mutualisms on oceanic islands. *Perspectives in Plant Ecology Evolution and Systematics* **12**: 131-43.

Last PR et al. (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecol Biogeogr 20: 58-72.

Perez I, Anadon JD, Diaz M, *et al.* 2012. What is wrong with current translocations? A review and a decision-making proposal. *Frontiers in Ecology and the Environment* **10**: 494-501.

Polak T and Saltz D. 2011. Reintroduction As an Ecosystem Restoration Technique. *Conservation Biology* **25**: 424-25.

Ripple WJ and Beschta RL. 2012. Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction. *Biological Conservation* **145**: 205-13.

Ritchie EG, Elmhagen B, Glen AS, *et al.* 2012. Ecosystem restoration with teeth: what role for predators? *Trends in Ecology & Evolution* **27**: 265-71.

13 Appendices

Appendix 1: Staff engaged on the project

Nicholas Bax, Senior Research Scientist, Director Marine Hub, TAFI, UTAS

Neville Barrett, Research Scientist, University of Tasmania

Alistair Hobday, Senior Research Scientist, CSIRO Marine Research

Ruth Casper, Institute of Marine and Antarctic Studies, University of Tasmania, Australia

Appendix 2: Eastern Blue Groper Review – IMAS Technical report

INSTITUTE FOR MARINE AND ANTARCTIC STUDIES
UNIVERSITY OF TASMANIA

Review of the Eastern Blue Groper (*Achoerodus viridis*)

Casper RM, Barrett NS, Bax N and Hobday AJ

The Institute for Marine and Antarctic Studies (IMAS), established in 2010, comprises the University of Tasmania's internationally recognised expertise across the full spectrum of temperate marine, Southern Ocean and Antarctic research and education.

CONTACT US:

IMAS is currently located at two main campuses:

Sandy Bay:
IMAS – Sandy Bay
Building 49 (between the Law Building and the University Gym)
Cnr Alexander Street & Grosvenor Street
Sandy Bay Tasmania Australia
Telephone: +61 3 6226 2937

Postal address:
IMAS – Sandy Bay
Private Bag 129, Hobart TAS 7001

Taroona:
IMAS – Taroona
Nubeena Crescent
Taroona Tasmania Australia
Telephone: +61 3 6227 7277

Postal address:
IMAS – Taroona
Private Bag 49, Hobart TAS 7001

Tasmania

IMAS – in collaboration with the Tasmanian State Government

translatingnatureintoknowledge

www.imas.utas.edu.au

FRDC-DCCEE Project No: 2010/564

Pre-adapting a Tasmanian coastal ecosystem to ongoing climate change through re-introduction of a locally extinct species

Principal Investigator: Nic Bax

For milestone due 30 September 2011:

Review of the Eastern Blue Groper

RM Casper[1], NS Barrett[1], N Bax[1,2], AJ Hobday[2]

[1] *Institute of Marine and Antarctic Studies, University of Tasmania*
[2] *CSIRO Climate Adaptation Flagship*

Keywords: climate change; managed translocation; ecosystem resilience; adaptation

Table of Contents

1. Summary

In this project, we are investigating translocation as an adaptation strategy to offset the impacts of climate change on coastal ecosystems. Specifically, we are examining the scientific, legal and social feasibilities of managed translocation of locally extinct top predator species or likely future climate migrants, where this would benefit the receiving ecosystem in terms of enhancing resilience to climate change. As a test case, we are considering the managed translocation of the Eastern Blue Groper (EBG; *Achoerodus viridis*) as a means of pre-adapting coastal reefs to ongoing warming of waters off eastern Tasmania.

As part of this process, the purpose of this report is to:

- review the history of EBG in Tasmania
- review the known ecology of EBG
- assess the potential for EBG to benefit Tasmanian coastal reefs, and
- identify important knowledge gaps

Close examination of the historical evidence, together with a review of the ecology of the EBG, has led us to conclude that it is unlikely that the EBG was present in Tasmania in the 1800s, and if present, was certainly not common. However, EBG are currently present in very small numbers in north-eastern Tasmanian waters. It is likely that this reflects a southward range expansion of EBG as a result of the southerly movement of the East Australian Current. The EBG is a fish species adapted to warm temperate coastal reef environments. The EBG present in Tasmania are currently at the southern edge of their range. In addition, EBG are protogynous hermaphrodites which change sex from female to male at around 10 years of age. Consequently, it is expected that it would take many years for a reproductively viable population of EBG to establish naturally in Tasmania. This process could be speeded up by managed translocation of EBG into Tasmanian waters, following demonstration of clear environmental benefits and jurisdictional agreement.

The east coast of Tasmania is warming much faster than the global average. Associated changes to the community structure and function of some Tasmanian coastal reef communities have been rapid and dramatic. A prominent example is the southward range expansion of the long-spined sea urchin *Centrostephanus rodgersii* into Tasmanian waters since the 1970s. In parts of eastern Tasmania, the establishment of *C. rodgersii* in high densities has resulted in a shift from macroalgal habitat to urchin grazed barrens habitat, with a loss of over 150 species normally associated with macroalgal forests. One untested hypothesis is that reproductively viable populations of mature EBG could mitigate some of the effects of climate change on Tasmanian coastal reef communities. Of particular interest is the influence that EBG may have in reducing the negative ecosystem impacts of *C. rodgersii*. In NSW, adult EBG are commonly seen in association with urchin grazed barrens and are thought to be a key predator of *C. rodgersii*. Based on evidence from NSW, populations of EBG in Tasmania may have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This suggests that any proposed translocation of EBG for this purpose would need to be part of a larger integrated management plan.

Although adult EBG in mainland waters appear to tolerate a range of habitats that vary in depth and degree of shelter, the requirements of larval and juvenile EBG are more specific. Establishing ecologically viable populations of EBG in Tasmania would depend on the availability of suitable juvenile habitat in shallow, sheltered seagrass or kelp. It is not

known where EBG spawn, how larvae move from the continental shelf to seagrass beds, or how juveniles move from inner estuarine reefs to adult habitat on open coastal reefs. Linkages between estuaries and rocky reefs are important for sustaining populations of EBG, but the specific connectivity required, such as distances, movement corridors, stepping stones of natural habitat, are not known. EBG are particularly susceptible to spearfishing and gillnetting. It is therefore unlikely that EBG populations will become ecologically significant in Tasmanian coastal reefs, either naturally or through managed translocation, unless they are protected from fishing.

2. Introduction

Climate change is currently acknowledged as a major threat to the integrity of marine ecosystems worldwide (Thomas et al. 2004; Halpern et al. 2008). In Australia, ocean temperatures have increased, with south-western and south-eastern waters warming much faster than the global average (Ridgway 2007; Poloczanska et al. 2009; Lough and Hobday 2011). Of particular importance is the continued strengthening of the East Australian Current. Warmer, saltier water now extends 350km further south than 60 years ago (Ridgway 2007). The associated ecological changes are significant and include southward range expansions into south-eastern waters of sub-tropical phytoplankton species, temperate fish and the long-spined sea urchin *Centrostephanus rodgersii* (Ling 2008; Poloczanska et al. 2009; Last et al. 2011). In parts of eastern Tasmania, the establishment of *C. rodgersii* in high densities has resulted in a shift from macroalgal habitat to urchin grazed barrens habitat, with a loss of over 150 species normally associated with macroalgal forests (Ling 2008).

This ecological shift and loss in biodiversity in Tasmanian waters was not necessarily inevitable. When faced with disturbances such as climate change, ecosystems may resist the impacts and recover from them, or change profoundly and shift to an alternate stable state (Palumbi et al. 2008). Biological communities are particularly vulnerable to climatic fluctuations if they are also subject to other stressors which have eroded biodiversity and ecosystem function, such as environmental degradation and overharvesting (Paine et al. 1998; Hughes and Connell 1999; Georgiadis et al. 2003; Palumbi et al. 2008; Ling et al. 2009; Frelich and Reich 2010). Locally adapted species and genetic diversity appear to buffer the stability and recovery potential of ecosystem function and services against recurrent perturbations (Stachowicz et al. 1999; Hooper et al. 2005; Worm et al. 2006; Ehlers et al. 2008; Cheal et al. 2010). For example, an increase in species invasions with climate change has been related to loss of native species diversity (Stachowicz et al. 1999; Harvell et al. 2002; Worm et al. 2006), and marine systems with higher biocomplexity may have more stable fisheries productivity (Hilborn et al. 2003; Worm et al. 2006; Bundy et al. 2010).

The progressive and selective removal of the largest available fish and invertebrates has pervaded the history of global fishing (see Roberts 2007), and this has further increased the vulnerability of biological communities to the effects of climate change. Species that live longer and grow bigger, and are allowed to do so, are more resilient to environmental variations because they have more opportunities to reproduce successfully. An accumulation of age/size classes tends to smooth out fluctuations, such as recruitment variability, over time. In addition, bigger individuals produce disproportionately more eggs, so that preferential fishing of large individuals lowers reproductive output and long term productivity. The recovery rate of populations following disturbances is positively related to productivity, rates of recruitment, growth and survival (Myers and Worm 2003; Babcock et al. 2010; Bui et al. 2010). Further, in marine ecosystems, top predators are often keystone species, where their ecological role can not be replaced by other species within the system. Loss or absence of top predators can considerably reduce the ability of ecosystems with low redundancy to resist change (Palumbi et al. 2008).

There is evidence that the ecological shift from macroalgal habitat to urchin barrens habitat in Tasmania has been exacerbated by low numbers of large predators. In Tasmanian Marine Reserves protected from fishing since 1992, the numbers of large fishes and rock lobsters are much higher than in reference fished areas, while the abundances of *C. rodgersii* are dramatically lower (Edgar et al. 2009; Ling et al. 2009; Johnson et al. 2011). In addition, some of Tasmania's largest predatory reef fishes, including the Eastern Blue Groper (*Achoerodus viridis*), have reportedly become locally extinct since the early 1900s, probably as a result of fishing (Last et al. 2011).

The Eastern Blue Groper (EBG; Figures 1-2) is a large long lived wrasse that is currently most common on the east coast of temperate mainland Australia. The diet of adult EBG includes mussels and sea urchins (Gillanders 1999). There are reports indicating that the EBG is also extending its range southward into north-eastern Tasmania waters as a result of the southerly movement of the East Australian Current (Last et al. 2011). However, the range expansion of the EBG is much slower than that of *C. rodgersii*, and it is expected that it would take many years for ecologically significant populations of EBG to establish naturally in Tasmania. This process could be facilitated by managed translocation of EBG into Tasmanian waters, following demonstration of clear environmental benefits and jurisdictional agreement.

The ecological effect of high densities of *C. rodgersii* is one of the first of major impacts associated with climate change in Tasmanian waters, but there is no reason to believe it will be the last. The development of practical strategies to mitigate the impacts of climate change is not matching the pace of ongoing alterations to the environment. Strategies that stabilise whole ecosystems are likely to be the most effective means of adapting biological communities to climate change (Hulme 2005). Managed translocation to support adaptation to climate change can be expected to be most successful when it takes a systems level approach rather than a single issue approach.

In this project, we are investigating the scientific, legal and social feasibilities of the managed translocation of locally extinct top predator species or likely future climate migrants, where this would benefit the receiving ecosystem. As a test case, we are considering the managed translocation of the Eastern Blue Groper as a means of pre-adapting coastal reefs to ongoing warming of waters off eastern Tasmania (Casper et al. 2011).

As part of this process, the purpose of this report is to:

- review the history of EBG in Tasmania
- review the known ecology of EBG
- assess the potential for EBG to benefit Tasmanian coastal reefs, and
- identify important knowledge gaps

It is beyond the scope of this report to carry out a risk assessment or investigate the logistics of translocating EBG into Tasmania. Other components of this project will develop generic protocols for these elements and the EBG/Tasmanian test case will be assessed within those frameworks.

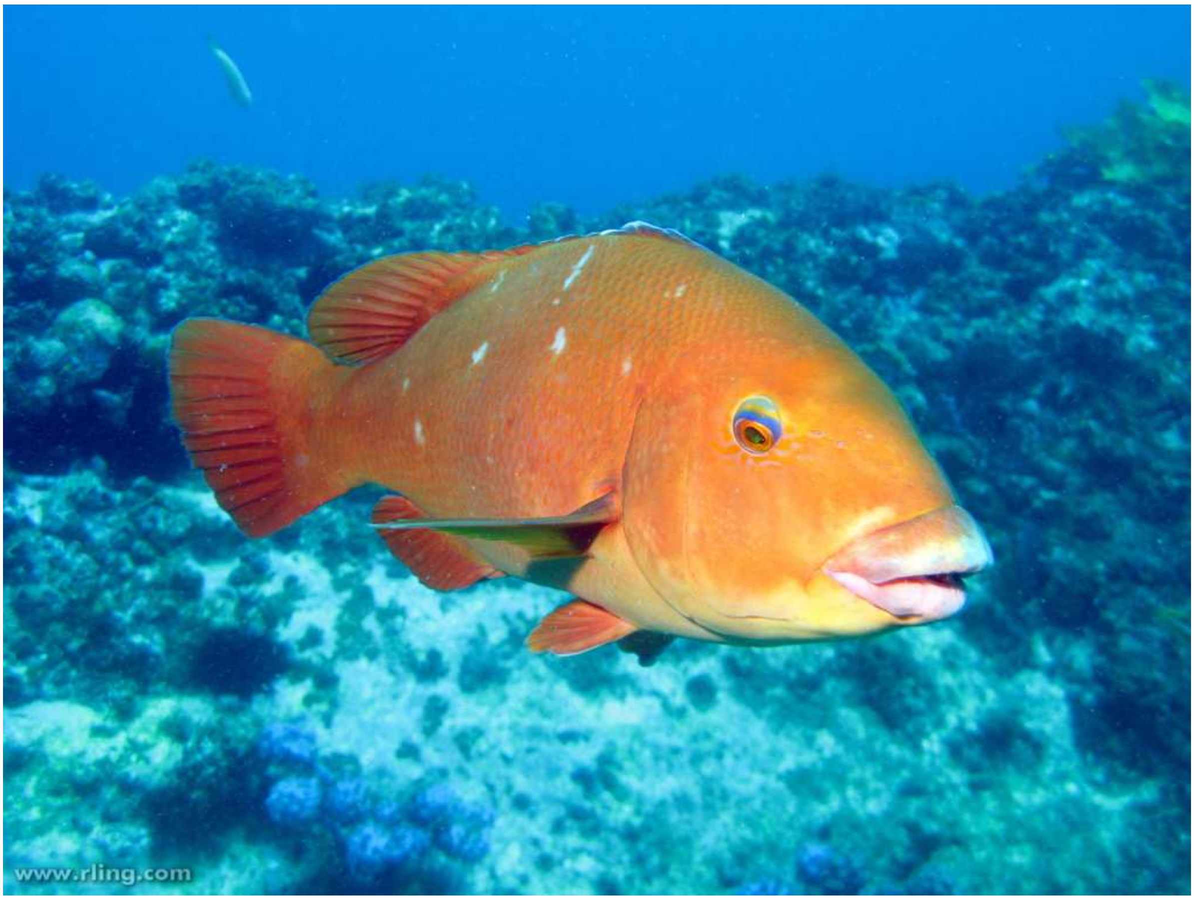


Figure 1. Female Eastern Blue Groper (*Achoerodus viridis*) at Ulladulla, NSW.
Image: Richard Ling. Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/rling/4645408299

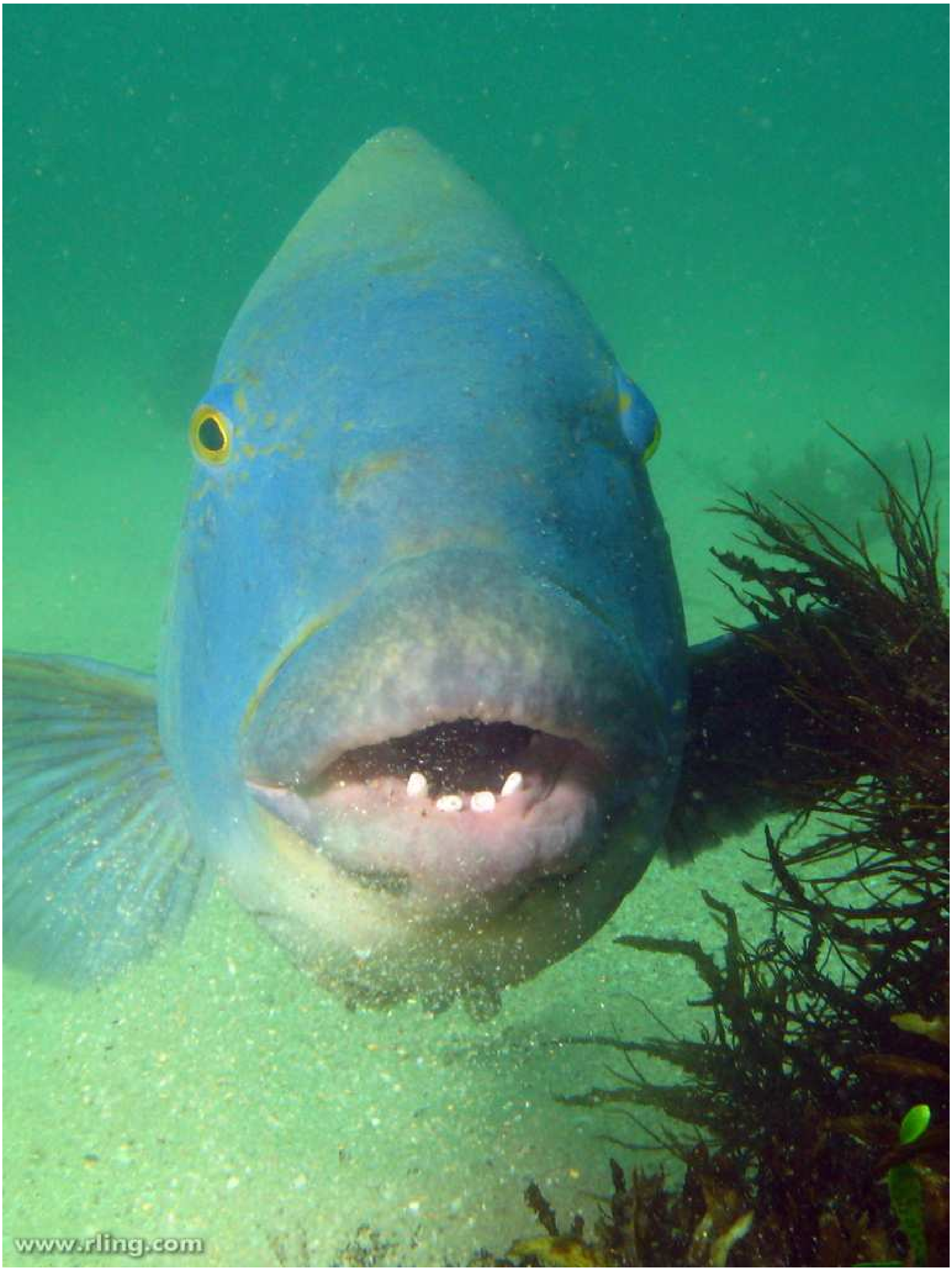


Figure 2. Male Eastern Blue Groper (*Achoerodus viridis*) at Manly NSW.
Image: Richard Ling. Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/rling/3245832577/

Figure 3. Bluethroat Wrasse or Blue Head (*Notolabrus tetricus*) at Swan Bay, Victoria. Image: Saspotato. Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/saspotato/4628807175/

3. Methods

3.1 History of the Eastern Blue Groper in Tasmania

Based on some historical reports, the EBG was apparently present in Tasmanian waters in the late 1800s and disappeared in the early 1900s (Last et al. 2011). Within this period, the EBG was referred to by multiple scientific and common names and these names did not necessarily refer exclusively to the EBG. Therefore, an extensive search of historical records was carried out to confirm the presence of EBG populations in Tasmania, to determine where they existed and when and why they disappeared.

Electronic searches for potential references to the EBG in Tasmania were conducted using:

- Web of Knowledge scientific database (http://www.isiwebofknowledge.com)
  - search for biological and archaeological records dating back to 1864
- TROVE digital newspaper database (http://trove.nla.gov.au/newspaper)
  - search of 22 Tasmanian newspaper and magazine titles from 1816-1954

Manual searches were also conducted on the following hard copies:

- Royal Society of Tasmania papers and proceedings (1849-1970)
- Royal Commission on the Fisheries of Tasmania (1883)
- Superintendent and Inspector of Fisheries reports (1885-1887)
- Fisheries Board general report (1889)
- Commissioners of Fisheries reports (1911-1923)

3.2 Ecology of the Eastern Blue Groper

The life history characteristics, distribution and abundance of the EBG were compiled using a combination of peer-reviewed literature, technical reports and unpublished data. The latter include Reef Life Survey (RLS) data (http://reeflifesurvey.com/; Edgar and Stuart-Smith), Marine Biodiversity (MB) data (Edgar, Barrett and Stuart-Smith), Victorian Subtidal Reef Monitoring Program (SRMP) data, post-graduate reports and theses, and expert opinion. The SRMP data are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. The visual census methods used to generate RLS, MB and SRMP data are detailed in Edgar and Barrett (1997; 1999) and Edmunds and Hart (2003). The RLS, MB and SRMP datasets used in this report are summarised in Tables 1 and 2.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1992			MB Tas	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas		
1993				MB Tas	MB Tas	MB Tas		MB Tas	MB Tas	MB Tas		
1994	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas			MB Tas	MB Tas	MB Tas	MB Tas
1995				MB Tas	MB Tas	MB Tas	MB Tas	MB Tas		MB Tas		
1996			MB Tas	MB Tas	MB Tas **MB NSW**	MB Tas						
1997			MB Tas	MB Tas	MB Tas				MB Tas	MB Tas		
1998			MB Tas	MB Tas	MB Tas MB Vic SRMP Vic				MB Vic SRMP Vic	MB Vic SRMP Vic		
1999	MB Tas	MB Tas	MB Tas	MB Tas	MB Tas MB Vic SRMP Vic	MB Vic SRMP Vic	MB Vic SRMP Vic		MB Tas SRMP Vic	MB Tas SRMP Vic	MB Vic SRMP Vic	MB Vic SRMP Vic
2000	SRMP Vic	MB Tas SRMP Vic	MB Tas SRMP Vic		SRMP Vic **MB NSW**	MB Tas SRMP Vic		SRMP Vic	MB Tas	MB Tas	MB Vic SRMP Vic	SRMP Vic

Table 1. Summary of temporal coverage of marine fish survey datasets in Tasmania (Tas), Victoria (Vic) and New South Wales (NSW). RLS: Reef Life Survey, MB: Marine Biodiversity, SRMP: Subtidal Reef Monitoring Program. SRMP are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. Entries in **bold** indicate Eastern Blue Groper sightings.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
2001	SRMP Vic	MB Tas **SRMP Vic**	MB Tas SRMP Vic	MB Tas SRMP Vic	MB Tas SRMP Vic **MB NSW**	SRMP Vic **MB NSW**	MB Tas SRMP Vic		MB Tas		SRMP Vic	SRMP Vic
2002	SRMP Vic	MB Tas SRMP Vic	MB Tas SRMP Vic	SRMP Vic	SRMP Vic	SRMP Vic		SRMP Vic			SRMP Vic	
2003	SRMP Vic	SRMP Vic	SRMP Vic	SRMP Vic	SRMP Vic **MB NSW**	**MB NSW**						SRMP Vic
2004	SRMP Vic		MB Tas **SRMP Vic**	MB Tas SRMP Vic	**MB NSW**	MB Tas **MB NSW**	SRMP Vic	SRMP Vic			SRMP Vic	SRMP Vic
2005	SRMP Vic	MB Tas SRMP Vic	SRMP Vic	MB Tas SRMP Vic	SRMP Vic **MB NSW**	**MB Tas** **MB NSW**						SRMP Vic
2006		**SRMP Vic**	MB Tas SRMP Vic	MB Tas	MB Tas SRMP Vic **MB NSW**	MB Tas SRMP Vic **MB NSW**	MB Tas		MB Tas	MB Tas	MB Tas	MB Tas SRMP Vic

Table 1 continued. Summary of temporal coverage of marine fish survey datasets in Tasmania (Tas), Victoria (Vic) and New South Wales (NSW). RLS: Reef Life Survey, MB: Marine Biodiversity, SRMP: Subtidal Reef Monitoring Program. SRMP are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. Entries in **bold** indicate Eastern Blue Groper sightings.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2007	MB Tas	MB Tas	MB Tas	**MB Tas**		**MB Tas**						**MB NSW**
2008	RLS Tas	RLS Tas **RLS NSW**	MB Tas RLS Tas RLS Vic **RLS NSW**	MB Tas RLS Tas RLS Vic **RLS NSW**	RLS Tas **RLS Vic** **MB NSW** **RLS NSW**	RLS Tas RLS Vic **RLS NSW**	MB Tas **RLS Vic** **RLS NSW**	**RLS Vic** **RLS NSW**	RLS Tas RLS Vic **RLS NSW**	**RLS Vic** **RLS NSW**	RLS Tas **RLS Vic** **RLS NSW**	RLS Tas **RLS Vic** SRMP Vic **RLS NSW**
2009	RLS Tas **RLS Vic** **RLS NSW**	RLS Tas **RLS Vic** **RLS NSW**	MB Tas RLS Tas **RLS Vic** **SRMP Vic** **RLS NSW**	MB Tas RLS Tas RLS Vic SRMP Vic **RLS NSW**	MB Tas RLS Vic **SRMP Vic** **MB NSW** **RLS NSW**	**MB Tas** RLS Vic SRMP Vic **MB NSW** **RLS NSW**	**RLS Vic** **RLS NSW**	**RLS Vic** **RLS NSW**	RLS Vic **RLS NSW**	RLS Vic **RLS NSW**	RLS Tas **RLS Vic** **RLS NSW**	RLS Tas RLS Vic SRMP Vic **RLS NSW**
2010	RLS Tas RLS Vic **RLS NSW**	MB Tas RLS Tas RLS Vic SRMP Vic **RLS NSW**	RLS Vic **SRMP Vic** **RLS NSW**	MB Tas RLS Vic **RLS NSW**	MB Tas RLS Vic **RLS NSW**	SRMP Vic **RLS NSW**	SRMP Vic **RLS NSW**	RLS Vic **RLS NSW**	RLS Vic **RLS NSW**			SRMP Vic

Table 1 continued. Summary of temporal coverage of marine fish survey datasets in Tasmania (Tas), Victoria (Vic) and New South Wales (NSW). RLS: Reef Life Survey, MB: Marine Biodiversity, SRMP: Subtidal Reef Monitoring Program. SRMP are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. Entries in **bold** indicate Eastern Blue Groper sightings.

Survey	Region	Description of main areas surveyed	No. sites surveyed	Depth range surveyed (m)	No. fish species sighted	No. individual fish sightings*
MB	Tas	North west, north, east, south east and south west coasts, Bass Strait Islands	279	1-10	164	912 696
RLS	Tas	Orford to Southport, Bicheno, Devonport, west Flinders Island	139	1-22.4	106	68 789
MB	Vic	Bunurong, Port Phillip heads, Wilson's Promontory	54	2-16	85	35 966
RLS	Vic	Mallacoota to Lawrence Rocks with most sites in Port Phillip Bay	118	1-21	144	131 011
SRMP	Vic	Twofold shelf, Wilson's Promontory, Bunurong, Phillip Island, Port Phillip Bay, western central Victoria, central Otway	31	2-16	168	186 929
MB	NSW	Batemans Bay, Jervis Bay	54	2-10	241	655 269
RLS	NSW	Byron Bay to Cape Howe	366	0.4-42	595	1 278 252

Table 2. Summary of marine fish survey datasets in Tasmania (Tas), Victoria (Vic) and New South Wales (NSW). RLS: Reef Life Survey, MB: Marine Biodiversity, SRMP: Subtidal Reef Monitoring Program. SRMP are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. *This number does not indicate the total number of individual fish present because individual fish may be recorded more than once, e.g. when a site is surveyed on multiple occasions.

Survey	Region	Description of areas where EBG sighted	No. sites EBG sighted	Depths EBG sighted (m)	No. individual EBG sightings*
MB	Tas	Kent Group, King Island	6	5-10	9
RLS	Tas	n/a	0	n/a	0
MB	Vic	n/a	0	n/a	0
RLS	Vic	Mallacoota to Lakes Entrance	8	3-18	34
SRMP	Vic	Cape Howe, Point Hicks	17	5-14	85
MB	NSW	Batemans Bay, Jervis Bay	51	2-10	2 605
RLS	NSW	Byron Bay to Green Cape	243	2-36.5	2 588

Table 3. Summary of Eastern Blue Groper (EBG) sightings in marine fish survey datasets in Tasmania (Tas), Victoria (Vic) and New South Wales (NSW). RLS: Reef Life Survey, MB: Marine Biodiversity, SRMP: Subtidal Reef Monitoring Program. SRMP are Victorian marine monitoring data used with the permission of Parks Victoria and Department of Sustainability and Environment. *This number does not indicate the total number of individual fish present because individual fish may be recorded more than once, e.g. when a site is surveyed on multiple occasions.

4. Results

4.1 History of the Eastern Blue Groper in Tasmania

The following is a chronological summary of records relevant to the historical presence of EBG (*Achoerodus viridis*) in Tasmania.

1. 1842: Richardson presented descriptions of ~30 fish species that were collected from Port Arthur by the naturalist T. J. Lempriere (Richardson 1842). These descriptions are very detailed and clearly based on first hand examination of individual specimens. There are no descriptions of species that could be EBG. This list does include a description of *Labrus tetricus*, which a synonym of *Notolabrus tetricus* (Richardson 1840) (Eschmeyer and Fricke 2011). The common names for *N. tetricus* include Bluehead, Bluenose, Bluethroat Wrasse and Blue-throated Parrotfish (Last et al. 1983; Gomon et al. 2008; Figure 3).

2. 1862: A description of *Cossyphus gouldii* (Richards.) is included in the catalogue of fishes in the British Museum (Gunther 1862). This description is based on a stuffed specimen from Western Australia and is consistent with that of the Western Blue Groper (WBG; *Achoerodus gouldii*). *Cossyphus gouldii* and *A. gouldii* are the same species; they were both originally listed as *Labrus gouldii* Richardson 1840 (Gunther 1862; Gomon et al. 2008).

3. 1870s: Local naturalist M. Allport compiled a series of lists of Tasmanian fish collections (Allport 1876). Included was a list of 47 specimens sent to Dr. Gunther at the British Museum on the ship "Windward" in 1874. Specimen No. 2 is described as "Large red fish – no local name (see outline)". Dr. Gunther identified specimen No. 2 as *Cossyphus gouldii* and also commented "more specimens desired". Specimen No. 7 is described by Allport as "Parrot fish (red with blue and yellow fins)". This fish was identified by Dr. Gunther as *Labrichthys tetricus*, which is probably referring to *Labrichthys tetrica*, another synonym for *Notolabrus tetricus* (Eschmeyer and Fricke 2011).

4. 1881: *Cossyphus gouldii* (Richards.) is listed in a catalogue of fishes of Australia (Macleay 1881). It is identified as the "Blue Groper" of Sydney fishermen, but is described as occurring in Western Australia and Port Jackson. The morphological description is identical with that from Gunther (1962), which is acknowledged as the source. At this time, it appears that the EBG and WBG were regarded as one species and referred to as *C. gouldii*.

5. 1882: *Cossyphus gouldii* (Rich.) is listed as the Blue Groper in a catalogue of fishes of Tasmania (Johnston 1882). It is identified as a member of the Parrotfish family, Labridae, comprising nine species including six *Labrichthys* spp. Two of these are listed synonyms for *Notolabrus tetricus* (*Labrichthys cuvieri* and *L. tetrica*; Eschmeyer and Fricke 2011). The difficulty in correctly identifying these fish is acknowledged by Johnston who comments "I have good reason to believe that dependence on colour markings, however peculiar and brilliant, is to a great extent delusive. Like the genus *Monocanthus*, many of them change colour with age" (Johnston 1882).

   The morphological description of *C. gouldii* is clearly taken directly from Gunther (1862) and Macleay (1881), which are acknowledged as the source. The description therefore refers to the morphology of the WBG and not the EBG. Although Johnston states that “Of the 188 species known to exist in Tasmanian waters I have personally examined the general characters of about 145 species”, no information is presented that confirms first hand examination of any *C. gouldii* specimens.

The Blue Groper is also described as exceedingly good, though little appreciated food. It is unclear, however, if this description is taken from local Tasmanian opinion or from NSW, as the culinary virtues of the Blue Groper described in a NSW Fisheries Report are also cited. *Cossyphus gouldii* is referred to as common but there is no mention of where it is found or its distribution etc. This type of information is included for some other species listed.

6. 1883: *Cossyphus gouldii* Blue Groper is the only fish from the family Labridae included in a list of principle edible fishes in Tasmania (Anon 1883). It is listed as a ‘middle grounds’ fish, i.e. “fishes frequenting lower portions of large estuaries, or on fishing banks – from 3-8 fathoms deep, in the neighbourhood of still deeper water”. The middle grounds are further described as including “those fishing reefs and banks lying in the outer and more exposed situation of estuaries, such as Wedge and Adventure Bays, in the estuary of the Derwent, in depth of water from five to six fathoms”. The Blue Groper is described as being “common during the season only”. It is unclear why the EBG, a sedentary fish, would not be common all the year round. In the middle grounds, fish were chiefly caught using grab-all nets and ordinary handlines. Although described as one of the principal edible fishes in Tasmania and common in the middle fishing grounds, EBG are not mentioned in a list of 15 principal fish caught in the middle grounds or in a list of 7 principal fish exported.

7. 1884: In an international fisheries exhibition, Australasia was represented by NSW and Tasmania alone (Whymper 1884). There is no mention of a fish that could be the EBG.

8. 1886: In a schedule of Tasmanian marine market fish, there are no fish described from a list of 35 species that could be EBG or *N. tetricus* (Anon 1886).

9. 1887: Due to the uncertainty of the identity of “the large species of Parrot Fish, abundant on many parts of the Tasmanian coast, and familiarly known to fishermen by the title of the ‘Blue Head’”, a coloured drawing of the Tasmanian Blue Head was submitted by W. S. Kent to D. Ogilby of Sydney who identified the fish as not *C. gouldii*, but rather as *Labricthys cerulieus*, a species he had recently described. Reference to the type specimen contained in the Australian Museum confirmed this identification (Kent 1888). In addition, although “*C. gouldii* was enumerated in Mr Johnston’s catalogue…Mr. Johnston had stated that he had not seen a specimen himself, but that the late Mr. Morton Allport had recorded it as having been found in Tasmanian waters” (Morton 1888).

10. 1887: The following entry is found in an official Fisheries Establishment report to the Parliament of Tasmania: “The large Parrot-fish or ‘Blue Head’ of the Tasmanian fishermen, apparently referred to by Allport and Johnston to *Cossyphus gouldii* (Rich.), has proved to be a new species of *Labricthys*, recently described by Mr. D. Ogilby (Proc. Lin. Soc. NSW., 1887), under the title of *L. cyaneus*” (Anon 1887). The revised identification of the Tasmanian ‘Blue Head’ appears to have changed here from *L. cerulieus* (Kent 1888) to *L. cyaneus.* A description of *L. cyaneus* as cited could not be found, but a description of *L. cyanogenys* was (Ramsay and Ogilby 1888). Identifications of Blue Head as *Labricthys ceruleus* (Kent 1888) and *L. cyanogenus* (Ramsay and Ogilby

1888) are synonyms for the Bluethroat Wrasse *Notolabrus tetricus* (Richardson 1840) (Eschmeyer and Fricke 2011). The reference to *L. cyaneus* appears to be a transcription error as this species name has never been validated (Eschmeyer and Fricke 2011). In a schedule of Tasmanian marine market fish, there are no fish described from a list of 35 species that could be EBG or *N. tetricus* (Anon 1887).

11. 1889: In a schedule of Tasmanian marine market fish, there are no fish described from a list of 35 species that could be EBG or *N. tetricus*. In a return of sale of fish in Hobart fish market for the financial year of 1888/89, there are no species listed that could be EBG or *N. tetricus* (Anon 1889).

12. 1890: In a complete list of the 214 Tasmanian species known at the time, Blue Head is included as one of 13 species within Labridae (Parrot Fish Family; Johnston 1890). Blue Head is now referred to as *Cossyphus cerulaeus* (Ogilby) and is the only species in this group for which no morphological information is presented. The reference to Blue Head as *Cossyphus cerulaeus* by Johnston here appears to be a whimsical and isolated event as this species name has never been validated (Eschmeyer and Fricke 2011). Five *Labrichthys* species are listed as Labridae, again including *L. cuvieri* and *L. tetrica*, both of which are synonyms for *N. tetricus* (Eschmeyer and Fricke 2011). The Blue Head (*N. tetricus*) is now represented by three species in this list, i.e. *C. cerulaeus*, *L. cuvieri* and *L. tetrica*. The uncertainty of correct identifications expressed by Johnston (1882) are still apparent. Blue Head is described as abundant all the year round and although good food, not brought to market. There are no fish listed as sold in Hobart fish market during 1888 that could be EBG or *N. tetricus* (Johnston 1890).

13. 1908-1910: Amateur scientist E. Westlake interviewed 95 Tasmanians to create a record of Tasmanian Aboriginal history, culture and language. Interviewees confirmed that Aborigines speared and ate scalefish, including “Blue Head” and “Parrot Fish” (reported in Taylor 2007).

14. 1911-1915: There are no fish listed as sold in Hobart fish market for the years 1911-1915 that could be EBG or *N. tetricus* (Anon 1912-1924).

15. 1916: In a book of fishes of Australia, Roughley (1916) includes Groper *Achoerodus gouldii* (Rich.) as a member of the Labridae family. Groper are described as having two forms, being the Red Groper and the Blue Groper. Roughley comments that these forms probably represent the females and males respectively of the same species. *Achoerodus gouldii* are described as being abundant in NSW and occurring less frequently in Victoria, Tasmania and Western Australia. The morphological description seems to be a combination of WBG and EBG features. For example, the WBG has 33-37 lateral line scales and the EBG has 41-45 lateral line scales (Gomon et al. 2008). Roughley’s Groper has 39-45 lateral line scales. It is appears that *C. gouldii* is now known as *A. gouldii*, and that the EBG and WBG are still regarded as one species. Roughley does not detail his sources of information except to say that “The works of Ogilby and Stead and the various Royal Commission reports on the New South Wales fisheries have been extensively consulted”. All these sources are very NSW-centric and the basis for indicating the presence of *A. gouldii* in Tasmania is not apparent.

16. 1916-1919: Parrot Fish are included as sold in the Hobart fish market for the first time in 1916 (14 dozen). In 1917, sales of Parrot Fish peak at 582 dozen, comprising ~3% of the number of fish sold. In 1918, 76 dozen were sold (Anon 1912-1924).

17. 1920-1922: There is now also a fish market in Launceston. Combined annual Parrot Fish sales in Hobart and Launceston fish markets range from 83-241 dozen (Anon 1912-1924).

18. 1923: No Parrot Fish are sold in either Hobart or Launceston fish markets (Anon 1912-1924). There are no fish listed as sold that could be EBG or *N. tetricus* (Anon 1912-1924)

19. 1923: A list of the fishes of Tasmania includes the Blue Groper *A. gouldii* (Rich.). The morphological description is attributed to Roughley (1916). The Groper is also described as a common species around the rocky section of the coast, but the source of this information is not cited (Lord 1923; Lord and Scott 1924).

20. 1951: In a book of fishes of Australia, Groper *Achoerodus gouldii* is included in a section on Parrot-Fishes and Wrasses. The Groper is described as occurring in every state with the possible exception of Tasmania (Roughley 1951). It appears that the EBG and WBG are still regarded here as one species.

21. 1951: The only record from the TROVE search referring to Blue Groper in Tasmania describes the formation of the Underwater Spearfishing Association of Tasmania. "The Hobart group would concentrate on spearing trumpeter, parrot fish, and blue groper along the rocky foreshores at Taroona, Kingston Beach, and Opossum Bay". There is no evidence that the EBG was present anywhere in Tasmania in the 1950s. It appears that confusion still occasionally existed between the EBG and *N. tetricus*. *Notolabrus tetricus* are currently conspicuous along the rocky foreshores of Taroona, Kingston Beach and Opossum Bay (Edgar and Stuart-Smith, unpublished RLS data), and it is likely that this was also the case in the 1950s.

22. 1974: In a book of fishes of southern Australia, the distribution of the Blue Groper *Achoerodus gouldii* (Richardson) is described as "All Australian states, but the record of the species for Tasmania is doubtfully correct" (Scott et al. 1974). Again, the EBG and WBG are still regarded as one species.

23. 1978: An aboriginal midden was excavated from Rocky Cape. All fish bones were estimated to be over 3500 years old, representing a minimum of 500 individual fish. Four of these were unidentifiable, but the rest were all identified as belonging to the genus *Pseudolabrus* (reported in Stockton 1982). These fish are predominantly *Notolabrus tetricus* and *N. fucicola*, synonyms for *P. tetricus* and *P. fucicola* respectively (Eschmeyer and Fricke 2011; P. Last, pers.comm.).

24. 1983: In a book on fishes of Tasmania, Blue Groper are not listed. It is stated, however, that adult male Purple Wrasse *Pseudolabrus fucicola* "which are mostly purplish in colour, may have been confused with young blue groper (*Achoerodus gouldii*). The latter species was recorded in Tasmania last century but has not been seen since" (Last et al. 1983). *Pseudolabrus fucicola* is a synonym for *Notolabrus fucicola* (Eschmeyer and Fricke 2011).

4.2 Ecology of the Eastern Blue Groper

4.2.1 Morphology

Blue gropers [*A. viridis* and *A. gouldii* (Western Blue Groper; WBG)] are the largest temperate reef fish in Australia (Gillanders 1999). They are wrasses, members of the Family Labridae. The larvae of EBG can be distinguished from other labrids. They are highly and distinctly pigmented and have a high myomere count (28). Their finray counts are D XI, $_{11}$ AIII, $_{11}$ P1 16-18 (Leis and Hay 2004). The fin spine and ray counts of adult EBG and WBG are identical (D XI, $_{11}$ A III, $_{11}$ C 14 P 16-18 V I, $_{5}$), but the numbers of lateral line scales differ (EBG: LL 41-45; WBG: LL 33-37; Gomon et al. 2008). The EBG and WBG have a similar overall shape, distinctive fleshy lips and peglike teeth, but differ in size and colouration (Hutchins and Swainston 1986). Maximum sizes of EBG and WBG are 1m TL and 18kg, and 1.75m TL and 40kg respectively (Gillanders 1999; Gomon et al. 2008). Juvenile EBG have been described as green, later changing to brown (Gillanders 1999), grey with several yellowish spots (Gomon et al. 2008), and greyish brown, brownish orange and green (Hutchins and Swainston 1986). Female EBG are red to brown and may have a series of pale spots on their sides (Figure 1; Hutchins and Swainston 1986; Gillanders 1999; Gomon et al. 2008). Male EBG are grey to blue (Figure 2; Hutchins and Swainston 1986; Gillanders 1999). A distinctive feature of EBG are the blue and orange scribble lines radiating from the eyes of most sizes (Hutchins and Swainston 1986; Gillanders 1999).

4.2.2 Reproduction and growth

Like many Labridae, EBG are protogynous hermaphrodites. They start life as females and transform as adult females into functional males (Gillanders 1995b). As a result, the sex ratio tends to be strongly biased towards females. This is apparent in SRMP data where females comprised 63-100% of EBG individuals sighted in any sampling month where sex was recorded. In a Sydney based study, most females matured between 2+ and 4+ years, at 240-280mm SL (Gillanders 1995b). The age and size at sex change may vary between reefs. For example, at 2 different sites near Botany Bay, all fish over 520mm were male at site 1, but at site 2 all fish over 500mm were male. At site 1, all fish aged <19 years were female and all fish over 20 years were male. At site 2, however, there was considerable overlap in age distributions of males and females. Although males were generally older than females, the age of males ranged from 10-29+ years (Gillanders 1995b).

As with most protogynous labrids, a change in colour accompanies sex reversal in the EBG. This colour change may also be partially related to size as blue females tend to be larger than other females (Gillanders 1995b). Although sex change appears to occur at a critical size (~500-600mm SL), social and behavioural factors may also be important. For example, the size at sex change may be influenced by social hierarchies as well as densities of males and females (Gillanders 1995b; Gillanders 1999).

There is a lack of information on the reproductive behaviour of EBG. Adult EBG live on coastal rocky reefs, but their spawning behaviour and locations are unknown. EBG spawn between June and October. Settlement mostly occurs between July and September, implying that that the larval life of EBG may be 2-4 weeks (McNeill et al. 1992; Worthington et al. 1992; Gillanders 1995b; Leis and Hay 2004). A study on the larval development of EBG on the central coast of NSW indicates that most of the larval phase occurs on the continental shelf, where they remain at depth (20-30m) during the day. Larvae then settle into estuarine seagrass beds at 7-8mm and metamorphose into juveniles at ~10mm (Leis and Hay 2004). Evidence from otolith microchemistry of EBG adults, however, suggests that recruits settle in both seagrass and rocky reef environments (Gillanders and Kingsford 1996). It is not known how larvae move from the continental shelf to these juvenile habitats.

Recruitment into seagrass appears to occur in pulses. In a study of juveniles at Botany Bay, abundances of juveniles increased significantly in July and then again in October, representing two cohorts. These cohorts remained in the habitat for at least 3-4 months (Worthington et al. 1992). Growth rates varied, being slowest in winter (0.21mm day^{-1}) when water temperatures were lowest. Growth rates peaked at 0.39mm day^{-1}, just prior to loss of the cohort from the habitat (Worthington et al. 1992). The growth rates of adult EBG have not been directly measured, but otolith analysis has indicated that growth rates of females (180-350mm SL) from estuarine reefs and open coastal reefs are similar (Gillanders 1997a). The average size of EBG aged 2 years is 230mm SL (0.26kg), at 10 years is 480mm SL (2.4kg), at 20 years is 620mm SL (5.3kg) and at 30 years is 725mm SL (8.4kg; Gillanders 1999). EBG may live for at least 35 years (Gillanders 1995b).

4.2.3 Habitat

Juvenile EBG are most abundant in shallow areas of inner estuarine reefs while large adults (>400mm SL) are most abundant in deeper areas of more exposed coastal reefs (Gillanders 1997b; Gillanders 1999). Size frequency patterns of abundance together with otolith microchemistry and growth rate analyses suggest that EBG undergo post-recruitment migrations from juvenile habitats in shallow (1-3m), sheltered seagrass or kelp to deeper (>5m), exposed rocky reef adult habitat (Gillanders and Kingsford 1993; Gillanders and Kingsford 1996; Gillanders 1997a; Gillanders 1997b; Gillanders and Kingsford 1998).

Patterns of juvenile density in different habitats are probably determined by the availability of shelter, food and the presence of competitors and predators (Gillanders and Kingsford 1998). EBG do not settle on bare sand (Bell et al. 1987; Gillanders and Kingsford 1993) and few larvae settle in seagrass beds with <25 leaves/m^2 because these do not provide sufficient shelter (Worthington et al. 1991). In *Zostera capricorni* seagrass, relative abundances of juvenile EBG indicate a preference for areas with long dense leaves compared to long thin, short dense and short thin leaves (Bell and Westoby 1986). In rocky reef habitats in Sydney and the central coast of NSW, small EBG (<250mm SL) are found almost exclusively in shallow (3-10m) fringe or *Ecklonia* forest habitats. They are rare or absent in deeper urchin grazed barrens (3-20m) and sponge garden (15-22m) habitats (Fisheries Research Institute 1987; Gillanders and Kingsford 1993; Gillanders and Kingsford 1998; Curley et al. 2002; Morton and Gladstone 2011). These habitat associations are likely to be related to the availability of shelter from predators as well as the availability of suitable prey items. For example, juveniles feed on crustaceans frequently found in algae (Gillanders and Kingsford 1998; Curley et al. 2002; Morton and Gladstone 2011).

Larger EBG are less restricted by depth and habitat type as they are less dependent on shelter and are capable of consuming larger and harder prey items, such as mussels and urchins (Gillanders and Kingsford 1993; Gillanders and Kingsford 1998; Morton 2007). Adult EBG are habitat generalists and their distribution and abundance does not appear to be determined by the proportional representation of habitats (Gillanders and Kingsford 1998; Morton and Gladstone 2011). The densities of adult EBG are similar across a range of habitats that vary in depth and degree of shelter (Gillanders and Kingsford 1998; Curley et al. 2002; Fulton and Bellwood 2004). Although some studies have reported comparable abundances of adult EBG in urchin grazed barrens and *Ecklonia* habitats (Gillanders and Kingsford 1998; Curley et al. 2002), large EBG (750-849mm SL) may have a preference for urchin grazed barrens habitat (Morton and Gladstone 2011).

4.2.4 Foraging ecology

The EBG is a predominantly carnivorous benthic predator that consumes a wide variety of prey items (Gillanders 1995a). There is only one published study on the detailed foraging ecology of the EBG. This study investigated the diet, feeding behaviour and foraging habitat use of different size classes of the EBG in the Sydney region (Gillanders 1995a). The diet of recruits (17-26mm SL) was dominated by different prey items depending on habitat. Those collected in seagrass consumed mainly tanaids, while rocky reef recruits ate mainly harpacticoid copepods. The diet of post-recruitment EBG on rocky reefs varied with size and was also related to habitat. Juvenile fish (<150mm SL) consumed gammarid amphipods and other crustaceans in shallow fringe habitat, whereas adult fish (>200mm SL) ate more hard bodied prey such as mussels and urchins in deeper turf and barrens habitats (Gillanders 1995a). Size specific dietary shifts in EBG are reflected by size related habitat shifts, but are also probably influenced by factors such as morphology and behaviour. For example, adult EBG are capable of crushing shells and biting at oysters, abalone and limpets. They also attack and consume urchins by flipping them over and cracking them open (Gillanders 1999).

Variation in diet also occurred among seasons and sites. This probably reflects differences in prey availability, which may be influenced by variation in the composition and abundance of mobile invertebrates, the density of EBG and their competitors, and social interactions (Gillanders 1995a). For example, the damselfish White Ears (*Parma microleptis*) is the main species seen to interact with the EBG, although there is little dietary overlap. *Parma microleptis* are territorial and chase away much larger EBG. Behavioural interactions have also been observed between the EBG and Crimson-banded Wrasse (*Notolabrus gymnogenis*), Mado (*Atypichthys strigatus*), Goatfish (family Mullidae) and Morwong (Family Cheilodactylidae; Glasby and Kingsford 1994; Gillanders 1999).

The foraging rates (bites/min) of EBG varied with size. Juveniles fed at a greater rate than small females, and females fed at a greater rate than males. Variation in feeding rates between sizes and sexes are likely related to factors such as different energy demands, social and mating demands and the size of prey consumed. The pattern of feeding was not diurnal (Gillanders 1995a).

4.2.5 Distribution and abundance

According to the published literature, EBG are distributed along the east coast of Australia from Hervey Bay, Queensland to Wilson's Promontory, Victoria (Hutchins and Swainston 1986; Edgar 1997; Gillanders 1999). The biogeographic affinity of the EBG is eastern Australian warm temperate (Burchmore et al. 1985; Last et al. 2011), and this is reflected in their abundance pattern across their range. For example, EBG population densities appear to be highest on the central coast of NSW and around Sydney (Bell et al. 1987; Worthington et al. 1991; Gillanders and Kingsford 1998; Curley et al. 2002; Morton and Gladstone 2011). RLS, MB and SRMP data confirm that EBG are widespread along the NSW coast, less common along the Victorian east coast and have occurred in small numbers around some Bass Strait Islands since 2005 (Tables 1-3). In NSW, MB and RLS surveys have spanned the entire coastline (n=420 sites) and included all seasons across multiple years (n=45 months; Tables 1 and 2). EBG have been recorded in all these surveys (Table 1), and at 70% of the sites surveyed (Tables 2-3). In Victoria, MB, RLS and SRMP surveys have included 203 sites extending from the NSW/Victorian border to the south-western Victorian coast over multiple years (n=91 months; Tables 1-2). EBG have been recorded only at sites north of Lakes Entrance (n=25 sites) and only in small numbers (119 individual fish sightings recorded in Victorian surveys compared to 5193 in NSW; Table 3). The densities of EBG in Victoria are highest at Cape Howe and Beware Reef, the most northern survey sites (Edmunds et al. 2011;

S. Howe and M. Rodrigue, Parks Victoria; M. Edmunds, Australian Marine Ecology, pers. comms.). In Tasmania, MB and RLS surveys have spanned most of the coastline with the exception of the central west coast, and include some sites off Bass Strait Islands (Table 2). Surveys have been carried out at 418 sites over multiple years (n=101 months; Table 1). Only 9 individual EBG sightings have been recorded on these surveys (n=6 sites). Again, these sightings are at the most northern survey sites, in the Bass Strait (Table 3). The Redmap website (www.redmap.org.au) documents an additional sighting of a single EBG (30 cm length) on the north east Tasmanian coast in March 2004.

Published surveys indicate that densities of EBG are relatively low compared to other fish species, even on the central coast of NSW and around Sydney where they are most common (Middleton et al. 1984; Fisheries Research Institute 1987; Fisheries Research Institute 1990; Fulton and Bellwood 2004; Curley 2007; Morton and Gladstone 2011). EBG do not school (Gillanders 1999) and this is supported by MB, RLS and SRMP data where most of the sightings involve single animals. Anecdotally, individual EBG are believed to be sedentary and remain on the same reef for many years (Gillanders 1999; Curley 2007). This has been supported by the results of a recent tagging study indicating that juveniles and adult male and female EBG have very small home ranges (K. Lee et al. unpublished data).

5. Discussion

5.1 History of the Eastern Blue Groper in Tasmania

On the basis of both ecological and historical evidence, it is unlikely that the EBG was present in Tasmania in the 1800s, and if present, was certainly not common. Firstly, the biogeographic affinity of EBG is eastern warm temperate (Last et al. 2011). Tasmanian waters are classified as cool temperate. Any occurrence of EBG in Tasmania would have been as extra-limital warm temperate vagrants and as such, uncommon and probably restricted to north-eastern coastal waters. Secondly, EBG are blue only as large females and males, usually when >500mm SL (Gillanders 1995b). Blue EBG (Figure 2) would have been distinctive from Blue Head (*N. tetricus*; Figure 3) in Tasmania because the latter are not blue all over, have a broad white vertical band and are also smaller (to 420mm SL; Gomon et al. 2008). The Blue Head (*N. tetricus*) would not have been described as the largest species of Parrot Fish in Tasmania (Kent 1888; Record 9 in Results) if the EBG had also been present in any numbers. In addition, in a population of EBG, blue individuals are relatively uncommon because EBG are protogynous hermaphrodites with the sex ratio strongly biased towards females (Gillanders 1995b; Figure 1). Apart from Allport's "large red fish" identified by Gunther as *C. gouldii* (Allport 1876; Record 3 in Results), there is no suggestion in the records of female EBG being present in Tasmania. It is possible that adult male Purple Wrasse *Notolabrus fucicola* were assumed to be young Blue Groper (Record 24 in Results).

Cossyphus gouldii and *Labrichthys tetricus* occur in the same Allport collection of Tasmanian fish identified by Gunther (Allport 1876; Record 3 in Results). *Labrichthys tetricus* is a synonym for *Notolabrus tetricus* (Richardson 1840) (Bluehead or Blue-throated Parrotfish; Last et al. 1983; Eschmeyer and Fricke 2011). Of *C. gouldii*, Gunther comments that more specimens are desired (Record 3 in Results). This implies that this fish was distinctive in some way and not common, and/or that he was not completely confident of his identification. It appears that Gunther did misidentify some of Allport's specimens. For example, specimen No. 16 was identified as *Scorpaena panda*, which is a synonym for *Neosebastes pandus* (Richardson 1842), the Bighead Gurnard Perch found in South Australia and south Western Australia. It is more likely that Specimen No. 16 was the then recently described and similar species *N. scorpaenoides* (Guichenot 1867), the Common Gurnard

Perch found in South Australia, Victoria and Tasmania (Allport 1876; Gomon et al. 2008; Eschmeyer and Fricke 2011). Some misidentifications are not surprising as in a letter to Allport, Gunther comments that the collection "arrived in a soft condition and required long and patient treatment to restore their firmness" and that some specimens "were irretrievably lost" (Allport 1876). It is probable that the specimen identified by Gunther as *L. tetricus* was *N. tetricus*, known as the Blue Head in Tasmania, and that the specimen identified as C. *gouldii* was a different species.

There is no other historical reference to the EBG in Tasmania that is supported by information suggesting first hand experience of EBG in Tasmania. It is possible that the Blue Groper appeared in lists because Gunther had identified a Tasmanian fish as *C. gouldii* (Allport 1876; Record 3 in Results) and also because of assumptions that the Blue Head of Tasmania was the Blue Groper of Sydney (Records 9-10 in Results). In Johnston (1882), the morphological description of the EBG is taken from published descriptions of the WBG and is clearly not from first hand examination of specimens. Although the Blue Groper is described as common, there is no information presented to support this (as for some other species in this catalogue), such as where they are locally abundant (Johnston 1882; Record 5 in Results). In addition, there is a report that Johnston had never actually seen an EBG, but that Allport had recorded it as having been found in Tasmanian waters (Morton 1888; Record 9 in Results). In other lists of fishes of Tasmania (Lord 1923; Lord and Scott 1924), the morphological descriptions of EBG are again attributed to mainland sources (Roughley 1916) and do not indicate direct examination of Tasmanian specimens (Records 15 and 19 in Results).

Notolabrus tetricus are common on Tasmanian coastal reefs and often co-occur with the closely related *Notolabrus fucicola* (Last et al. 1983). These species have probably been abundant in Tasmania for millennia. The *Pseudolabrus* species identified as dominating the fish remains in Rocky Cape middens (Stockton 1982; Record 23 in Results) are predominantly *N. tetricus* and *N. fucicola* (synonyms for *P. tetricus* and *P. fucicola* respectively, Eschmeyer and Fricke 2011; P. Last, pers.comm.). In the 1800s, it had been assumed that the "largest species of Parrot Fish" in Tasmania, known as the "Blue Head", was the EBG (*C. gouldii*). Enough uncertainty existed, however, to prompt Mr. Kent to verify this identification when he visited the Australian Museum in Sydney (Kent 1888; Record 9 in Results). The identity of the Tasmanian Blue Head was confirmed as *L. ceruleus* and *L. cyanogenus*, both synonyms of *N. tetricus*, and not as *C. gouldii* (Kent 1888; Ramsay and Ogilby 1888; Eschmeyer and Fricke 2011; Records 9-10 in Results). In a Tasmanian fishery report, Blue Groper are described as common during the season only (Anon 1883; Record 6 in Results). The EBG is a sedentary fish (Gillanders 1999; Curley 2007; K. Lee at al. unpublished data), and its abundance does not vary greatly between seasons (Curley 2007). It is probable that the Blue Groper was again confused here with *N. tetricus*, as the blue throat of *N. tetricus* males are much brighter during the breeding season, which could lead to a perceived seasonality (N. Barrett, pers. obs.).

The only potential real evidence for the presence of EBG in Tasmania in the 1800s was Allport's specimen No. 2, described as a large red fish and identified by Gunther at the British Museum as *C. gouldii* (Allport 1876; Record 3 in Results). This specimen has recently been located at the British Natural History Museum (BMNH 1875.11.12.5), with photographs (Figure 4) and meristics provided by the Senior Pisces Curator (J. Maclaine). With the aid of these, Allport's specimen No. 2 has been identified as *Bodianus flavipinnis* (Gomon 2001) by M. Gomon (Senior Curator, Ichthyology, Museum Victoria) and P. Last (Ichthyologist, CSIRO). *Bodianus flavipinnis* is an Australasian endemic occurring in waters from south-eastern Queensland to south-eastern Tasmania and around the North Island of New Zealand (Gomon 2006). No fish from any of Allport's collections remain in Tasmania. There are some other fish specimens from the 1800s at the Tasmanian Museum and Art Gallery (TMAG), but none of these are the EBG (P. Last, pers. comm.). There are no otolith collections from this time (K. Medlock, Senior Vertebrate Curator TMAG, pers. comm.).

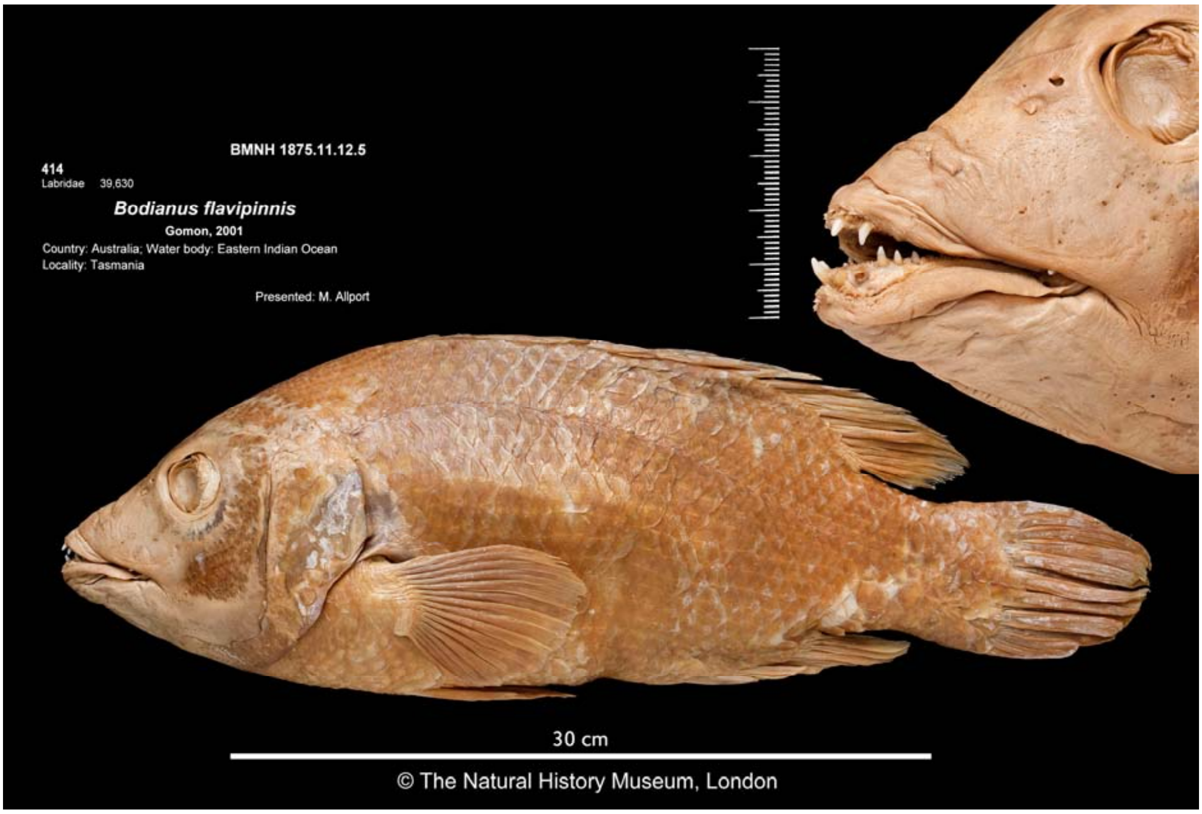


Figure 4. Photograph of Mr. Allport's specimen No. 2 identified in 1875 by Dr. Gunther as *Cossyphus gouldii* (Record 3 in Results). This specimen was subsequently identified in 2011 by Dr. Gomon as *Bodianus flavipinnis*. Image: H. Taylor, © Natural History Museum, London.

5.2 Potential for the Eastern Blue Groper to benefit Tasmanian coastal reefs

It is concluded that EBG were not present in Tasmanian coastal waters in the 1800s in ecologically significant numbers, if at all. However, EBG are currently present in very small numbers in northern Tasmanian waters (Tables 2 and 3). It is likely that this reflects a southward range expansion of EBG as a result of the southerly movement of the East Australian Current. The northern and eastern coastal waters of Tasmania are continuing to warm rapidly and it appears inevitable that the Tasmanian marine environment will become core habitat for some species from northern bioregions in the future (Ridgway 2007; Poloczanska et al. 2009; Last et al. 2011).

The EBG is a fish adapted to warm temperate coastal reef environments (Gillanders 1995b; Gillanders 1995a; Gillanders 1999; Gomon et al. 2008). The EBG present in Tasmania are currently at the southern edge of their range. Further, EBG are protogynous hermaphrodites which change sex from female to male at around 10 years of age (Gillanders 1995b; Gillanders 1999). Consequently, it is expected that it would take many years for a reproductively viable population of EBG to establish naturally in Tasmania. This process could be speeded up by managed translocation of EBG into Tasmania waters. While it is beyond the scope of this review to carry out a risk assessment for this, the potential for EBG populations to benefit Tasmanian coastal reefs, as well as important knowledge gaps are highlighted below.

As a large, long lived fish species, reproductively active and mature populations of EBG are likely to exhibit sustained high levels of reproductive output and productivity over time. This in turn may buffer these populations against environmental variations, such as those driven by climate change (Myers and Worm 2003; Babcock et al. 2010; Bui et al. 2010). The east coast of Tasmania is warming much faster than the global average (Ridgway 2007; Lough and Hobday 2011) and reproductively viable populations of mature EBG could mitigate the effects of climate change on Tasmanian coastal reef communities.

Of particular interest is the influence that EBG may have on the invasiveness of *C. rodgersii* in Tasmania. Adult EBG are habitat generalists and are commonly seen in association with urchin grazed barrens, especially when large (Gillanders and Kingsford 1998; Curley et al. 2002; Morton and Gladstone 2011). Adult EBG consume *C. rodgersii* (Gillanders 1995a; Gillanders 1999) and are likely to be a key predator of *C. rodgersii* (S. Howe, Parks Victoria, pers. comm.). However, once urchin grazed barrens are established, it appears that only low densities of *C. rodgersii* are required to maintain this state (M. Kingsford, pers. comm.). Populations of EBG in Tasmania may therefore have greater potential to improve the resilience of macroalgal habitat against an ecological shift to urchin grazed barrens habitat, than to reverse a stable urchin grazed barrens habitat back to macroalgal habitat. This indicates that any managed translocation of EBG which included control of *C. rodgersii* as one of its aims would need to be part of a larger integrated response to the expansion of *C. rodgersii*.

Although adult EBG appear to tolerate a range of habitats that vary in depth and degree of shelter (Gillanders and Kingsford 1998; Curley et al. 2002; Bellwood et al. 2006), the requirements of larval and juvenile EBG are more specific (Bell and Westoby 1986; Bell et al. 1987; Fisheries Research Institute 1987; Worthington et al. 1991; Gillanders and Kingsford 1993; Gillanders and Kingsford 1998; Curley et al. 2002; Morton and Gladstone 2011). Establishing ecologically viable populations of EBG in Tasmania would depend on the availability of suitable juvenile habitat in shallow, sheltered seagrass or kelp. Recruitment to these areas would also need to coincide with the availability of large numbers of suitable prey items, such as amphipods and copepods (Gillanders 1995a; Morton and Gladstone 2011). However, the factors influencing recruitment of EBG are not fully understood. For example, in a study on the recruitment of fish species associated with seagrass in NSW (n=16 sites), abundances of EBG recruits at one site (Pilot Harbour) were dramatically higher than at other sites. The reasons for this were not clear but may have been related to the shape of the harbour, oceanography and hydrography outside the harbour, or post-settlement survival of larvae (McNeill et al. 1992).

In addition, it is not known where EBG spawn, how larvae move from the continental shelf to seagrass beds, or how juveniles move from inner estuarine reefs to adult habitat on open coastal reefs (Gillanders 1995b; Gillanders and Kingsford 1996; Leis and Hay 2004). Linkages between estuaries and rocky reefs are important for sustaining populations of EBG, but the specific connectivity required, such as distances, movement corridors, stepping stones of natural habitat, are not known (Curley et al. 2002; Gillanders et al. 2003; B. Gillanders, A. Jordan pers. comms.). Further, it is not known what relative contributions different EBG juvenile habitats, such as seagrass and kelp, make to the adult population. There is also a lack of information on many aspects of the behavioural ecology of EBG, such as reproductive behaviour, and intra-specific and inter-specific social behaviours. For example, the factors determining which females transform into males and the age or size at which this occurs is not well understood (Gillanders 1995b; Gillanders 1999). Similarly, although EBG may form part of typical assemblages at particular sites and habitats (Morton 2007), and behavioural interactions between EBG and other fish species are often observed (Glasby and Kingsford 1994; Gillanders 1999), the significance of these associations to the functional ecology of EBG populations is not known.

It is unlikely that populations of EBG will become ecologically significant in Tasmanian coastal reefs, either naturally or through managed translocation, unless they are protected from fishing. EBG are particularly susceptible to spearfishing and gillnetting. This has resulted in protection in NSW and Victoria. In NSW, EBG may only be taken by line (bag limit of 2 over 30 cm length, on1y 1 over 60cm length; www.dpi.nsw.gov.au/fisheries). In Victoria, EBG are fully protected from fishing until April 2012, with a view to securing permanent protection following a review (http://new.dpi.vic.gov.au/fisheries).

There are potential benefits to hastening the range expansion of EBG in Tasmania to assist adaptation to climate change of temperate reefs with reduced apex predator abundance; the potential for control of *C. rodgersii* is currently the most prominent benefit. However, the unexpected consequences of introducing generalist vertebrate predators to new habitats for the purpose of biological control are also well known and the need for a clearly developed decision and risk assessment framework is well documented (e.g. Bax et al. 2001). The next stage of this project will start to address how such decisions could be made.

6. Acknowledgements

We are most grateful to librarians Christine Evans (UTAS) and Joel MacKeen (CSIRO) for their expert assistance. We also thank Martin Gomon, Steffan Howe, Alan Jordan, Peter Last, James Maclaine and Mark McGrouther for their assistance with this project.

7. References

Allport M (1876) *List of Tasmanian fish c.1870-1876*

Anon (1883) Royal Commission on the fisheries of Tasmania, Hobart

Anon (1886) Superintendent and inspector of fisheries: report for 1885. Parliament of Tasmania, Hobart

Anon (1887) Superintendent and inspector of fisheries: report for 1886-7. Parliament of Tasmania, Hobart

Anon (1889) Fisheries Board: second general report. Parliament of Tasmania, Hobart

Anon (1912-1924) Commissioners of Fisheries: Reports for 1911-23. Parliament of Tasmania, Hobart

Babcock RC, Shears NT, Alcala AC, Barrett NS, Edgar GJ, Lafferty KD, McClanahan TR, Russ GR (2010) Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. Proc Natl Acad Sci U S A 107: 18256-18261 doi 10.1073/pnas.0908012107

Bax N, Carlton JT, Mathews-Amos A, Haedrich RL, Howarth FG, Purcell JE, Reiser A, Gray A (2001) Conserving marine biodiversity through the control of biological invasions. Conservation Biology 451: 145-176

Bell JD, Westoby M (1986) Importance of local changes in leaf height and density to fish and decapods associated with seagrasses. J Exp Mar Biol Ecol 104: 249-274

Bell JD, Westoby M, Steffe AS (1987) Fish larvae settling in seagrass - do they discriminate between beds of differennt leaf density. J Exp Mar Biol Ecol 111: 133-144

Bellwood DR, Hughes TP, Hoey AS (2006) Sleeping functional group drives coral-reef recovery. Current Biology 16: 2434-2439 doi 10.1016/j.cub.2006.10.030

Bui AOV, Ouellet P, Castonguay M, Brethes JC (2010) Ichthyoplankton community structure in the northwest Gulf of St. Lawrence (Canada): past and present. Mar Ecol-Prog Ser 412: 189-205 doi 10.3354/meps08687

Bundy A, Shannon LJ, Rochet MJ, Neira S, Shin YJ, Hill L, Aydin K (2010) The good(ish), the bad, and the ugly: a tripartite classification of ecosystem trends. ICES J Mar Sci 67: 745-768 doi 10.1093/icesjms/fsp283

Burchmore JJ, Pollard DA, Bell JD, Middleton MJ, Pease BC, Matthews J (1985) An ecologicl comparison of artificial and natural rocky reef fish communities in Botany Bay, New South Wales, Australia. Bull Mar Sci 37: 70-85

Casper RM, Hobday AJ, Bax N, Barrett NS (2011) Pre-adapting Tasmanian coastal reefs to climate change http://arnmbrorg/content/images/uploads/Pre-adapting_Tasmanian_Coastal_Reefs_to_Climate_Changepdf. Marine Adaptation Network, Hobart

Cheal AJ, MacNeil MA, Cripps E, Emslie MJ, Jonker M, Schaffelke B, Sweatman H (2010) Coral-macroalgal phase shifts or reef resilience: links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs 29: 1005-1015 doi 10.1007/s00338-010-0661-y

Curley BG (2007) Estimating dispersal and population connectivity for temperate reef fishes at multiple spatial scales. PhD thesis, James Cook University

Curley BG, Kingsford MJ, Gillanders BM (2002) Spatial and habitat-related patterns of temperate reef fish assemblages: implications for the design of Marine Protected Areas. Marine and Freshwater Research 53: 1197-1210 doi 10.1071/mf01199

Edgar GJ (1997) Australian Marine Life: the plants and animals of temperate waters. Reed Books, Kew, Victoria, Australia

Edgar GJ, Barrett NS (1997) Short term monitoring of biotic change in Tasmanian marine reserves. J Exp Mar Biol Ecol 213: 261-279

Edgar GJ, Barrett NS (1999) Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. J Exp Mar Biol Ecol 242: 107-144

Edgar GJ, Barrett NS, Stuart-Smith RD (2009) Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes. Ecological Applications 19: 1967-1974 doi 10.1890/09-0610.1

Edmunds M, Hart S (2003) Parks Victoria Standard Operating Procedure: Biological Monitoring of Subtidal Reefs. Parks Victoria, Melbourne

Edmunds M, Stewart K, Pritchard K (2011) Victorian subtidal reef monitoring program: the reef biota within the Twofold Shelf Bioregion. Parks Victoria, Melbourne

Ehlers A, Worm B, Reusch TBH (2008) Importance of genetic diversity in eelgrass Zostera marina for its resilience to global warming. Mar Ecol-Prog Ser 355: 1-7 doi 10.3354/meps07369

Eschmeyer WN, Fricke R (2011) Catalog of Fishes electronic version 14 July. http://research.calacademy.org/research/ichthyology/catalog/fishcatmain.asp

Fisheries Research Institute NSW (1987) Fish habitats, fish and fisheries of Jervis Bay, with emphasis on Hare Bay

Fisheries Research Institute NSW (1990) Jervis Bay marine ecological studies, 2nd interim report

Frelich LE, Reich PB (2010) Will environmental changes reinforce the impact of global warming on the prairie-forest border of central North America? Front Ecol Environ 8: 371-378 doi 10.1890/080191

Fulton CJ, Bellwood DR (2004) Wave exposure, swimming performance, and the structure of tropical and temperate reef fish assemblages. Marine Biology 144: 429-437 doi 10.1007/s00227-003-1216-3

Georgiadis N, Hack M, Turpin K (2003) The influence of rainfall on zebra population dynamics: implications for management. Journal of Applied Ecology 40: 125-136

Gillanders B (1999) Blue groper. In: Andrew N (ed) Under Southern Seas: the ecology of Australia's rocky reefs. UNSW Press, Sydney, pp 188-193

Gillanders BM (1995a) Feeding ecology of the temperate marine fish *Achoerodus viridis* (Labridae): Size, seasonal and site-specific differences. Marine and Freshwater Research 46: 1009-1020

Gillanders BM (1995b) Reproductive biology of the protogynous hermaphrodite *Achoerodus viridis* (Labridae) from south-eastern Australia. Marine and Freshwater Research 46: 999-1008

Gillanders BM (1997a) Comparison of growth rates between estuarine and coastal reef populations of *Achoerodus viridis* (Pisces: Labridae). Mar Ecol-Prog Ser 146: 283-287

Gillanders BM (1997b) Patterns of abundance and size structure in the blue groper, *Achoerodus viridis* (Pisces, Labridae): Evidence of links between estuaries and coastal reefs. Environmental Biology of Fishes 49: 153-173

Gillanders BM, Able KW, Brown JA, Eggleston DB, Sheridan PF (2003) Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Mar Ecol-Prog Ser 247: 281-295

Gillanders BM, Kingsford MJ (1993) Abundance patterns of *Achoerodus viridis* (Pisces: Labridae) on estuarine and exposed rocky reefs: possible linkages. In: Battershill CB, Schiel DR, Jones GP, Cresse RG, MacDiarmid AB (eds) Proceedings of the Second International Temperate Reef Symposium. NIWA Marine, Wellington, Auckland, New Zealand, pp 93-98

Gillanders BM, Kingsford MJ (1996) Elements in otoliths may elucidate the contribution of estuarine recruitment to sustaining coastal reef populations of a temperate reef fish. Mar Ecol-Prog Ser 141: 13-20

Gillanders BM, Kingsford MJ (1998) Influence of habitat on abundance and size structure of a large temperate reef fish, *Achoerodus viridis* (Pisces : Labridae). Marine Biology 132: 503-514

Glasby TM, Kingsford MJ (1994) *Atypichthys strigatus* (Pisces, Scorpididae) - an opportunistic planktivore that responds to benthic disturbances and cleans other fishes. Australian Journal of Ecology 19: 385-394

Gomon M (2006) A revision of the labrid fish genus *Bodianus* with descriptions of eight new species. Records of the Australian Museum Supplement 30: 1-133

Gomon M, Bray D, Kuiter R (2008) Fishes of Australia's southern coast. Museum Victoria, Melbourne

Gunther A (1862) Catalogue of the fishes in the British Museum. British Museum, London

Halpern BS, Walbridge S, Selkoe KA, Kappel CV, Micheli F, D'Agrosa C, Bruno JF, Casey KS, Ebert C, Fox HE, Fujita R, Heinemann D, Lenihan HS, Madin EMP, Perry MT, Selig ER, Spalding M, Steneck R, Watson R (2008) A global map of human impact on marine ecosystems. Science 319: 948-952 doi 10.1126/science.1149345

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Ecology - Climate warming and disease risks for terrestrial and marine biota. Science 296: 2158-2162

Hilborn R, Quinn TP, Schindler DE, Rogers DE (2003) Biocomplexity and fisheries sustainability. Proc Natl Acad Sci U S A 100: 6564-6568 doi 10.1073/pnas.1037274100

Hooper DU, Chapin FS, Ewel JJ, Hector A, Inchausti P, Lavorel S, Lawton JH, Lodge DM, Loreau M, Naeem S, Schmid B, Setala H, Symstad AJ, Vandermeer J, Wardle DA (2005) Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. Ecological Monographs 75: 3-35

Hughes TP, Connell JH (1999) Multiple stressors on coral reefs: A long-term perspective. Limnology and Oceanography 44: 932-940

Hulme PE (2005) Adapting to climate change: is there scope for ecological management in the face of a global threat? Journal of Applied Ecology 42: 784-794 doi 10.1111/j.1365-2664.2005.01082.x

Hutchins B, Swainston R (1986) Sea fishes of southern Australia: complete field guide for anglers and divers. Swainston Publishing, Perth, Western Australia

Johnson CR, Banks SC, Barrett NS, Cazassus F, Dunstan PK, Edgar GJ, Frusher SD, Gardner C, Haddon M, Helidoniotis F (2011) Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. J Exp Mar Biol Ecol in press doi 10.1016/j.jembe.2011.02.032

Johnston RM (1882) *General and critical observations on The Fishes of Tasmania; with a classified catalogue of all the known species*. Papers & Proceedings of the Royal Society of Tasmania

Johnston RM (1890) *Further Observations upon the Fishes and Fishing Industries of Tasmania, together with a revised list of indigenous species*. Papers & Proceedings of the Royal Society of Tasmania: 22-46

Kent SW (1888) Tasmanian fishes and Notes on the identity of certain Tasmanian fishes. Papers & Proceedings of the Royal Society of Tasmania

Last PR, Scott EOG, Talbot FH (1983) Fishes of Tasmania. Tasmanian Fisheries Development Authority, Hobart

Last PR, White WT, Gledhill DC, Hobday AJ, Brown R, Edgar GJ, Pecl G (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecology and Biogeography 20: 58-72 doi 10.1111/j.1466-8238.2010.00575.x

Leis JM, Hay AC (2004) Larval development of *Achoerodus viridis* (Pisces : Labridae), the Australian eastern blue groper. Ichthyological Research 51: 46-51 doi 10.1007/s10228-003-0192-4

Ling SD (2008) Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. Oecologia 156: 883-894 doi 10.1007/s00442-008-1043-9

Ling SD, Johnson CR, Frusher SD, Ridgway KR (2009) Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci U S A 106: 22341-22345 doi 10.1073/pnas.0907529106

Lord C (1923) A list of the fishes of Tasmania. Papers & Proceedings of the Royal Society of Tasmania: 60-73

Lord CE, Scott HHA (1924) Synopsis of the Vertebrate Animals of Tasmania. Synopsis of the Vertebrate Animals of Tasmania: Unpaginated

Lough JM, Hobday AJ (2011) Observed climate change in Australian marine and freshwater environments. Marine and Freshwater Research 62: 684-999

Macleay W (1881) Descriptive catalogue of the fishes of Australia. Proc Linn Soc New South Wales 5 and 6

McNeill SE, Worthington DG, Ferrell DJ, Bell JD (1992) Consistently outstanding recruitment of 5 fish species to a seagrass bed in Botany Bay, NSW. Australian Journal of Ecology 17: 359-365

Middleton MJ, Bell JD, Burchmore JJ, Pollard DA, Pease BC (1984) Structural differences in the fish communities of *Zostera capricorni* and *Posidonia australis* seagrass meadows in Botany Bay, New South Wales. Aquat Bot 18: 89-109

Morton A (1888) Tasmanian fishes. Papers & Proceedings of the Royal Society of Tasmania

Morton JK (2007) The ecology of three species of wrasse (Pisces: Labridae) on temperate rocky reefs of New South Wales, Australia. PhD thesis, University of Newcastle

Morton JK, Gladstone W (2011) Spatial, temporal and ontogenetic variation in the association of fishes (family Labridae) with rocky-reef habitats. Marine and Freshwater Research 62: 870-884

Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. Nature 423: 280-283 doi 10.1038/nature01610

Paine RT, Tegner MJ, Johnson EA (1998) Compounded perturbations yield ecological surprises. Ecosystems 1: 535-545

Palumbi SR, McLeod KL, Grunbaum D (2008) Ecosystems in action: Lessons from marine ecology about recovery, resistance, and reversibility. Bioscience 58: 33-42 doi 10.1641/b580108

Poloczanska ES, Hobday AJ, Richardson AJ (2009) Report card of marine climate change for Australia 2009. In: NCCARF (ed) http://wwwoceanclimatechangeorgau/content/images/uploads/Report_card_webpdf

Ramsay EP, Ogilby JD (1888) Descriprions of new Australian fishes. Proc Linn Soc New South Wales 2: 242-243

Richardson J (1842) Description of a collection of fish formed at Port Arthur, Tasmania. The Tasmanian Journal of Natural Science, Agriculture, Statistics, &c 1

Ridgway KR (2007) Long-term trend and decadal variability of the southward penetration of the East Australian Current. Geophysical Research Letters 34: L13613

Roberts C (2007) The unnatural history of the sea. Island Press, Washington

Roughley TC (1916) Fishes of Australia and their technology. Government Printer, Sydney

Roughley TC (1951) Fish and fisheries of Australia. Angus and Robertson, Sydney

Scott TD, Glover CJM, Southcott RV (1974) The marine and freshwater fishes of South Australia. Government Printer, Adelaide

Stachowicz JJ, Whitlatch RB, Osman RW (1999) Species diversity and invasion resistance in a marine ecosystem. Science 286: 1577-1579

Stockton J (1982) Stone wall fish-traps in Tasmania. Australian Archaeology 14: 107-114

Taylor R (2007) The polemics of eating fish in Tasmania: the historical evidence revisited. Aboriginal History 31

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, de Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Peterson AT, Phillips OL, Williams SE (2004) Extinction risk from climate change. Nature 427: 145-148 doi 10.1038/nature02121

Whymper F (1884) The fisheries of the world: an illustrated and descriptive record of the international fisheries exhibition, 1883. Cassell & Co, London

Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314: 787-790 doi 10.1126/science.1132294

Worthington DG, Ferrell DJ, McNeill SE, Bell JD (1992) Growth of 4 species of juvenile fish associated with the seagrass *Zostera capricorni* in Botany Bay, New South Wales. Australian Journal of Marine and Freshwater Research 43: 1189-1198

Worthington DG, Westoby M, Bell JD (1991) Fish larvae settling in seagrass - effects of leaf density and an epiphytic alga. Australian Journal of Ecology 16: 289-293

Appendix 3: MT Decision Framework Strategy paper

STRATEGY PAPER
DRAFT7 AUGUST 2012

DECISION FRAMEWORK FOR ASSESSING THE PROPOSED MANAGED TRANSLOCATION OF SPECIES X FOR THE BENEFIT OF THE RECEIVING ECOSYSTEM WITHIN A CLIMATE CHANGE CONTEXT

This decision framework is to be used to assess proposals to translocate species as a management strategy for ecosystem level problems that are linked to climate change impacts. The framework includes consideration of scientific, social, economic and governance issues. Adaptive management is incorporated as an integral component to promote ongoing learning with consequent appropriate and timely responses by management. The design of the framework is based on a Common Assessment and Reporting Framework model (MACC 2010) to facilitate implementation across the science/policy interface (Figure 1).

The framework consists of a series of steps (Part A) which are guided by a set of principles (Part B). Roman numerals refer to relevant guiding principles in Part B. Part A is divided into consecutive sections, each consisting of one or more decision steps. At each step, the decision results in either progression to the next decision step or in recommendation of one or more management actions (Table 1). Each section in Part A deals with decisions pertaining to one or more issues categories (i.e. scientific, social, economic, governance). The decisions made in each section should therefore be made by people with appropriate expertise and authority.

For example, decisions in the first section, ‘Agree on objectives’, should involve collaboration between individuals who, as a group, are able to provide relevant advice on scientific, social, economic and governance issues. The section ‘Establish current understanding’ deals with scientific issues, so decisions here should be made by scientists. Any actions taken, however, are a governance issue. This recognises that while recommendations can be made by scientific, social and economic experts as a result of this decision process, management responses are also influenced by considerations external to this process.

Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. Finally, this decision framework is not intended to be prescriptive. Rather, it is presented as a generic model which can be modified to suit individual situations as required.

Figure 1. Schematic of decision framework for managed translocation as an ecosystem level climate change adaptation strategy. Dashed lines indicate governance issues. See text for detailed explanation. Modified from MACC (2010).

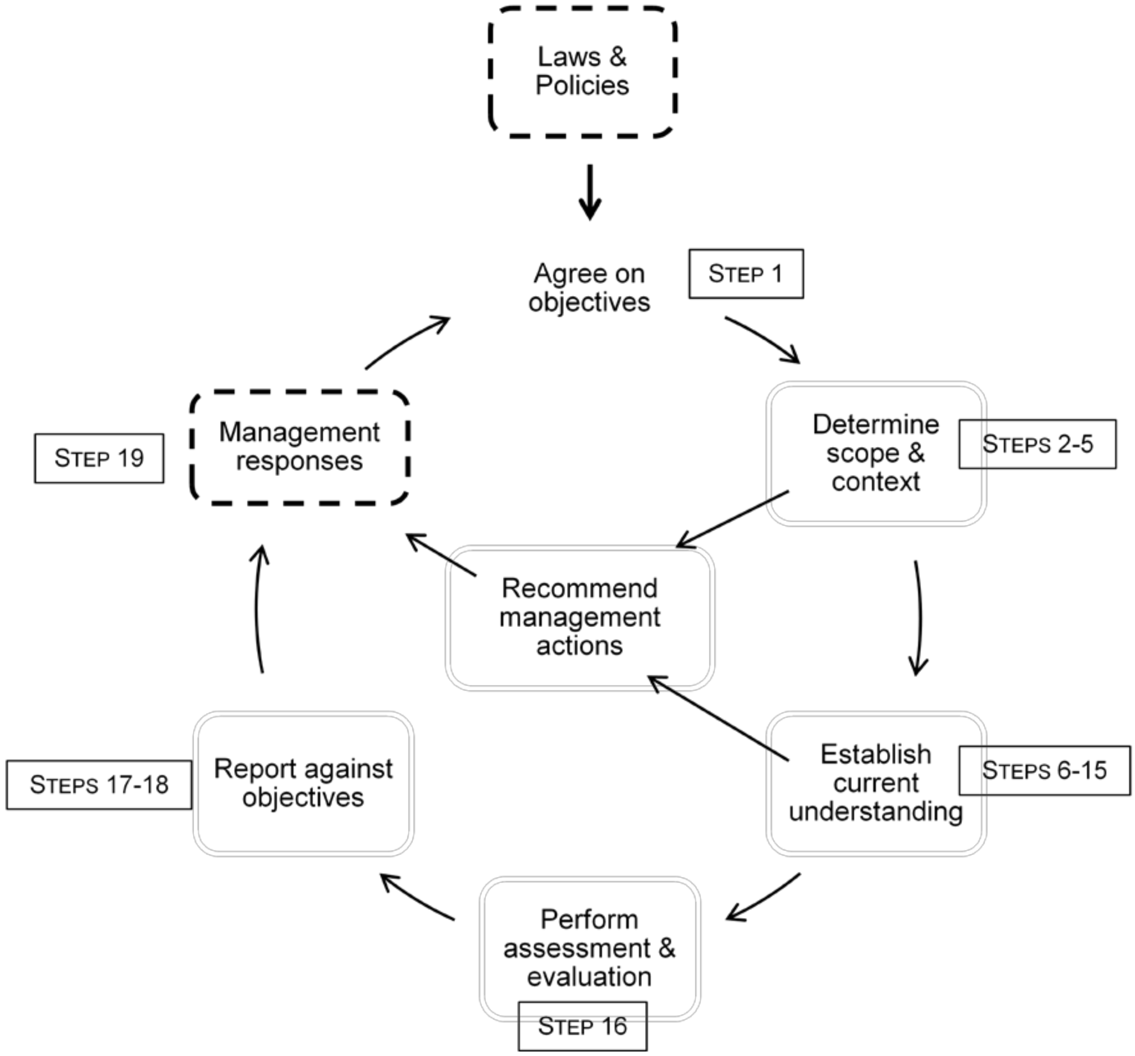


Table 1. Recommended management actions referred to in Part A of decision framework.

A. Investigate alternate management strategies, including managed translocation of alternate species and a 'do-nothing' option
B. Fill data gaps and return to the appropriate level/s of the decision framework
C. Investigate complementary management strategies to address non-climate change effects
D. Implement a reversible pilot managed translocation project with adaptive management procedures
E. Implement a more extensive managed translocation project with adaptive management procedures
F. Implement management strategies to reverse any undesired effects of the MT project

Definitions

Ecosystem: a dynamic complex of plant, animal and micro-organism communities and the non-living environment interacting as a functional unit. A well defined ecosystem has strong interactions among its components and weak interactions across its boundaries (MilleniumAssessment 2003)

MT: the proposed managed translocation of Species X

MT project: the implemented managed translocation of Species X

Risk: the function of the likelihood of an event and the consequence of the event should it occur (Anon 2004)

PART A: STEPS

Agree on objectives

- o scientific, social, economic and governance issues

1. Define the ecological, social, economic and regulatory terms of reference of the problem (see Principle I, Part B for more information)
   -> go to step 2

Determine scope and context

- o social, economic and governance issues

2. What is the risk of failure of MT due to social acceptance? (Principles I, II)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A** (Table 1)
   Yes -> document these and go to step 3
   Low -> go to step 3

3. What is the risk of failure of MT due to economic issues? (Principles I, III)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 4
   Low -> go to step 4

4. What is the risk of failure of MT due to governance? (Principles I, IV)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 5
   Low -> go to step 5

5. What is the risk of inadequate adaptive management following implementation of MT? (Principle V)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 6
   Low -> go to step 6

Establish current understanding

- o scientific issues

6. Is there reasonable theoretical and/or empirical evidence for MT to meet the stated aims of management? (Principle VI)
   No -> see Recommended Management Actions **A** or **B**
   Yes -> go to step 7

7. Is MT technically feasible? (Principle VII)
    - No -> see Recommended Management Actions **A** or **B**
    - Yes -> go to step 8

8. What is the risk of adverse effects of MT on Species X or the donor ecosystem? (Principle VIII)
    - High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
        - No -> see Recommended Management Action **A**
        - Yes -> document these and go to step 9
    - Low -> go to step 9

9. What is the risk of Species X failing to establish in the recipient area? (Principle IX)
    - High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
        - No -> see Recommended Management Action **A**
        - Yes -> document these and go to step 10
    - Low -> go to step 10

10. What is the risk of invasiveness of Species X in the recipient area? (Principle X)
    - High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
        - No -> see Recommended Management Action **A**
        - Yes -> document these and go to step 11
    - Low -> go to step 11

11. What is the risk of disease transmission to the recipient area? (Principle XI)
    - High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
        - No -> see Recommended Management Action **A**
        - Yes -> document these and go to step 12
    - Low -> go to step 12

12. What is the risk of an experimental pilot MT being irreversible? (Principles V, VIII, X, XI, XII)
    - High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
        - No -> see Recommended Management Action **A**
        - Yes -> document these and go to step 13
    - Low -> go to step 13

13. What is the risk of failure of MT to achieve the stated aims of management due to compounding non-climate impacts? (Principles I, XIII)
    - High, Moderate -> see Recommended Management Action **C**
    - Low -> go to step 14

Review decisions (steps 14-15)

- scientific, social, economic and governance issues

14. What is the risk that inadequate data have underestimated a risk assessed as 'Low' in decision steps 2-13? (Principle XIV)

    High, Moderate -> Is it feasible to fill these data gaps?

    No -> see Recommended Management Action **A**

    Yes -> see Recommended Management Action **B**

    Low -> go to step 15

15. Have all feasible mitigation measures been implemented so that the levels of risk are Low in decision steps 2-14?

    No -> see Recommended Management Action **A**

    Yes -> see Recommended Management Action **D** and go to step 16

Adaptive management (steps 16-19)

Perform assessment and evaluation

- scientific, social, economic and governance issues

16. Is there evidence of any positive or negative ecological, social, economic or governance effects associated with the MT project? (Principles I - VI, VIII - XI, XIII)

    -> document the evidence, including any important data gaps, and then go to step 17

Report against objectives

- scientific, social, economic and governance issues

17. Are there any ecological, social, governance or economic benefits or threats arising from or to the MT project?

    -> respond based on findings in step 16 and then go to step 18

18. Is the MT project achieving the stated aims of management (with respect to time since implementation)?

    -> respond based on findings in steps 16-17 and then go to step 19

Management responses

- governance issues

19. Determine and implement appropriate management response/s, e.g. revisit step 1 and/or implement Recommended Management Actions B and/or E or F

PART B: PRINCIPLES GUIDING DECISIONS IN PART A

I. Define the ecological, social, economic and regulatory terms of reference of the problem (Sutherland et al. 2006; Cundill et al. 2011), including:
   i) aim/s, e.g. intended benefit/s to receiving ecosystem (Lipsey and Child 2007)
   ii) temporal and spatial scales of the problem (Macdonald 2009; Tongway and Ludwig 2011)
   iii) temporal and spatial scales of the management approach (Tongway and Ludwig 2011)
   iv) stakeholders
   v) decision makers
   vi) transparency, where the decision making process at each step is clearly defined, accessible, communicated effectively and involves all those with an interest in the outcome (IUCN 1998; Lockie and Rockloff 2005; Soorae 2008; Macdonald 2009; Richardson et al. 2009; Smith and Bangs 2009; Lockwood 2010; Lorenzen et al. 2010; Koehn et al. 2011)

II. Assess the risk of failure of MT associated with social acceptance (IUCN 1998; Allen et al. 2001; Lockie and Rockloff 2005; Soorae 2008; Macdonald 2009; Richardson et al. 2009; Lockwood 2010). Mitigation considerations include:
   i) transparency of process
   ii) a structured process of local participation that emphasises shared learning and locally relevant indicators and methods
   iii) evaluation of socio-economic impacts including attention to equity (the benefits, costs and risks across groups are balanced in an equitable way) and vulnerability (the most vulnerable human populations, and human health)

III. Assess the risk of failure of MT associated with economic issues. Considerations include socio-economic impacts (see principal II iii) above), cost-benefit analyses of alternate management strategies (Macdonald 2009), and ensuring that sufficient funding is available for effective implementation and adaptive management of MT (Soorae 2008).

IV. Assess the risk of failure of MT associated with governance. Considerations include adequacy of the interface between science and policy formation, adequacy of policy for dealing with climate change scenarios, and cross-jurisdictional consistencies and coordination (IUCN 1998; Short 2009; Lockwood et al. 2010; Lorenzen et al. 2010; Burbidge et al. 2011; Philippart et al. 2011).

V. Adaptive management is an essential component of management strategies with uncertain consequences (Fulton 2011). The sequence below is followed iteratively (IUCN 1998; Allen et al. 2001; MilleniumAssessment 2003; Lockie and Rockloff 2005; Dunwiddie et al. 2009; Macdonald 2009; Lockwood et al. 2010; Lorenzen et al. 2010; Tongway and Ludwig 2011):
   i) repeated measurements of indicators are made (i.e. monitoring)
   ii) trends and uncertainty are re-evaluated
   iii) management is adjusted as appropriate as new insights are gained

   Adequate monitoring of Species X and other populations at the recipient site is required to assess the success of establishment of Species X, to provide early warning of signs of invasiveness or disease, and to indicate if the stated aims of management are being achieved. Appropriate indicators should be chosen for these purposes. Robust indicators demonstrate cause and effect linkages, are representative, reliable and feasible, and identify critical thresholds or the irreversibility of change (McAlpine and Loyn 2000; Fourqurean and Rutten 2003; MilleniumAssessment 2003; Bundy et al. 2010).

VI. Strategies with a low probability of achieving the stated aims of management are not viable even if they represent low risk, low cost options (Bellwood et al. 2006; Casini et al. 2009).

VII. Assess the technical feasibility of translocating the animals in question, e.g. logistic or biological constraints (Hoegh-Guldberg et al. 2008; Macdonald 2009; Richardson et al. 2009).

VIII. Assess the risk of MT to translocated species/populations in donor and recipient ecosystems, e.g. threats to viability (IUCN 1998; Soorae 2008). Also assess the risk of MT resulting in reduction or loss of ecosystem structure, function or service in the donor ecosystem (Moir et al. 2012).

IX. Assess the risk of failure of translocated populations to establish in recipient area. Mitigation considerations include:
- i) maximising genetic diversity of the founder population (Frankham 2009; Lorenzen et al. 2010; Burbidge et al. 2011)
- ii) maximising population size to maximise genetic diversity (Frankham 2009; Lorenzen et al. 2010; Burbidge et al. 2011)
- iii) timing of translocation and release strategy (IUCN 1998; Soorae 2008; Lorenzen et al. 2010; McDonald-Madden et al. 2011)
- iv) suitability analysis of potential translocated species/populations/classes (IUCN 1998; Cassey et al. 2008; Soorae 2008; Lorenzen et al. 2010)
- v) confirming availability of suitable habitat and absence of significant threats at the recipient site/s (IUCN 1998; Hoegh-Guldberg et al. 2008; Soorae 2008)

X. Assess the risk of invasiveness of Species X in the recipient area, including genetic effects via inter- and intra-specific hybridisation leading to heterosis (hybrids out-compete local progeny) and/or outbreeding depression (reduced fitness; Lorenzen et al. 2010; Weeks et al. 2011). An invasive species is a taxon that causes significant adverse effects to the environment, economy or human health (Lodge et al. 2006; Mueller and Hellmann 2008; Loss et al. 2011). Mitigation considerations include:
- i) the reversibility of the intervention (Soorae 2008; Macdonald 2009)
- ii) appropriate monitoring of local populations for evidence of invasiveness at the recipient site (Burbidge et al. 2011)
- iii) use of invasive biology literature (Loss et al. 2011; Olden et al. 2011)

XI. A disease and health management program is required to mitigate any risk of disease transmission to the recipient area (Lorenzen et al. 2010).

XII. A reversible pilot experiment should precede extensive implementation to improve understanding of the ecological, social, economic and governance effects of the MT. Pilot MT projects should incorporate well formulated testable hypotheses and use experimental and/or modelling techniques to minimise the risk of irreversibility (Lipsey and Child

2007; Soorae 2008; Dunwiddie et al. 2009; Macdonald 2009; Ritchie and Johnson 2009; Green et al. 2010; Lorenzen et al. 2010; Loss et al. 2011; Olden et al. 2011).

XIII. Assess the risk of failure of MT to achieve the stated aims of management due to compounding non-climate change impacts. Where relevant, complementary strategies to address non-climate change threats should be incorporated into the overall management plan (Hoegh-Guldberg et al. 2008; Koehn 2011; Loss et al. 2011; Wernberg et al. 2011)

XIV. At each decision step, assess if data are adequate for robust assessments to be made:

i) use the best available information (Lockie and Rockloff 2005; Macdonald 2009)
ii) incorporate measure/s of uncertainty (Lockie and Rockloff 2005; Hoegh-Guldberg et al. 2008)
iii) define an acceptable threshold level of uncertainty (Richardson et al. 2009)

If the scientific evidence is inadequate for a robust assessment at any decision step:

i) identify what data/information are required to allow a robust assessment to be made (Macdonald 2009)
ii) conduct a cost/benefit analysis on filling the data gaps
iii) where feasible, fill the data gaps and return to the appropriate level/s of the decision framework

References

Allen W, Bosch O, Kilvington M, Harley D, Brown I (2001) Monitoring and adaptive management: resolving social and organisational issues to improve information sharing in natural resource management. Natural Resources Forum 25: 225-233

Anon (2004) Risk Management Guidelines (HB 436:2004). Standards Australia, Sydney and Standards New Zealand, Wellington

Bellwood DR, Hughes TP, Hoey AS (2006) Sleeping functional group drives coral-reef recovery. Current Biology 16: 2434-2439 doi 10.1016/j.cub.2006.10.030

Bundy A, Shannon LJ, Rochet MJ, Neira S, Shin YJ, Hill L, Aydin K (2010) The good(ish), the bad, and the ugly: a tripartite classification of ecosystem trends. ICES J Mar Sci 67: 745-768 doi 10.1093/icesjms/fsp283

Burbidge AA, Byrne M, Coates DJ, Garnett S, Harris S, Haywood MW, Martin TG, McDonald-Madden E, Mitchell NJ, Nally S, Setterfield SA (2011) Is Australia ready for assisted colonization? Policy changes required to facilitate translocations under climate change. Pacific Conservation Biology 17: 259-269

Casini M, Hjelm J, Molinero J-C, Lovgren J, Cardinale M, Bartolino V, Belgrano A, Kornilovs G (2009) Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. Proc Natl Acad Sci U S A 106: 197-202 doi 10.1073/pnas.0806649105

Cassey P, Blackburn TM, Duncan RP, Lockwood JL (2008) Lessons from introductions of exotic species as a possible information source for managing translocations of birds. Wildlife Research 35: 193-201 doi 10.1071/wr07109

Cundill G, Cumming GS, Biggs D, Fabricius C (2011) Soft systems thinking and social learning for adaptive management. Conservation Biology 26: 13-20

Dunwiddie PW, Hall SA, Ingraham MW, Bakker JD, Nelson KS, Fuller R, Gray E (2009) Rethinking conservation practice in light of climate change. Ecological Restoration 27: 320-329 doi 10.3368/er.27.3.320

Fourqurean JW, Rutten LM (2003) Competing goals of spatial and temporal resolution: monitoring seagrass communities on a regional scale. In: Busch DE, Trexler JC (eds) Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, pp 257-288

Frankham R (2009) Genetic considerations in reintroduction programmes for top-order, terrestrial predators. In: Hayward MW, Somers MJ (eds) Reintroduction of top-order predators. Blackwell Publishing, West Sussex, UK

Fulton EA (2011) Interesting times: winners, losers, and system shifts under climate change around Australia. ICES J Mar Sci 68: 1329-1324

Green BS, Gardner C, Linnane A, Hawthorne PJ (2010) The Good, the Bad and the Recovery in an Assisted Migration. Plos One 5: 8 doi e1416010.1371/journal.pone.0014160

Hoegh-Guldberg O, Hughes L, McIntyre S, Lindenmayer DB, Parmesan C, Possingham HP, Thomas CD (2008) Assisted colonization and rapid climate change. Science 321: 345-346 doi 10.1126/science.1157897

IUCN (1998) Guidelines for re-introductions. IUCN, Gland, Switzerland and Cambridge, UK

Koehn JD (2011) Climate change and Australian marine and freshwater environments, fish and fisheries: introduction. Marine and Freshwater Research 62: 981-983

Koehn JD, Hobday AJ, Pratchett MS, Gillanders BM (2011) Climate change and Australian marine and freshwater environments, fish and fisheries: synthesis and options for adaptation. Marine and Freshwater Research 62: 1148-1164

Lipsey MK, Child MF (2007) Combining the fields of reintroduction biology and restoration ecology. Conservation Biology 21: 1387-1390

Lockie S, Rockloff S (2005) Decision frameworks: assessment of the social aspects of decision frameworks and development of a conceptual model. Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, Rockhampton, Queensland

Lockwood M (2010) Good governance for terrestrial protected areas: A framework, principles and performance outcomes. Journal of Environmental Management 91: 754-766 doi 10.1016/j.jenvman.2009.10.005

Lockwood M, Davidson J, Curtis A, Stratford E, Griffith R (2010) Governance Principles for Natural Resource Management. Society & Natural Resources 23: 986-1001 doi 10.1080/08941920802178214

Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Mack RN, Moyle PB, Smith M, Andow DA, Carlton JT, McMichael A (2006) Biological invasions: Recommendations for US policy and management. Ecological Applications 16: 2035-2054 doi 10.1890/1051-0761(2006)016[2035:birfup]2.0.co;2

Lorenzen K, Leber KM, Blankenship HL (2010) Responsible Approach to Marine Stock Enhancement: An Update. Reviews in Fisheries Science 18: 189-210 doi 10.1080/10641262.2010.491564

Loss SR, Terwilliger LA, Peterson AC (2011) Assisted colonization: Integrating conservation strategies in the face of climate change. Biological Conservation 144: 92-100 doi 10.1016/j.biocon.2010.11.016

MACC (2010) Identification of assessment priorities for implementation of national or cross-jurisdictional monitoring, evaluation and reporting in marine, coastal and estuarine environments. MACC Research and Development Working Group, Sydney

Macdonald DW (2009) Lessons learnt and plans laid: seven awkward questions for the future of reintroductions. In: Hayward MW, Somers MJ (eds) Reintroduction of top-order predators. Blackwell Publishing, West Sussex, UK

McAlpine C, Loyn R (2000) Assessing and monitoring of forest fragmentation: questions of spatial pattern, scale and methods. In: Hale P, Petrie A, Moloney D, Sattler P (eds) Management for suatainable ecosystems. Centre for Conservation Biology, University of Queensland, Brisbane

McDonald-Madden E, Runge MC, Possingham HP, Martin JM (2011) Optimal timing for managed relocation of species faced with climate change. Nature Climate Change doi 10.1038/NCLIMATE1170

MilleniumAssessment (2003) Ecosystems and Human Well-being: A Framework for Assessment. Island Press, Washington DC

Moir ML, Vesk PA, Brennan KEC, Poulin R, Hughes L, Keith DA, McCarthy MA, Coates DJ (2012) Considering Extinction of Dependent Species during Translocation, Ex Situ Conservation, and Assisted Migration of Threatened Hosts. Conservation Biology 26: 199-207 doi 10.1111/j.1523-1739.2012.01826.x

Mueller JM, Hellmann JJ (2008) An assessment of invasion risk from assisted migration. Conservation Biology 22: 562-567

Olden JD, Kennard MJ, Lawler JJ, Poff NL (2011) Challenges and Opportunities in Implementing Managed Relocation for Conservation of Freshwater Species. Conservation Biology 25: 40-47 doi 10.1111/j.1523-1739.2010.01557.x

Philippart CJM, Anadón R, Danovaro R, Dippner JW, Drinkwater KF, Hawkins SJ, Oguz T, O'Sullivan G, Reid PC (2011) Impacts of climate change on European marine ecosystems: Observations, expectations and indicators. J Exp Mar Biol Ecol 400: 52-69

Richardson DM, Hellmann JJ, McLachlan JS, Sax DF, Schwartz MW, Gonzalez P, Brennan EJ, Camacho A, Root TL, Sala OE, Schneider SH, Ashe DM, Clark JR, Early R, Etterson JR, Fielder ED, Gill JL, Minteer BA, Polasky S, Safford HD, Thompson AR, Vellend M (2009) Multidimensional evaluation of managed relocation. Proc Natl Acad Sci U S A 106: 9721-9724 doi 10.1073/pnas.0902327106

Ritchie EG, Johnson CN (2009) Predator interactions, mesopredator release and biodiversity conservation. Ecol Lett 12: 982-998 doi 10.1111/j.1461-0248.2009.01347.x

Short J (2009) The characteristics and success of vertebrate translocations within Australia. Department of Agriculture, Fisheries and Forestry, Canberra

Smith DC, Bangs EE (2009) Reintroduction of wolves in Yellowstone National Park: history, values and ecosystem restoration. In: Hayward MW, Somers MJ (eds) Reintroduction of top-order predators. Blackwell Publishing, West Sussex, UK

Soorae PS (2008) Global re-introduction perspectives: re-introduction case-studies from around the globe. IUCN/SSC Re-introduction Specialist Group, Abu Dhabi, UAE

Sutherland WJ, Armstrong-Brown S, Armsworth PR, Brereton T, Brickland J, Campbell CD, Chamberlain DE, Cooke AI, Dulvy NK, Dusic NR, Fitton M, Freckleton RP, Godfray HCJ, Grout N, Harvey HJ, Hedley C, Hopkins JJ, Kift NB, Kirby J, Kunin WE, Macdonald DW, Marker B, Naura M, Neale AR, Oliver T, Osborn D, Pullin AS, Shardlow MEA, Showler DA, Smith PL, Smithers RJ, Solandt JL, Spencer J, Spray CJ, Thomas CD, Thompson J, Webb SE, Yalden DW, Watkinson AR (2006) The identification of 100 ecological questions of high policy relevance in the UK. Journal of Applied Ecology 43: 617-627 doi 10.1111/j.1365-2664.2006.01188.x

Tongway DJ, Ludwig JA (2011) Restoring disturbed landscapes: putting principles into practice. Island Press, Washington DC

Weeks AR, Sgro CM, Young AG, Frankham R, Mitchell NJ, Miller KA, Byrne M, Coates DJ, Eldridge MD, Sunnucks P, Breed MF, James EA, Hoffman AA (2011) Assessing the benefits and risks of translocations in changing environments: a genetic perspective. Evolutionary Applications doi 10.1111/j.1752-4571.2011.00192.x

Wernberg T, Russell BD, Moore PJ, Ling SD, Smale DA, Campbell A, Coleman MA, Steinberg PD, Kendrick GA, Connell SD (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. J Exp Mar Biol Ecol 400: 7-16 doi 10.1016/j.jembe.2011.02.021

Appendix 4: Translocations as an ecosystem-level climate change adaptation strategy: A practical decision support plan

TRANSLOCATIONS AS AN ECOSYSTEM-LEVEL CLIMATE CHANGE ADAPTATION STRATEGY: A PRACTICAL DECISION SUPPORT PLAN

Ruth M Casper[1], Neville S Barrett[1], Nic Bax[1,2], Alistair J Hobday[2*]

[1]Institute of Marine and Antarctic Studies, University of Tasmania, Australia
[2]CSIRO Climate Adaptation Flagship, Tasmania, Australia *(alistair.hobday@csiro.au)

Abstract

In the face of rapid climate change, protecting ecosystem function may sometimes be better served by focussing on the ecological function of species rather their historical range. The stability of ecosystems may be particularly compromised where species which perform major ecological roles have been removed. In this context, translocation of species to restore keystone roles has potential as an effective ecosystem-level climate change adaptation strategy. Translocating species is, however, a controversial and hotly debated issue. In order to realise the potential benefits of this strategy while minimising the potential risks, we develop and test a practical decision framework for assessing ecosystem oriented translocation proposals. This method will provide clear guidance to decision makers and help prioritise areas for future research. Above all, this approach is intended as a tool to facilitate progressive and constructive discussion, as well as assessment and implementation of translocation proposals as a climate change adaptation strategy.

In a nutshell

- In an era of climate change, translocations have potential to provide profound benefits at an ecosystem-level
- We develop and test a practical decision framework for assessing ecosystem oriented translocations that systematically considers relevant scientific, socio-economic and governance issues
- The process highlights the strengths and risks associated with each proposal
- This facilitates decision making by managers and allows informed decisions on the most constructive research directions to be made

Recent rapid climate change is acknowledged as a major threat to the integrity of aquatic and terrestrial ecosystems. The impacts of climate change on biological processes are already apparent as shifts in species geographic range, changes in community composition and alterations in ecosystem form and function (Brierley and Kingsford 2009; Chen *et al.* 2011). These effects are expected to continue (Williams *et al.* 2007), with one study predicting a turnover of over 60% of marine faunal biodiversity by 2050 (Cheung *et al.* 2009). The appearance of novel 21st century climates and the disappearance of some extant climates mean that the historic range of some species may not remain suitable for their survival (Williams *et al.* 2007). The corollary is that areas outside the historic range of some species may become suitable, as indicated by climate change migrants (Thomas 2011). There is also growing evidence that the stability of many ecosystems (a function of resistance and resiliance; M.A. 2003) is compromised by the compounding effects of climate change and other disturbances, such as fishing, pollution or disease. As a consequence, alternate stable states and novel ecosystems are emerging (Paine *et al.* 1998).

Recognition of these processes is increasingly prompting calls for paradigm shifts in conservation management of ecosystem function, where aiming to restore historical ecosystems is no longer always appropriate. Proponents instead support protecting ecosystem function by focussing on the ecological function of species rather than their historical range (Jackson and Hobbs 2009; Walther *et al.* 2009). Consistent with this approach is the integration of species introduction biology and restoration ecology, where conservation translocation (CT; Panel 1) of species is carried out for the explicit benefit of the receiving ecosystem (Lipsey and Child 2007). This scenario has particular application where ecosystems may be destabilised because of a loss in functional redundancy (Palumbi *et al.* 2008). This appears more likely where species which perform major ecological roles, such as keystone species, are removed or are functionally diminished. The ensuing trophic cascades result in multiple effects including changes in species composition, reduced biodiversity and ecosystem state shifts (Casini *et al.* 2009; Ritchie and Johnson 2009). Limited studies in this nascent field show that restoring or maintaining keystone ecological roles can help to reverse or prevent these effects, with concomitant improved ecosystem function (Salo *et al.* 2008; Gibbs *et al.* 2010; Lindegren *et al.* 2010; Kemp *et al.* 2012; Ripple and Beschta 2012).

In this context, CT of species has the potential to contribute positively to conservation management as an ecosystem-level climate change adaptation strategy (Sala 2006; Ritchie *et al.* 2012). While the likelihood of CT resulting in harmful effects appears to be low, these can be serious if they do occur (Mueller and Hellmann 2008; Schlaepfer *et al.* 2011). Consequently, translocating species is a controversial and hotly debated issue (Lawler and Olden 2011). However, a decision framework to realise the potential benefits of this strategy while minimising the potential risks is currently lacking. In particular, a model to systematically consider relevant scientific, social, economic and governance issues is needed (Marris 2011). Such a framework would provide clear guidance to decision makers.

With the aim of providing constructive progress to this evolving discussion, we present a practical decision framework for assessing CT proposals as an ecosystem-level climate change adaptation strategy. This decision framework is not intended to be prescriptive. Rather, it is presented as a generic model which can be modified to suit individual situations as required. To illustrate this, we test the utility of this framework using example CT projects where the goal is to benefit the receiving ecosystem.

▪ The decision framework design

In order to facilitate implementation across the science/policy interface, we modelled the decision framework design on the widely accepted adaptive management cycle (Holling 1978; Figure 1). Based on potential concerns associated with CT proposals identified in the scientific literature, we also incorporated a series of risk assessments of relevant socio-economic, governance and scientific issues. In consultation with three experts with socio-economic and governance knowledge at the level of Australian state government, we developed and refined the framework iteratively using a proposed CT of the eastern blue groper (EBG; *Achoerodus viridis*) from NSW to Tasmanian coastal reefs in Australia (Casper *et al.* 2011).

The framework consists of a series of decision steps (WebPanel 1; Figure 1) which are guided by a set of principles (WebPanel 2). Depending on the response at each step, the decision maker is guided to the next step or to one or more recommended management actions (WebTable 1). For the most comprehensive assessment of a proposal, however, as much information as possible should be completed at all steps.

Management objectives are articulated at step 1. Risk analyses of socio-economic and governance issues (steps 2-5), and scientific issues (steps 6-13) are then carried out. Although the decision steps in the framework are sequential, collection of the corresponding data is unlikely to always be linear. Therefore, the framework includes a review section (steps 14-15) where prior decisions are revisited in light of the complete set of data collected during the process. This minimises the risk of underestimating uncertainty at any of the decision steps. If a CT project is implemented, appropriate performance indicators should be monitored and then evaluated at step 16. Findings and recommendations are then reported to management (steps 17-18), who then determine and implement appropriate responses (step 19).

The decisions at each step should be informed by people with appropriate expertise and authority (I.U.C.N. 2012). For example, decisions at step 1 ('Determine management objectives'), would involve individuals who are able to provide relevant advice on scientific, social, economic, governance and regulatory issues. Steps 6-13 deal with scientific issues, so need to be informed by scientists. Any decisions and actions, however, are a governance issue. This recognises that while recommendations can be made by social, economic and scientific experts as a result of this decision process, management responses (step 19) are also influenced by other considerations.

- **Testing the decision framework**

Following development of the decision framework, we searched the scientific literature for examples with which to test it. Very few ecosystem oriented CTs have been proposed or carried out (Polak and Saltz 2011). Of these, even fewer have sufficient published information available to enable adequate testing of the decision framework. Here, we test four suitable proposed or implemented CT projects (Tables 1 and 2; WebTable 2). The EBG is the only example where the project is an ecosystem-level climate change adaptation strategy (Casper *et al.* 2011). Although the other projects tested have alternate ecosystem benefits as their primary goals (Table 2; WebTable 2), all acknowledge that ecosystem-level mitigation of climate change impacts is a likely additional benefit [dingo (Canis lupus dingo; Ritchie *et al.* 2012); European beaver (Castor fiber; Hood and Bayley 2008); large and giant tortoises (Testudinidae; Hansen *et al.* 2010)].

For the EBG example, decisions at each step within the framework are based on our own research (Casper *et al.* 2011) and expert advice. For the other examples, decisions at each step and any recommended and implemented management actions are based on the available literature. The outcomes of our assessments of each example used to test the decision framework are summarised in Table 2 and detailed in WebTable 2.

- **Conclusions**

Conservation translocations are increasingly being considered as a climate change adaptation strategy. This has mostly been as a means of conserving populations or species (Perez *et al.* 2012), but there is also growing recognition of the potential for this strategy to provide profound benefits at an ecosystem-level, for example through restoration of seagrass beds (Irving *et al.* 2011), oyster reefs (Beck *et al.* 2011), plant-animal mutualisms (Kaiser-Bunbury *et al.* 2010) and predator-prey relationships (Ripple and Beschta 2012). It is likely that contemporary and future rapid climate change scenarios will see an increasing need for timely and transparent decisions to be made on CT proposals.

Although still low, the number of peer-reviewed articles on species reintroductions that are ecosystem oriented has increased rapidly in recent years (n=0 before 1990, n=18 from 1991 to 1999, n=45 from 2000 to 2009; Polak and Saltz 2011). In most cases, however, there is a lack of clear description of the process. In addition, it is often uncertain how or indeed if, socio-economic and governance issues were considered. The need for a comprehensive decision framework with which to assess CT proposals has exacerbated the lack of progress in the current, often highly charged, debate surrounding this strategy. Our model for assessing CT proposals systematically considers relevant socio-economic, governance and scientific issues.

In doing so, the strengths and risks associated with different proposals are clearly highlighted. For example, for both the EBG and dingo proposals, our framework suggests that a CT project should not be implemented at this stage, but for different reasons. The aims of the EBG proposal are inadequately supported by the available scientific evidence. By contrast, the aims of the dingo proposal are supported by good scientific evidence, but the associated socio-economic and governance risks are high. The value of the decision framework in identifying strengths and risks is realised by completing all steps as much as possible. For example, even though alternate strategies to CT were recommended early on in the assessment of the EBG proposal (step 6), completing subsequent steps provided a more complete evaluation of all the issues associated with this proposal. This allowed more comprehensive recommendations to management (Table 2; WebTable 2).

Importantly, this process also facilitates prioritising areas for future research. For example, what data would be most useful to overcome the obstacles identified in the assessment of the proposal? In addition, the research questions identified in this way are not biased towards scientific issues. Socio-economic and governance impediments to achieving the aims of a proposal are highlighted in the same manner. This allows informed decisions on the most constructive research directions to be made in any particular case.

The decision framework also incorporates an adaptive management facility which allows for ongoing assessment and management of scientific, social, economic and governance issues once a pilot CT has been implemented. The European beaver and giant tortoise test cases illustrate this. In the case of the beaver, it is too soon to determine any positive or negative effects arising from the CT, which is therefore currently being monitored closely as a limited pilot project. The tortoise CT pilot project has been going for longer. Ongoing monitoring and evaluation indicate associated ecological and economic benefits and no threats. In response to these findings, the tortoise CT project has been expanded (Table 2; WebTable 2).

Although this decision framework was developed to assess CT proposals as an ecosystem-level climate change adaptation strategy, we have demonstrated that this model can also successfully test CT proposals with other ecosystem oriented goals from a range of ecological contexts (Tables 1 and 2; WebTable 2). This decision framework is a flexible and utilitarian model for assessing CT proposals, which can be modified where necessary and used effectively across a variety of situations. Above all, this framework is intended as a tool to facilitate progressive and constructive discussion, as well as assessment and implementation of conservation translocation proposals as a climate change adaptation strategy.

▪ Acknowledgements

We thank Jo Klemke, Grant Pullen and Greg Johannes for their expert advice on socio-economic, regulatory and governance issues. This paper is an output for FRDC-DCCEE Project 2010/564, supported by CSIRO and UTAS.

Panel 1. Definition of terms.
Conservation translocation: the intentional movement of organisms from one site to another with the aim of conservation benefit at the population, species or ecosystem level (I.U.C.N. 2012). *Ecosystem*: a dynamic complex of plant, animal and micro-organism communities and the non-living environment interacting as a functional unit. A well defined ecosystem has strong interactions among its components and weak interactions across its boundaries (M.A. 2003). *Invasiveness*: the ability of a taxon to cause significant adverse effects to the environment, economy or human health in a given context (Mueller and Hellmann 2008). *Risk*: the function of the likelihood of an event and the consequence of the event should it occur (Anon 2004).

- **References**

Anon. 2004. Risk Management Guidelines (HB 436:2004). Standards Australia, Sydney and Standards New Zealand, Wellington.

Beck MW, Brumbaugh RD, Airoldi L, *et al.* 2011. Oyster Reefs at Risk and Recommendations for Conservation, Restoration, and Management. *Bioscience* **61**: 107-16.

Brierley AS and Kingsford MJ. 2009. Impacts of climate change on marine organisms and ecosystems. *Current Biology* **19**: R602-R14.

Casini M, Hjelm J, Molinero J-C, *et al.* 2009. Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* **106**: 197-202.

Casper RM, Barrett NS, Bax N, *et al.* 2011. Review of the eastern blue groper. Hobart: Institute of Marine and Antarctic Studies. http://eprints.utas.edu.au/11977.

Chen IC, Hill JK, Ohlemuller R, *et al.* 2011. Rapid range shifts of species associated with high levels of climate warming. *Science* **333**: 1024-26.

Cheung WWL, Lam VWY, Sarmiento JL, *et al.* 2009. Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries* **10**: 235-51.

Gibbs JP, Sterling EJ and Javier Zabala F. 2010. Giant Tortoises as Ecological Engineers: A Long-term Quasi-experiment in the Galapagos Islands. *Biotropica* **42**: 208-14.

Hansen DM, Donlan CJ, Griffiths CJ, *et al.* 2010. Ecological history and latent conservation potential: large and giant tortoises as a model for taxon substitutions. *Ecography* **33**: 272-84.

Holling CS (ed.). 1978. Adaptive environmental assessment and management.

Hood GA and Bayley SE. 2008. Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. *Biological Conservation* **141**: 556-67.

I.U.C.N. 2012. Guidelines for reintroductions and other conservation translocations. IUCN Species Survival Commission. http://issg.org/.

Irving AD, Connell SD and Russell BD. 2011. Restoring Coastal Plants to Improve Global Carbon Storage: Reaping What We Sow. *Plos One* **6**:

Jackson ST and Hobbs RJ. 2009. Ecological Restoration in the Light of Ecological History. *Science* **325**: 567-69.

Kaiser-Bunbury CN, Traveset A and Hansen DM. 2010. Conservation and restoration of plant-animal mutualisms on oceanic islands. *Perspectives in Plant Ecology Evolution and Systematics* **12**: 131-43.

Kemp PS, Worthington TA, Langford TEL, *et al.* 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries* **13**: 158-81.

Lawler JJ and Olden JD. 2011. Reframing the debate over assisted colonization. *Frontiers in Ecology and the Environment* **9**: 569-74.

Lindegren M, Diekmann R and Mollmann C. 2010. Regime shifts, resilience and recovery of a cod stock. *Marine Ecology-Progress Series* **402**: 239-53.

Lipsey MK and Child MF. 2007. Combining the fields of reintroduction biology and restoration ecology. *Conservation Biology* **21**: 1387-90.

M.A. 2003. Ecosystems and Human Well-being: A Framework for Assessment. Washington DC: Island Press.

Marris E. 2011. Rambunctious garden. Saving nature in a post-wild world. New York: Bloomsbury.

Mueller JM and Hellmann JJ. 2008. An assessment of invasion risk from assisted migration. *Conservation Biology* **22**: 562-67.

Paine RT, Tegner MJ and Johnson EA. 1998. Compounded perturbations yield ecological surprises. *Ecosystems* **1**: 535-45.

Palumbi SR, Mcleod KL and Grunbaum D. 2008. Ecosystems in action: Lessons from marine ecology about recovery, resistance, and reversibility. *Bioscience* **58**: 33-42.

Perez I, Anadon JD, Diaz M, *et al.* 2012. What is wrong with current translocations? A review and a decision-making proposal. *Frontiers in Ecology and the Environment* **10**: 494-501.

Polak T and Saltz D. 2011. Reintroduction As an Ecosystem Restoration Technique. *Conservation Biology* **25**: 424-25.

Ripple WJ and Beschta RL. 2012. Trophic cascades in Yellowstone: The first 15 years after wolf reintroduction. *Biological Conservation* **145**: 205-13.

Ritchie EG, Elmhagen B, Glen AS, *et al.* 2012. Ecosystem restoration with teeth: what role for predators? *Trends in Ecology & Evolution* **27**: 265-71.

Ritchie EG and Johnson CN. 2009. Predator interactions, mesopredator release and biodiversity conservation. *Ecology Letters* **12**: 982-98.

Sala E. 2006. Top predators provide insurance against climate change. *Trends in Ecology & Evolution* **21**: 479-80.

Salo P, Nordstrom M, Thomson RL, *et al.* 2008. Risk induced by a native top predator reduces alien mink movements. *Journal of Animal Ecology* **77**: 1092-98.

Schlaepfer MA, Sax DF and Olden JD. 2011. The Potential Conservation Value of Non-Native Species. *Conservation Biology* **25**: 428-37.

Thomas CD. 2011. Translocation of species, climate change, and the end of trying to recreate past ecological communities. *Trends in Ecology & Evolution* **26**: 216-21.

Walther G-R, Roques A, Hulme PE, *et al.* 2009. Alien species in a warmer world: risks and opportunities. *Trends in Ecology & Evolution* **24**: 686-93.

Williams JW, Jackson ST and Kutzbach JE. 2007. Projected distributions of novel and disappearing climates by 2100 AD. *Proceedings of the National Academy of Sciences of the United States of America* **104**: 5738-42.

Table 1. Summary characteristics of taxa used to test decision framework for conservation translocation projects.

Taxa	*Habitat*	*Climatic zone*	*Ecological niche*
eastern blue groper	marine	temperate	large predator
beaver	semi-aquatic riparian	temperate	keystone herbivore
dingo	terrestrial	semi-arid	keystone predator
giant tortoise	terrestrial	tropical	keystone fructivore

Table 2. Summary outcomes of conservation translocation (CT) proposals used to test the decision framework described in WebPanels 1&2. For detail, see WebTable2.

	Insert Figure 2a here	**Insert Figure 2b here**	**Insert Figure 2c here**	**Insert Figure 2d here**
	CT of eastern blue groper (*Achoerodus viridis*) from NSW to Tasmania, Australia	**CT of European beaver (*Castor fiber*) to Scotland**	**CT of dingo to rangelands in semi-arid western NSW**	**CT of large and giant tortoises to Round Island, Mauritius**
Aim	To improve resilience of kelp dominated Tasmanian coastal reefs at risk of shifting to climate change mediated urchin barrens (*Centrostephanus rodgersii*; CR) dominated ecosystems.	To benefit Scotland's wider biodiversity through the effects of beaver foraging and engineering activities on woodland and aquatic habitats.	To increase biodiversity of small and medium sized native vertebrates through suppression of invasive mesopredator populations and increase plant biomass and biodiversity through suppression of irrupting herbivore populations.	To restore extinct keystone frugivore seed dispersal and herbivory functions of *Cylindraspis* spp. (Testudinidae) through taxon substitution with captive sourced *Aldabrachelys gigantea* and *Astrochelys radiata* (Testudinidae).
Outcome	It was assessed that significant effort is required to provide reasonable scientific evidence to support this aim. Effort is also needed to mitigate social and governance risks. Investigation of alternate management strategies is therefore recommended. This could include data gathering to assess the feasibility of mitigating these risks to acceptable levels, or increasing the abundance of an existing CR	Significant scientific and economic evidence supports the aim of this proposal. Following necessary mitigation of social and related governance risks, a reversible pilot CT project was implemented. Ongoing monitoring is being carried out, but it is too early to determine if the aim of this CT project is being achieved or if there are any associated	Although there is good scientific evidence supporting the aim of this proposal, significant mitigation effort is required to reduce the social, economic and governance risks to a level compatible with its likely success. Investigation of alternate management strategies is therefore recommended. This could include data gathering to assess the feasibility and	The aim of this proposal is supported by scientific evidence. Following mitigation of some risks associated with ecological issues, a reversible pilot CT project was implemented. Ongoing monitoring and evaluation has provided evidence of ecological and economic benefits arising from this CT project. It has been assessed that the aim of the CT project

	predator in this region, the southern rock lobster (*Jasus edwardsii*). .	ecological, social, economic or governance benefits or threats. The adaptive management program is continuing and there are currently no published plans to expand the project.	usefulness of implementing a reversible pilot experiment using radio-collared dingos within a fenced protected area	is being achieved. The initial project has subsequently been expanded.

Figure 1.

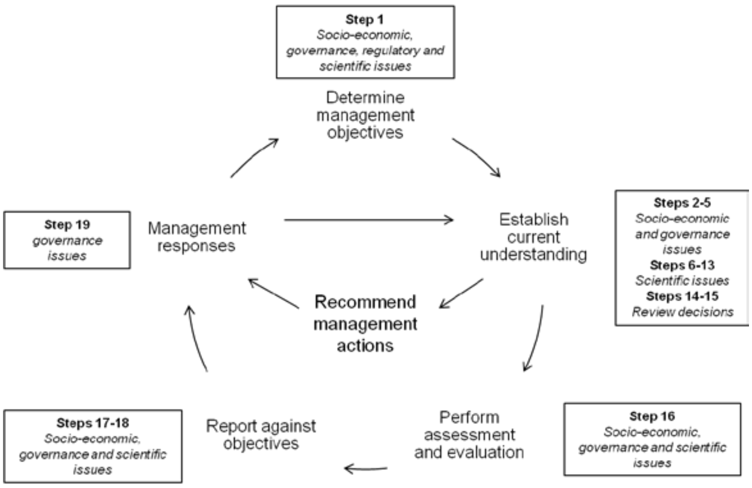

Step 1
Socio-economic, governance, regulatory and scientific issues
Determine management objectives
Establish current understanding
Steps 2-5
Socio-economic and governance issues
Steps 6-13
Scientific issues
Steps 14-15
Review decisions
Recommend management actions
Perform assessment and evaluation
Step 16
Socio-economic, governance and scientific issues
Report against objectives
Steps 17-18
Socio-economic, governance and scientific issues
Management responses
Step 19
governance issues

Figure 2a. pic of eastern blue groper ± map…

Figure 2b. pic European beaver ± map…

Figure 2c. pic of dingo ± map…

Figure 2d. pic of large/giant tortoise ± map….

Figure Captions

Figure 1. Schematic of decision framework for conservation translocation as an ecosystem-level climate change adaptation strategy. See text and WebPanels 1 and 2 for detailed explanation.

Figure 2a. Pic of eastern blue groper ± map ….

Figure 2b. Pic of European beaver ± map …

Figure 2c. Pic of dingo ± map ….

Figure 2d. Pic of large or giant tortoise ± map ….

Appendix 5: Web-only Materials

WebPanel 1. Steps in decision framework for assessing conservation translocation proposals

Note:
Roman numerals refer to the relevant guiding principles in WebPanel 2.
'CT' refers to the proposed conservation translocation of Species X.
'CT project' refers to the implemented conservation translocation of Species X.

Determine management objectives

- *scientific, social, economic, governance and regulatory issues*

1. Define the ecological, social, economic, governance and regulatory terms of reference of the problem (see Principle I, WebPanel 2 for more information)
   -> go to step 2

Establish current understanding

- *social, economic and governance issues*

2. What is the risk of failure of CT (Panel 1) failing due to social acceptance? (Principles I, II)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A** (WebTable 1)
   Yes -> document these and go to step 3
   Low -> go to step 3

3. What is the risk of failure of CT due to economic issues? (Principles I, III)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 4
   Low -> go to step 4

4. What is the risk of failure of CT due to governance? (Principles I, IV)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 5
   Low -> go to step 5

5. What is the risk of inadequate adaptive management following implementation of CT? (Principle V)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 6
   Low -> go to step 6

- *scientific issues*

6. Is there reasonable theoretical and/or empirical evidence for CT to meet the stated aims of management? (Principle VI)
   No -> see Recommended Management Actions **A** or **B**
   Yes -> go to step 7

7. Is CT technically feasible? (Principle VII)
   No -> see Recommended Management Actions **A** or **B**
   Yes -> go to step 8

8. What is the risk of adverse effects of CT on Species X or the donor ecosystem? (Principle VIII)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 9
   Low -> go to step 9

9. What is the risk of Species X failing to establish in the recipient area? (Principle IX)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 10
   Low -> go to step 10

10. What is the risk of invasiveness of Species X in the recipient area? (Principle X)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 11
   Low -> go to step 11

11. What is the risk of disease transmission to the recipient area? (Principle XI)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 12
   Low -> go to step 12

12. What is the risk of an experimental pilot CT being irreversible? (Principles V, VIII, X, XI, XII)
   High, Moderate -> Would feasible mitigation measures reduce this risk to Low?
   No -> see Recommended Management Action **A**
   Yes -> document these and go to step 13
   Low -> go to step 13

13. What is the risk of failure of CT to achieve the stated aims of management due to compounding non-climate impacts? (Principles I, XIII)
   High, Moderate -> see Recommended Management Action **C**
   Low -> go to step 14

Review decisions

- *scientific, social, economic and governance issues*

14. What is the risk that inadequate data have underestimated a risk assessed as 'Low' in decision steps 2-13? (Principle XIV)
    High, Moderate -> Is it feasible to fill these data gaps?
    No -> see Recommended Management Action **A**
    Yes -> see Recommended Management Action **B**
    Low -> go to step 15

15. Have all feasible mitigation measures been implemented so that the levels of risk are Low in decision steps 2-14?
    No -> see Recommended Management Action **A**
    Yes -> see Recommended Management Action **D** and go to step 16

Perform assessment and evaluation

- *scientific, social, economic and governance issues*

16. Is there evidence of any positive or negative ecological, social, economic or governance effects associated with the CT project (Table 1)? (Principles I - VI, VIII - XI, XIII)
    -> document the evidence, including any important data gaps, and then go to step 17

Report against objectives

- *scientific, social, economic and governance issues*

17. Are there any ecological, social, governance or economic benefits or threats arising from or to the CT project?
    -> respond based on findings in step 16 and then go to step 18

18. Is the CT project achieving the stated aims of management (with respect to time since implementation)?
    -> respond based on findings in steps 16-17 and then go to step 19

Management responses

- *governance issues*

19. Determine and implement appropriate management response/s, e.g. revisit step 1 and/or implement Recommended Management Actions B and/or E or F

WebPanel 2. Principles guiding decisions in steps of WebPanel 1

I. Define the ecological, social, economic, governance and regulatory terms of reference of the problem (Sutherland *et al.* 2006), including:
   i) aim/s, e.g. intended benefit/s to receiving ecosystem (Lipsey and Child 2007)
   ii) temporal and spatial scales of the problem (Tongway and Ludwig 2011)
   iii) temporal and spatial scales of the management approach (Tongway and Ludwig 2011)
   iv) stakeholders
   v) decision makers
   vi) transparency, where the decision making process at each step is clearly defined, accessible, communicated effectively and involves all those with an interest in the outcome (I.U.C.N. 2012)

II. Assess the risk of failure of CT associated with social and cultural acceptance (Richardson *et al.* 2009; I.U.C.N. 2012). Mitigation considerations include:
   i) transparency of process
   ii) a structured process of local participation that emphasises shared learning and locally relevant indicators and methods
   iii) evaluation of socio-economic impacts including attention to equity (the benefits, costs and risks across groups are balanced in an equitable way), vulnerability (the most vulnerable human populations, and human health) and informed consent

III. Assess the risk of failure of CT associated with economic issues (I.U.C.N. 2012). Considerations include socio-economic impacts (see principal II iii) above), cost-benefit analyses of alternate management strategies (Macdonald 2009), and ensuring that sufficient funding is available for effective implementation and adaptive management of CT (Soorae 2008).

IV. Assess the risk of failure of CT associated with governance. Considerations include adequacy of the interface between science and policy formation, adequacy of policy for dealing with climate change scenarios, and cross-jurisdictional consistencies and coordination (Dale *et al.* 2010; Burbidge *et al.* 2011; I.U.C.N. 2012).

V. Adaptive management is an essential component of management strategies with uncertain consequences (Fulton 2011). The sequence below is followed iteratively (M.A. 2003; I.U.C.N. 2012):
   i) repeated measurements of indicators are made (i.e. monitoring)
   ii) trends and uncertainty are re-evaluated
   iii) management is adjusted as appropriate as new insights are gained

Adequate monitoring of Species X and other populations at the recipient site is required to assess the success of establishment of Species X, to provide early warning of signs of invasiveness or disease, and to indicate if the stated aims of management are being achieved. Appropriate indicators should be chosen for these purposes. Robust indicators demonstrate cause and effect linkages, are representative, reliable and feasible, and identify critical thresholds or the irreversibility of change (McAlpine and Loyn 2000; M.A. 2003; Bundy *et al.* 2010).

VI. Strategies with a low probability of achieving the stated aims of management are not viable even if they represent low risk, low cost options (Bellwood *et al.* 2006; Casini *et al.* 2009).

VII. Assess the technical feasibility of translocating the animals in question, e.g. logistic or biological constraints (Hoegh-Guldberg *et al.* 2008; Macdonald 2009; Richardson *et al.* 2009).

VIII. Assess the risk of CT to translocated species/populations in donor and recipient ecosystems, e.g. threats to viability (Soorae 2008; I.U.C.N. 2012). Also assess the risk of CT resulting in reduction or loss of ecosystem structure, function or service in the donor ecosystem (Moir *et al.* 2012).

IX. Assess the risk of failure of translocated populations to establish in recipient area. Mitigation considerations include:

i) maximising genetic diversity of the founder population (Frankham 2009; Lorenzen *et al.* 2010; Burbidge *et al.* 2011)
ii) maximising population size to maximise genetic diversity (Frankham 2009; Lorenzen *et al.* 2010; Burbidge *et al.* 2011)
iii) timing of translocation and release strategy (McDonald-Madden *et al.* 2011; I.U.C.N. 2012)
iv) suitability analysis of potential translocated species/populations/classes (Cassey *et al.* 2008; van Katwijk *et al.* 2009; I.U.C.N. 2012)
v) confirming availability of suitable habitat and absence of significant threats at the recipient site/s (Hoegh-Guldberg *et al.* 2008; van Katwijk *et al.* 2009; I.U.C.N. 2012)

X. Assess the risk of invasiveness of Species X in the recipient area, including genetic effects via inter- and intra-specific hybridisation leading to heterosis (hybrids out-compete local progeny) and/or outbreeding depression (reduced fitness; Lorenzen *et al.* 2010; Weeks *et al.* 2011). Mitigation considerations include:

i) the reversibility of the intervention (Soorae 2008; Macdonald 2009)
ii) appropriate monitoring of local populations for evidence of invasiveness at the recipient site (Burbidge *et al.* 2011)
iii) use of invasive biology literature (Loss *et al.* 2011; Olden *et al.* 2011)

XI. A disease and health management program is required to mitigate any risk of disease transmission to the recipient area (Lorenzen *et al.* 2010; I.U.C.N. 2012).

XII. A reversible pilot experiment should precede extensive implementation to improve understanding of the ecological, social, economic and governance effects of the CT. Pilot CT projects should incorporate well formulated testable hypotheses and use experimental and/or modelling techniques to minimise the risk of irreversibility (Lipsey and Child 2007; Dunwiddie *et al.* 2009; Macdonald 2009; Lorenzen *et al.* 2010; Loss *et al.* 2011).

XIII. Assess the risk of failure of CT to achieve the stated aims of management due to compounding non-climate change impacts. Where relevant, complementary strategies to address non-climate change threats should be incorporated into the overall management plan (Hoegh-Guldberg *et al.* 2008; Koehn 2011; Loss *et al.* 2011; Wernberg *et al.* 2011)

XIV. At each decision step, assess if data are adequate for robust assessments to be made:

i) use the best available information (Lockie and Rockloff 2005; Macdonald 2009)

ii) incorporate measure/s of uncertainty (Lockie and Rockloff 2005; Hoegh-Guldberg *et al.* 2008)

iii) define an acceptable threshold level of uncertainty (Richardson *et al.* 2009)

If the scientific evidence is inadequate for a robust assessment at any decision step:

i) identify what data/information are required to allow a robust assessment to be made (Macdonald 2009)

ii) conduct a cost/benefit analysis on filling the data gaps

iii) where feasible, fill the data gaps and return to the appropriate level/s of the decision framework

WebTable 1. Recommended management actions referred to in WebPanel 1	
A	Investigate alternate management strategies, including conservation translocation of alternate species and a ‘do-nothing’ option
B	Fill data gaps and return to the appropriate level/s of the decision framework
C	Investigate complementary management strategies to address non-climate change effects
D	Implement a reversible pilot conservation translocation project with adaptive management procedures
E	Implement a more extensive conservation translocation project with adaptive management procedures
F	Implement management strategies to reverse any undesired effects of the conservation translocation project

WebTable 2. Outcomes of conservation translocation (CT) proposals used to test the decision framework described in WebPanels 1&2

	CT of eastern blue groper from NSW to Tasmania, Australia	**CT of European beaver to Scotland**	**CT of dingo to rangelands in semi-arid western NSW**	**CT of large and giant tortoises to Round Island, Mauritius**
Decision step	**Response and potential for risk mitigation**			
Determine management objectives				
1 **Aim**	To improve resilience of kelp dominated Tasmanian coastal reefs at risk of shifting to climate change mediated urchin barrens (*Centrostephanus rodgersii*; CR) dominated ecosystems (Ling 2008; Ling *et al*. 2009; Casper *et al*. 2011; Ling and Johnson 2012).	To benefit Scotland's wider biodiversity through the effects of beaver (*Castor fiber*) foraging and engineering activities on woodland and aquatic habitats (S.W.T. 2007a).	To increase biodiversity of small and medium sized native vertebrates through suppression of invasive mesopredator populations and increase plant biomass and biodiversity through suppression of irrupting herbivore populations (Dickman *et al*. 2009; Wallach *et al*. 2010; Letnic *et al*. 2012).	To restore extinct keystone frugivore seed dispersal and herbivory functions of *Cylindraspis* spp. (Testudinidae) through taxon substitution with captive sourced *Aldabrachelys gigantea* and *Astrochelys radiata* (Testudinidae; Hansen *et al*. 2008; Griffiths and Harris 2010; Griffiths *et al*. 2010).
Establish current understanding				
2 **Social risk**	**Moderate** - a) Concerns about loss of eastern blue groper (*Achoerodus viridis*; EBG) from NSW populations. Yes. Community engagement. Target most abundant populations (Casper *et al*. 2011) and avoid iconic populations (e.g. Arnott 2010).	**Moderate**. Yes. Widespread local support exists for a trial reintroduction at Knapdale, but ongoing community engagement and education is required (Campbell *et al*. 2007;	**High**. Concerns about attacks on livestock as well as a culture of dingo persecution. Yes. Community engagement. Reversible pilot experiments to demonstrate quantifiable	**Low/Moderate**. Potential concerns about introducing non-native species. Yes. Community engagement. Release small numbers of individuals in a reversible experiment. Release on

	Moderate - b) Concerns about risk to TAS recipient ecosystems. Yes. Community engagement. Moderate - c) Concerns about gillnetting bans to protect translocated animals. Yes. Community engagement. Choose low gillnet use recipient sites and limit gillnet bans to those sites.	S.W.T. 2007b; Kemp *et al.* 2012).	benefits to biodiversity and reduction of grazing pressure from macropods and feral goats. Implementation of strategies to counteract economic loss (Dickman *et al.* 2009; Letnic *et al.* 2012).	uninhabited island avoids direct human conflict (Griffiths *et al.* 2010; Griffiths *et al.* 2012).
3 **Economic risk**	**Low**. Translocation of EBG, an iconic species, could have positive economic benefits to TAS.	**Low**. Favourable cost-benefit analysis results (Campbell *et al.* 2007).	**Moderate/High**. Concerns about stock loss (numeric and genetic) and costs of predator control. Yes. Alternate methods of stock protection. Compensation schemes directed to predicted high dingo activity areas (Fleming *et al.* 2001; Dickman *et al.* 2009; Letnic *et al.* 2012).	**Low**. Cost effective (Griffiths *et al.* 2010; Griffiths *et al.* 2012).
4 **Governance risk**	**Moderate/High -** a) Concerns about lack of protection of EBG in TAS resulting in them being fished. Yes. Provide regulatory protection status. **Moderate** - b) Concerns about breaching current NSW fishing regulations (www.dpi.nsw.gov.au/fisheries). Yes. Work within regulations or modify regulations.	**Moderate**. Yes. Regulatory approval has been granted for a scientifically monitored, time limited and site specific trial reintroduction at Knapdale (S.W.T. 2007a; Anon 2008; Russell 2008).	**High**. Legislation mandates the eradication of dingos in western NSW. Yes. Change legislation (Dickman *et al.* 2009; Anon 2012).	**Low** (Griffiths *et al.* 2010).
5 **Adaptive management risk**	**Low** – provided that mechanisms and funding have been organised as an integral part of Step 1.	**Moderate**. Yes. Adaptive management strategies and mechanisms have been provided for a pilot MT at Knapdale (S.W.T. 2007a;	**Low** - provided that mechanisms and funding have been organised as an integral part of Step 1.	**Low**. Previous long term monitoring of biota provides valuable comparative data. Ongoing long term monitoring is

		Anon 2008).		planned and is facilitated by permanent occupation of the island by wardens (Griffiths *et al.* 2010).
6 Reasonable scientific evidence?	**No**. There is insufficient evidence. Large EBG eat CR, but there are no quantitative or feeding preference data (Gillanders 1995a; Gillanders and Kingsford 1998; Curley 2007; Morton and Gladstone 2011). EBG do not feed diurnally (Gillanders 1995a), so would presumably forage to some extent at night when smaller CR come out of hiding (Ling and Johnson 2012). Recommend management action A or B (e.g. feeding preference experiments; WebTable 1).	**Yes**. Significant evidence exists for ecosystem level benefits of beavers (reviewed in Rosell *et al.* 2005; Jones *et al.* 2009; Ciechanowski *et al.* 2011; Kemp *et al.* 2012).	**Yes**. Significant evidence exists (reviewed in Letnic *et al.* 2012).	**Yes** (Hnatiuk 1978; Hambler 1994; Gibbs *et al.* 2008; Hansen *et al.* 2008; Gibbs *et al.* 2010; Griffiths *et al.* 2010; Hansen *et al.* 2010; Griffiths *et al.* 2011).
7 Technically feasible?	**Yes**. Labridae have successfully been translocated, cultured and used in aquaculture (Treasurer 2005).	**Yes**. Managed translocations of beavers have been successful throughout Europe (Macdonald *et al.* 1995; Nolet and Rosell 1998; Halley and Rosell 2002).	**Yes** (McNiven 2008; Anon 2012).	**Yes** (Hambler 1994; Gibbs *et al.* 2008).
8 Risk to species and donor ecosystem	**Moderate**. Concerns about inadequate male:female ratio remaining in donor ecosystem to maintain current population growth. Yes. Naturally occurring male:female ratios are highly variable amongst populations (Gillanders 1995b). Select donor individuals from a number of relatively abundant populations and do not remove leading up to or during	**Low/Moderate**. Yes. Use donor animals from relatively abundant populations, e.g. Latvia, Russia, Scandinavia (Halley and Rosell 2002).	**Low/Moderate**. Although dingo populations are conserved in certain reserves, they are threatened by wild dog control and loss of habitat (Anon 2012). Yes. Select donor individuals from a number of relatively abundant populations.	**Low/Moderate**. Concerns because both species are endangered in their native habitats, which are also vulnerable to flooding due to climate change. Yes. MT of captive bred individuals to other Indian Ocean islands could prevent

	reproductive periods.			extinction. Attend to the husbandry of translocated individuals appropriately (Hambler 1994; Griffiths *et al.* 2010; Hansen *et al.* 2010; Griffiths *et al.* 2012).
9 Risk of failing to establish	**Moderate**. Concerns about being fished. Yes. Community engagement. Provide regulatory protection status.	**Low/Moderate**. Yes. Viable populations are highly likely to establish following release of 20+ individuals at suitable habitat sites. Scandinavian beavers have been assessed as the most taxonomically suitable donor animals for MT to Scotland and Knapdale has been assessed as the most suitable recipient site for a pilot MT (Webb *et al.* 1997; Kitchener and Lynch 2000; Parker *et al.* 2000; South *et al.* 2000; S.W.T. 2007a).	**High** – a) Concerns about persecution in recipient sites. Yes. Implement socio-economic mitigation measures (Steps 2 and 3). **Low/Moderate** – b) Concerns about inadequate water preventing development of functionally effective dingo populations. Yes. Provide artificial water sources if necessary (Letnic *et al.* 2012).	**Low/Moderate**. Concerns that causes of extinction of original species or other threats are present. Yes. Identify and control factors that threaten translocated tortoises, e.g. introduced predators, hunting, disease, inadequate resources (Hambler 1994; Gibbs *et al.* 2008; Hansen *et al.* 2008; Hansen *et al.* 2010; Griffiths *et al.* 2012).
10 Invasiveness risk	**Low**. EBG have a low reproductive rate and adults are sedentary (Gillanders 1995b; K. Lee et al. unpublished data).	**Low/Moderate**. Yes. Translocate to site with good habitat barriers to spread, e.g. Knapdale. Monitor effects of translocated animals on environment, economy and public health. Predetermine exit strategy conditions and mechanisms (Halley and	**Low** – a) Concerns associated with environmental or human health impacts (Letnic *et al.* 2012). **Low/Moderate** – b) Concerns about significant adverse economic effects. Yes. Implement socio-economic mitigation	**Low** – a) Concerns associated with uncontrolled population growth or undesirable impacts on native vegetation (Griffiths *et al.* 2010; Hansen *et al.* 2010). **Low/Moderate** – b) Concerns that introduced tortoises could assist the

		Rosell 2002; S.W.T. 2007a; Kemp *et al.* 2012).	measures (Steps 2 and 3).	spread of invasive plants. Yes. Release tortoises into fenced and weeded areas. Conduct field experiments on seed ingestion rates, post-digestion dispersal and viability rates, integrated with cost/benefit analyses (Hansen *et al.* 2008; Hansen *et al.* 2010), i.e. recommended management action B (WebTable 1). This can be integrated within a reversible pilot MT project (management action D). **Low/Moderate** – c) Concerns that tortoises could introduce exotic plant material. Yes. Appropriate quarantine period with controlled diet prior to MT (Griffiths *et al.* 2010; Hansen *et al.* 2010).
11 **Disease risk**	**Low** – provided that animals are screened, quarantined and treated appropriately prior to MT (Treasurer 2005).	**Low/Moderate**. Yes. Screen, quarantine and treat appropriately prior to and after MT (S.W.T. 2007a; Goodman *et al.* 2012).	**Low** – provided that animals are screened, quarantined and treated appropriately for disease prior to and after MT.	**Low** – provided that animals are screened, quarantined and treated appropriately prior to and after MT. Healthy captive animals are easy to source (Griffiths *et al.* 2010; Hansen *et al.* 2010; Griffiths *et al.* 2012).

12 Risk of irreversibility	**Low**. EBG have a low reproductive rate and adults are sedentary. Adults can also be tagged and located and removed if necessary (Gillanders 1995b; K. Lee et al. unpublished data; Arnott 2010).	**Low/Moderate**. Yes. Incorporate a monitoring program with an exit strategy into the MT program. Tag translocated animals and ensure adequate resources for effective monitoring of their movements (S.W.T. 2007a).	**Low/Moderate**. Concerns that dingos could escape experimental area, reproduce rapidly and cause significant stock loss. Yes. Fence pilot experimental area. Use desexed dingos. Radio collar dingos.	**Low**. Tortoises have long generation times and subadults and/or single sex adults can be used. Tortoises can be contained within fenced areas or can be located via radio-tracking and removed if not within enclosures (Hamann 1993; Hansen *et al.* 2008; Griffiths and Harris 2010; Griffiths *et al.* 2010; Hansen *et al.* 2010).
13 Risk of compounding climate and non-climate impacts	**Moderate/High**. Concerns about being fished. Yes. Community engagement. Provide regulatory protection status.	n/a as climate change mitigation is not primary aim	n/a as climate change mitigation is not primary aim	n/a as climate change mitigation is not primary aim
14 Risk of underestimated risk assessments in steps 2-13	**Moderate**. Concerns associated with insufficient scientific evidence supporting the aim of the proposal. Yes. See Step 6.	**Low** (S.W.T. 2007a).	**Low** (Fleming *et al.* 2001; Dickman *et al.* 2009; Wallach *et al.* 2010; Anon 2012; Letnic *et al.* 2012).	**Low** (Griffiths *et al.* 2010; Hansen *et al.* 2010).
15 All risks mitigated to 'Low' in steps 2-14?	**No**. Significant mitigation effort is required to provide reasonable scientific evidence to support the aim of this proposal (Step 6). Effort is also needed to mitigate social and governance risks (Steps 2, 4, 9, 13). Recommend management action A. Alternate management strategies could include data gathering (management action B) to assess the feasibility of mitigating	**Yes**. Recommend management action D (WebTable 1). Management response (Figure 1) is to accept this recommendation and a 5 year reversible pilot experiment was implemented at Knapdale in mid-2009 (S.W.T. 2007a;	**No**. Although there is good scientific evidence supporting the aim of this proposal, significant mitigation effort is required to reduce the social, economic and governance risks to a level compatible with its likely success.	**Yes**. Recommend management action D (WebTable 1). Management response (Figure 1) is to implement reversible hypothesis driven pilot experiments (non-breeding individuals contained within fenced area or radio-

	these risks to acceptable levels, or increasing the abundance of an existing CR predator in this region, the southern rock lobster (*Jasus edwardsii*).	Russell 2008; S.W.T. 2012).	Recommend management action A (WebTable 1). An alternate management strategy that could be considered is a reversible pilot experiment (management action D) as described in Step 2, using radio-collared dingos within a fenced protected area in western NSW. This could reduce these risks significantly. Recommend management action B (data gathering) to assess the feasibility and usefulness of management action D.	tracked) with ongoing monitoring (Griffiths and Harris 2010; Griffiths *et al.* 2010).
Perform assessment and evaluation				
16 Effects?	n/a as proposal not implemented	Minimal effects on fluvial geomorphology and river habitat (Perfect and Gilvear 2011). No significant effect on fish habitats (Kettle-White *et al.* 2011). Significant impacts on aquatic vegetation related to the rise in water levels caused by damming of outflows (Willby *et al.* 2011). Noticeable effects on woody vegetation, largely	n/a as proposal not implemented	Positive ecological evidence: Preferential grazing of exotic vegetation with regeneration of native plant populations. Consumption and dispersal of the large seeds of an endemic palm. Translocation successful in the short term (Griffiths *et al.* 2010; Hansen *et al.* 2010; Griffiths *et al.* 2012). Negative ecological

		limited to 10m from the water; vegetation may ultimately shift from broadleaf deciduous woodland to swamp or bog (Moore *et al.* 2011).		evidence: None evident, but ongoing monitoring for long term effects is planned (Griffiths *et al.* 2010). Positive economic evidence: Low maintenance, cost effective weed control (Griffiths *et al.* 2010; Griffiths *et al.* 2012).
Report against objectives				
17 Benefits or threats?		It is premature to draw conclusions on the possible effects of beavers on aquatic vegetation, whether positive or negative, or determine the longer-term response of woody vegetation to beaver browsing (Moore *et al.* 2011; Willby *et al.* 2011). Socio-economic effects have not yet been evaluated (Moran and Hanley-Nickolls 2012).		Ecological benefits: Control of fruiting weeds that outcompete native plants. Restoration of native large seed dispersal, thereby improving population recruitment and gene flow. Indication that MT can be a viable conservation strategy for receiving ecosystem as well as translocated species (Griffiths and Harris 2010; Griffiths *et al.* 2012). Economic benefits: Potential to redistribute weed control resources to alternate restoration activities (Griffiths *et al.* 2010).
18		It is too soon to assess this,		Yes (Griffiths *et al.* 2010;

Achieving aims?	but will be determined based on results from ongoing adaptive monitoring (Harrington *et al.* 2011; Kettle-White *et al.* 2011; Moore *et al.* 2011; Perfect and Gilvear 2011; Willby *et al.* 2011; Moran and Hanley-Nickolls 2012).	Hansen *et al.* 2010; Griffiths *et al.* 2012).
Management responses		
19 Management response?	Continue adaptive monitoring program (Harrington *et al.* 2011; Kettle-White *et al.* 2011; Moore *et al.* 2011; Perfect and Gilvear 2011; Willby *et al.* 2011; Moran and Hanley-Nickolls 2012).	Expand experiments by introducing more tortoises with ongoing adaptive management (Griffiths *et al.* 2012; M.W.F. 2012).

- **WebReferences**

Anon. 2008. Beaver Reintroduction Project Licence Conditions. Landscape and Habitats Division, Scottish Government. http://www.scottishbeavers.org.uk/docs/files/general/BeaverLicenceConditions.pdf.

Anon. 2012. Wild Dogs. NSW Government Office of Environment and Heritage. http://www.environment.nsw.gov.au/pestsweeds/WildDogs.htm.

Arnott I. 2010. Blue Groper. Australian Broadcasting Corporation. http://www.abc.net.au/catalyst/stories/2830467.htm.

Bellwood DR, Hughes TP and Hoey AS. 2006. Sleeping functional group drives coral-reef recovery. *Current Biology* **16**: 2434-39.

Bundy A, Shannon LJ, Rochet MJ, *et al.* 2010. The good(ish), the bad, and the ugly: a tripartite classification of ecosystem trends. *Ices Journal of Marine Science* **67**: 745-68.

Burbidge AA, Byrne M, Coates DJ, *et al.* 2011. Is Australia ready for assisted colonization? Policy changes required to facilitate translocations under climate change. *Pacific Conservation Biology* **17**: 259-69.

Campbell RD, Dutton A and Hughes J. 2007. Economic impacts of the beaver. Report for the Wild Britain Initiative. Scottish Wildlife Trust. http://www.scottishbeavers.org.uk/docs/files/general/EconomicImpacts.pdf.

Casini M, Hjelm J, Molinero J-C, *et al.* 2009. Trophic cascades promote threshold-like shifts in pelagic marine ecosystems. *Proceedings of the National Academy of Sciences of the United States of America* **106**: 197-202.

Casper RM, Barrett NS, Bax N, *et al.* 2011. Review of the eastern blue groper. Hobart: Institute of Marine and Antarctic Studies. http://eprints.utas.edu.au/11977.

Cassey P, Blackburn TM, Duncan RP, *et al.* 2008. Lessons from introductions of exotic species as a possible information source for managing translocations of birds. *Wildlife Research* **35**: 193-201.

Ciechanowski M, Kubic W, Rynkiewicz A, *et al.* 2011. Reintroduction of beavers Castor fiber may improve habitat quality for vespertilionid bats foraging in small river valleys. *European Journal of Wildlife Research* **57**: 737-47.

Curley BG. 2007. Estimating dispersal and population connectivity for temperate reef fishes at multiple spatial scales (PhD dissertation). Townsville, Qld: James Cook University.

Dale PER, Dale MB, Dowe DL, *et al.* 2010. A conceptual model for integrating physical geography research and coastal wetland management, with an Australian example. *Progress in Physical Geography* **34**: 605-24.

Dickman CR, Glen AS and Letnic M. 2009. Reintroducing the dingo: can Australia's conservation wastelands be restored? In: Hayward MW and Somers MJ (Eds). Reintroduction of top-order predators. West Sussex, UK: Balckwell Publishing.

Dunwiddie PW, Hall SA, Ingraham MW, *et al.* 2009. Rethinking conservation practice in light of climate change. *Ecological Restoration* **27**: 320-29.

Fleming P, Corbett L, Harden R, *et al.* 2001. Managing the impacts of dingoes and other wild dogs. Canberra: Bureau of Rural Sciences.

Frankham R. 2009. Genetic considerations in reintroduction programmes for top-order, terrestrial predators. In: Hayward MW and Somers MJ (Eds). Reintroduction of top-order predators. West Sussex, UK: Blackwell Publishing.

Fulton EA. 2011. Interesting times: winners, losers, and system shifts under climate change around Australia. *Ices Journal of Marine Science* **68**: 1329-24.

Gibbs JP, Marquez C and Sterling EJ. 2008. The role of endangered species reintroduction in ecosystem restoration: Tortoise-cactus interactions on espanola island, Galapagos. *Restoration Ecology* **16**: 88-93.

Gibbs JP, Sterling EJ and Javier Zabala F. 2010. Giant Tortoises as Ecological Engineers: A Long-term Quasi-experiment in the Galapagos Islands. *Biotropica* **42**: 208-14.

Gillanders BM. 1995a. Feeding ecology of the temperate marine fish *Achoerodus viridis* (Labridae): Size, seasonal and site-specific differences. *Marine and Freshwater Research* **46**: 1009-20.

Gillanders BM. 1995b. Reproductive biology of the protogynous hermaphrodite *Achoerodus viridis* (Labridae) from south-eastern Australia. *Marine and Freshwater Research* **46**: 999-1008.

Gillanders BM and Kingsford MJ. 1998. Influence of habitat on abundance and size structure of a large temperate reef fish, *Achoerodus viridis* (Pisces : Labridae). *Marine Biology* **132**: 503-14.

Goodman G, Girling S, Pizzi R, *et al.* 2012. Establishment of a health surveillance program for reintroduction of the Eurasian beaver (*Castor fiber*) into Scotland. *Journal of wildlife diseases* **48**: 971-8.

Griffiths CJ, Hansen DM, Jones CG, *et al.* 2011. Resurrecting Extinct Interactions with Extant Substitutes. *Current Biology* **21**: 762-65.

Griffiths CJ and Harris S. 2010. Prevention of Secondary Extinctions through Taxon Substitution. *Conservation Biology* **24**: 645-46.

Griffiths CJ, Jones CG, Hansen DM, *et al.* 2010. The Use of Extant Non-Indigenous Tortoises as a Restoration Tool to Replace Extinct Ecosystem Engineers. *Restoration Ecology* **18**: 1-7.

Griffiths CJ, Zuel N, Tatayah V, *et al.* 2012. The Welfare Implications of Using Exotic Tortoises as Ecological Replacements. *Plos One* **7**:

Halley DJ and Rosell F. 2002. The beaver's reconquest of Eurasia: status, population development and management of a conservation success. *Mammal Review* **32**: 153-78.

Hamann O. 1993. On vegetation recovery, goats and giant tortoises on Pinta Island, Galapagos, Ecuador. *Biodiversity and Conservation* **2**: 138-51.

Hambler C. 1994. Giant tortoise *Geochelone gigantea* translocation to Curieuse Island (Seychelles) - success or failure? . *Biological Conservation* **69**: 293-99.

Hansen DM, Donlan CJ, Griffiths CJ, *et al.* 2010. Ecological history and latent conservation potential: large and giant tortoises as a model for taxon substitutions. *Ecography* **33**: 272-84.

Hansen DM, Kaiser CN and Mueller CB. 2008. Seed Dispersal and Establishment of Endangered Plants on Oceanic Islands: The Janzen-Connell Model, and the Use of Ecological Analogues. *Plos One* **3**:

Harrington LA, Feber R and Macdonald DW. 2011. The Scottish Beaver Trial: Ecological monitoring of the European beaver *Castor fiber* and other riparian mammals – First Annual Report 2010. Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/450.pdf.

Hnatiuk SH. 1978. Plant dispersal by Aldabran giant tortoise, *Geochelone gigantea* (Schweigger). *Oecologia* **36**: 345-50.

Hoegh-Guldberg O, Hughes L, Mcintyre S, *et al.* 2008. Assisted colonization and rapid climate change. *Science* **321**: 345-46.

I.U.C.N. 2012. Guidelines for reintroductions and other conservation translocations. IUCN Species Survival Commission. http://issg.org/.

Jones K, Gilvear D, Willby N, *et al.* 2009. Willow (Salix spp.) and aspen (Populus tremula) regrowth after felling by the Eurasian beaver (Castor fiber): implications for riparian woodland conservation in Scotland. *Aquatic Conservation-Marine and Freshwater Ecosystems* **19**: 75-87.

Kemp PS, Worthington TA, Langford TEL, *et al.* 2012. Qualitative and quantitative effects of reintroduced beavers on stream fish. *Fish and Fisheries* **13**: 158-81.

Kettle-White AHJ, Macintyre CM, Stanworth HA, *et al.* 2011. The Scottish Beaver Trial: Survey of fish populations 2009. Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/467.pdf.

Kitchener AC and Lynch JM. 2000. A morphometric comparison of the skulls of fossil British and extant European beavers, *Castor fiber*. *Scottish Natural Heritage Review* **127**: i-ii, 1-31.

Koehn JD. 2011. Climate change and Australian marine and freshwater environments, fish and fisheries: introduction. *Marine and Freshwater Research* **62**: 981-83.

Letnic M, Ritchie EG and Dickman CR. 2012. Top predators as biodiversity regulators: the dingo Canis lupus dingo as a case study. *Biological Reviews* **87**: 390-413.

Ling SD. 2008. Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. *Oecologia* **156**: 883-94.

Ling SD and Johnson CR. 2012. Marine reserves reduce risk of climate-driven phase shift by reinstating size- and habitat-specific trophic interactions. *Ecological Applications* **22**: 1232-45.

Ling SD, Johnson CR, Frusher SD, *et al.* 2009. Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. *Proceedings of the National Academy of Sciences of the United States of America* **106**: 22341-45.

Lipsey MK and Child MF. 2007. Combining the fields of reintroduction biology and restoration ecology. *Conservation Biology* **21**: 1387-90.

Lockie S and Rockloff S. 2005. Decision frameworks: assessment of the social aspects of decision frameworks and development of a conceptual model. Rockhampton, Queensland: Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management.

Lorenzen K, Leber KM and Blankenship HL. 2010. Responsible Approach to Marine Stock Enhancement: An Update. *Reviews in Fisheries Science* **18**: 189-210.

Loss SR, Terwilliger LA and Peterson AC. 2011. Assisted colonization: Integrating conservation strategies in the face of climate change. *Biological Conservation* **144**: 92-100.

M.A. 2003. Ecosystems and Human Well-being: A Framework for Assessment. Washington DC: Island Press.

M.W.F. 2012. Tortoise re-wilding. Mauritius Wildlife Foundation. http://www.mauritian-wildlife.org/application/index.php?tpid=30&tcid=80.

Macdonald DW. 2009. Lessons learnt and plans laid: seven awkward questions for the future of reintroductions. In: Hayward MW and Somers MJ (Eds). Reintroduction of top-order predators. West Sussex, UK: Blackwell Publishing.

Macdonald DW, Tattersall FH, Brown ED, *et al.* 1995. Reintroducing the European beaver to Britain: Nostalgic meddling or restoring biodiversity? *Mammal Review* **25**: 161-200.

Mcalpine C and Loyn R. 2000. Assessing and monitoring of forest fragmentation: questions of spatial pattern, scale and methods. In: Hale P, Petrie A, Moloney D, *et al.* (Eds). Management for suatainable ecosystems. Brisbane: Centre for Conservation Biology, University of Queensland.

Mcdonald-Madden E, Runge MC, Possingham HP, *et al.* 2011. Optimal timing for managed relocation of species faced with climate change. *Nature Climate Change*

Mcniven IJ. 2008. Inclusions, exclusions and transitions: Torres Strait Islander constructed landscapes over the past 4000 years, northeast Australia. *Holocene* **18**: 449-62.

Moir ML, Vesk PA, Brennan KEC, *et al.* 2012. Considering Extinction of Dependent Species during Translocation, Ex Situ Conservation, and Assisted Migration of Threatened Hosts. *Conservation Biology* **26**: 199-207.

Moore BD, Sim D and Iason GR. 2011. The Scottish Beaver Trial: Woodland monitoring 2010. . Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/462.pdf.

Moran D and Hanley-Nickolls R. 2012. The Scottish Beaver Trial: Socio-economic monitoring – First report 2011. Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/482.pdf.

Morton JK and Gladstone W. 2011. Spatial, temporal and ontogenetic variation in the association of fishes (family Labridae) with rocky-reef habitats. *Marine and Freshwater Research* **62**: 870-84.

Nolet BA and Rosell F. 1998. Comeback of the beaver Castor fiber: An overview of old and new conservation problems. *Biological Conservation* **83**: 165-73.

Olden JD, Kennard MJ, Lawler JJ, *et al.* 2011. Challenges and Opportunities in Implementing Managed Relocation for Conservation of Freshwater Species. *Conservation Biology* **25**: 40-47.

Parker H, Rosell F and Holthe V. 2000. A gross assessment of the suitability of selected Scottish riparian habitats for beaver. *Scottish Forestry* **54**: 25-31.

Perfect C and Gilvear D. 2011. The Scottish Beaver Trial: Collection of fluvial geomorphology and river habitat data 2010. . Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/489.pdf.

Richardson DM, Hellmann JJ, Mclachlan JS, *et al.* 2009. Multidimensional evaluation of managed relocation. *Proceedings of the National Academy of Sciences of the United States of America* **106**: 9721-24.

Rosell F, Bozser O, Collen P, *et al.* 2005. Ecological impact of beavers Castor fiber and Castor canadensis and their ability to modify ecosystems. *Mammal Review* **35**: 248-76.

Russell M. 2008. Beaver Reintroduction Project Licence Confirmation. Minister for Environment, Scottish Government. http://www.scottishbeavers.org.uk/docs/files/general/BeaverLicenceLetter.pdf.

S.W.T. 2007a. Scottish Beaver Trial licence application. Scottish Wildlife Trust. http://www.scottishbeavers.org.uk/docs/files/general/BeaverApplicationWeb.pdf.

S.W.T. 2007b. Trial reintroduction of the European beaver to Knapdale, Mid-Argyll. Local Consultation Report. Scottish Wildlife Trust. http://www.scottishbeavers.org.uk/docs/files/general/SBT2007_ConsultationReport_Dec07.pdf.

S.W.T. 2012. Official Home of the Scottish Beaver Trial. Scottish Wildlife Trust. http://www.scottishbeavers.org.uk.

Soorae PS (ed.). 2008. Global re-introduction perspectives: re-introduction case-studies from around the globe. Abu Dhabi, UAE: IUCN/SSC Re-introduction Specialist Group.

South A, Rushton S and Macdonald D. 2000. Simulating the proposed reintroduction of the European beaver (Castor fiber) to Scotland. *Biological Conservation* **93**: 103-16.

Sutherland WJ, Armstrong-Brown S, Armsworth PR, *et al.* 2006. The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology* **43**: 617-27.

Tongway DJ and Ludwig JA. 2011. Restoring disturbed landscapes: putting principles into practice. Washington DC: Island Press.

Treasurer JW. 2005. Cleaner fish: a natural approach to the control of sea lice on farmed fish. *Veterinary Bulletin* **75**: 17N-29N.

Van Katwijk MM, Bos AR, De Jonge VN, *et al*. 2009. Guidelines for seagrass restoration: Importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. *Marine Pollution Bulletin* **58**: 179-88.

Wallach AD, Johnson CN, Ritchie EG, *et al.* 2010. Predator control promotes invasive dominated ecological states. *Ecology Letters* **13**: 1008-18.

Webb A, French DD and Flitsch ACC. 1997. Identification and assessment of possible beaver sites in Scotland. *Scottish Natural Heritage Research Survey and Monitoring Report* **94**: 1-16.

Weeks AR, Sgro CM, Young AG, *et al.* 2011. Assessing the benefits and risks of translocations in changing environments: a genetic perspective. *Evolutionary Applications*

Wernberg T, Russell BD, Moore PJ, *et al.* 2011. Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. *Journal of Experimental Marine Biology and Ecology* **400**: 7-16.

Willby NJ, Casas Mulet R and Perfect C. 2011. The Scottish Beaver Trial: Monitoring and further baseline survey of the aquatic and semi-aquatic macrophytes of the lochs 2009. Scottish Natural Heritage Commissioned Report. http://www.snh.org.uk/pdfs/publications/commissioned_reports/455.pdf.

Appendix 6: Newsletter February 2012 – a progress report on the 'Eastern Blue Groper' project

Pre-adapting Tasmanian Coastal Reefs to Climate Change

Newsletter February 2012

A progress report on the ‘Eastern Blue Groper’ project

The rationale and aims of this project are explained in an information sheet which can be found at:
http://arnmbr.org/content/images/uploads/Information_Sheet_7.pdf

Briefly:

- there is growing evidence that populations of large predators may stabilise marine ecosystems against recurrent disturbances, such as those associated with climate change
- this project is investigating managed translocation as a strategy to enhance large predator populations to protect ecosystem function against the impacts of climate change
- this is a feasibility study only, examining the scientific, social and regulatory aspects of managed translocation within a climate change context; we will not be undertaking releases of marine species
- in Australia, one of the most prominent repercussions of climate change is the southward range expansion of the long spined sea urchin (*Centrostephanus rodgersii*) from eastern mainland waters down the east coast of Tasmania
- there is evidence that the loss of large predators through fishing has contributed to the establishment of sea urchins in high densities on some Tasmanian reefs, thereby converting macroalgal habitat to urchin barrens habitat with a dramatic reduction in biodiversity
- some historical reports also suggest that the eastern blue groper (*Achoerodus viridis*), a large predator wrasse, was present in Tasmania during the 1800s but became locally extinct by the early 1900s
- as a consequence, the managed translocation of the eastern blue groper (EBG) into Tasmanian coastal reefs appeared to be an ideal test case scenario with which to develop this potential strategy for improving resilience to climate change

As an initial step in this process, it was important to confirm the presence of EBG in Tasmania, establish where they existed and when and why they disappeared. The resulting review of the EBG can be found at: http://eprints.utas.edu.au/11977/

Briefly:

- based on our review of ecological and historical evidence, it is unlikely that the EBG was present in Tasmania in colonial times, and if present, was certainly not common
- EBG currently occur in very small numbers in north-eastern Tasmanian waters
- like the long spined sea urchin, it appears that the EBG is a climate change migrant, with a southward range expansion into Tasmanian waters as a result of the southerly movement of the East Australian Current
- however, as these EBG are currently at the southern edge of their ecological range and EBG are hermaphrodites which change sex from females to males at ~10 years of age, it would take many years for reproductively viable populations of EBG to establish naturally in Tasmania
- this process could be assisted by managed translocation of EBG into Tasmanian waters provided there are clear environmental benefits and jurisdictional agreement
- it is unlikely that EBG populations will become ecologically significant in Tasmanian coastal reefs, either naturally or through managed translocation, unless protected from fishing

The next stage of this project is to develop a decision framework for managed translocation within a climate change context, where the objective is to maintain ecosystem services. This will inform a strategy paper to be prepared by September 2012.

This process will consider issues such as:

- risk analysis
- ecosystem services trade-offs
- choosing between alternate and complementary strategies
- monitoring options
- management actions required to optimise the probability of success
- communication, consultation and engagement with stakeholders
- adaptive management

This project has included and will continue to include:

- consultation with the project steering committee
- discussion through presentations at conferences, workshops and stakeholder meetings
- open invitations for discussion with any interested parties

---

For further information or discussion on this project please contact Ruth.Casper@csiro.au

Research Team: Nic Bax, Neville Barrett, Alistair Hobday, Ruth Casper
Funding: FRDC-DCCEE Project 2010/564, supported by CSIRO and UTAS

Appendix 7: Information Sheet 7 – Re-introducing an iconic fish species, the eastern blue groper (*Achoerodus viridis*), could make Tasmanian reef ecosystems more resilient to the impacts of climate change

NCCARF
National
Climate Change Adaptation
Research Facility
Adaptation Research Network
MARINE BIODIVERSITY AND RESOURCES

School of Geography and Environmental Studies University of Tasmania
Private Bag 76, Hobart TAS 7001, Australia
Phone: 03 6226 2134 Fax: 03 6226 7628
arnmbr@arnmbr.org
www.nccarf.edu.au/marine/

This information sheet was prepared by Ruth Casper, Alistair Hobday, Nic Bax, Neville Barrett. Editor: Neil Holbrook

Pre-adapting Tasmanian Coastal Reefs to Climate Change

Re-introducing an iconic fish species, the eastern blue groper (Achoerodus viridis), could make Tasmanian reef ecosystems more resilient to the impacts of climate change.

Waters off eastern Tasmania are warming much faster than the global average

The warm East Australian Current now extends 350km further south than 60 years ago[1]. This shift in the East Australian Current is associated with significant changes to marine ecosystems in eastern Tasmania. Warm temperate species from the north, including the invasive long-spined sea urchin (*Centrostephanus rodgersii*), have become more abundant since the 1970s. Areas where long-spined sea urchins have aggregated in high densities, known as barrens, have shown a loss of at least 150 species normally associated with macroalgal beds[2,3]. Such declines in biodiversity may have flow-on effects to the rest of the ecosystem.

Biodiversity is positively linked to marine ecosystem stability and productivity[4-7]

Species and genetic diversity have both been found to enhance the ability of marine ecosystems to withstand recurrent perturbations[4,5,8]. Regions with higher species richness may also have more stable fisheries productivity[4,9]. In addition, loss of native species diversity is related to an increase in species invasions[4,10]. In Tasmanian Marine Protected Areas where fishing pressure is removed long term, abundances of large fishes and southern rock lobsters (*Jasus edwardsii*) are significantly increased while long-spined sea urchin populations are dramatically reduced[11].


Photo: Scott Ling


Image: Saspotato; Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/saspotato/3332566841/

Loss of top predators is associated with undesirable changes

Some of Tasmania's largest predatory reef fishes, including the eastern blue groper, have become functionally extinct since the late 1800s. Other large fish species have been greatly reduced in abundance[3]. The ability of long-spined sea urchin populations to reach levels where destructive grazing occurs may be associated with ecological overfishing of its primary predator in eastern Tasmania, the southern rock lobster[12].

Implications for managers and decision makers

Tasmanian fisheries account for 23% of total Australian fisheries production[13]. Reef associated fisheries, including abalone (*Haliotis rubra*), southern rock lobster and some finfish species, are most likely to be impacted by sea urchin barrens formation[14]. Native species diversity appears to buffer the stability and recovery potential of ecosystem services against rapid environmental change[4,10]. Maintaining or enhancing locally adapted populations of large fishes and other top predators may promote the resilience of Tasmanian reef ecosystems to adverse impacts of climate change, such as species invasions, loss of biodiversity and reduced productivity.

information sheet 7
Pre-adapting Tasmanian Coastal Reefs to Climate Change

Re-introducing the eastern blue groper could pre-adapt Tasmanian coastal reefs to ongoing warming of waters off eastern Tasmania

The eastern blue groper is a temperate wrasse that grows to 18kg, and currently occurs on the east coasts of NSW and Victoria. Using the blue groper as a test case, the FRDC-DCCEE has funded a 2 year project to investigate the scientific, legal and social feasibility of re-introducing locally extinct top predator species where this would benefit the receiving ecosystem.

The 'blue groper' project – our objectives

1. Establish under what conditions re-introductions might be considered
2. Develop a national framework to evaluate potential re-introductions of native marine species
3. Design a monitoring program to determine the effects of a trial re-introduction
4. Reach a critical decision point on whether to re-establish blue groper in Tasmania or to take an alternate approach to enhance top predators on temperate reefs as indicated by the research

Key features of the 'blue groper' project

- This test case is within a region undergoing rapid climate change: the process has national and global relevance
- We will develop risk assessment procedures and protocols for adaptive management
- Heighten awareness of climate change issues in Tasmanian waters through collaboration with local communities

Image: Richard Ling; Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/rling/438035922/

References

1. Ridgway KR (2007) Long-term trend and decadal variability of the southward penetration of the East Australian Current. Geophys Res Lett 34: L13613
2. Ling SD (2008) Range expansion of a habitat-modifying species leads to loss of taxonomic diversity: a new and impoverished reef state. Oecologia 156: 883-894
3. Last PR et al. (2011) Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishing practices. Global Ecol Biogeogr 20: 58-72
4. Worm B et al. (2006) Impacts of biodiversity loss on ocean ecosystem services. Science 314: 787-790
5. Cheal AJ et al. (2010) Coral-macroalgal phase shifts or reef resilience: links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef. Coral Reefs 29: 1005-1015
6. Duffy JE & Stachowicz JJ (2006) Why biodiversity is important to oceanography: potential roles of genetic, species, and trophic diversity in pelagic ecosystem processes. Mar Ecol Prog Ser 311: 179-189
7. Palumbi SR et al. (2009) Managing for ocean biodiversity to sustain marine ecosystem services. Front Ecol Environ 7: 204-211
8. Ehlers A, Worm B & Reusch TBH (2008) Importance of genetic diversity in eelgrass Zostera marina for its resilience to global warming. Mar Ecol Prog Ser 355: 1-7
9. Bundy A et al. (2010) The good(ish), the bad, and the ugly: a tripartite classification of ecosystem trends. ICES J Mar Sci 67: 745-768
10. Stachowicz JJ, Whitlatch RB & Osman RW (1999) Species diversity and invasion resistance in a marine ecosystem. Science 286: 1577-1579
11. Edgar GJ, Barrett NS & Stuart-Smith RD (2009) Exploited reefs protected from fishing transform over decades into conservation features otherwise absent from seascapes. Ecol Appl 19: 1967-1974
12. Ling SD, Johnson CR, Frusher SD & Ridgway KR (2009) Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci USA 106: 22341-22345
13. ABARE (2010) Australian Fisheries Statistics 2009. Australian Bureau of Agricultural and Resource Economics, Canberra, Australia
14. Johnson CR et al. (2011) Climate change cascades: shifts in oceanography, species' ranges and subtidal marine community dynamics in eastern Tasmania. J Exp Mar Biol Ecol doi:10.1016/j.jembe.2011.02.032

For more information on this project contact Nic Bax (Nic.Bax@csiro.au) or Ruth Casper (Ruth.Casper@csiro.au)

This information sheet was published in April 2011

About the Marine Adaptation Network

The Adaptation Research Network for Marine Biodiversity and Resources (aka. the Marine Adaptation Network) is hosted by the University of Tasmania and convened by Assoc Prof Neil Holbrook. The Network is supported by 14 partner institutions nation-wide. It comprises a holistic framework of interconnecting marine themes that cross-cuts climate change risk, marine biodiversity and resources, socio-economics and policy. This interdisciplinary network aims to build adaptive capacity and adaptive response strategies for the effective management of marine biodiversity and natural marine resources under climate change. For more information on the Marine Adaptation Network, or to subscribe to become a member of the Network, please visit <www.nccarf.edu.au/marine/>