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

Casper RM, Barrett NS, Bax N and Hobday AJ

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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:
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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

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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.

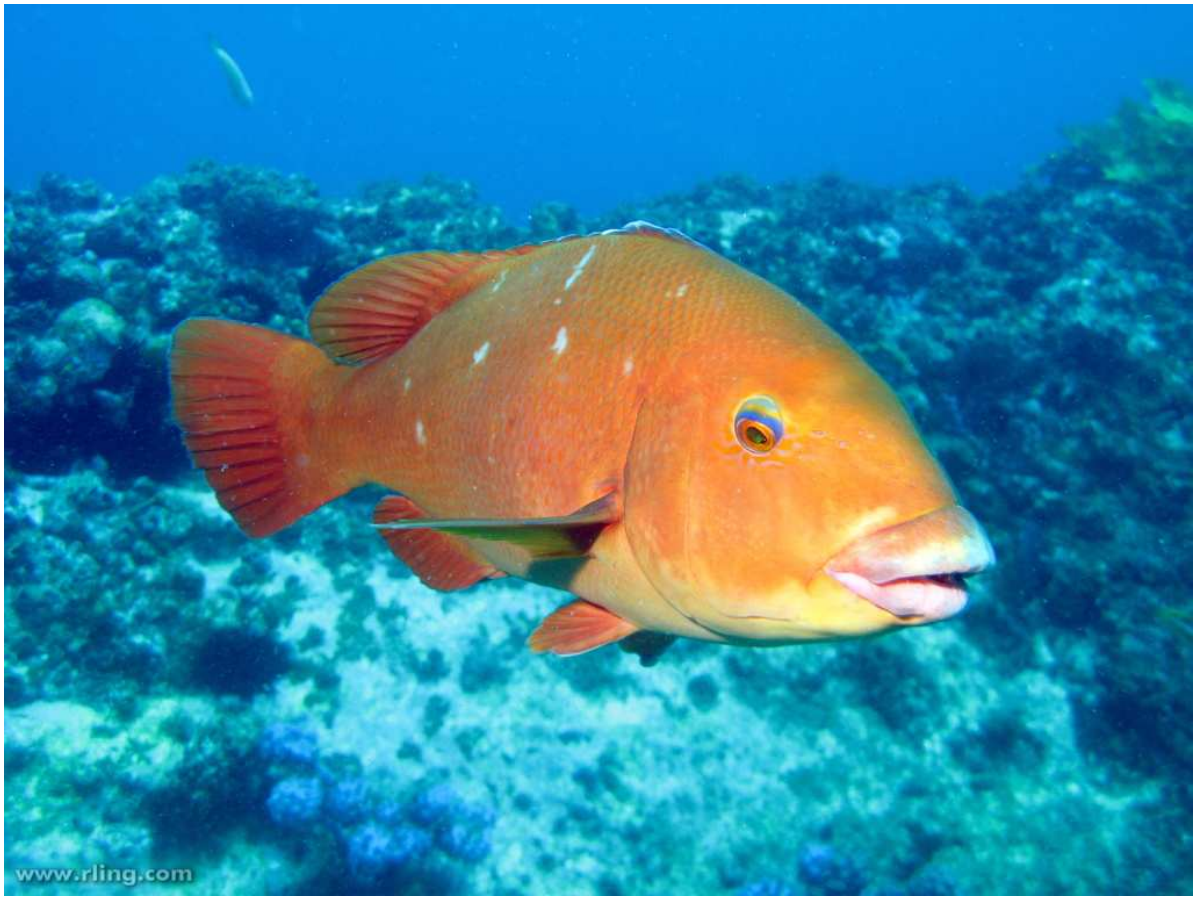

Figure 1. Female Eastern Blue Groper (*Achoerodus viridis*) at Ulladulla, NSW.
Image: Richard Ling. Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/rling/4645408299

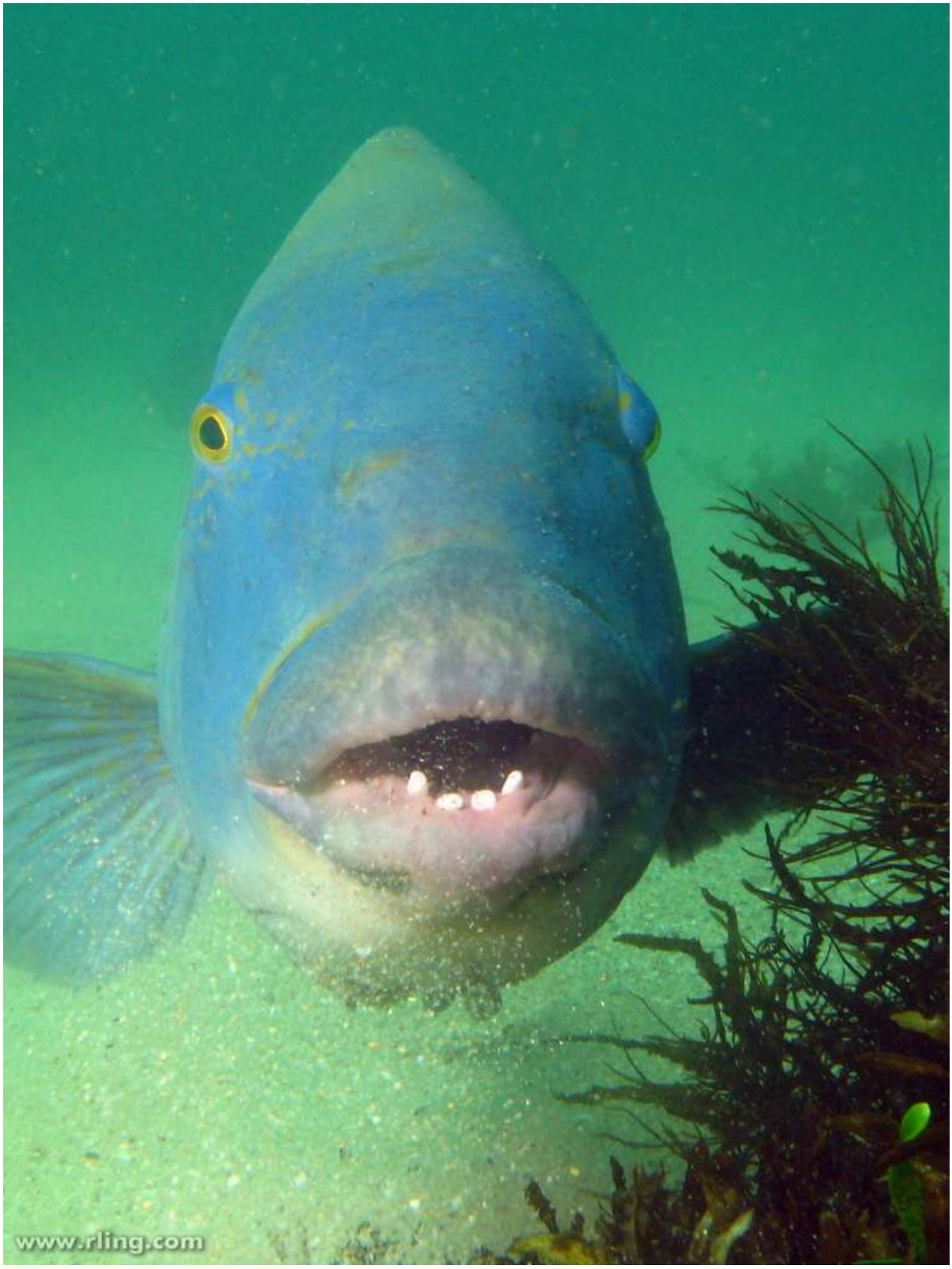

Figure 2. Male Eastern Blue Groper (*Achoerodus viridis*) at Manly NSW.
Image: Richard Ling. Source: Used under Creative Commons CC BY-NC-SA 2.0 from http://www.flickr.com/photos/rling/3245832577/

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	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.).

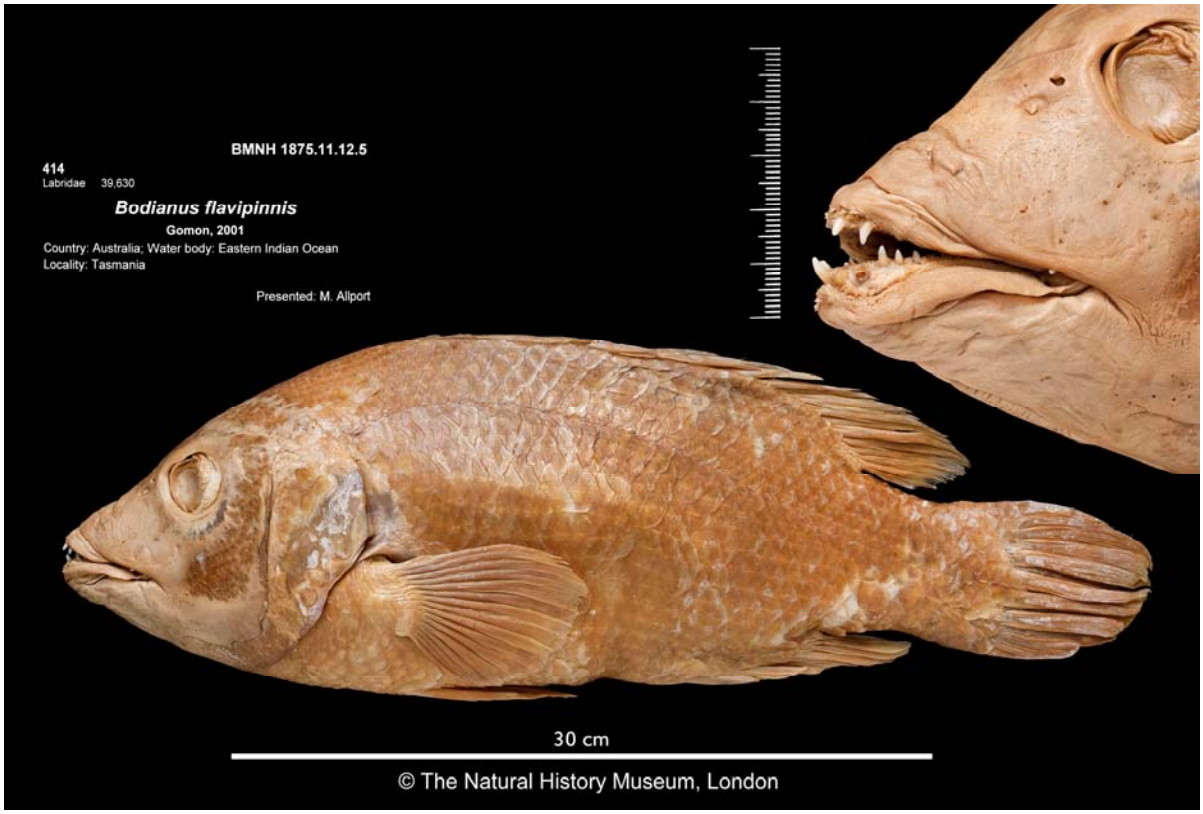

Figure 4. Photograph of Mr. Allport's specimen No. 2 identified in 1875 by Dr. Gunther as *Cossyphus gouldii* (Record 3 in Results). This specimen was subsequently identified in 2011 by Dr. Gomon as *Bodianus flavipinnis*. Image: H. Taylor, © Natural History Museum, London.

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.

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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