The Comparative Performance of the Management of the Individual Threats to Marine Environments and Fisheries Resources

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Abbreviations

Al	Aluminium
ANZECC	Australia and New Zealand Environment and Conservation Council
As	Arsenic
CAR	Comprehensive, Adequate and Representative
CBD	United Nations Convention on Biological Diversity
Cd	Cadmium
CO_2	Carbon Dioxide
Cs	Caesium
Cu	Copper
Cr	Chromium
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
EEZ	Exclusive Economic Zone
ESD	Ecological Sustainable Development
FAO	Food and Agriculture Organization (of the United Nations)
Fe	Iron
FRAB	Fishery Research Advisory Body
FRDC	Fisheries Research and Development Corporation

GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GMSL	Global Mean Sea Level
Ha	Hectare
ICI	Imperial Chemical Industries
ICRP	International Commission on Radiological Protection
ICOLL	Intermittently Closed and Open Lakes and Lagoons
IPCC	Intergovernmental Panel on Climate Change
IUU	Illegal Unreported and Unregulated (Fishing)
kL	kilo litre
km	kilometre
L	Litre
m	meter
MEMA	Marine Estate Management Authority
mm	millimetre
MBO	Monosulfidic Black Ooze
mgl^{-1}	milligram per litre
ML	Mega Litre
NGO	Non-Governmental Organisation
Ni	Nickel
NRSMPA	National Representative System of Marine Protected Areas
NSW	New South Wales
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PCB	Polychlorinated biphenyl
ppb	parts per billion
Sr	Strontium
TBT	Tributyl Tin
UN	United Nations

UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UV	Ultra Violet radiation
UV-B	Ultra Violet (B band)
WWF	World Wildlife Fund
WWII	World War 2
Y	Yttrium
Zn	Zinc
Zr	Zirconium
˚C	Degrees Celsius
$	Australian dollars
μgL^{-1}	micro grams per litre

Executive Summary

What the report is about

This study was undertaken by Robert (Bob) Kearney (Emeritus Professor of Fisheries University of Canberra ACT) and Graham Farebrother (Senior Research Fellow Sydney Fish Market) between June 2013 and July 2014. The drivers behind the project were the continued observation of threats to marine environments and fishery resources being left inadequately managed; much earlier damage has not been rectified and declines in many marine environments are obviously continuing. At the same time there has been inadequate critical evaluation of the claim that comprehensive, adequate and representative marine areas have actually been protected by a national commitment to marine parks that is not based on addressing threats. It had become increasingly apparent to the authors that efficient cost-effective management of threats in conjunction with the sustainable use of resources that are increasingly needed by a growing human population must give much greater priority to the identification, assessment and prioritisation of at least the obvious threats.

The research consisted of a desktop study accessing peer reviewed literature; intergovernmental reports, treaties and conventions; federal state and local government reports; federal and state Acts; non-governmental organisation statements and reports; and, information from a variety of experts and key stakeholders.

Background

Marine environments and fishery resources are subject to a myriad of threats. Some are understood and managed, some are acknowledged but not well managed and others have yet to be either recognised or managed. Against this backdrop, global and Australian populations are increasing and demands for marine access, marine ecosystem services and marine resources including seafood are increasing. From these observations and the findings of previously peer reviewed and published material including that authored and co-authored by the authors of this report it was evident that marine and fishery resource management have been misdirected from the path of effective ecological sustainable development. Sustainable development and ecological sustainable development, agreed to both internationally and within Australia, require that management be securely based on cost-effectively addressing identified threats while enabling and encouraging ongoing and equitable access to and availability of natural resources for human populations. Australia has not demonstrated that marine environments are being adequately protected and appropriately managed. A major reason for this failure it because Australia has avoided giving appropriate priority to taking a threats-based approach to its marine management.

Aims/objectives

The aims and objectives of this study and report are to identify and prioritise marine environment and fishery threats and to assess the effectiveness of the management of them. A further aim was to examine the effectiveness and ability of Australia's marine protected areas, that are not based on addressing identified threats, to afford an appropriate level of protection of marine environments and ecosystems while also allowing for the long-term human use of living marine resources. By identifying and prioritising threats, it is hoped that responsible agencies and managers will have the evidence or impetus needed to be able to re-assess and where necessary, realign management efforts.

Methodology

As a starting point, a review of the literature on global marine environment and fishery threats was conducted. This review was further refined by examining the changes over time of marine environment and fishery management priorities published by competent global bodies. As a framework for the categorisation of threats, a contemporary and relevant listing from the UN Convention on Biological Diversity was selected and enhanced with two additional categories (‘ocean based activities’ and ‘perception/ideology’). Identified threats and their effects were detailed and then positioned in a NSW context by examining their relevance to case studies of seven NSW estuaries. Case studies of the estuaries (North Coast – Cudgen Creek, Richmond River and Clarence River; Sydney Metropolitan - Botany Bay and Port Hacking; and, South Coast – Lake Conjola and Baragoot Lake) that were chosen in consultation with the Chairman of the NSW FRAB demonstrated the level of change that human development has caused and highlighted the magnitude of pressures that they face now and will likely face in the future. A table containing the set of identified and categorised threats was constructed and each threat was scored on a set of parameters including the threat’s temporal scale, intensity of immediate effects, and accumulation potential; ease, feasibility, cost and time for effective management; and, the performance of existing management. Based on the scoring of categories within this table, priority threats that are deemed to warrant enhanced management were identified. In addition, key statements throughout the report have been reproduced in **bold** to signify their heightened level of importance.

Results/key findings

The report discusses how the outcomes of threats to coastal marine environments are highlighted by the particularly obvious changes to estuaries. Estuaries are inextricably linked to the broader marine ecosystems and it is obvious they have been subjected to drastic and highly visible changes and that pressures from threats are ongoing and in some cases intensifying. They are therefore the outstanding indicators of the impacts of threats.

The knock-on effects of the pressures to fishery resources are surmised to be extensive although because of the complexity of marine systems, they are difficult or even impossible to quantify accurately. It is evident that greater resources are required to identify and manage both current threats and new threats as and when these occur. The present degree of reliance on and belief in marine protected areas to provide marine protection is seriously questioned, as is the predominant action within them of closing areas to all fishing regardless of a lack of identification of the impacts of the many other threats and quantification of the impact from particular forms of fishing. It is suggested that enhanced and long-term monitoring and evaluation of marine systems, not only in estuaries and in-shore areas, is needed to assess the impacts of threats and monitor environmental and resource changes. Such monitoring needs to be much more comprehensive and the indicators used should be expanded from the current limited set. With regard to fishery resources there is a need to focus on the habitats and conditions needed to support the many different fish populations rather than the current emphasis on estimating time-series changes to the relative biomass of selected species. Understanding of local conditions and local monitoring are needed to promote effective management. These actions should then form the basis of local and regional management that can, when necessary, constitute action associated with obligations to international commitments. It is important that bland, one-size-fits-all, actions that are promoted internationally do not take precedence when and where they are not ideally suited to local conditions, existing management capabilities, environmental attributes, pressures and threats.

Implications for relevant stakeholders

The examination of marine environment and fishery threats, and the assessment of their level of management, suggests that changes to marine conservation efforts and fishery management should be made. It is evident that many of the identified threats are not best managed by area management in any form, including marine protected areas, and that the main pressure on many fishery resources is not from fishing at its current level but emanates from a combination of land-based activities such as habitat destruction and water quality impacts from industrial, agricultural and domestic activities. In addition, it is evident that long-term advantage could be gained by community education programmes, guided by evidence-based assessments and holistic evaluation of the principles of ecologically sustainable development. These could inform relevant stakeholders of the importance of cost-effective management of threats in the context of sustainable resource utilisation.

Recommendations

There is great need to identify the set of indicators, particularly those centred on fish habitat and environmental conditions conducive to species' viability, which could be used to monitor marine environment and fishery resource health. In addition policy revision is needed to accommodate the accumulating effects of non-traditional threats such as endocrine disruptors and nano-particles and to monitor new and novel activities and substances as and when they impact marine environments. Importantly it is evident that greater knowledge is needed regarding the spectrum of ideologies and perceptions that exist within the community that can drive or hinder effective marine and fishery resource management.

Keywords

marine environment threat management; fishery threat management; marine threats; ecological sustainable development; marine protected areas

1 Introduction

Planet Earth is showing the increasing impact of anthropogenic pressure in many different ways. These include a plethora of both recognised and yet to be identified or accepted threats to marine environments and the resources they contain. Many of these threats are inadequately described and most remain ineffectively managed. There is growing appreciation that most, if not all, do need to be understood and the knowledge of how to manage some of them, at least individually, is improving. Despite this, agreement on the priorities for management, even on a national scale remains elusive; international agreement on a binding commitment to address effectively even the most obvious priorities often remains aspirational. Some broad, but not binding, international commitments to lofty but inadequately described objectives may even distract local efforts.

Definitive lists of the threats to the marine environments and fisheries resources of NSW and of priorities for addressing those threats have not been given adequate priority in the marine conservation and fisheries management processes. We believe this deficiency has seriously detracted from the efficient pursuit of effective management of the NSW aquatic coastal and marine environments and resources. The relatively recent independent scientific audit of marine parks in NSW (Beeton et al., 2012) identified the need to take a more holistic and threats-based approach to the conservation and management of the total marine estate.

This report does not contend to present definitive prioritisation of threats. What it does do is provide a list of the more prominent threats, discussion of at least some of the more obvious characteristics of each and their likely future impacts, particularly where there is evidence of the impacts they have already had in NSW. The relevance of many of the threats that are discussed and the actual impacts they are having are confirmed in a series of detailed case-studies of selected estuaries from throughout NSW where the impacts of the majority of threats to marine systems are concentrated and most obvious. We suggest that in combination, these assessments can inform the determination of priorities for the management of the broader NSW marine estate.

There are many threats to marine ecosystems and their categorisation can be somewhat subjective. As acknowledging subjectivity and minimising it where possible are key strategies in this report it was considered appropriate to use an internationally accepted outline of the major threats as the baseline. Accordingly the categories of threats to marine systems outlined by the Convention on Biological Diversity (CBD) have been used as the basis for categorising the types of threats to the marine systems and fisheries resources of NSW. Individual threats within these broad categories (Table 1) have then been selected on the basis of their assessed relevance to NSW. In many cases this relevance has been confirmed in the seven case-study estuaries. Key statements throughout the report have been reproduced in **bold** to signify their heightened level of importance.

2 The Development of the Approach

The primary purpose of this project is to provide an assessment of the management of different threats to marine environments and fisheries resources using as the example, NSW estuaries where the effects of the majority of threats are most apparent and relatively well documented, as the example. In pursuing this purpose two primary objectives were determined: first, to compare the different threats to marine systems and fisheries resources and second, to identify the priorities for addressing (managing) each type of threat.

In accordance with the directive from FRDC the assessment of threats and their management has been focussed on NSW although references to Australia-wide and global issues are provided where relevant and necessary for comparative purposes. Acknowledging the directive from the NSW FRAB (Peter Dundas-Smith (Chairman NSW FRAB) May 2013) we have given greater detail in comments on the "comparison of the relative effectiveness of the management of priority threats within marine parks".

Because of the prominence of the interface between terrestrial and marine systems in the expression of threats to marine systems and fisheries resources in NSW, the project is focussed on estuaries and in-shore environments and resources. These are the source of the best descriptions of the impacts of many of the major threats. In so doing seven estuaries, three north coast (Cudgen Creek, Richmond River and Clarence River), two metropolitan (Botany Bay and Port Hacking) and two south coast (Lake Conjola and Baragoot Lake) were selected in consultation with the Chairman of the NSW FRAB as case studies.

In refining the approach it became obvious that some background was necessary on what constitutes a threat, what these threats individually or collectively actually threaten and why and how they should be managed. Key questions that should be addressed in this process are:

2.1 What are threats and why should they be managed?

One prominent and relevant definition of a threat is "*something that gives indication of causing evil or harm*" (Macquarie Dictionary, 2005). This definition in itself indicates why a call for action is implicit in acceptance that a threat is significant. It would be logical to anticipate that the priority for action to provide protection against the impact of a threat would be determined by informed consideration of the many factors that influence the degree of impact and the costs of addressing or not addressing it. Unfortunately however, a structured, strategic approach to the management of threats is not always a feature of the management of marine environments and seldom a feature of the management of fisheries resources or the regulation of fishing.

Consideration of the management of threats to marine systems is clouded by the immense variability, complexity and inter-related nature of marine systems. Evaluation of the effectiveness of management of threats is further complicated by the multitude of alternative opinions and interpretations of virtually every aspect of this evaluation, including, but by no means limited to: what is actually a threat, exactly what is threatened, what is the scale in space and time of the impact of the threat and what is the feasibility of ameliorating the threat, including what is the cost and how long will it take?

Achieving effective management of threats is the more confounded because the management or amelioration of each threat is seldom done against a background of agreed priorities for dealing with every threat, or agreement on who has final responsibility for the management of each. It is relatively easy to identify potential threats and even to anticipate their likely impacts; the literature listing and discussing them is extensive. It is the prioritising of threats in the context of their long-term and strategic implications that has largely evaded description. In the absence of strategic direction, management actions have been disproportionately dominated by short-term, localised solutions to the most intensely publicised or visible threats, both real and perceived. The more diffuse and strategic issues, such as the inter-relationships among threats and the regional implications of local actions, have tended to remain in the 'too hard basket', not just in NSW but globally.

The logical prioritisation of management to address threats could be anticipated to begin with an accurate description of all threats. It could also be anticipated to incorporate description of what it is that is being threatened, the value of what is threatened, the harm that is anticipated, an estimation of the severity of that harm, the likelihood that harm will occur and the probability that management action will result in a cost-effective diminution of harm. If the answers to these question lead to the conclusion that addressing the threat is a high priority then equally logically what follows are the further questions, who should address it and where, when and how. This project is restricted to identification of threats and impacts and an attempt to prioritise the need for, or appropriateness of, management of each. The issue of who should take responsibility for the necessary management in cases where current efforts are inadequate is beyond its scope, but in many cases the responsible agency is easily identified.

The extreme dynamism of marine systems also means that prioritisation of the management of threats should be based on more than just current threats to the *status quo*. Many impacts and activities that may initially be positive have the potential to become a threat if thresholds are surpassed or priorities change and the magnitude of the impact increases to such an extent that 'evil or harm' becomes a reality. Nutrient load in marine systems is one example; nutrients are an essential attribute when in balance but in excess they threaten ecosystems. Fishing is another; numerous forms of well-managed fishing provide sustainable seafood and repeatable enjoyment, whereas destructive fishing practices and/or serious overfishing, when they are allowed to occur, can be real threats.

2.1.1 What is being threatened?

This project is focused on evaluation of the threats to marine environments and fisheries resources. Marine environments, including estuaries are immensely complex, interconnected and subject to often extreme natural variation. Nonetheless there is a high degree of individuality to most of them. This variability and individuality, coupled with the variable manifestation of each threat, create a limitless array of physical entities, situations, systems and relationships that can be threatened. This complexity necessitates a holistic approach to viable solutions but limits the value of generalisation about the impacts of various threats and how to address them.

Individual threats will impact varying components of marine systems differently. Considerable priority must therefore be given to determination, in so far as is possible, of what it is that each putative threat may impact and the degree to which that impact is actually harmful. Unfortunately the management of marine systems and fisheries resources in Australia has been seriously compromised by inadequate description of the threats to each marine system and prioritisation of management in accordance with the severity of the threat even though such actions are mandated by the Intergovernmental Agreement on the Environment (Commonwealth of Australia, 1992).

As the types of threat and their impacts vary enormously, for example from deliberate physical modification of environments, often resulting in destruction of habitats, to the insidious effects of a plethora of different forms of pollution, it is not surprising that prioritising the management of the multitude of options and combinations will be subjective and influenced by opinion. While the influence of individual opinion must be acknowledged the value of this and similar reviews will be greatly influenced by the degree to which objectivity can be demonstrated.

In this report two primary strategies have been adopted in an attempt to maximise transparency and to constrain subjectivity and opinion. First, seven estuaries that spanned the range in size, geographic distribution and degree of human settlement across NSW were selected for detailed evaluation. The purpose of these evaluations was to show how the estuaries of NSW have actually been impacted by the many different threats and to facilitate estimation of likely future impacts in these estuaries and elsewhere. These case studies, although themselves selected, provide some enhancement of the objectivity of threat assessments by providing examples of how the impacts of threats to marine systems in NSW have been most obviously manifest and what outcomes management has been able to achieve. We believe that the information presented in these case studies provides a level of reality that represents an objective baseline for subsequent more generalised assessment of threats. Second, informed in part by the case studies and particularly the discussion in the text of this report, in particular Section 8, the most prominent characteristics of the impact of each major type of threat have been ranked. In order to minimise subjectivity and to increase transparency the provision of a single estimate of the total magnitude of each impact or threat was avoided. As an alternative those characteristics of each threat and its impact that could be comparatively quantified based on the case studies and the scientific literature, were selected.

The characteristics selected here for ranking are: the spatial and temporal scale of the impact of each threat, its initial intensity, its propensity to accumulate over time, the ease, feasibility and cost of managing it and the time likely to be necessary for effective management. They were evaluated for each threat type in a NSW context, discussed in the text under each category, and summarised in Table 1. Table 1 also includes an estimate of the effectiveness (performance) of what management has, or has not, been attempted to date as a final ranking. Estimation of the relative effectiveness of the management that has been attempted is for most threats even more subjective than the other measures and must, therefore, be treated with great caution. However, some evaluation of the relative effectiveness of previous management attempts is vital for informing decisions on how management might be modified (adaptive management) and the likely success of additional, enhanced or continued management.

2.1.2 What is the value of what is threatened? (Why does it warrant protection?)

As with many relative terms, value is in the eye of the beholder. There is an extremely broad spectrum of reasons why something may be of considerable value to some but of little interest to others, for example one small ocean beach or estuary may be of great value to local residents but have lower priority for the much larger number of people who never visit the area. What is of value to one stakeholder may not interest others, or may even be a threat to some; for example a particularly massive fish catch may be of value to the catcher and those who get to eat it but may be perceived by other fishers as a threat to their immediate or future catches. At the other end of the spectrum there are some things, particularly iconic entities such as the Great Barrier Reef that are valued by the great majority, even if the reasons for value may vary. The interpretation of value by governments, and managers representing governments, requires an integrated perspective that absorbs pluralistic demands, reflects democratic processes and accommodates immediate priorities and the long-term interests of current and future generations. In this report, the value of different marine environments or fisheries resources is, as detailed above, acknowledged to be subjective. The impact of this subjectivity has, however, been constrained and made more transparent by the discussion of each threat and by the scores given to the individual characteristics of each.

2.1.3 The definition of ‘evil or harm’

As for ‘value’, ‘evil or harm’ as used in the definition of ‘threat’ above, can be asserted on the basis of individual perception or even ideology. Agents that have the ability to cause impacts that can be determined by relevant criteria to be harmful are clearly threats, the subject of this review. Australia has unfortunately not developed unambiguous definitions of harm and has predominantly not based marine conservation, and to a lesser degree, fisheries management on addressing threats (for example RIS, 2012).

In the absence of agreed criteria for determining harm, change is often uncritically assumed to be harmful; humans tend to be fearful of change (Holling and Meffe, 1996), particularly when it is not deliberate and by their own doing. As a result agents of change are often uncritically accepted as threats. In the course of this review it has become increasingly obvious that the failure of many managers of marine environments and fisheries resources to adequately differentiate change from harm represents a major short-coming. Even the most sustainable use of resources and the most sustainable forms of development result in at least some change; change is bonded to the very fabric of the human venture. **Continuing failure to differentiate change from harm is itself a significant threat to the future of effective environmental management and sustainable resource use (ESD)**.

Change should not be uncritically assumed to be a threat of such significance that it triggers the need for its prevention; most actions in the animal kingdom produce some change, for example big fish eat small ones and every human breath consumes oxygen and produces carbon dioxide, a greenhouse gas. Evaluation of the need for management of each change should include balanced assessment of the benefit derived from causing the change and the degree to which that change is a threat. In the greater environment there are many causes of change and it is in a constant state of flux, forever evolving (changing); evolution itself being a manifestation of change. **Unfortunately poorly interpreted measures of change are often used as measures of the amount of harm done, even though many forms of change can be natural phenomena and inevitable in marine environments**, for example seasonal, inter-annual or inter-decadal variability in the abundance of individual fish species.

2.1.4 The severity of the harm that is observed or anticipated

Estimation of the severity of the relative harm of each threat can be less subjective than the determination of the value of what is threatened. None the less, in evaluation of the severity of the harm from individual threats, the extent of that harm is seldom adequately assessed against relevant pre-determined criteria. Obviously the physical magnitude of the impact, including the intensity of the impact and the size and location of the area affected, will be implicit in most conclusions. The timescale of the impact, including the time necessary to ameliorate the impact, should be given similar prominence in the management priority setting process; for example the impact from major physical change, such as the removal of habitat by ‘reclamation’ of marine areas is effectively permanent, whereas the temporal impact of a chemical discharge can be expected to vary depending on the nature of the chemical and efforts that are made to neutralise or remove it. Changes to fisheries resources that have been caused by fishing have been repeatedly demonstrated in Australia to be relatively quickly reversible when appropriate efforts are made (Kearney, 2013) with at least some recovery usually achieved within the time of one or two life-cycles of the species.

2.1.5 The likelihood of harm occurring

While there will be uncertainty over what impact a threat may cause and the periodicity of that impact, the level of uncertainty can be estimated for many threats, at least to the extent that the priority for management can be justified. For example there can be little doubt that some harm will occur if habitats are destroyed by physical 'development' and not replaced, but there is considerable uncertainty over the impact of gradual redistribution of resources or habitats within marine environments, for example mangrove encroachment in estuaries, or even the redistribution of species that is anticipated with climate change (IPCC, 2007). Similarly, it can be assumed that the release into marine environments of hazardous chemicals with a long half-life will cause longer-term impacts (relatively more harm) than the impact of chemicals such as bio-degradable, organic fertilisers, that in addition to potential negative impacts can have some positive impact on productivity as nutrients and/or readily break down to non-threatening substances. **The impact of transient threats may be equivocal or even determined to not warrant additional management** in some circumstances.

2.1.6 The probability that management action will result in a measurable and sustainable benefit

The likelihood of management ameliorating harm and/or preventing future harm and doing so cost-effectively is logically greater if that management is targeted as precisely as possible at the cause of the identified harm (the threat to something of value). Unfortunately, however**, management of threats to Australia's marine environments and fisheries resources has seldom been based on robust identification of threats and comprehensive evaluation of the costs and benefits of the alternatives for addressing them**. A prominent example, the National Representative System of Marine Protected Areas (NRSMPA), detailed in section 10, does not take a threats-based approach.

The lack of description of how predicted benefits from management action are to be confirmed and measured is another common failing of marine management in Australia and elsewhere. It greatly constrains the determination of net benefit from changes that may, or may not, result from management action. It also constrains the design and implementation of adaptive actions to improve the efficiency of management (adaptive management).

Managers of threats face great difficulty in determining the relative priorities for addressing inadequately identified and defined threats to individual, localised or national values that are themselves poorly described. Furthermore, the priorities for protecting each value are seldom accompanied by unanimous agreement between stakeholder groups.

3 Human Driven Environmental Change

As humans utilise land and marine resources and develop terrestrial and coastal areas, major impacts occur. In most countries the resulting changes have been spread over millennia. Assessing change spread over such a timescale is difficult as knowledge of the baseline unperturbed system has slowly eroded with generations of inhabitants.

The pace of change and magnitude of impacts, in many global locations, has increased with industrialisation, particularly from the 18th century, and generally accelerated with the onset of rapid technological change and associated more rapid population increases of the mid to late 20th century. As a result, and particularly since the 1980s, addressing and managing change and impacts has become an important global issue for civil society, governments and international organisations.

In Australia, the situation is somewhat unusual. Indigenous populations who have inhabited Australia for some 40 to 60,000 years (Flood, 2004) hunted, gathered and managed their landscape with prominent use of fire. Over time, they changed the balance of flora and fauna and it is also thought that certain megafauna were driven to extinction (Flannery, 2012). The type of change and the degree of total change to Australian landscapes intensified greatly following the onset of European settlement in 1788. Many of the human driven changes that have shaped European landscapes and seascapes over millennia have been compressed in Australia into a period of around two hundred years. As a result, the impacts of many changes are more acute and can be more obviously identified and better understood.

As European settlement spread in Australia, major changes occurred to land use. Typical settlement patterns involved the intense utilisation of various natural resources. As detailed in the case studies settlers rapidly logged areas for valuable timber, cleared land of native vegetation, introduced domesticated farm animals and feral species such as rabbits and foxes, predominantly from Europe and cultivated crops and produce that were introduced from around the world. Areas were sub-divided and drained, human populations grew and the demands for resources such as arable land, water, timber and other building materials increased alongside the need for waste disposal and transport networks. Nascent industries such as animal carcase processing, tanneries, metal works and soap manufacture coupled with human waste disposal resulted in waterway pollution. In the post WWII period and particularly since the 1980s there has been rapid industrialisation, large population increases, increasing affluence, increased levels of mining, increased demand for transport infrastructure, increases in globalised trade necessitating port developments, and expansion and increased demand for leisure pursuits. These increases have placed further pressures on resources such as water, land and recreational areas, and created increasing volumes of waste for disposal. Much of this rapid change, often associated with a preference for development in coastal regions and in particular those associated with estuaries, has affected river catchments, estuaries, coastal land and consequently the quality of water in rivers, estuaries and the open sea. It should be of no surprise that there have been accompanying large scale changes to riverine, estuarine and marine ecosystems. particularly where the linked marine ecosystems are close to shore or where marine biota readily move between the distinct systems or rely upon other species that either reside in or move between riverine, estuarine and marine areas.

Consequences of human activities on aquatic environments have included: increased sediment and nutrient loads, changed flows in most estuaries and coastal tributaries, increased run-off volumes and changed levels of catchment and riverine erosion and deposition. Human activity also resulted in a great variety of pesticides and other chemicals entering the marine environment. Engineered changes to the landscape include drainage, flood mitigation, the construction of dams, bridges, roads and railways, the dredging of shipping channels and the reclamation of aquatic areas as land. These activities have resulted in more than the visibly obvious changes that include the loss of saltmarsh habitats, and damage to seagrass beds and benthic habitat. Less visible impacts include changed salinity; water pH changes such as those resulting from disturbance of acid sulfate soils; reduced dissolved oxygen levels from altered flood-plain use and altered inundation effects and patterns; and, reduced connectivity in waterways resulting from both purposeful human-made changes to water drainage and flow, and indirectly from many forms of infrastructure developments.

3.1 Human activities and pressures

Population growth, shown globally and for Australia (figures 1 and 2) is primary to and indicative of the growth of resource use and impact that humans have on and demand from the earth system. There is little evidence that population growth will cease in the period relevant to the threats described in this report. Coupled with increasing affluence and the use of new materials and technologies current trends in population strongly indicate the increasing need to effectively manage all aspects of human activities while more fully utilising resources in a sustainable fashion. The Australian economy is projected to grow by 2.7% per year to 2050 while the population is expected to increase from 22.2 million (2010 figure) to between 30.2 million and 35.9 million in 2050 (SOE, 2011). Effective management of resources and environments will be needed to underpin this growth.

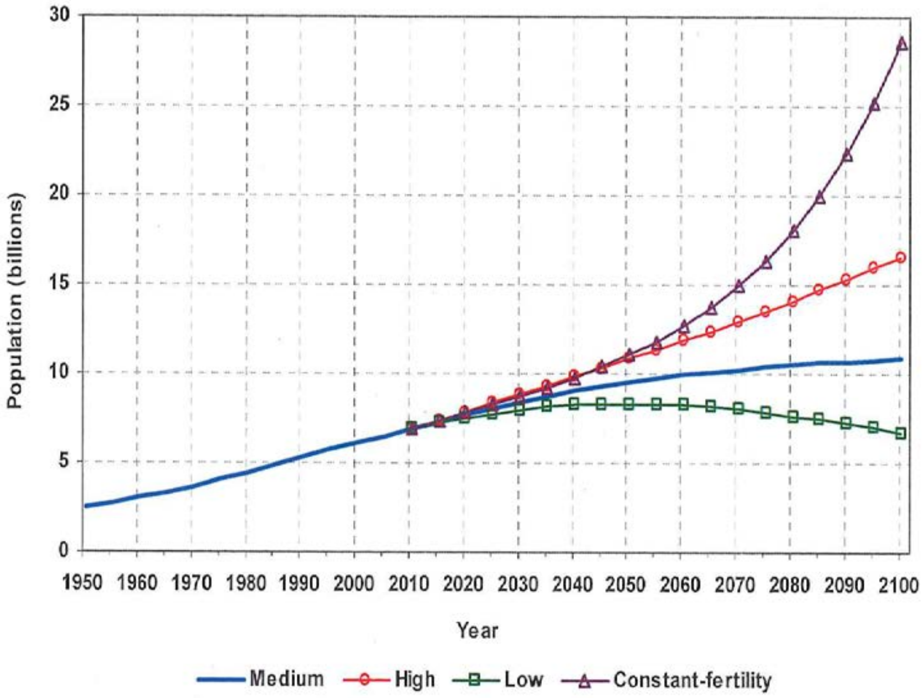

Figure 1 Population of the world, 1950-2100 showing possible projections according to different fertility rates (United Nations, 2013).

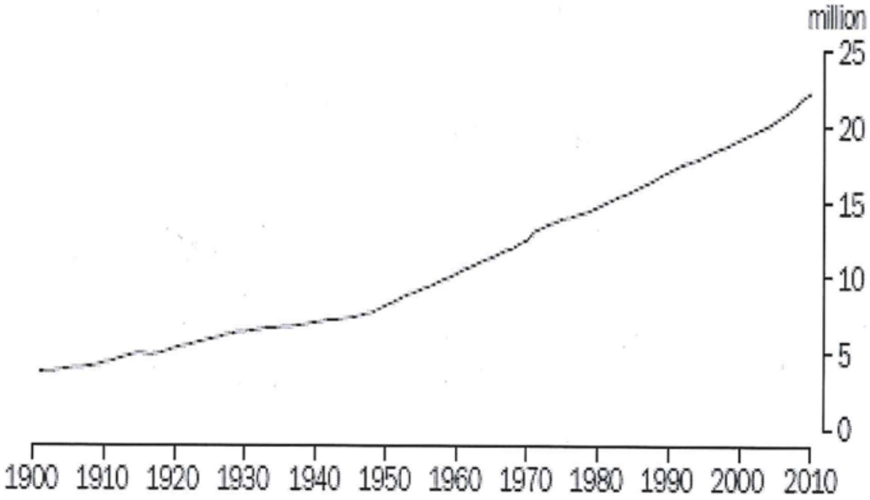

Figure 2 Population of Australia 1900-2010 Population of Australia 1900-2010 (ABS, 2012b).

More specifically, the following categorisation of major activities helps to demonstrate where impacts originate and to clarify the numerous threats to the marine environment. Such clarification aids the prioritisation of the need for effective management especially in a world with increasing population and affluence.

3.2 Industry

Typically, initial industrial activity includes the production and processing of agricultural products (sugar, grains, meat, fruit and vegetables), transport development (ports, rail, road, bridges), construction, manufacturing of building materials, and the provision of goods and services required by newly established and long-term populations. As economic activity increases, diverse operations such as energy generation, oil and gas production, mining, petrochemicals, heavy engineering, industrial food processing, construction material manufacturing (cement etc.), commercial and retail zones, and health care facilities are typically established. These operations all impact land use, catchment functionality, and water quality and hence, marine ecosystems and fisheries resources.

3.3 Agriculture

Much agriculture requires the removal of native vegetation and the introduction of exotic flora and fauna. It also causes riparian damage and changes to land through drainage and reclamation. Of particular relevance to coastal NSW, the reclamation and drainage of acid sulfate soils exposes them to oxygen causing the production of large volumes of acidic leachate and runoff. This, in turn, can cause the release of toxic quantities of iron (Fe), aluminium (Al)) and heavy metals (Fitzpatrick and Shand, 2008). "*The acid, metals (mainly Al), metalloids and non-metals released can potentially leach into waterways, kill fish, other aquatic organisms and vegetation, and can even degrade concrete and steel pipes and structures to the point of failure*" (Fitzpatrick and Shand, 2008 p.43).

The inundation of pasture grasses, usually introduced, can create anoxic conditions that can have much wider consequences during, or immediately following times of flood. The resulting anoxic water mass can lead to extensive kills of virtually all living aquatic organisms in affected areas, for example in the Richmond and Clarence Rivers (see case studies sections 4.1.2 and 4.1.3). Nutrient loading from animal waste and fertiliser runoff affects primary production in adjacent water bodies and can lead to eutrophication. Pesticide use, particularly the past use of halogenated hydrocarbons that are persistent pollutants, can adversely affect marine biota, and water extraction and damming of rivers both change flow rates and patterns.

3.4 Urbanisation

The aggregation of human dwellings and associated activities creates a multitude of variable impacts on marine environments. The most obvious are listed in Table 1 in the category of land based pollution and eutrophication. Other direct threats are covered under alterations to physical habitat. The concentrated demands of cities on ecosystem services, including the need for food and water and the assimilation of wastes, is likely to increase as urban populations increase globally and in Australia.

4 Case Studies

Case studies were chosen from north coast, Sydney metropolitan, and south coast regions in consultation with the Chairman of the NSW FRAB. The primary objectives of the selection process were to cover the geographic extent of coastal NSW, the wide size-range and types of estuaries (creeks, rivers, bays and lagoons) and the range of known and prominent threats to the full suite of estuaries in NSW and the well-being of the resources they support. Information on these estuaries was compiled from the published literature and direct contact with the relevant local and state government agencies. The report by Roper et al (2011) “State of the catchments 2010” as the prominent Government review of the status of all NSW estuaries was used as a baseline for each of the assessments in this report. Drafts of the contents of each case study detailed in this report were forwarded to the relevant local management agencies for comment before finalisation.

The development history of each case study is summarised so that the present condition and the pressures that each is currently subject to can be understood in the context of changes that have been driven by human development and natural resource use.

It is clear from the evidence discussed in the seven case study estuaries that there have been many and dramatic changes to the estuaries of this State and that what attempts there have been to ameliorate those changes have been seriously inadequate. It has also become apparent that while there is some awareness by the general public of declines in marine systems there is telling ignorance of the detail of the many problems, their causes (threats) and what needs to be done to address them. Public understanding of cause of effect is inadequate or even misguided due to the inadequacy of available in-depth analyses. In this regard the report by Roper et al 2011 is a commendable beginning to a formal monitoring, evaluation and reporting process. It must be noted however, that the data included in Roper et al. are insufficient to support quite a number of the classifications they derived and conclusions they have reached for individual estuaries (clearly evident in the case studies in this report, particularly Cudgen Creek and Richmond River). This failing must not be taken as a criticism of the process of monitoring, evaluation and reporting begun by Roper et al but rather it should be recognised as a call for the additional data and analyses necessary to provide on-going assessment of the causes and effects of changes to the coastal ecosystems of NSW. Regular updates on the status of the State's many estuaries are required within a guiding context that acknowledges the varied and major impacts that many estuaries have been subjected to, particularly since European settlement. It is obvious that structured and ongoing monitoring is essential and it is recommended that further assessments be provided at least every five years for all estuaries and every two to three years for those estuaries assessed to be subject to major threats and for those that are known to not be improving.

4.1 North Coast

4.1.1 Cudgen Creek

A small creek (2.15 km^2) with a catchment of 68.61km^2 (Table 1 Roper et al., 2011) on the far north coast of NSW, managed by the Tweed Shire Council, with its mouth at the popular coastal township of Kingscliff. It is currently classified as a trained, open barrier river (Table 7 Roper et al., 2011), but before it was trained, (deliberately modified in 1967 (NSW Government, 2012)) it was classified as an ICOLL (Intermittently Closed and Open Lakes and Lagoons).

Cudgen Creek has not been given an overall condition rating in the NSW- wide classification of Roper et al. (Table 25, 2011) which is fortuitously of little consequence; the parameters, including time-scale, used for this rating system would not have reflected that Cudgen Creek is now a totally different system in a totally different condition to what it was up to the 1950s. The recent reports of the presence of the introduced, invasive and dominating species Tilapia *sp*. in Cudgen Creek (NSW DPI, 2014, Chambers, 2014) further discussed below and in sections 7.4 and 8.1.4 further demonstrate the extent and impact of changes affecting this waterway and the broader aquatic environment (NSW DPI, 2014).

In the Estuarine Monitoring Evaluation and Reporting (MER) Report the Pressure Rating for Cudgen Creek of 2.5 is high, in fact the equal second highest in the Northern Rivers region of NSW (Table 48 Roper et al., 2011). We contend that its absolute value should be even higher. The limited number of pressure influences that have been considered for Cudgen Creek have generally been given high scores; the only ones given low scores being 'disturbed habitat' and 'fishing'. For the category of disturbed habitat the Roper et al. report states, "*Currently data on only the presence of foreshore structures and aquaculture leases have been used*" (2011 p.146). The Report acknowledges the limitations of this process and the need to include a much greater range of factors in future estimations of disturbed habitat. Cudgen Creek has a limited number of foreshore structures but the foreshore itself of most of the downstream reach of the Creek has been totally changed such that the previously prominent natural rocky structure has been largely removed. There is no aquaculture in the Creek but the native Sydney rock oyster beds that were a feature of the foreshore in the 1950s are now absent.

Cudgen Creek has been subjected to extreme habitat disturbance, particularly the lower reaches, which included the mining of the whole bed of several kilometres of the creek close to the mouth in the 1950s and 1960s, to a depth at the time of approximately 15 meters. In addition the great majority of the eastern foreshore between the Creek and the Pacific Ocean was mined numerous times between 1945 and 1980 – as recently as 2011 some 14,000m^3 of sand was pumped from the lower reaches of the Creek for adjacent beach nourishment (NSW Government, 2012).

Significant parts of foreshore areas, including wetlands, have been 'reclaimed' since the path of the Creek was modified beginning with the construction of the bridge just south of the township of Kingscliff, in the 1950s. Inundation of, and natural drainage through these wetlands produced the 'tea-tree' brown stain to the water that was a dominant characteristic of the Creek through to the 1960s. Surrounding land use has resulted in a high degree (68.6%) of disturbance (Appendix 7 Roper et al., 2011). This included considerable clearing of vegetation around Cudgen Lake and extensive and in parts intensive, agriculture including sugar cane in the catchment areas of the tributaries, Clothiers Creek and Reserve Creek.

Fishing is considered by Roper et al., to not be a pressure, simply because in the absence of comprehensive data the process that was used is based on the presence or absence of commercial fishing and aquaculture; neither is currently permitted in the Creek. It is of interest that the Creek supported two commercial mesh-net fishers prior to about 1953/4. However, the Creek is subject to relatively heavy and increasing recreational fishing pressure, particularly in the lower reaches, and the middle reaches of the Creek have at times been subjected to illegal fishing, particularly in the form of set nets for prawns.

The reported changes in the seagrass, mangrove and salt-marsh areas, for example the 91% reported loss of salt-marsh between 1985 and 2006 alone (Appendix 15 Roper et al., 2011) are indicative of a very high degree of alteration to the Creek. However, as the period covered in the only available assessment does not include benchmark data from before the era of dredging and before the bridge and training walls were constructed even the large amount of change that has been reported greatly underestimates the degree to which the Creek has been modified. An example of significant change to habitats includes: the complete removal by mining in the 1960s of extensive sand/mud flats that were immediately above where the bridge now spans the Creek. There were also historically significant seagrass beds below the bridge but recent reports show a complete absence of seagrass in the lower reaches of the Creek.

The Raw Pressure data (Appendix 20 Roper et al., 2011) only reflect data post 1996, i.e. recent pressures. They also appear to underestimate the rate of population growth in the rapidly developing area surrounding the Creek. The shire's current population is approximately 89,000 and is estimated to reach more than 128,000 by 2031 (Tweed Shire Council, 2013) with 10% of this population currently or expected to be concentrated in the Kingscliff area (as reported in 'ID the population experts', 2011).

Accumulated Impacts:

Cudgen Creek has been subject to extreme physical modification which intensified with the sand-mining for rutile and zircon of the general area during the Second World War and construction of the bridge across it in the mid-1950s. The approaches to the bridge were 'reclaimed' from the Creek bed and the span of the bridge greatly reduced the width of the Creek at this location. This reduction was so great as to restrict total flow, most noticeably during spring tides and floods. The physical impact of this restriction is apparent in the significantly altered pattern of sand movement and deposition above and below the bridge. The extent of this modification was of such magnitude that areas that had originally been part of the Creek bed were subsequently so far above normal tidal levels that they were 'reclaimed' for park-land.

Deliberate physical modification of the creek was continued with the mining of the Creek bed and down-stream foreshore and culminated with the construction of two training walls in 1967 (NSW Government, 2012).The impact of these walls changed the Creek from an intermittently closed and open system to one that is permanently open. The training walls also resulted in the relocation of the mouth of the creek from a variable position on a long sandy beach area to permanently abutting a largely intertidal, rock outcrop. Much of this natural rock outcrop and associated inter-tidal environment has been permanently covered by the construction of the southern rock wall and by sand build-up that followed that construction. The training walls also gave the Creek extensive rock areas on both banks of its entrance. The impact of the relocation and reconstruction of the mouth of the Creek in combination with it being held permanently open on the types and quantities of fish and crustaceans that would recruit to the Creek, particularly as eggs and larvae, cannot be evaluated beyond the assumption that considerable change could be expected to have occurred.

The incursion of sand into the Creek that followed the repositioning and redirection (previously facing predominantly north to currently being more east facing) of its mouth by the construction of the training walls completely changed the morphology of the Creek, particularly below the bridge where the depth and width of the Creek were both considerably reduced. The extensive rocky foreshore on the northern side of the Creek was within a few years almost completely covered by sand and most of the natural deep holes and those that had been deepened by sand mining were filled in to a residual depth of little more than a meter.

The hydrology of the Creek has been drastically modified as a result of changes to the structure of the Creek and modification to the foreshores and catchment. This has been most obviously expressed in the disappearance of the tee-tree tinted brown colour that was a feature of the Creek and was dominant even at the mouth of the Creek at all but full tide. However, as most of the major changes to the hydrology occurred prior to the period covered by the available data the degree of change over the last 60 years cannot be quantified, but must be assumed to be greatly underrepresented in the data that have been used to classify the Creek in the most recent Government assessment (Roper et al., 2011).

Conclusions:

Cudgen Creek provides an excellent example of why there is a need to differentiate the causes of change from both continuing threats and the likelihood and appropriateness of remedial action. The lower reaches of the Creek now constitute a totally different ecosystem to that which was present in the same area before deliberate human intervention which accelerated in the 1950s. The causes of the most dramatic changes have been: 1. the narrowing of the Creek to minimise the cost of construction of a bridge, 2. the mining of the bed of the Creek, primarily for rutile and zircon, 3. mining of the foreshores and coastal plain, 4. the construction of training walls to keep the Creek permanently open as a means of preventing inundation of the flood plain and also to improve transit for small fishing vessels between the Creek and the ocean, and 5. the reclaiming of previously inundated 'wetlands' for agriculture and construction. As the Creek runs through areas with some of NSW's most rapid urban development it continues to be also subject to elevated levels of the more common pressures of human population growth (see other case-study estuaries).

The likelihood of previous stressors being ameliorated and the extent to which they represent ongoing threats are outlined below:

1. Additional bridge construction remains a threat, particularly noting the great expansion of urban development in the region, however effects should be manageable. It is however, most unlikely the negative impacts of previous bridge construction will be adequately ameliorated (several areas have been ‘reclaimed’).
2. Sand- mining for rutile and zircon has now ceased in the area. Its damaging effects have been accepted (many houses have been built on the modified catchment of the Creek) and the on-going threat appears to have been removed, however the negative effects of the mining that has occurred will not be redressed. Even if restoration was physically possible the costs of restoration to pre-mining conditions would be hundreds of millions of dollars and would impact the hundreds of residences that have been constructed on affected areas.
3. The Creek will not be restored to an intermittently open and closed system; the training walls will not be removed, even if it was possible for less than prohibitive cost (many, likely tens of, millions of dollars) to do so. The local community now appreciates the amenity provided by the permanently open access to the ocean and the clear, though shallow, ocean water that dominates the down-stream areas of the Creek (fish habitat has effectively been replaced by amenity for swimming and waterside recreation).
4. Restoration of at least some wetlands and/or creation of alternative areas are possible at what would appear to be manageable cost. Noting the recorded loss of almost all seagrass and 91% of salt-marsh habitats and that these estimates do not account for the devastation of the 1950s and 1960s, restoration of inter-tidal habitats and protection of remaining remnants is a justifiable priority.
5. The very recent discovery of Tilapia *sp* in the Creek is another indicator of major change that will be extremely difficult to manage (NSW DPI, 2014). This introduced pest-fish has the ability to colonise and dominate a wide range of freshwater and estuarine environments and it has been found to be impossible to eradicate in many open systems to which it has been introduced. The likelihood of it spreading to other NSW estuary and freshwater systems is of great concern.

One characteristic of the greater Cudgen Creek system leaves it particularly vulnerable to further changes to the structure of the Creek bed. The lake at the headwaters of the Creek, Cudgen Lake, is a ‘perched lake’ (Tweed Shire Council, 2012), i.e. it is slightly higher than sea-level. This elevation contributes to the low salinity in the Lake and the surrounding tributaries and the upper reaches of the Creek that influence its importance to fresh water species, such as estuary perch and Australian bass and its utility as a nursery area for other species, such as school and king prawns. There have been proposals to dredge the Creek from the Lake to the mouth to provide greater small boat access to the Lake. Such dredging can be anticipated to impact the drainage of the Lake and as it is a perched lake, increased drainage constitutes a great threat to the hydrology of the lake and possibly even its continued existence, at least in its current form.

That there have been dramatic changes to Cudgen Creek as an ecological entity cannot be questioned. The impact that these changes have had on fisheries resources is much less obvious.

There can be little doubt that fisheries resources will have been impacted in numerous ways by the major changes to the bathymetry and hydrology of the Creek and to riparian and broader catchment areas, but there are not the necessary data to enable assessment of the precise nature of these changes or their net effect. The sanding-over of the rocky foreshore and oyster beds of the Creek and the loss of seagrass and salt-marsh habitats would be expected to decrease the relative abundance of those species that show a dependence on, or a preference for, these habitats. The shallowing of the lower reaches of the Creek would be expected to decrease the relative abundance of larger individuals of several species and to reduce the relative prevalence of some predator species.

The fact that the Creek is now permanently open may well have increased the utility of the Creek to species that would have previously been excluded episodically. This could be expected to have been of greater significance for those species that use the Creek as a nursery area and whose access to either the Creek or the ocean had previously been blocked on occasion at critical stages of their life cycle. It could be expected that some species that recruit to the Creek as eggs and/or larvae, for example school and king prawns, would have been excluded in some years prior to the permanent opening of the Creek. The net result of this on the total production of these species and the total productivity of the Creek can only be surmised.

The threats to the future fisheries production of the Creek could be assumed to be similar to those for most northern NSW creeks and rivers, i.e. the general impacts of urbanisation and poorly managed development or agricultural activities. Specific threats include acidic and deoxygenated runoff associated with acid-sulfate soils and inundated grass-lands, agricultural runoff from extensive sugar cane and introduced pine plantations, and intensive vegetable growing in the catchment areas of the Lake and the lower Creek (OzCoasts, 2013b, Tweed Shire Council, 2012).

Noting that recruitment of fish and crustaceans with a marine component to their life cycle to estuaries such as Cudgen Creek can be relatively independent of abundance in the Creek itself (as demonstrated by the migratory nature of most species and by the recovery of the Richmond River even after episodic total fish kills; see Richmond River case study) it is most likely that the impact of the level of recreational fishing in the Creek will be largely restricted to the short-term, localised abundance of target species. Provided region-wide management of recreational fishing is adequate to ensure the sustainability of targeted fish populations and to maintain ecosystems that are impacted, recreational fishing should not represent a major threat to the marine systems of Cudgen Creek or the fisheries resources associated with the Creek.

4.1.2 Richmond River

The Richmond River is located in northern NSW with its mouth at Ballina. It is managed across four local government areas, Ballina, Byron, Lismore and Richmond Valley. The area of the water body has been estimated at 38.38 km^2, including 0.6km^2 of saltmarsh and the catchment has a total area of 6900 km^2 (Table 1 Roper et al., 2011).

The Richmond is classified as an open trained barrier river by Roper et al. who give it an overall Condition Rating of 4.5, corresponding to ‘very good’ (Table 25, 2011). This positive classification is surprising given the relatively high Pressure Rating score by the same authors (detailed below), the changes that the river has been subjected to and the ongoing impacts from land use, drainage, and restrictions to tidal flows. The individual scores that have contributed to the very good Condition Rating are less than convincing: *chlorophyll a* is good but the data are more than 3 years old; there are no data for turbidity or macroalgae; mangrove data are baseline only; however the available figures on seagrass and saltmarsh suggest great increases, 69% and 505% respectively, in the period 1985 to 2006 (Appendix 15 Roper et al., 2011). Recognising the very small number of data points and the limitations of comparing time series data collected using different research methodologies, acknowledged by Roper et al., and possibly affected by changes in technology, the level of these reported increases must be considered with great caution.

The favourable Condition Rating by Roper et al. is the more surprising when it is noted that the catchment is described by Geoscience Australia as being 75% cleared of natural cover with the floodplain affected by acid sulfate soils, flood mitigation works, riparian losses and wetland loss (OzCoasts, 2013b). Current land use data reported by Roper et al. indicates that 56% of the catchment is disturbed with over 90% of the disturbed land being used for agricultural purposes (Appendix 7 Roper et al., 2011). The current total flow of the River is estimated to be 38.3% greater than the flow from the catchment's pre-cleared condition (Appendix 8 Roper et al., 2011) but this assessment would be subject to variation depending upon the actual level of catchment clearing. To help estimate the level of impact to the aquatic environment, changes to the catchment hydrology should be considered alongside impediments to natural tidal influx from numerous barrages and training walls.

The Pressure Rating of Roper et al. is 2.5, which is at the moderate end of the high category. This rating is influenced by very high pressure from sediment input and tidal flow change, high pressure from cleared land, nutrient input and fishing, moderate pressure from population, low pressure from freshwater flow, and very low pressure from disturbed habitat. Other sources of information suggest that the Richmond River has indeed been subjected to extensive and intensive pressures (threats) and that these have had such impact that the condition of the River would be more accurately described as very poor, at least in so far as comparison to its pre-European-settlement state.

To put the relativity of the changes to the Richmond River in the context of management of anthropogenic impact a brief history of what has happened to the River is appropriate:

Prior to European settlement the area was home to the Bundjalung people who had migrated from northern Australia some 6000 years previously (Daley, 1955). Initial European observations in 1828, at the time of 'discovery' of the River and exploration of approximately 30km upstream from the mouth, were of *"many Aborigines on the lower Richmond"* (Daley, 1955 p.1). In the early 1840's it was estimated that their number was approximately 100; and, a further estimate in 1847 was of between 400 and 500 (Daley, 1955). By 1871, the European settler population of Lismore, within the River's catchment, was 93, rising very quickly to 4542 by 1901 (Lismore City Council, nd). Initial European descriptions of the area indicate that the banks of the River were of thick mangrove swamp to the east while to the west and north of the River, to the McPherson Range, was a dense forested area (The Big Scrub) containing much valuable timber. Only 1% of this ecological community, which had an original size of some 75,000 hectares, remains (DPI, 2012). At the southern extent of The Big Scrub, Tuckean Swamp was recorded as being some 13km by 8km in size on a map dated 1840-1855 (Daley, 1955).

After attempts at rearing sheep that failed due to the area's subtropical climate, the mid-19th century saw parts of the Richmond River catchment being used for cattle grazing with the use of areas prone to flooding being restricted to the dry season. Graziers were joined by timber-cutters in the early 1840s who targeted cedar and opened up more land to the graziers (Lismore City Council, nd). Sawmills were established from the 1850s onwards, the dairy industry was established in the 1880s and a sugar refinery began operations in 1881 (Daley, 1955). The lower Richmond River as far upstream as Lismore was used as a commercial port from the 1880s, primarily for shipping timber. Port operations ceased in the late 1960s due to competition resulting from the improved efficiency in road and rail transport (GHD, 2005).

After 1861, various areas of NSW were subdivided and opened up to farming (National Archives of Australia, 2011). A stipulation of the land acts of 1861 was that purchasers should live on their land for 3 years. The resulting land use practices had great impact on the Richmond River and its associated wetlands, as discussed below.

Tuckean Swamp is a particularly high profile area facing both short-term and long-term conservation and management challenges (RRCC NSW, 2013). The Swamp is a 23,000 hectare wetland and associated catchment containing a rich and diverse assortment of terrestrial and aquatic flora and fauna (RRCC NSW, 2013) that drains into the Richmond River through the Tuckean Broadwater. Some late 19th century land divisions within the Tuckean swamp contained no high land and flooding became a barrier to further development. Typical of European management practices of the day, drains were constructed in an effort to secure flood protection and increase the utility and productivity of the land. Private drains were constructed from the 1880s with public funded action taking place from 1910.

Unbeknown to the users and managers of the area at the time, oxidation of the drained and exposed soils created excess acidic runoff. This problem was exacerbated when the Bagotville barrage was constructed in 1971. The barrage was designed to prevent the ingress of estuarine water during periods of high tide which was considered to be adversely affecting farm land. An unforseen outcome however was the build-up of acidic water, exacerbated by the exclusion of the flushing and buffering effects from tidal, brackish waters, upstream of the barrage. This resulted in a drastically changed ecosystem characterised by the presence of sterile, dead, acidic water.

When periodic floods occur, large volumes of acidic water, also low in dissolved oxygen, affect lower reaches of the Richmond River, causing massive ‘fish-kills’ (RRCC NSW, 2013). These events affect all biota in the downstream reaches of the River and would be more accurately titled ‘total biota kills’. Tuckean Swamp is now identified as *“an acid sulphate* (sic) *soil hotspot”* (RRCC NSW, nd-a).

Natural processes linked to flood events have historically caused fish kills in numerous NSW estuaries, as witnessed since the early 1900s (Moore, nd). Official records of the mortality events have only been kept since the 1970s but anthropogenic change to catchments and floodplains is implicated in exacerbating the events. A particularly extensive fish-kill took place in 2001 (Dawson, 2002). An initial suspected main cause of fish-kills was pesticides but later assessments identified other major causes. It is now recognised that acid runoff and leachate from drained and exposed acid sulfate soils and deoxygenation due to breakdown of inundated pastures aggravate the conditions that lead to fish-kill events (RRCC NSW, 2013, Wong et al., 2010). In recent times, efforts have been made to reduce the effects and impacts of human intervention that are known to exacerbate naturally occurring unfavourable conditions for aquatic biota. Tidal flows have been partially restored through the Bagotville barrage; excess drainage has been curtailed; native, flood tolerant pasture species have been planted; and stock have been excluded from some waterways and many acid-sulfate hotspots. As a result of this management, water quality and ecosystem improvements have been recorded in at least some areas (RRCC NSW, nd-a), but much of the problem remains.

Current agriculture activity in the Richmond region is dominated by sugarcane production in the coastal zone with dairy and beef cattle operations alongside forestry activities occurring further inland (CMA Northern Rivers, 2013). In the absence of detailed evaluation of the run-off of agricultural chemicals it is impossible to estimate their impacts on marine systems and fisheries resources.

However, there is little doubt that the management of these activities could be further improved in the context of securing aquatic environmental integrity.

Significant changes to the estuary mouth were made in the late 19th and early 20th centuries with the construction of breakwaters and training walls, and dredging around the entrance bar. Wide-scale maintenance dredging continued until 1974. More recently, in the 1990s, localised dredging has been carried out in North Creek for the construction of Prospect Bridge. A trawler harbour was built between 1966 and 1967. This serviced in excess of 30 vessels in the 1970s with only 8 remaining in 2005 (GHD, 2005). According to a 2005 report on recreational boat use of the lower Richmond River, it is expected that up to a 50% increase in demand for boating infrastructure, predominantly for recreational boating, could occur by 2015.

Conclusions:

The Richmond valley has a sub-tropical climate that is perceived to be excellent and, in association with outstanding ocean beaches and beautiful hinterland the region has outstanding appeal as a place of residence and for tourism, both of which are predicted to continue to increase the local population significantly (DPI, 2012). As a result the general pressures associated with population growth must be anticipated to continue to be significant threats. The way in which these are prioritised and the degree to which they are managed will largely determine the future of aquatic environments in the region.

The Richmond River and its catchment have been changed dramatically since European settlement less than 200 years ago. Most of these changes have resulted from deliberate modification of both the River itself and of much of the catchment. The mouth of the River has been transformed by the construction of extensive rock breakwaters and training walls and parts of the lower reaches of the River have been dredged. The banks of considerable parts of the River have been modified, including by the clearing of mangroves to facilitate shipping and boating, and many wetlands and small tributaries have been drained to facilitate agriculture and to reduce the threat of inundation, including of houses and farm buildings. Much of the catchment has been logged and subsequently cleared for agriculture and urban development. While the negative impacts of these activities are now appreciated and the threat of them continuing unabated is being addressed to at least some degree, the threat has not been removed and the impacts of earlier actions will not be fully redressed.

One obvious manifestation of the accumulated changes, in particular to the drainage of acid-sulfate soils, the inundation of non-native vegetation and the restriction of the flow of estuarine water, has been episodic kills of most biota in the downstream reaches of the River by deoxygenated and acidic water. In recent years the causes of the impact and continued threat have been identified (Wong et al., 2010) and some success has been achieved in addressing the threat (Richmond Valley Council, 2007, RRCC NSW, 2013), however, **the lack of comprehensive management of such a major and obvious problem that is largely fixable at a cost that appears reasonable in light of the resulting benefits (see table 1 and (Creighton, 2013)) casts a pall over the state-wide conservation priority setting process**.

The pressure to the aquatic systems of the Richmond River from fishing has been assessed by Roper et al. as high, however the accuracy, and particularly the relativity of this rating, are seriously questioned. Commercial fishing in the River and the region generally has decreased in recent years to approximately 20% of historical levels (Fisheries NSW unpublished catch data) due to a large degree to closures of much of the River to commercial fishing in ‘recreational fishing havens’. It is probable that these closures have masked the contribution that the continued decline in the health of the River has had on fisheries production.

Recreational fishing is continuing to increase but significant impacts specific to fishing in the Richmond River, other than the managed removal of target species, are not apparent. Noting the recovery of the River after total ‘fish-kills’, discussed below, the managed removal of target species by relatively benign techniques should not be interpreted as a significant threat to the marine ecosystems of the River or the fisheries resources it supports.

The possible negative impacts of fishing should be considered in the context of the impacts of fishing across the State and the impacts of other threats to the aquatic systems of the Richmond River: The species targeted by fishers in the River are common to at least adjacent estuaries and many to the State generally. The relatively rapid recovery of target species after total ‘fish kills’, discussed below, confirms the degree of inter-connectivity with surrounding areas. Effective management is most likely to arise from actions across the whole area of distribution of the resources. Under current total resource management paradigms additional fisheries management specific to the Richmond River is unlikely to result in detectable benefit to the total fisheries productivity of this River or the State.

Assessment of the impact of fishing must be done in the context of the related impacts of the suite of anthropogenic threats. Of particular relevance to assessment of the impact on marine systems of direct removal of fish by fishing is the comparison with the massive and indiscriminate mortality of marine creatures, including fish, caused by the creation and episodic discharges of deoxygenated and acidic water. Two specific aspects of these incidents are particularly relevant to assessment of the impact of fishing: first, the fraction of the standing population of fish and other aquatic organisms killed or displaced by these incidents (as discussed below) far exceeds that by fishing and; second, the total mortality of aquatic organisms resulting from poor water quality affects the abundance and distribution of virtually all aquatic organisms in the area, including many that are neither directly, nor obviously indirectly, impacted by fishing.

Quite remarkably, following the total biota kills the relative abundance of the species that are usually targeted by commercial and recreational fishing have recovered to levels assessed to be sustainable in a relatively short time, usually within months (NSW Government, 2013b). Even after the extensive 2001 event all additional fishing restrictions were removed within eight months (Macbeth et al., 2002). Thus if the impact of widespread mortality of all components of the ecosystem is ameliorated naturally, even within a severely ‘shocked’ system, there should be little concern over the sustainability of the impacts of fishing that harvests much smaller percentages of only target species in ways that are already subject to reasonable management and do not have such absolute impacts on all trophic levels.

There can be little doubt that the accumulated impacts of direct and indirect human intervention on the aquatic systems of the Richmond River, documented above, represent a major threat to the use, and even the sustainability, of the fisheries resources of the River and other areas dependent on it. **The current priority for management of the threats to fisheries resources in this region clearly lies with addressing the threats to aquatic systems (fish habitats and environments) more generally.**

The primary fisheries management lesson that should be learned from the impacts of the 'fish-kills' in the Richmond River is that the management of fisheries resources must include the management of not only those activities that directly and deliberately impact fish and their immediate habitats but of the full suite of threats to fish and other aquatic organisms and the habitats that support them. Obviously threats that originate at any location within the catchment and which impact significant components of the catchment must be given priority that is commensurate with the level of the threat that they pose In keeping with the Intergovernmental Agreement on the Environment threats should be managed and addressed in order of their severity (Commonwealth of Australia, 1992). In the case of the Richmond River there should be no doubt that deoxygenation and acidification of water are much greater threats to the fisheries resources than is fishing in any current form. **The available evidence confirms that the management of habitat and water quality issues must be given higher priority than further regulation of fishing.**

The progressive decline in the commercial fishery based in the Richmond River (Fisheries NSW unpublished catch data) is of concern. The primary reasons for this decline are very likely the accumulated impacts of declining water and habitat quality in the River system on total fish abundance coupled with the decreased commercial fishing effort associated with increased allocation of fisheries resources of the River to recreational users. Similar, or even greater, declines in habitats and water quality and resulting reduced commercial fish catches are apparent in other case study estuaries, indicating a wide-spread decline in the supply of seafood from commercial fisheries that is made available to local and regional consumers.

4.1.3 Clarence River

The Clarence River is located in northern NSW with its mouth at Yamba and its source in the Queensland border district. It is some 380km in length and lies predominantly within the Clarence Valley local government area (Regional Development Australia - Northern Rivers, 2014). Its catchment of 22,700km^2 is the largest in south eastern Australia and its tidal section is over 108 kilometres long (Government of NSW, 2009). Its large alluvial floodplain supports significant agricultural industries and the river is used commercially for fishing including prawn trawling. The waterway is also used for a variety of tourism related and recreational activities (Clarence Valley Council, 2010).

The Clarence is classified as an open, trained barrier river by Roper et al. who gave it an overall Condition Rating of 3.3, corresponding to the upper part of the 'fair' category (Table 25, 2011). The individual scores that have contributed to the fair Condition Rating are: *chlorophyll a*, good but the data are more than 3 years old; there are no data for turbidity or macroalgae; mangrove data are baseline only; however the available figures on seagrass and saltmarsh suggest a decrease of 46% and increase of 48% respectively, in the period 1985 to 2006 (Appendix 15 Roper et al., 2011). Acknowledging the limitations of comparing time series data collected using different research methodologies and possibly affected by changes in technology, noted by Roper et al. the level of these reported figures must be considered with great caution.

The catchment is impacted by an array of engineered drainage and flood mitigation measures including the list below of infrastructure managed by the council and summarised in the *SOE Supplementary Report 2009-2010 (Clarence Valley Council, 2010)*

Structure	Quantity
Levees	110 km
Floodgated natural watercourses and drains	234 km (including 157 individual drains)
Floodgate structures	494 (including 300 major floodgates)
Riverbank rock armouring	24 km
Bridges	53

(Clarence Valley Council, 2010 Table 13)

"*The Northern Rivers Fisheries Project reported that 92% of the 14,700 hectares of Clarence wetlands has been affected by drainage. This has reduced the quality of habitat for fish, other aquatic species and water birds*" (Clarence Valley Council, 2010). Acid sulfate soil exposure has resulted in very acidic water in drains and waterways with water pH readings as low as 2.5 being recorded (Clarence Valley Council, 2010). The catchment is described as being 39% disturbed (Appendix 7 Roper et al., 2011), natural tidal flushing is impeded by barrages and training walls (OzCoasts, 2013b) and the current total flow is estimated to be 22.6% greater than the flow from the catchment's pre-cleared condition (Appendix 8 Roper et al., 2011).

In addition to changes due to agricultural development, the estuarine ecosystem has been affected by dredging and the construction of canal estates and road causeways. The estuarine and freshwater reaches of the river are also impacted by the "*discharge of sewage from unsewered towns and rural residential areas, sewered towns and animal wastes*" (Clarence Valley Council, 2010).

The Council's biodiversity management department, established in 2005, reports that introduced or translocated-pest problems exist due to the presence of rabbits, foxes, cane toads, pandanus plant hoppers, yellow crazy ants, Jack Dempsey cichlid fish, and straying and feral cats and dogs while land clearing and inappropriate fire management regimes also pose significant biodiversity threats (Clarence Valley Council, 2010, Wright, 2010).

There are in excess of 200 sugar cane farms in the Clarence Valley. These are concentrated on the lower reaches of the river in the proximity of Maclean and Harwood. The sugar industry supports approximately 1,000 jobs and contributes an estimated $103 million to the local economy each year. Sugar has been produced at the Harwood site since 1874 (Clarence Valley Council, 2010).

The Clarence River has been commercially fished since the 1880s (Gardiner, 2006) and supports the second largest commercial fishery in NSW (Clarence River Fishermen's Co-Operative Ltd, nd). Products include wild caught ocean and estuary species and the Clarence River is one of three estuaries in the State where prawn trawling is permitted (Clarence Valley Council, 2010), the others being the Hunter and Hawkesbury estuaries. The 2006 catch value from 199 fishers was $19.9 million (Clarence River Fishermen's Cooperative 2007, cited in Clarence Valley Council, 2010). The river is also a *"favoured recreational fishing location"* (Government of NSW, 2009). Although not a direct indicator of the health of the Clarence River estuary it is of note that the freshwater reaches of the Clarence River support the major remaining population of the fully protected eastern cod (Government of NSW, 2009).

As with other areas in the north-coast region, the initial major European commercial activity was the logging of cedar. The Clarence Valley was first mapped in 1838 and the area quickly reached its peak in timber production in the 1840s; by the 1850s the timber industry was already in decline. Timber processing does, however, remain a significant component of the local economy ($110 million in 2002) with major mills located at Grafton, Glenreagh and Koolkhan. Timber for the larger mills is mainly sourced from the State Forest resource while the smaller mills are fed from private native forests. Plantations to supplement these sources were also established in the late 1980s (Clarence Valley Council, 2010). Beef cattle, dairy and general farming are also important contributors to the economy. Sheep were introduced to the region but suffered from footrot due to the subtropical climate, wheat suffered from rust and the sugar industry had a difficult start with the commercial failure of a sugar mill. Raising beef cattle was in the early days of settlement deemed impractical because of the distance to Sydney and a solution to support economic growth was found in the dairy industry.

Over time, uses of the river have included the transport of cedar, wool, and also gold, tin, corn, sugar, bones and horns, tallow, and hides. Navigation across the bar was initially difficult and between 1850 and 1896 17 ships were wrecked at the Yamba entrance. To establish reliable and safe access, harbour work, incorporating the construction of training walls and channel stabilisation, was conducted over three main periods, 1862-1889, 1893-1903, and 1950-1971 (Government of NSW, nd-a). Commercial river transport ceased in 1954 due to competition from road and rail transport (Gardiner, 2006).

The Pressure Rating of Roper et al. for the River as a whole is 3.0, which is the mid-range of their moderate category (Table 48, 2011). This rating is influenced by very high pressure from tidal flow impacts, high pressure from sediment input and presumed pressure from fishing, (presumably because when trawling is present, pressure is assumed, not because of any direct data on the impact of trawling; discussed below). There is no obvious evidence that fishing is exerting high pressure on the river-system. Other influences on the rating include, moderate pressure from cleared land and nutrient input, low pressure from population and freshwater flow, and very low pressure from disturbed habitat (this is in stark contradiction to the above-mentioned reports of 92% of the system's wetlands having been affected by drainage [Clarence Valley Council 2010]).

According to the catchment management authority, ***"the key catchment management issues are riverbank erosion, gully erosion, invasive weeds, fire management practices an*** **[sic]** ***acid sulphate soils*"** **(CMA Northern Rivers, 2013). It is noteworthy that these issues were not given consideration in the Roper et al. estuary classification and condition report (Roper et al., 2011)** which had been previously designed around parameters that could be directly compared across the State's many estuaries.

Conclusions:

The Clarence River is the largest riverine estuary system in NSW. Because of its great size and only moderate human population density throughout its catchment it could be expected to be in relatively good condition; but it is not. With approximately 92% of its wetlands affected by deliberate drainage and 39% of its catchment being described as disturbed it faces broad-scale pressures. The most specific and extreme threats to aquatic ecosystems and fisheries resources are presented in the form of drainage of riparian land and the resulting acidic and deoxygenated water run-off, similar to that described above in some detail for the Richmond River. The cause of these major problems are well known and while some attempts are being made to reduce the impacts (some limited restoration of waterway connectivity has been achieved, an example being the reconnection of Shallow Channel with estuarine water after a period of some 80 years (WetlandCare Australia, 2008)). Much greater effort would appear to be justified, particularly noting the relative importance of the Clarence River system as a nursery and reserve for numerous fish species that populate the greater northern rivers region.

Noting the magnitude of the system and the relatively limited fish catch that is taken from it, it is difficult to see the justification for the high pressure rating for fishing ascribed to the River by Roper et al. As noted above, the presence of commercial fishing in the River, particularly trawling, is presumably responsible for this elevated rating. Here it must be noted that the short-term impacts of trawling on the bottom biota of the trawled areas of the River in its current state was assessed to be negligible, or even not detectable (Underwood, 2007). Impacts of trawling as carried out in the Clarence were considered by the same author to be most unlikely to be significant in comparison with the impacts of the frequent major flooding that occurs in this river system (Underwood, 2007). This is in stark contrast to the episodic total biota kills that result from the deoxygenated ('black-water') water discharges into the river (further discussed under the Richmond River, above) and the estimate that 92% of the River's wetlands have been affected by deliberate drainage.

4.2 Sydney Metropolitan

4.2.1 Botany Bay

Botany Bay is located in the southern part of Sydney, with its northern shores being some 10 Km from the central business district. It has an open almost circular shape with a 'length' of 8.72km, a 'width' of 7.77km and a narrow entrance of 1.37km. It is extensively modified (OzCoasts, 2013b). Natural water depths are generally less than 5m but increase to 10m at the entrance. Dredging is used to maintain a 20 metre depth where needed for the intensive commercial shipping that uses the Bay.

Botany Bay commands a central position in modern Australia's identity with links to early British exploration and it having been the designated arrival point of the First Fleet in 1788, the event that initiated European settlement of Australia. Prior to this, there was a long period of habitation in the area by Aboriginal people who utilised camps along the Cooks River and the Bay itself (SACL, 2009). Aboriginal *"people of the Dharawal nation - the Gweagal (Fire Clan, centred on the southern shore of Botany Bay) and the Kameygal (Spear Clan, from Kamay, the north shore of Botany Bay)"* (Government of NSW, nd-c) hunted, fished and gathered food and other materials from the Bay and its immediate surrounds.

Early European settlers cleared land of trees for timber and to create farm land, introduced crops, raised horses and used Aboriginal midden heaps rich in oyster shells to manufacture lime for construction. The bay was originally named Stingray Harbour by Captain Cook but this was changed in recognition of the diverse collection of botanic samples collected by the botanist Sir Joseph Banks. Cook's description of the area as being suitable for agriculture with a good water supply was instrumental in the British government's decision to establish a penal colony (City of Botany Bay Council, 2013).

In 1813 the first damming of streams took place to provide power for a wool mill and a flour mill in the areas now known as Mill Pond and Engine Pond (SACL, 2009). In the 1830s market gardening was established, irrigation trenches were cut and commercial fishing began to cater to the growing colony's population. Between 1859 and 1886 water was pumped from swamps in the Botany Bay area to supply the city of Sydney and its suburbs. During this period, the area also hosted an increasing number of industries for processing wool, leather, animal carcases and timber that impacted the area and added to the level of drainage of the swampland. Water supply from Botany Bay was recognised as becoming unreliable from 1869 onwards and an alternative source was developed (the Nepean scheme). All that remains of the pumping station today is a chimney stack inside the perimeter of Sydney airport (City of Botany Bay Council, 2013). In 1916 sewage pumping infrastructure was installed on what is now airport land, as part of the Southern and Western Suburbs Ocean Outfall Sewer System that is still in use.

In the early 20th century the level of population, housing, and industry all increased in the vicinity of Sydney and various forms of transport infrastructure were developed. Industrial development, being devoid of effective regulation at the time, resulted in the Cooks River and Botany Bay becoming severely polluted, particularly with industrial wastes (City of Botany Bay Council, 2013).

Changes that were made to the Cooks River were at the extreme end of impacts resulting from European settlement. The catchment and riparian zone were cleared of much natural vegetation and increasingly impervious surfaces were established in the catchment which increased peak flows during rainfall events. Industrial, agricultural and domestic wastes entered the river as Sydney's level of commercial activity increased and the population rose. Dredging and channel modification, including the concreting of significant parts of the Cooks River bank since the 1930s to prevent erosion, and the moving of its mouth has further impacted ecosystem functionality. In recent years, efforts have been made to naturalise some sections of the river by removing concrete lining and restoring native vegetation (NSW Government, nd).

Two particularly large and important transport operations have been established in the area, Sydney (Kingsford Smith) Airport and Port Botany. The airport comprises 907 hectares of land leased to the Sydney Airport Corporation Ltd by the Australian Government (SACL, 2009). Originally the area was marshland and wetland containing the final reaches of the Cooks River. An aircraft manufacturing facility was established in 1919 on what was by then, grazing land for cattle and in 1920 the site was designated as an aerodrome. In 1921 the site was acquired by the Commonwealth as a component of a planned national airport network. The site was expanded in the 1930s prior to the establishment of a new passenger terminal in 1940. Military and civilian expansion occurred during World War II and after the war more land was acquired and the Cooks River diverted and given an artificial entrance some 1.5km south of its original point to facilitate runway construction. Aircraft design changes requiring longer runways led to the extension into Botany Bay of the main north-south runway in 1968. Further extension work was performed in 1972 and in 1989 construction began of a third runway that extends into the bay, this was opened in 1994.

The third runway, *"involved the reclamation of some 170 hectares of Botany Bay using approximately 15 million* m^3 *of sand dredged from within the bay"* (Herbert et al., 1996). This fill, that was moved over a twelve month period, is retained behind 7km of vertical pre-cast concrete walls (Herbert et al., 1996). To limit environmental impacts, areas of marine sediments identified as being contaminated with heavy metals such as cadmium, chromium and mercury were avoided during construction.

The airport is now described as *"one of Australia's single most important pieces of infrastructure"* (SACL, 2009 p.4) contributing $8 billion directly to the NSW economy or $16.5 billion including flow-on effects. It provides some 206,000 jobs (75,000 directly plus 131,000 indirectly).

Sydney airport management recognises that operations encompass several forms of environmental threats including the use and/or spills of fuels, lubricants, solvents, paints, herbicides and firefighting chemicals; the disturbance of identified acid sulfate soils; the disposal of contaminated and general waste from packaging materials; the operation of maintenance and office facilities; and, sewage and waste water disposal. Environmental management plans and strategies are in place to remove and reduce impacts (SACL, 2009).

Port Botany was established in the 1930s and expanded in the 1970s. More recent expansion is described as being *"one of the biggest infrastructure projects undertaken in Australia in 30 years"* (Sydney Ports Corporation, 2012). To facilitate the most recent expansion, more than 80 hectares of the Bay was 'reclaimed'; a process facilitated by dredging other sections of the Bay. The port handles almost a third of Australia's containerised trade which requires a large volume of supporting rail and road vehicle movements. The NSW state-owned corporation, Sydney Ports, manages the commercial port in Sydney Harbour and oversees critical regulatory, security and safety functions of the Botany Bay port within a 99 year lease arrangement of State owned port assets to NSW Ports Consortium (Sydney Ports Corporation, nd). Together the two ports handle in excess of $61 billion worth of trade each year. The operation adds $2.5 billion to the NSW economy and generates more than 17,000 jobs. In the 2011/12 financial year, Port Botany alone handled more than 2 million twenty-foot-equivalent containers in addition to bulk liquids (refined fuels, gases, chemicals and other liquids) associated with 2,179 vessel visits to Port Botany and Sydney Harbour combined (Sydney Ports Corporation, 2012). Port activities continue to increase; bulk liquid handling capability was expanded between 2012 and 2013 with the construction of a new $80 million facility next to the existing bulk-liquid berth. Provision has also been made for the establishment of a third bulk-liquid berth to *"boost bulk liquids capacity when the need arises"* (Sydney Ports Corporation, 2012 p.24)

With Sydney airport and Port Botany in close proximity, the area has developed into a nationally important commercial hub with a variety of business interests adjacent to residential areas. Much of this and associated activity, alongside the indirect and direct utilisation and needs of Greater Sydney's population of just under 4.4 million (ABS, 2012a) impact the Botany Bay catchment and consequently affect water quality, marine systems and fisheries resources.

Sediment analyses of key elements conducted in Botany Bay indicates that while levels are below the "high" level in the *recommended sediment quality guidelines* outlined in *Australia and New Zealand Guidelines for Fresh and Marine Water Quality* (Table 3.5.1 ANZECC, 2000), anthropogenic influences are apparent from higher levels of lead and zinc to the east of the mouth of the Cooks River (Albani, 2008), in addition, "*As, Ni, Y and Cu* [Arsenic, Nickel, Yttrium and Copper] *are present in inflated concentration off Cooks River, Quibray Bay, Woolooware Bay, off Georges River and around the Port Development. In particular chromium* [Cr] *and zirconium* [Zr] *show a high concentration off the oil terminal at Kurnell, while strontium* [Sr] *shows a very high concentration (greater than 10 times the median) off Inscription Point. The input from the Scarborough Ponds is significant for As and Y, although much less than the values measured in the Ponds. It is interesting to note the similar occurrences of higher concentrations of As, Cu and Cr in Woolooware and Quibray bays as these three elements have been used as treatment to give less-durable timbers a longer life in any* *applications* [sic], *both in the ground and under water, such as marinas, piers and oyster farms*" (Albani, 2008 p.20).

The Botany Bay Groundwater Cleanup Project further highlights the level of industrial impact in the area. A number of commercial operators, including the predecessor of Orica (the company managing the current clean-up programme), ICI Australia, caused chlorinated hydrocarbon compounds to contaminate groundwater from their operating sites (Orica, 2013). The contamination, the type of which is now controlled by regulation, is the result of over a century of industrial activity. As a result of this contamination, several suburbs have restrictions in place against the access and use of groundwater. Naturally, the groundwater flows south-west towards Botany Bay at between 110 and 150m per year although this flow, restored in the late 1980s, was previously disrupted by large-scale pumping. Orica is extracting and treating between 6 and 7 Ml of water per day that is affected by plumes of contamination. Utilising this process, water from several depths that is variously contaminated by different contaminants is claimed to be prevented from entering Botany Bay (Orica, 2013).

The Bay has been subjected to extremely high levels of shoreline change, different land uses and dredging. Prior to the construction of the Airport's third runway, "*550Ha had been dredged and 140Ha reclaimed, together representing 15% of the bay area*" (Jones, 1981 p.369). For the 3rd runway, completed in 1994, a further 15 million m^3 of material was dredged and an additional 170Ha reclaimed (Herbert et al., 1996)

On the southern shores of the Bay, almost directly south of the airport, Towra Point Nature Reserve is a conservation area. It was acquired as a 282 Ha site in 1975 to help meet international obligations regarding the protection of endangered and migratory birds and wetlands. The site now includes parts of adjacent bays and in 1984 it was listed as a wetland of international importance under the Ramsar Convention (Government of NSW, nd-d).

Roper et al. (table 27 2011) give Botany Bay an overall condition rating of 2.8, at the lower range of "fair". It has an overall pressure rating of 2.8, (the higher end of "moderate") with the prominent pressures being population and sediment and nutrient input. As a result of the way the limited data have been used by Roper et al. disturbed habitat is listed as very low, even though the Botany Bay catchment is 61.5% disturbed (appendix 7 Roper et al., 2011). Between 1985 and 2006 seagrass was reported to increase by 57%, mangrove by 43% while saltmarsh decreased by 52% (appendix 15 Roper et al., 2011).

Conclusions

Botany Bay has been subject to several stages of use and development by both indigenous people and since European settlement. The modern day catchment and land forms around the bay are severely changed from their pre-European settlement condition. The area has been subject to a great deal of deliberate, engineered change, especially from the airport and port developments that are now firmly established and of great economic importance to the area and the nation. There will likely be further engineered change in the future as port capacity and associated land based infrastructure are tuned to current and future economic activity; at the time of approval for the construction of the third airport runway plans were produced for a fourth runway that if implemented, would involve 'reclamation' of a great deal more of the Bay. There is a legacy, evident from sediment analyses and contaminated groundwater adjacent to the water body, of past very heavy pollution from an era when regulations concerning pollution and effluent discharges were lax. Ongoing threats exist from urban run-off, illegal discharges, and potential spills and accidents from industrial and commercial operations.

In view of the social and economic significance of the infrastructure developed in and around Botany Bay it is extremely unlikely that it will be significantly 'restored' in the interests of marine systems or fisheries resources; even if local impacts were socially acceptable, the costs of restoration would be prohibitive (many billions of dollars). It is far more likely that there will be additional coastal development projects that will entail new or expanded threats.

There are numerous less obvious and more insidious threats than coastal development that are having significant impact on Botany Bay. These include pollution in many forms and introduced organisms such as the 'weed' *Caulerpa taxifolia* (Creese et al., 2004). In fact Botany Bay as the site of Australia's major container-cargo port is a 'hot-spot' for introduced marine species and a risk assessment has been completed (Glasby and Lobb, 2008). While more attempts are being made to minimise new threats and to acknowledge existing ones it is likely the accumulated impacts on Botany Bay of human population growth in the greater Sydney basin will continue to increase. The less obvious impacts of urbanisation are further discussed under Port Hacking, below, and as Botany Bay is fed by the Georges and Cooks Rivers, the catchments of which have much greater population densities and industrial development, the threats to Botany Bay from these same sources can be expected to be much greater than are the corresponding threats to Port Hacking.

Less prominent threats to the aquatic resources of the Bay will continue to come from a variety of sources including recreational boating and smaller forms of water craft, such as windsurf and kite boards. A primary threat from boating is the effect of increased and accumulated impacts of existing vessel mooring in the Bay and from antifoulant paints (discussed in sections 7.3.9 and 7.6.2). Wind-driven small craft are extremely numerous across much of the Bay when weather conditions are suitable (the Bay is unusually amenable to such activities). While they are unlikely to have detectable impact on the physical attributes of the bay or even obvious bottom biota they are most likely to cause significant redistribution, and effective loss of available habitat, for surface dwelling fish species such as garfish that are frightened by fast surface-cutting activity. As these surface species are an important food item for larger pelagic species it is likely there will be at least some broader implications on fisheries resources and consequently access to them.

The available evidence suggests that if fishing in Botany Bay has had a negative impact on marine systems or the long-term sustainability of fisheries resources this impact would be insignificant in comparison with that from other anthropogenic activities in the area. There appears little doubt that other anthropogenic activities in and around the Bay would have had more impact on fishing than fishing would have had on the well-being of the Bay and its ecosystems. It had been suggested that commercial prawn trawling and beach hauling had had a negative impact on the distribution of seagrasses and other bottom biota. While the magnitude and significance of this impact were debatable, particularly in comparison with other obvious (development) and insidious (pollution) impacts, they are no longer of great relevance as all commercial fishing has now been banned in Botany Bay. Fishing has not been demonstrably a major or irreversible threat to Botany Bay and now that fishing in the Bay is restricted to recreational activities the threat is further constrained.

4.2.2 Port Hacking

Port Hacking is the southernmost of Sydney's four large estuaries. It is located some 30km from central Sydney with the Royal National park to its south and Cronulla and adjoining suburbs on its northern foreshore. The estuary has an area of 11.70km^2 with a catchment of 165.34km^2 (Table 1 Roper et al., 2011). It is an open, drowned river valley with numerous large 'arms' that are themselves drowned valleys. The only river input is from the Hacking River, and this is very limited compared to that from other rivers in the Sydney region. The indices of change in flow are all of the order of one fifth to one tenth of other metropolitan estuaries (Appendix 8 Roper et al., 2011).

Port Hacking has an index rating of good and a condition score of 4 for fish assemblages (only five NSW estuaries have been given a higher score). It has relatively low total fishing pressure and has been closed to commercial fishing since 1902. It has an overall condition rating of 3.5, in the range of 'good', but based on surprisingly few parameters for a large metropolitan estuary (Table 27 Roper et al., 2011). It has an overall pressure rating of 3.3 (the less pressure end of 'moderate') with the prominent pressures being population growth and disturbed habitat (Table 50 Roper et al., 2011). While parts of the Port itself have been seriously disturbed, primarily from dredging, only 17.7% of the catchment has been modified. This is slight when compared to that for other metropolitan estuaries which typically have modifications to their catchments in the range of 60% to 90+% (Appendix 7 Roper et al., 2011). This low level of catchment disturbance for Port Hacking is largely attributable to dominance of the catchment by the Royal National Park, which forms the southern shore of the Port and through which the Hacking River flows.

The available analyses suggest that accepting the limitation inherent in the comparison between data sets from different time periods and variable analytical techniques, seagrass (15%), mangrove (7%) and saltmarsh (21%) all increased in the period 1985 to 2006 (Appendix 15 Roper et al., 2011). On other scores, such as the normalised pressure data, Port Hacking scores well compared to other metropolitan estuaries. The *chlorophyll a* indicator for the Port shows a low median level and tight distribution however this is thought to be influenced by sampling stations being located close to the estuary mouth where they are affected by proximity to oceanic conditions.

There is evidence of human settlement in the Port Hacking area spanning some 8,000 years and it is suggested that evidence of prior habitation may well be present in submerged lands. Before European settlement people in the immediate area were of the Gweegal tribe of the Dharawal group that spanned the area from Botany Bay to Shoalhaven (Albani and Cotis, 2007).

The name Hacking comes from the Quartermaster, Henry Hacking of the first fleet vessel HMS Sirius although the area was originally known as Port Aiken after a seaman from a different first fleet ship, HMS Supply. By the early 19th century there was European settlement in the area but little development of the estuary in spite of increased recreation and leisure activities popular with the growing population of Sydney. After WWII the residential potential of the area was exploited and a greater portion of the northern catchment was used for urban purposes. More recently, especially since the 1980s recreational use of the waterway has increased greatly. This increase is associated with population growth and increased affluence of residents and visitors, more people resident in the surrounding areas, the availability and popularity of larger and more powerful boats, an increase in the number of jetties and boat ramps and a larger number of boat-moorings. As a result there has been increased erosion of banks and increased exposure of the waterway to disturbance and pollution, including chemicals associated with recreational boat use (Albani and Cotis, 2007).

To facilitate boat access including ferry operations, dredging has been conducted in selected parts of Port Hacking since 1881. From at least the 1850s dredging was also used to extract large quantities of shell grit to produce lime, needed for construction as Sydney developed. This shell grit extraction, at least from the 1920s to the early 1970s, was associated with sea grass reductions, with some but not complete recovery evident in more recent years (Albani and Cotis, 2007). This same mining caused extensive changes to the geomorphology of the southern sections of the Port with dredged channels and holes breaking the continuity of the extensive sand flats. Most of the obvious damage has been slowly ameliorated over time and regrowth of *Zostera* has occurred in many areas but *Posidonia* beds that were impacted have not recovered, and in numerous areas continue to decline. Other purposeful changes made to the water body have included the dredging of some 300,000 tonnes of sand in 1901-2 for the creation of a fish hatchery in Cabbage Tree Basin (Albani and Cotis, 2007).

Port Hacking is popular for recreational activities that benefit from extensive areas of clean and clear water. The estuary's reputation as a relatively undisturbed environment is enhanced by its southern boundary being the Royal National Park. Its usage continues to be bolstered by the large population base of Sydney (Albani and Cotis, 2007). This increased usage, with the associated building and use of marinas and increased boat-moorings, have numerous direct and insidious effects on marine environments, including seagrass beds. Boat propellers and traditional block and chain boat moorings ('swing' moorings) that can denude areas of seagrass around the seabed point of attachment continue to cause considerable damage and affect the extent and viability of areas of marine vegetation (The Source, 2009, West, 2011).

Despite the limited exposure of Port Hacking to agricultural and industrial impacts pollution is still an issue. Past urban construction, especially that of the 1950s and 1960s, and rural development in the 1850s is associated with large influxes of sediment. According to the Port Hacking Protection Society (SSEC, 1997) some 5 to 10 tonnes of sediment was washed into the waterway from a single typical construction site during storm events prior to the late 1990s. While this impact is now subject to management, including financial penalties for offenders, breaches do occur. Runoff from nearby roads carries toxicants and litter and that from residential areas typically contains a variety of chemicals including pesticides and nutrients from garden maintenance and fertiliser use that are washed into the estuary either directly or via the storm water system.

Results of heavy metal analyses of sediment samples from Gunnamatta Bay (the most easterly of the bays in Port Hacking) show a pronounced gradient in concentrations from very high levels at the upper end of the Bay decreasing towards the more oceanic, open end: Pb (Lead) ranges between 194.40 and 7.90ppm; Cu (Copper) 110.70 and 11.80ppm; Zn (Zinc) 208.50 and 11.40ppm; As (Arsenic) 10.60 and 3.90ppm; and, Cr (Chromium) 25.20 and 1.45ppm while Cd (Cadmium) at 1.50ppm showed no variation (Mares, 2003). The ANZECC 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* contain trigger levels of concentrations of metal toxicants in marine waters (ANZECC, 2000) for different levels of protection. For Pb, the trigger level is 12ppb (μgL^{-1}) to protect 80% of species, 6.6ppb to protect 90%, 4.4ppb to protect 95%, and 2.2ppb to protect 99%. To date, toxicology testing is largely confined to assessments of acute effects on sediment-dwelling invertebrates and benthic algal responses. Chronic exposure from sediment disturbance and ocean dumping of spoil is not well understood (Simpson et al., 2005). Following any disturbance of human-contaminated sediments or dumping of contaminated spoil, the resulting high water concentrations of toxicants would be expected to adversely affect or prove hazardous to a variety of marine biota.

Recreational users of the Port introduce litter and other pollutants into the system. Untreated sewage release to the NSW marine environment has been prohibited since 1998 and breeches can attract on-the-spot fines or legal action. Boat discharges can be identified by high levels of faecal coliforms, oils, grease, detergents and heavy metals that cannot be attributed to other sources (SSEC, 1997).

Illegal dumping of pesticides and other materials including solvents, cooking oil, building site waste and car batteries has been recorded. In addition, the legal disposal of residential and human waste has and does occur in the catchment with sewage effluent being collected for some 100 years at the Sanitary Depot at Helensburgh up until its closure in 1991. The Cronulla sewage treatment plant was upgraded to tertiary standards in 2001 but prior to this upgrade some 82 megalitres of secondary treated effluent was discharged into the ocean near the mouth of the estuary per day in dry conditions and up to 150 megalitres per day in wet conditions.

Pressure ratings for Port Hacking are very high for population and disturbed habitat (attributable to dredging) within the Port itself, high for sediment input, low for cleared land, nutrient input and freshwater flow and very low for tidal flow and fishing (Table 50 Roper et al., 2011).

Conclusions:

Human driven change to Port Hacking is limited compared to other metropolitan estuaries, but it is certainly not negligible. Past direct impacts such as dredging of channels and sediment inflow still affect the ecological functioning of the water body and even though dredge-mining of shell grit has been prohibited since the 1970s the impacts of earlier activity are still apparent. The visible impacts are diminishing and future dredging of shell grit is unlikely.

High levels of toxicants are present in sediments and concentrated in the upper reaches of bays and inlets. These toxicants could be expected to impact the ecology within those sediments and have the potential to damage various other marine species if disturbed (Simpson et al., 2005). Even though the management of stormwater run-off and sewage discharge has improved considerably there is still input of toxicants and the risk remains that the threat for the future will be accumulative.

The channels in the downstream areas of the Port are still regularly dredged to facilitate boat access and this activity, together with the natural mobility of some sandy sediments in shallow areas, leads to the redistribution of channels and sand-spits with associated impacts on seagrasses and other habitats. The presence of the introduced ‘weed’ *Caulerpa taxifolia* in Port Hacking and its ability to colonise disturbed areas relatively quickly exacerbates the problems caused by dredging. The boating community of Port Hacking have come to expect that dredging of the channels is ongoing and it appears most unlikely it will cease in the foreseeable future. However the efficiency of dredging that minimises collateral damage while maintaining boat access may well be able to be improved.

Boating within the Port affects water quality, including through non-compliance of regulations designed to prevent disposal of wastes and through the sheer surface area covered by antifoulant paints. In addition, the mooring of boats continue to cause considerable direct physical damage to seagrass beds. Reduction in the number of boats using the Port appears most unlikely so success in reducing the impacts appears to lie in a combination of stakeholder education, tighter regulations and more complete compliance with them, and the adoption of improved technologies including mooring designs and less toxic antifoulants.

As much of the catchment is the Royal National Park agricultural inputs can be anticipated to remain low. Industrial activity in the region is minimal but urban runoff, including that from roads, does cause harmful discharge into the Port and resulting localised high concentrations of contaminants, including heavy metals, in sediments. Although the total pollution-related threats are minor compared to those in other metropolitan estuaries the relatively low level of total anthropogenic impact on Port Hacking makes the management of these known sources of pollution proportionately more significant. General population increases can be anticipated to strain existing waste treatment and storm-water management infrastructure and add to other human habitation impacts, thereby further affecting total contamination of the Port.

Fishing pressure is relatively light in the Port and total catches have remained low compared to other large estuaries in the State. The relatively limited river discharge into the Port results in comparatively restricted total productivity of fisheries resources. This productivity, although limited has not been demonstrated to be greatly altered by any single anthropogenic impact, however, the accumulated impacts of increased urbanisation, particularly stormwater run-off, dredging and boating cause obvious changes that are accepted to be detrimental. Heavy metal contamination, primarily from stormwater from roads and domestic sites, is a threat to vulnerable organisms and may well be a threat to the suitability of fish from parts of the Port for human consumption. However, for as long as impacts cannot be attributed to specific threats it is difficult to prioritise the management that is necessary to address each threat or their collective impacts. This problem with prioritising action is exacerbated when the impacts of the threats to Port Hacking are considered in the context of the much greater threat from these and other factors in other metropolitan estuaries.

Provided State-wide management of recreational and commercial fishing is adequate to ensure the sustainability of the stocks of key species, fishing within Port Hacking and its immediate surrounds should not represent a significant threat to the fisheries resources of the Port or the region more generally. The only major non-specific threat from fishing in Port Hacking is that associated with boating in general.

The continuing ban of commercial fishing in the Port reduces the supply of fish to local markets of at least some species, as it does from all NSW estuaries that are closed to commercial fishing. However, related increases in landings by recreational fishers can be anticipated to compensate for at least some the lost total production of some, but not all, species.

4.3 South Coast

4.3.1 Lake Conjola

Lake Conjola is situated on the NSW south coast approximately 200km south of Sydney and 50km south of Nowra in the local government area of the City of Shoalhaven. The estuary has an area of 6.694km^2 within a catchment of 139.09km^2 (Table 7 Roper et al., 2011). The catchment is mostly steep with a mountainous western section. Land use comprises forest and grazing for beef and dairy cattle, and there are nine small villages around the lake and along the coast (Haines and Vienot, 2007, Shoalhaven Water, nd). The area to the north of the Lake is the 11,000ha Conjola National Park (Government of NSW, nd-b). The permanent population in the area is below 500 although the temporary population increases greatly during holiday periods.

The Lake is classified as an ICOLL (Intermittently Closed and Open Lakes and Lagoons). Worldwide, ICOLLs are rare and most of Australia's ICOLLS are located on the NSW south coast. Management of ICOLLs and their use pose particular problems regarding water quality, environmental integrity and stakeholder involvement and perception. During periods of closure water characteristics change, salinity decreases, the water changes colour and exchanges of biota with the open sea are much reduced. During open periods, larger fish and prawns move to the ocean and younger fish enter the Lake (see Cudgen Creek case study for further discussion).

Between 1937 and 1999, Lake Conjola was open for 62% of the time with the remaining 38% being comprised of eight separate closures. These closures, that could extend in time to several years, were all initiated by severe storms (Shoalhaven City Council, 2013). Between 1991 and 2013, mechanical opening of the lake was performed several times "*to alleviate minor, nuisance flooding*" (Shoalhaven City Council, 2013). According to the local authority, there is a common belief that "*keeping the Lake open is the best way to avoid flooding and 'improve' the Lake*" (Shoalhaven City Council, 2013) but it has been observed that flooding can arise from rainfall events, inundation from the ocean when the lake is open or when high tides and rough seas combine to force sea-water over the embankment, or a combination of these events. Importantly, opening and closing events are increasingly recognised as being a part of a natural environmental cycle.

The local council viewed investment in a sewerage system ($64,000,000 Conjola Regional Sewerage Scheme completed in 2008 (Shoalhaven Water, nd)) and the implementation of a flood risk plan as more appropriate priorities for maintaining the sustainability of the Lake than spending the estimated millions of dollars on training walls and large scale dredging that would be necessary to keep the entrance permanently open.

Water quality in the area is affected by human disturbance that, beginning in the nineteenth century, has centred on logging and grazing (Government of NSW, nd-b). Current impacts include run off containing sediments and pollution, particularly after heavy rain. Lake Conjola has been given an overall Condition Rating of 4.4 which is in the mid-range of very good (Table 28 Roper et al., 2011). The rating was derived from a less than complete data set; no data for macroalgae, and baseline data only for mangrove. The condition of seagrass is stated as being poor while *chlorophyll a*, turbidity, saltmarsh and fish are all reported to be very good although the fish data are indicated as being over 3 years old at the time they were considered (Table 28 Roper et al., 2011). It is noteworthy that the abundance of the dominant seagrass in the Lake, *Zostera*, varies considerably and has been reported to have virtually disappeared at times in the last decade to be replaced by the introduced *Caulerpa* *taxifolia*, to the extent that Lake Conjola represented the most intense domination of this pest species in NSW (Creese et al., 2004).

The Pressure Rating of 4.6 indicates very low impact. Individually, pressures from cleared land, population levels, and nutrient input are low while pressures from sediment input, freshwater flow, disturbed habitat, tidal flow and fishing are very low (Table 51 Roper et al., 2011)

Conclusions

With a low permanent population, minimal coastal and lake foreshore development and mostly non-intensive land use in the catchment, human impacts on Lake Conjola are limited. Despite some calls for permanent opening of the estuary, the system has been left in a more natural state with intervention at the opening only taking place to address particular inundation events. The completion of the local sewerage system in 2008 has further reduced pollution impacts to the estuary resulting in a minimally impacted water body. Gradual population growth remains a continuing threat but one that is less than that for many NSW coastal regions.

The possibility of permanent opening of the Lake remains the single biggest threat to the integrity of current marine systems but determination of the likely impact of this action, should it occur, on fisheries resources remains equivocal.

4.3.2 Baragoot Lake

Baragoot Lake is approximately 3km from Bermagui and 309km south-southwest of Sydney. The area is the traditional home of the Yuin indigenous people. European settlement of the area began in the 1830s. Several national parks are located north, south and west of the area and tourism, including for recreational fishing on nearby beaches is important to the local economy. The area is managed by the Bega Valley Shire Council.

The estuary is tiny, with an area of 0.471km^2 within a catchment of 12.61km^2. It is classified as an intermittently closed and open lagoon with its dominant condition being closed (Table 7 Roper et al., 2011). There is no major urban component to the catchment, however, 1995 data indicate that 34.15% of the catchment is used for cropping, pasture and plantations while 62.17% consists of native woody vegetation (OzCoasts, nd).

Baragoot Lake has been given an overall Condition Rating of 2.6 by Roper et al. (2011). This rating is at the division between fair and poor in their classification of NSW estuaries. Most importantly for consideration of Baragoot Lake as a case study, this Condition Rating is in contrast to the Pressure Rating of 4.5 (very low pressure) from these same authors. Thus the Roper et al. information suggests that the Lake has relatively limited human induced pressures and yet, based on the criteria used for comparing estuaries, it is not in good condition. There are several possible explanations for this apparent anomaly. One possibility relates to how the inconsistency in the quality and quantity of data available for the many different estuaries throughout NSW impacts comparative classification. The specific assessment of Baragoot Lake is influenced by inadequate or irrelevant data on two of the parameters that are influential in the classification scheme; there were no data for macroalgae and data on mangroves were not applicable because of the absence of mangrove in this particular lake. The data on other parameters that were available demonstrate great variability; the conditions of seagrass and *chlorophyll a* are reported as being very poor and fish assemblages poor, while in contrast turbidity was reported to be good and saltmarsh very good (Table 28 Roper et al., 2011). In fact the parameters listed in Roper et al are of very limited relevance to the assessment of the status of Baragoot Lake and a similar problem appears common to all NSW ICOLLs. It is also noteworthy that the Roper et al. assessment of seagrass as very poor is in contrast to the information available elsewhere. Another possible explanation is that the Lake has been periodically impacted by natural pressures (water quality declines resulting from drought and deoxygenation of water from episodic inundation of plant material, including algae) that in the case of Baragoot Lake are not direct anthropogenic pressures.

Roper et al. indicate that between 1985 and 2006 the area of seagrass in the Lake decreased from 49,000 m^2 to 6,148 $m^{2,}$ (Appendix 15 Roper et al., 2011), this contrasts with the figure for current seagrass of 50,000m^2 provided by Geoscience Australia (OzCoasts, nd). If seagrass were given an individual score of 5 (very good) then the overall condition would be raised to the borderline position between good and fair. Further refinement of the *chlorophyll a* data, if this were valid, would likewise greatly influence the overall condition score.

The low Pressure Rating is largely a result of cleared land and nutrient input being low, and population, freshwater flow, disturbed habitat, tidal flow and fishing all being very low (Table 51 Roper et al., 2011).

Conclusions

Lack of data and variability of what are available are particular problems for small water bodies, such as Baragoot Lake, where sampling and surveys have been limited. Furthermore natural variability in the relevant parameters can be great for those that are intermittently open or closed to the ocean and even more so for lakes such as Baragoot that are shallow and thus subject to relatively high impact from weather conditions, particularly wind which can disturb sediments and redistribute nutrients held within them. When sampling is not effectively normalised for oceanic influence or environmental variables, natural variability can confound attempts to estimate change and to attribute that change to potential threats. Data variability appears to have influenced the available assessments of the condition of Baragoot Lake and the pressures on it.

The management of threats to marine environments:

Notwithstanding the limitations of the available data, it can be concluded that Baragoot Lake is currently relatively lightly impacted by anthropogenic influences but remains vulnerable to a suite of threats to its stability and perhaps even its individuality. The Lake does experience episodic introduction of nutrients associated with rainfall. The resulting increased algal productivity can be followed by die-off and decomposition and subsequent deoxygenation leading to extensive fish kills. These events are considered by the managers of the Lake to be natural events that are independent of anthropogenic influences (Dr Nick Yee, consultant to Bega Valley Shire Council; personal communication, April 2014).

Increased pressure from the non-specific impacts of human population growth can be anticipated and the Lake remains vulnerable to localised, more specific ‘development’. Prominent in this category is the possibility of the Lake being permanently opened to the ocean by the creation of training walls or increasingly intermittently opened by dredging. While permanent opening of the Lake could be anticipated to stabilise its condition, as assessed by several of the popular indicators of the condition of coastal waterways, it would totally transform the ecosystem of the Lake and change the role it plays in the broader coastal system.

There are no reliable data to enable assessment of the fisheries resources of the Lake. Anecdotal reports suggest that at certain times estuarine species such as bream and whiting can be taken in the Lake but that periods of reasonable abundance are fleeting. Because of the small size of the Lake and its insular nature the ‘natural’ fish kills that occur in the Lake would be expected to cause dramatic reduction in the total fish populations of impacted species. If fish kills result from natural injection of nutrients, even small amounts of development in the catchment, particularly of agriculture that used fertilisers, could be expected to increase the frequency of such events. Permanent or more frequent opening of the Lake would completely transform the fish assemblages present in the Lake. What impact this would have on the total fisheries resources of surrounding areas can only be guessed, but it should not be automatically assumed to be detrimental.

5 Broad Categorisation of Threats

Various bodies and organisations have published lists of threats to marine systems and impacts of these threats. These include GESAMP (Group of Experts on the Scientific Aspects of Marine Pollution), whose 1990 report stated, “*major causes of immediate concern in the marine environment on a global basis are coastal development and the attendant destruction of habitats, eutrophication, microbial contamination of seafood and beaches, fouling of the seas by plastic litter, progressive build-up of chlorinated hydrocarbons, especially in the tropics and subtropics, and accumulation of tar on beaches*” (GESAMP, 1990).

The United Nations Environment Programme (1990, cited in Kennish, 2002) provided a ranking of “*the most severe long-term anthropogenic problems plaguing the coastal environment of developing regions in south-east Asia:*

(1) Habitat destruction (coral reefs and mangroves), (2) Industrial pollution, (3) Sewage pollution, (4) Siltation/sedimentation, (5) Agricultural pollution, (6) Fisheries overexploitation, (7) Hazardous waste, (8) Oil pollution, (9) Sea level rise, (10) Coastal erosion, (11) Algal blooms/red tides, (12) Natural hazards”.

UNEP considered the many threats in freshwater environments and stated “*old and new threats to inland water quality include: poor sanitation, agricultural runoff loaded with excess fertilizer and herbicide; residues from medicines and other new chemical products; global climate change, which will elevate water temperature in some world regions and alter the dilution capacity of freshwater systems; and air pollution deposition into aquatic systems from local and distant sources (nitrogen and sulphur compounds and sometimes heavy metals, organic compounds, and other toxic pollutants). Ironically, another growing threat to water quality in many developing countries is the expansion in* *coverage of public water supply, as this is usually done without making adequate provision for facilities to treat the wastewater produced by the new water supply infrastructure. This is leading to increased and concentrated discharge of untreated sewage from communities to waterways, wetlands and coastal zones*" (UNEP, 2012).

A current list that encompasses the evolution of understanding of major threats to the marine environment, including more definitive identification of the specific fishing activities that are considered to represent threats, is available on the Convention of Biological Diversity (CBD) website. This list comprises "Land-based pollution and eutrophication; Overfishing, destructive fishing, and illegal, unreported and unregulated (IUU) fishing; Alterations of physical habitats; Invasions of exotic species; and Global climate change" (CBD, 2014). This list is used as a category framework in this report.

Each type of threat as relevant to NSW has been discussed in the text of this report, and where possible specific examples are provided in the case studies. Threats have been graded according to selected characteristics in Table 1. Two categories have been added by the authors of this report that they judge to be worthy of attention. These are 'ocean based activities' and 'perception/ideology'.

6 Tabulated Threats

Table 1 shows the identified threats to marine environments and fishery resources. The threats are described in section 7 and discussion of their assessment is given in section 8. The scoring rationale used in this table is described below in section 8.1. A more detailed version of this table is shown in appendix 1.

Table 1 summarised version of identified threats to marine environments and fishery resources.

ID #	CBD category	Threat Type	Ease	Feasability	Cost	Time	Total	Performance
	Threat Category and Description		Management of Threat					
1	Land based pollution and	heavy metals	2.0	2.0	1.5	2.5	8.0	d
2	eutrophication	halogenated hydrocarbons PCBs OCPs PBDEs	2.0	3.0	1.5	2.0	8.5	c-d
3		polycylic aromatic hydrocarbons PAHs	2.0	2.5	1.5	2.5	8.5	c-d
4		pharmaceuticals including medical hormones	2.0	1.5	2.0	3.0	8.5	d
5		endocrine disruptors including hormones	2.0	1.5	2.0	3.0	8.5	d
6		**eutrophication/nutrients/algal blooms and toxins**	3.5	4.0	3.5	4.0	15.0	c
7		pathogens	2.5	3.0	2.0	3.0	10.5	b-d
8		**acid sulphate run-off**	4.0	3.5	4.0	3.5	15.0	b-c
9		**litter, debris and micro plastics**	3.0	3.0	3.0	3.5	12.5	d
10		ocean dumping	4.5	3.0	3.5	4.5	15.5	b-d
11		tailings disposal	4.0	3.0	4.0	4.5	15.5	d
12		nano particles	1.5	2.0	1.5	2.5	7.5	d
13		noise /physical disturbance/light	2.0	1.5	4.0	4.5	12.0	d
14		thermal pollution	3.0	3.0	4.0	4.0	14.0	c
15		UV-B	2.5	3.5	3.0	3.0	12.0	b
16		radioactive substances	2.5	2.5	1.0	3.0	9.0	a&d*
17	Overfishing, destructive fishing,	overfishing	4.0	4.0	4.0	4.0	16.0	b-c
18	and illegal, unreported and	destructive fishing practices	4.0	4.0	5.0	4.0	17.0	b
19	unregulted (IUU) fishing	aquaculture	3.0	4.0	3.0	3.0	13.0	b-c
20		discarded fishing gear	3.5	3.5	4.5	4.5	16.0	d
21		managed fishing	3.5	3.5	4.0	4.0	15.0	a-b
22		IUU fishing	3.0	4.0	4.0	3.5	14.5	b
23	Alterations to physical habitats	mining terrestrial	3.0	2.0	3.0	3.5	11.5	d
24		mining ocean inc. oil and gas extraction	4.0	4.5	3.5	3.5	15.5	a-b
25		**dredging**	3.0	2.5	3.0	4.0	12.5	d
26		**altered flow regimes - salinity change**	4.0	2.0	1.5	2.5	10.0	d-e
27		**watershed alteration**	3.0	2.5	3.0	3.0	11.5	c-e
28		**watercourse change (inc. training walls)**	1.5	2.0	2.0	4.0	9.5	c-d
29		**coastal development**	3.0	2.0	2.0	3.0	10.0	b-d
30		tourism	4.0	3.0	3.5	4.0	14.5	c
31		**recreation**	4.0	2.0	4.0	4.5	14.5	d
32	Invasions of exotic species (Organisms)	introduced species and/organisms	1.5	2.0	1.5	2.0	7.0	b-d
33	Global climate change	temperature change	1.5	1.5	1.0	2.5	6.5	d
34		sea level rise	1.5	1.5	1.0	2.5	6.5	d
35		ocean acidification	1.5	1.5	1.0	2.5	6.5	d
36		changes to ocean currents	1.0	1.0	1.0	2.5	5.5	d
37		extreme weather events	1.0	1.0	1.0	2.5	5.5	d
38		mitigation activities (C sequestration algae farming, infrastructure)	2.5	4.5	4.5	3.5	15.0	d-e
39	Ocean based activities	ship related accidents wastes and debris	3.5	4.0	3.5	4.0	15.0	c-d
40		bilge water, tank washing, fuel use, antifoulants	3.0	4.0	3.5	3.0	13.5	c-d
42	Perception/ideology	**social/political (mis-use of evidence, biased misguided perceptions)**	2.0	3.0	4.0	3.5	12.5	d

Bolded "Threat Type" identified as priorities

* 'd' in the case of accidents e.g. Fukushima, 'a' for normal-use management

Management Ease
5 simple
4 moderate
3 intermediate
2 complex
1 impossible

Management Feasibility
5 likely
4 moderate
3 intermediate
2 unlikely
1 impossible

Management Cost
5 low
4 moderate
3 intermediate
2 high
1 extreme

Management Time
5 short - years
4 moderate - a decade
3 intermediate - decades
2 long - centuries

Management Performance
a managed - essentially solved
b good - improving and ongoing
c inadequate - attempted with minimal results or stalled
d ineffective - insufficient effort and/or little improvement
e none - not recognised or not managed

7 The Many Threats and Their Effects

Descriptions below are in accordance with the categories modified from the CBD and listed in Table 1. They have been abstracted for relevance to this project from the huge amount of literature available on virtually all of the identified categories of threats.

7.1 Land Based Pollution and Eutrophication

7.1.1 Heavy Metals

Heavy metals are discharged from many sources, including directly from industrial installations, from sewage treatment plants and from agricultural land that is drained and/or subject to a changed chemical balance. They are persistent as they are not subject to breakdown by bacterial actions (Clark, 2001). Metals do occur naturally and natural pathways do usually exist for their eventual incorporation into biotic systems, however, increased amounts and accumulation in certain high-impact areas are ongoing symptoms of high density industrialised living. Much of the increased heavy metal load is deposited in sediments in estuaries where it persists and poses an ongoing threat, particularly if it is subject to future disturbance. Depending on the heavy metal in question and the organism affected, there may be a tolerable level prior to concentrations becoming toxic or there may be an optimum level required by the organism before toxicity is experienced (Clark, 2001, Howells et al., 1990).

7.1.2 Halogenated Hydrocarbons

Halogenated hydrocarbons such as PCBs (polychlorinated biphenyls), a range of industrial process chemicals and additives, dioxins, and various pesticides (insecticides, herbicides, piscicides, seed dressings, livestock dips, fungicides, timber treatment etc.) including DDT are persistent in the marine environment. They accumulate in fatty tissue of marine organisms, magnify through trophic levels and can be consumed by humans in captured or farmed seafood (Clark, 2001). DDT is particularly toxic to fish. While certain particularly toxic compounds were withdrawn from general use in the 1970s, many of them still leach from urban and agricultural land and enter watercourses.

"*Halogenated hydrocarbons, most particularly DDT and its derivatives, now occur in all organisms in all environments, and a considerable quantity in total of the halogenated hydrocarbons in the sea is in the bodies of marine organisms and will continue to circulate within the food webs*" (Clark, 2001 p. 135). These xenobiotics have a range of effects including endocrine disruption, they impact reproductive ability and can be neurotoxic and carcinogenic (Howells et al., 1990). DDT can also interfere with calcium metabolism resulting in weakened egg shells (Clark, 2001) and presumably other hard animal parts, such as bones and exoskeletons that are calcium based.

"[T]*he use of different species, size differences, seasonal effects, different methods of quantification, etc., all interact to confound comparisons*" of the distribution and impacts of PCBs and DDT (Fowler, 1990). However, concentrations are generally higher in the vicinity of known industrial and agricultural inputs. In relation to human health, "*Synthetic chemicals are pervasive in the environment, but understanding of their potential to cause harm is limited. Several recent studies have shown associations between prenatal or postnatal exposure to certain pesticides or phthalates and reproductive disorders in humans. Reproductive effects of environmental chemicals in (aquatic)* *wildlife are well established; these may provide sentinels for human effects, especially on the fetus. Recent discoveries raise possibilities of effects of common environmental chemicals on endogenous hormones*" (Sharpe and Irvine, 2004 p.450).

7.1.3 PAH (polycyclic aromatic hydrocarbons)

Polycyclic aromatic hydrocarbons (PAHs) make up a group of over 100 chemicals that originate from natural sources such as volcanoes and forest fires and are also released to the environment by human activity. They are manufactured for industrial, medical, general consumer and research use or produced as by-products during the incomplete combustion of fuels and wastes. They are also produced by cigarette smoking and the charring of food (Government of South Australia, 2009, Kanaly and Harayama, 2000). Laboratory tests have indicated that reproductive problems and birth defects may occur as a result of exposure while chronic exposure in the workplace has been shown to result in a range of cancers, respiratory problems and diminished immune system functionality (ATSDR, 1995, Government of South Australia, 2009). PAHs may stick to particulate matter and by this route be deposited in aquatic environments (ATSDR, 1995). Crude oil derived PAHs from the 2010 Deepwater Horizon oil spill in the Gulf of Mexico have been shown to impact fish embryo heart development, impacting cardiac function and resulting in secondary malformations (Brette et al., 2014, Incardona et al., 2014). Polycyclic aromatic hydrocarbons bio-accumulate and can magnify through trophic structures. Their persistence in the environment is positively correlated to their molecular weight (Kanaly and Harayama, 2000) and the level of contamination in some relatively remote regions such as the Arctic is known to be increasing (GESAMP, 2012). Bioavailability in the marine environment may be increased if PAH contaminants in sediments degrade; transformed derivatives may also be highly mutagenic or carcinogenic (Maher and Aislabie, 1992).

7.1.4 Pharmaceuticals

Pharmaceuticals are designed to purposefully modify physiological pathways to control or manage medical conditions and their non-targeted use or exposure can have adverse outcomes. A variety of pharmaceutical products alongside disinfectants, radioisotopes and halogenated hydrocarbons have been measured in hospital wastewater systems (Choong et al., 2006). A far more common source is pharmaceuticals in waste water derived from use by the general population, from animal husbandry and from the disposal of unwanted products; illicit drug manufacture, use and disposal can also be a significant source (Daughton, 2001).

Many of the drug compounds in widespread use have been demonstrated to be present in streams in the USA (Kolpin et al., 2002) and there are many that are known to pass directly through sewage treatment plants and septic systems and enter rivers, estuaries and the open sea (Choong et al., 2006). Certain pharmaceutical compounds are chemically stable and persistent in the marine environment, especially when transported to sediments, while others have antibacterial effects and therefore resist breakdown (Choong et al., 2006, Kolpin et al., 2002). Furthermore, breakdown products may also be toxic either individually or synergistically. The negative effects of most pharmaceuticals would likely be sub-lethal in marine environments in the short-term and in the absence of programs that monitor presence and less than obvious effects the impacts would therefore, commonly remain undetected. Even if impacts were detected in the absence of specific research it is most unlikely they would be correctly attributed to pharmaceuticals. Individual pharmaceuticals have been shown to be toxic to marine organisms such as barnacle larvae but synergistic effects of combinations and the effects of breakdown products remain largely unknown (Choong et al., 2006).

The conclusion of recent work conducted in Europe was that while there are measurable amounts of a variety of pharmaceuticals in estuaries and harbours, the effects of these and especially the combined effects are by no means understood. **Potential chronic risks to marine biota exist and the situation is in need of ongoing monitoring and further study (Claessens et al., 2013). It appears that the risks should be given much greater priority in future management of Australian aquatic environments.**

7.1.5 Endocrine Disruption

The endocrine system of organisms relies upon the production of hormones in glands to control and regulate various functions. Hormones used for medical and veterinary purposes which enter the environment together with a multitude of other compounds produced by industrialised societies can interfere with this system. After exposure, hormone signals within the endocrine system may be augmented, antagonised, blocked or mimicked and outcomes include changes to reproductive ability, behaviour, and the immune system; they have also been reported to cause neurological problems and the development of tumours (U.S. Fish and Wildlife Service, 2013, WHO, 2012).

Endocrine disruptors such as some pesticides, including DDT and its breakdown product DDE, detergents, plasticisers, dioxin and PCBs, are persistent and accumulate in fatty tissue (WHO, 2012). Endocrine disruption is associated with falling male human fertility, a range of development changes, changed sex ratios in other animals and incidence of diseases (Kookana et al., 2007, WHO, 2012). Changes, linked to endocrine disruption, have also been observed in the aquatic environment. These include changes to various fish and mollusc sex ratios, to fish development and behaviour, the incidence of disease, the hatching success of marine birds, and also to salmonid thyroid function (Clark, 2001, WHO, 2012). Biomagnification through marine trophic levels is a major concern and poses a human health risk particularly where seafood forms a large part of dietary intake (WHO, 2012). It is recognised that much European and North American research in this field may not be wholly applicable to Australian conditions and its specific environments but nor can the problem be dismissed. As suggested by Kookana et al. (2007), **the pervasiveness and range of implicated compounds warrants further research and monitoring and likely increased management**.

7.1.6 Eutrophication

Organically rich agricultural runoff and effluent from untreated sewage and sewage treatment plants, food processing operations, mariculture and other industrial activity have a direct impact on primary productivity by increasing nutrient availability. Change can usually be anticipated and beneficial outcomes to ecosystems and increased fishery catches are possible in certain circumstances. However, over-fertilisation can result in excess plant growth, algal blooms, and depleted oxygen levels when stimulated growth is subject to bacterial decay (Clark, 2001). Algal blooms may be toxic, clog fish gills, create detrimental turbidity and shading, affect tourism and recreation and/or change the ecosystem balance (Clark, 2001). Excess primary production can be directly detrimental to ecosystem functionality through alteration to habitats and the promotion of toxic algae but resulting excessively reduced dissolved oxygen levels produce the most devastating local effects.

Increased biochemical oxygen demand during decomposition processes creates low dissolved oxygen conditions that are detrimental to marine life. Hypoxia (<2mgl^{-1} dissolved oxygen) and anoxia (0 mgl^{-1}) can result in the death of much marine biota, reduced secondary production, and lead to reduced ecosystem biodiversity. While many instances of eutrophication have direct links to human activity, it can also result from natural inundation of vegetation, particularly following rain events or rising water levels in closed waterways (as discussed for example for Baragoot Lake).

7.1.7 Pathogens

Pathogens (agents, including bacteria, viruses, and fungi, that cause disease), enteric bacteria and eggs of intestinal parasites may be water-born, and are particularly prevalent in effluent. They can cause outbreaks of human infections and diseases such as gastroenteric diseases, hepatitis, cholera and typhoid (Clark, 2001, Lepesteur, 2013). Pathogens may be endemic, or introduced to an area. As introduced pathogens commonly represent new threats against which there is little if any, inherent resistance, their impacts can be particularly damaging.

Pathogens may be re-distributed and/or concentrated through a range of human activities associated with transport, (particularly the translocation of species or substrate) waste disposal, farming and aquaculture. Plastic debris has recently been recognised as a vector supporting survival and transport of pathogens such as the highly damaging *V. harveyi* bacteria (Baztan et al., 2014). Filter feeding biota such as oysters and mussels can concentrate pathogens which may have impact on the marine organisms themselves while their subsequent consumption can be a health risk for other animals, including humans. Monitoring and reporting water quality for recreational use and controlling the production of seafood through shellfish area closures are important mechanisms for avoiding or reducing incidences of ill health in humans but **the priority for measures that prevent or ameliorate the impacts of exotic pathogens on most marine organisms is currently inappropriately low.**

7.1.8 Acidic Sulfate Run-off

"*Acid sulfate soils are associated with* [a] *wide range of waterlogged/anaerobic and/or drained environments*" (Fitzpatrick and Shand, 2008 p.6). As drainage and/or cultivation of sulfidic soils, such as those containing pyrite, exposes them to oxygen it results in the formation and chronic and acute discharges of sulfuric material and associated toxicants (RRCC NSW, nd-b). In Australia this was first observed in WA in 1914 when, after drainage, low- lying areas of Seven Mile Swamps that had been productive became highly mineralised and infertile (Fitzpatrick and Shand, 2008). The increase in acidity that results from the breakdown of sulfidic soils causes the release of major cations, anions, trace elements and metal ions. As acidity and toxic quantities of released materials are leached into the water they can kill fish and other aquatic organisms, and contaminate ground water and may even corrode steel and concrete (Fitzpatrick and Shand, 2008).

A further problem is the formation and accumulation of monosulfidic black ooze (MBO) material in acid sulfate landscapes. This forms in high nutrient conditions through the activity of algae and micro-organisms. If MBO is flushed into waterways during run-off events it rapidly oxidises leading to deoxygenation of the water and fish-kills (Fitzpatrick and Shand, 2008, RRCC NSW, nd-b). In a complex interaction partly dependent upon ambient weather conditions, deoxygenation of flood water and consequently the waterway system that it eventually drains through can be further exacerbated as flood intolerant introduced flora decays (Wong et al., 2010).

In some areas, such as in parts of the Clarence River, water pH readings as low as 2.5 have been recorded (Clarence Valley Council, 2010). In the Tuckean Swamp in the Richmond River catchment, discharges may also be extremely acidic with a pH of around 3.2 or even less in smaller drains and creeks and contain toxic levels of dissolved metals including aluminium (discussed in Richmond River case study).

Acidic runoff affects fish gill function and increases incidences of disease (RRCC NSW, nd-b). Hypoxic conditions exacerbated by MBO flushing can be extreme, such as the episodic events in several NSW estuaries which result in total mortality of all biota in the affected reaches of rivers (NSW Government, 2013b). **Acid sulfate run-off is one of the most acute threats to the marine environments and fisheries resources of NSW.** Direct economic losses from acid sulfate soil impacts to NSW fisheries were estimated in 2002 to be between $2.2 and 2.3 million per annum (OzCoasts, 2013a), but these estimates do not include the much greater and broader impacts on ecosystem function. Estimated ecosystem service values per hectare per year for mangroves and saltmarsh; wetlands and floodplains; and seagrass are estimated to be $11,320, $19,650 and $21,730 respectively while the value of mangroves to commercial fishing alone is estimated to be over $13,000 per hectare per year (Creighton, 2013).

7.1.9 Litter, Debris and Micro Plastics

These can range from large items, that are visibly intrusive and can create entanglement problems, to much smaller particles that can be ingested and/or can act as a vector for the transport of toxic substances. Litter and debris sourced from a variety of human activities can interfere with habitats and individuals of various species. Both onshore sources and shipping and boating are responsible for the creation of marine litter (Clark, 2001). Regulations against dumping of waste other than food stuffs by ships exist in the form of the International Convention for the Prevention of Pollution from Ships that came into effect in 1988 but these are thought to be "*widely disregarded*" (Clark, 2001 p. 185).

Discarded and lost fishing gear poses a particular form of threat as ropes nets and other equipment can remain intact for prolonged periods posing ongoing entanglement problems (discussed under overfishing, destructive fishing and illegal, unreported and unregulated fishing, section 8.1.2).

Micro plastics are increasingly being recognised as a threat. Most plastics do not readily decompose in the marine environment but through mechanical action they do fracture and many small pieces are created that can readily be ingested by marine animals. Use of plastic is ubiquitous and multiple products, sources and pathways exist for plastic pollution to become an accumulating feature of marine environments.

Modern, readily available water-based personal cleansing products containing micro plastic scrubbing particles that are flushed into waste water systems by a multitude of users epitomise the lack of awareness of, or concern given to, water quality issues (Fendall and Sewell, 2009). **There is a growing concern that the ingestion of micro-plastics is an increasingly problematic mechanism by which bio-accumulating and toxic substances can enter and contaminate marine food webs** (GESAMP, 2012).

Litter and debris may not be as great a problem in much of Australia as it is in other, particularly developing, countries; community and industrial practices in Australia are generally cognisant of the need to minimise such impacts, but the problem still persists. Where Australian waters meet those of developing countries to the north the problem is much more severe with plastic waste and discarded fishing nets being more prominent in coastal waters with extensive accumulations of debris washing ashore in even remote locations. **This issue demonstrates the connectivity of the aquatic environment and its susceptibility to trans-boundary impacts. Management of this threat is likely to need local clean-up responses and broader long-term multi-lateral actions including changes to accepted practices to secure amelioration.**

7.1.10 Ocean Dumping

Oceans have been and still are used by many countries to dump various wastes, dangerous substances and obsolete equipment. Typical items dumped include sewage sludge, dredge spoil, mine tailings, industrial waste, obsolete equipment, munitions, and radioactive waste (Clark, 2001). The 1972 London Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matters came into force in 1975 (UNEP, nd). Australia's response was the 1981 Environment Protection (Sea Dumping) Act which was further amended in response to the 1996 Protocol to the London Convention (Government of Australia, 2008). All sea dumping within Australian waters is regulated under a permit scheme and the dumping of some hazardous wastes such as biological and chemical munitions agents and radioactive waste is prohibited (Government of Australia, 2008). Australia's current dumping practices are considered good by world standards and the effects of dumping are stated as being relatively benign compared to those in other countries, it being "*widely recognised that land-based marine pollution exceeds pollution from dumping and other maritime activities*" (Government of Australia, 2008). However, controls are by no means completely effective; the recent decision to allow the dumping of dredged material from Queensland port expansion in the GBRMP has been broadly criticised because of the potential risks from toxicity and turbidity and damage to benthic habitats (Brodie, 2014). Ongoing industrial development in the vicinity of the GBR Marine Park is being monitored by UNESCO and is threatening the areas heritage listed status (UNESCO, 2013, UNESCO, 2014).

7.1.11 Tailings Disposal

The disposal of industrial wastes such as mine tailings and fly ash has similar impacts to the effects of dredge spoil. Inappropriate disposal of these materials can lead to intensive physical impacts through smothering and a variety of other extensive impacts such as increased turbidity or toxic effects if, for example, heavy metals or other chemical pollutants are present (Clark, 2001, Kennish, 2002).

7.1.12 Nano-particles

Nano-technology involves the production and usage of structures, devices and systems which have at least one dimension of between 1 and 100nm (Owen and Depledge, 2005). Materials at this scale may behave in previously undescribed ways in the environment and within living organisms. To date there is concern but limited knowledge of how exposure to and toxicity of such materials may affect species and environments, including the marine environment (Benn and Westerhoff, 2008, Chalew et al., 2012, Owen and Depledge, 2005).

As with the use of other materials and resources, ongoing assessment of negative impacts and benefits of nano-particles is necessary. Usage in some circumstances, such as the developing form of nanotechnology that can be used to remediate the persistent-chemical pollution of groundwater may provide benefits that outweigh impacts (Owen and Depledge, 2005). As with all threats however, assessment of the nature of the threat and benefits in different circumstances in which use or impacts may occur should drive the prioritisation of the utilisation and management of nano-technology that may affect marine systems.

7.1.13 Noise/Physical Disturbance/Light

Habitats may be rendered temporarily or permanently unsuitable through noise, physical disturbance or artificial light and certain species may have their normal behaviour or innate processes disrupted by the presence of one or more of these impacts. Transient sources of noise include shipping, seismic exploration, and weapons testing and use while more permanent sources can stem from activities associated with coastal development and include ports, airports, mineral extraction, and renewable and non-renewable energy production. Recreational activities concentrated in onshore areas including the use of jet skis, surf-boards, and wind and kite surf-boards, may also exclude certain surface-dwelling species such as garfish. Long-term or repeated exclusion may cause broader changes due to changed access by these species to preferred sheltered locations and altered prey/predator interactions (see for example Botany Bay case study).

Disruption to normal cycles of light and darkness and pulses of light during dark periods can disrupt many species activity and physiological cycles that are tuned to approximate a 24 hour period. Hatchling turtles and birds can be disorientated by artificial lighting, leading to greater mortality, and predator-prey interactions amongst fish that depend upon lunar cycles can be adversely affected (Gaston et al., 2013). The impacts from artificial lighting are dependent upon intensity, direction, duration and the spectral composition and are a function of how natural light sources and their characteristics are mimicked. **Human activities in urban areas, tourist facilities, industrial plants and along transport networks are typically associated with the installation of an array of artificial light types, typically without adequate, or any, consideration of the ecological consequences (Gaston et al., 2013) or the ways in which negative impacts can be minimised.**

7.1.14 Thermal Pollution

Thermal pollution in marine systems usually stems from industrial activities including power generation. In fresh-water systems thermal pollution is commonly related to cold water discharge from the bottom of large dams. Water from power stations can be discharged into aquatic environments at some 12 to 15 degrees Celsius above ambient temperature. Relatively large quantities of water, particularly if the power station is on a small lake or estuary, can be pumped through the cooling system resulting in mortality of a significant fraction of the smaller life-forms in the waterway. However, beyond the immediate outfall area, due to mixing, the obvious impacts of thermal pollution in estuaries and marine environments are thought to be restricted to within a few hundred meters of the outfall. Industrial installations that rely on water for cooling commonly have the associated problem of periodic chlorine treatment of their heat exchanger systems and associated pipework. This, alongside mechanical buffeting due to the pumping of water, may, by directly impacting fish eggs and larvae, be more damaging to aspects of the marine environment than temperature effects (Clark, 2001).

Some fish and bivalves thrive in the immediate vicinity of warmer water, especially in temperate areas and these can, under certain circumstances be perceived to be beneficial, at least for these species. **Artificial, preferential encouragement of species that would not normally thrive or even occur in an area must, however, always be questioned.**

7.1.15 UV-B

Reductions in stratospheric ozone levels caused by releases of certain industrial chemicals have resulted in greater transmission of UV-B radiation (Rowland, 1991), Enhanced levels of UV-B affect human health and terrestrial and marine ecosystems both directly and through changes to climatic conditions. Enhanced UV "*may adversely affect larval fish development and survival*" (CSIRO, 2006 p. 22) and affect plankton productivity through reducing the efficiency of photosynthesis (NASA, 2007). The Montreal Protocol is recognised as having led to impressive reductions in the release of ozone depleting chemicals but the target of returning to 1980 levels of stratospheric ozone is not expected to be reached until mid-century in mid-latitudes and later in high latitudes. Increased UV exposure may impact systems already stressed by ocean acidification and accelerate some biogeochemical cycles. Conversely as UV irradiance reduces, photochemical breakdown of pollutants will reduce, resulting in possible increases in persistence of and exposure to some organic pollutants (UNEP, 2010). **As such UV-B should be included in the expanding group of anthropogenic impacts on marine systems that are known to be of concern but for which there is inadequate understanding of how best to manage the effects and what priority should be ascribed to that management.**

7.1.16 Radioactivity

Common environmental sources of radioactivity beyond natural background levels include weapons testing, military hardware disposal (purposeful and accidental), waste disposal (military, industrial and medical), power station discharges, reprocessing plant discharges and nuclear accidents. Radioactivity can be in the form of alpha, beta or gamma rays and the biological effects depend upon the type of radiation, the radionuclide, the half -life, the chemical form of the radionuclide, the assimilation ratio, and the accumulating organ (Clark, 2001). The International Commission on Radiological Protection (ICRP) suggests that no threshold of zero risk exists and any exposure above background levels adds risk. However, legal exposure levels for humans are set so that increased risks are similar to those that already exist in other areas of industrial endeavour. Furthermore, critical-path analysis is used as part of the attempt to ensure that authorised emissions of radioactive waste are such that they do not result in unexpected exposure rates in marine biota and humans.

Ocean dumping of radioactive waste commenced in 1946 but is now internationally controlled. Under the London Dumping convention, high level waste disposal at sea was banned in 1972 and in 1994 the dumping of low and intermediate level solid waste was banned. According to Clark, prior to 2000 *"levels of radiation in the sea have so far produced no measurable environmental impact on marine organisms or ecosystems* (2001).

Accidents such as the release of radioactivity from the Fukushima Dai-Ichi nuclear power plants following earthquake and tsunami damage in March 2011 increase awareness of the threat of radionuclide contamination. Airborne fallout and contaminated cooling water containing gamma emitting ^{134}Cs and ^{137}Cs isotopes affected land and marine environments and *"ocean discharge channels peaked in early April* [2011] *at more than 50 million times pre-existing ocean levels of ^{137}Cs"* (Buesselera et al., 2012). Following dilution within the ocean and decay, some three months after the initial accident, however, risks to human health and marine organisms at a distance ≥30 km off Japan from ^{134}Cs and ^{137}Cs were assessed to be below those from naturally occurring background radiation present within seawater although other possible and yet to be assessed radionuclide threats were acknowledged (Buesselera et al., 2012).

The nature and source of a nuclear accident determines the type and amount of radionuclides released. The Chernobyl accident of 1986 included radionuclides not detected in the Fukushima accident (Buesselera et al., 2012) and to date neither sites are completely rehabilitated or open to the full range of activities previously practiced. Any accidental release of radiation has the potential to reduce environmental quality, affect living organisms, necessitate expensive remediation, and also adversely affect the image or perception of an area and its produce.

7.2 Overfishing, Destructive Fishing, and Illegal, Unreported and Unregulated (IUU) Fishing

In view of the importance of assessing the impact of fishing and of other impacts on fisheries resources to the objectives of this study extra detail is provided on issues related to fishing.

7.2.1 The general threat posed by fishing

Fishing is claimed by numerous groups, (e.g. Greenpeace International, 2014, WWF Australia, nd) to be the dominant threat to marine environments and to fisheries resources; over-fishing is prominent in most international reviews of threats to marine systems (see section 5).

Over-fishing is by definition excessive. It is a threat to the ongoing harvest of seafood and the condition of at least some components of aquatic ecosystems. Recovery from overfishing is species and circumstance dependent. However, providing that habitats are available and water quality is not compromised, traditional fisheries management tools when appropriately applied should normally result in recovery in biomass in time periods that are within one or two generations of the species in question. The prevention of over-fishing and recovery from it are not technologically difficult but can be constrained by the intent and capabilities of governments to take the actions that are known to be necessary.

Destructive fishing, also by definition, causes unsustainable harm to habitats and/or non-target species and can also affect the future availability of target species. It typically adversely impacts ecosystem health with the changes often being irreversible at least while the activity continues. Recovery may take decades or longer depending upon the nature and scale of the destructive activity and the intensity and efficiency of recovery actions.

Destructive fishing practices are not common in Australia and where they have been known to occur they are usually tightly regulated. Scallop dredging is one form of fishing that has been popular in some locations in Australia, that if used intensively can, in certain locations, represent a destructive practice. In NSW the demise of scallop populations in Jervis Bay in particular, is attributed to commercial scallop dredging, possibly due more to damage to the host environment that culminated in scallop stock collapse than the direct result of the removal of the scallops themselves. In contrast relatively benign fishing activities, including even scallop dredging in selected high energy areas with relatively unstructured substrates, can be managed such that ongoing harvest is possible, economic returns underpin sustainable operations, communities benefit and ecosystems remain in a healthy and functional state. By definition, well-managed fishing does not cause unsustainable or unacceptable environmental impacts and associated changes are essentially reversible. The failure to differentiate between the threats from excessive or damaging fishing and the changes caused by well-managed fishing underlies much of the confusion and common misconceptions associated with fishing.

The impacts of overfishing are frequently incorrectly asserted to be common to fishing more generally, even by scientific groups (for example SIMS, 2011) and government agencies (RIS, 2003). This widely promoted misinterpretation drives much public perception and is commonly at the heart of advocacy for restriction of fishing, including closing areas to all types of fishing, even in the absence of evidence of net negative impacts from fishing and regardless of which form(s) of fishing may be harmful and in need of additional management.

All forms of fishing do cause some change to some components of marine systems; removing or even displacing one fish by the strictest definition causes localised depletion. The failure to determine the degree to which each form of fishing is a threat to marine systems and how each form that is a threat should be managed most efficiently allows the priority for managing the impacts of fishing to become distorted.

Fisheries resources are complex and the management of the threats to them should be based on careful identification of at least the major threats and assessment of how best each of these threats should be managed. The impact of a threat to fisheries resources is usually detected in the form of a decline in a species that is the subject of commercial fishing: commercial catch records represent the most available and unfortunately, commonly the only indicator of the status of fish resources. For all the limitations of such data sets very few other components of marine environments have indicators that serially provoke management response.

Of great significance to the management of the threat to fisheries resources is the practice of automatically blaming fishing when a decline in catches or catch-rate is detected. Unless there is overwhelming and unavoidable evidence in the form of visibly obvious and huge numbers of dead fish (as is the case in the episodic ‘fish-kills’ in the northern rivers of NSW (see Richmond and Clarence Rivers’ case studies) and the virus-driven pilchard kills off much of southern Australia (Whittington et al., 2008)) other evidence and explanations are commonly not sought.

Very few other indicators of the health of marine environments that impact the abundance and availability of fisheries resources are adequately monitored and used in fisheries assessments. Determination of non-fishing impacts on fisheries is relatively rudimentary and seldom adequately quantified, even though many such impacts are known to occur, commonly with increasing frequency and severity. Unfortunately fishing, as quantified by commercial catch data, usually represents the only indicator of the well-being of fish stocks. Because there are seldom other definitive data specifically on the condition of those stocks and what has impacted them, when a problem is detected by a decline in fish catch the usual response it to ‘shoot the messenger’. The common management action in the absence of obvious evidence and a lack of compulsion and resources to adequately investigate, is more regulation of fishing: it is easy and cheap to bring in additional regulation of fishing and if fish abundance has declined, in the absence of the necessary evidence to describe cause and effect, very easy to convince the public that appropriate action has been taken.

Not only are the less obvious threats to fisheries resources seldom assessed but the real value of what is threatened and the severity of the harm (discussed in 2.1.3) are commonly underestimated. For example, considerations of management of the threats to fisheries resources in Australia does not begin with adequate description of why these resources are of value and might therefore be particularly worthy of protection. **The threats to future seafood security, additional to the threats to marine resources detailed in this report, that are seldom given appropriate priority include: the failure to develop new fisheries to accommodate accelerating human nutritional needs associated with population growth; the failure to develop markets for all products that are, or could be, produced from fishing; inadequate accommodation in resource assessments and policy discussions of resource use by competing, non-human users, including marine mammals and sea-birds; and, the failure to develop clearly defined principles for the allocation of resources between competing human users (for example between extractive and non-extractive users and among and within the extractive groups, including recreational, commercial and indigenous fishers)**.

Public perception of how marine environments must be conserved and used in Australia has been misled by inadequate evaluation of the threats from fishing compared to those from other sources of damage to marine environments (see for example the seven case studies, in particular those for Cudgen Creek and the Richmond River). There has been a similar lack of comparison of the environmental credentials of well-managed fishing with those of other forms of food production (well-managed fishing is actually an extremely environmentally friendly source of food (Kearney, 2013)). The resulting failure to prioritise future supply of seafood in the context of Australia's total food security has resulted in inadequate debate of the broader strategic issue. As a result distorted assertions of the negative impact of fishing and exaggeration of the benefits from further restriction of all types of fishing have been allowed to thrive without adequate assessment.

Projections of benefits of non-specific fishing closures in Australia have been disproportionately based on inappropriate generalisation of the outcomes of inadequate fisheries management in other countries (for example Pauly et al., 2002) and/or inaccurate predictions based on reported declines in the relative abundance of large individuals of some species (for example Worm et al., 2006). The underlying negative predisposition towards fishing has been fuelled by numerous shallow assumptions, including that because fishing kills fish the threat to the conservation of marine systems is so serious that it necessitates management beyond traditional fisheries management techniques (see for example Possingham, 2011). Many things kill fish. In most marine systems total mortality is dominated by predation from other fish, marine mammals and birds; seals alone consume an estimated 500,000 tonnes of fish per annum (based on data in Kearney et al., 2003) which is more than three times the total Australian commercial fish catch of all species combined. Furthermore, indirect human causes of mortality and suppression of recruitment, such as pollution and the aggregating impacts of other threats detailed in this study are not adequately determined and may well be increasing. In Australia the total mortality from commercial fishing is actually declining; total landings have stagnated or decreased and waste, including unwanted by-catch, has been considerably reduced by stricter controls on efficiency (for example by-catch reduction devices in trawl nets and mandatory live-release of by-catch in NSW estuarine haul-net fisheries). The case studies presented in this report provide the context for comparisons of the outcomes from the impacts of the threats to marine systems and fisheries resources from terrestrial-based activities with those posed by fishing as managed in NSW.

7.2.2 Illegal Unreported and Unregulated (IUU) Fishing

A particular threat to the sustainability of some fisheries and one that commonly disrupts the effective management of fisheries is illegal unreported and unregulated (IUU) fishing (FAO, 2014). Instances of large-scale, international illegal fishing have occurred in Australia, most notably in the remote Southern Ocean and in the far north of Australia's Exclusive Economic Zone. Problems have also been reported with foreign vessels targeting lucrative shark fin to the north of Australia as far east as the Torres Strait (Department of Agriculture, 2011). Illegal poaching of abalone and instances of domestic fishers illegally targeting sharks for fins off NSW represent specific examples of IUU fishing in NSW for which the threat remains. The scale of these offences is however not commensurate with the intensity of international activities that underpin the global priority for controlling IUU fishing.

Illegal unreported and unregulated fishing has the potential to result in overexploitation of stocks and may underscore longer term damage in the form of habitat degradation or loss. Illegal fishing and the non-reporting of catches where regulation exists undermines the effective management of fish stocks and of the impacts of permitted practices. While it is known that catches from IUU fishing in Australia do occur they are not currently major threats to the continued effectiveness of fishery management in this country. Issues associated with IUU fishing, particularly off West Africa where there have been major problems, are publicised by certain NGOs and either by design or accidentally have become confused and intertwined with understanding of the practices and impacts of managed fishing in Australia. Such confusion distorts the perception of fishing practices in general. It can subsequently distort the priorities given to marine conservation. It can also damage public confidence in the sustainability of well-managed harvesting of food from marine environments.

7.2.3 Managed Fishing

Unless constrained by the ideology that the removal of any fish from the ocean for human consumption is fundamentally harmful the impacts and threats from fishing should be considered on the specifics of each fishery, or at least, each type of fishing activity. To facilitate prioritisation of the management of what threats there might be from fishing in Australia and NSW fisheries more specifically some analysis of at least the most common forms of fishing is necessary.

7.2.3.1 Trawling

The forms of trawling employed in several different fisheries throughout NSW, and Australia more generally, vary considerably and great care is necessary in assessing the benefits and threats from each and the priority that should be given to their management.

Trawling is generally a non-specific fishing method; most organisms in the path of the trawl are vulnerable to at least some degree to capture, displacement or damage. Poorly managed trawling over structured benthic communities must therefore be assumed to represent a significant threat to those communities in the area that is trawled. Inadequately managed trawling has led to more over-fishing, even in Australia, than any other single form of fishing (Kearney, 2008b, McLoughlin, 2006). It is imperative for both marine systems and fisheries resources that bottom trawling, particularly over structured and stable bottoms, be effectively managed.

Trawling when well managed can be a relatively efficient means of accumulating food and it is often the only fishing method that enables optimum harvest levels from an area to be achieved. For numerous species, for example most prawn species, that cannot be captured efficiently by other techniques there may be no viable alternative means of harvest. Careful assessment of the optimum level of effort and catch is therefore necessary for each type of trawling in each type of location. Generalisation should be avoided.

Trawl nets and their use can be modified for different locations to increase their specificity and reduce unwanted impacts. Modifications in well-managed fisheries include gear designs that minimise or even totally eliminate damaging bottom contact and net modifications to reduce by-catch. Bottom trawling over or adjacent to hard substrates with associated vulnerable benthic communities requires precise management that adequately acknowledges the threat that such practices can pose. It must not be assumed, however, that all such trawling automatically represents a threat to broader marine systems; Savina et al. (2009) concluded from one of the very few studies to consider the effects of fish-trawling off NSW on biodiversity that in keeping with the benefits of intermediate disturbance at least some fish-trawling could be beneficial for biodiversity promotion.

Where trawling is an acknowledged threat, such as over structured hard-bottoms, the reservation of some fraction of trawlable areas is a commonly accepted strategy for the management of the total impact. Australia has, in recent years, taken an extremely conservative approach to area management of trawling. This has been particularly evident in fish-trawl fisheries with, for example, 97% of the known area of distribution of Orange Roughy being closed to trawling (Kearney and Goodsell, 2011) and approximately 85% of the fish-trawl grounds of south eastern Australia being closed for a variety of reasons to all bottom-trawling (Boag, 2012).

The threat from trawling over relatively unstructured soft-bottoms in high-energy locations, particularly those affected by strong currents, is usually minimal and most impacts are temporary. In areas where natural events, such as tides and floods, cause considerable movement in substrates and associated biota, for example in riverine estuaries, negative impacts of well-managed trawling may be inconsequential or even undetectable (see for example the study of the effects of trawling in the Clarence River by Underwood, 2007).

7.2.3.2 Surround netting

(including the use of purse-seine, lampara and haul nets).

Most forms of surround netting represent targeted and relatively precise harvesting of previously identified aggregations of selected species. As such they are amenable to precise management of effective effort and subsequent catches and incidental impacts by traditional fisheries management techniques, including targeted seasonal and area closures. By-catch can be a problem with many forms of surround netting and live-release of non-target species is usually a management priority, as it is with haul-netting in NSW estuaries. As catches from individual sets of gear are often relatively high compared to those from other gears precise management is usually necessary, even if only to manage the perception that large catches are always damaging.

7.2.3.3 Mesh-netting

Mesh-netting is a relatively effective, but often non-selective, method of taking at least some size-classes of multiple fish species present in an area. The poor selectivity of some mesh-netting activities can lead to entanglement and the killing or damaging of individuals of unwanted species, significantly including on occasions marine mammals such as seals, dolphins and dugong. The use of variable mesh sizes can also lead to entanglement and damage to undersized individuals of numerous species. The lack of selectivity and associated inefficiency of mesh-netting in some situations has led to it being banned in most off-shore environments and restricted greatly in many inshore areas. Because even small nets can be efficient for some species in some situations and the vessels and crew necessary to deploy them can be minimal, mesh-netting is a major component of small-scale estuarine fisheries which often produce the bulk of local product for regional seafood supply. Its lack of selectivity when not used correctly and the wide range of areas in which it can be effective also means that it can impact a variety of species that are managed in other fisheries. As a result mesh-netting must be tightly managed.

Because mesh-netting is still practiced in several major estuaries in NSW where it accounts for significant catches of species such as mulloway, bream, flathead and whiting that are targeted by anglers it is the target of particular acrimony from many recreational fishers.

7.2.3.4 Trapping

(including free-standing fish, lobster and crab traps and prawn trap-nets).

Indigenous Australian fishers traditionally used a variety of fish traps in estuaries and coastal areas. Rock-wall traps were particularly popular because of the episodic high yield of desired species. Such traps did cause some deliberate structural modification to very localised areas but the scale was extremely small and the degree of modification slight by modern coastal development standards. Furthermore there were few locations where they could be constructed to good effect. For a variety of reasons, including other uses since European settlement of the few suitable sites for rock traps this form of traditional indigenous trap-fishing has almost disappeared from NSW coastal waters.

Cane tunnel-traps that could be readily moved constituted another form of trapping that was popular with traditional indigenous fishers but with the increased availability of more efficient gear using more advanced materials this form of fishing is also no longer common.

Traditional trap fisheries took a very small portion of the total fish community and thus represented little threat to populations of target and/or incidental species.

At the other extreme are commercial floating fish traps which were relatively recently introduced (1980s) only to be totally banned in NSW because they were too efficient at catching a single species, kingfish. The highly public and politicised demands of other resource users, predominantly recreational fishers, were rewarded with the total removal, rather than the precise management, of the most efficient gear type for catching kingfish, floating traps.

The most common form of fish trapping in NSW employs bottom traps for fish species such as snapper and bream. Specialised traps for lobsters and crabs are also extremely common. The product from well-managed trapping is generally of very high quality and incidental impacts are usually relatively minor. Impacts can be effectively managed by effort and catch controls and gear modifications when found to be necessary.

Prawn trap-nets are relatively environmentally friendly and easily managed but they suffer from only being effective in very specific locations within rivers which are normally those that support predominantly juveniles of the target species. As such prawn trap-nets do not often represent the most efficient means of optimising the total yield from target, or incidentally-captured, species. Unfortunately the illegal use of trap-nets outside managed fisheries does occur to the detriment of licensed commercial and recreational fishers. However, such illegal activity is not widespread (there are limited locations where they are effective and these locations tend to be well known and hence easily guarded) and is unlikely to represent a serious threat to marine environments or the sustainability of total fisheries resources while it remains restricted in area and frequency.

7.2.3.5 Commercial line fishing

Hooks and lines are used in a huge variety of ways to take commercial catches of fish and smaller numbers of other species that includes squid and sharks. Some forms of line-fishing are extremely selective, for example pole and line fishing for tuna or kingfish, with little by-catch and incidental impact. International translocation of live bait and incidental species can be a significant threat from some high-seas pole-and-line fishing but such impacts are not currently an issue in Australia.

Other forms of line fishing, in particular baited long-lines, take a wide variety of fish and shark species some of which can be threatened species such as grey-nurse sharks. In the case of surface and mid-water long-lines the by-catch can include sea-birds which may be of threatened species. Careful management of all impacts of long-line fishing, including the total catches of target species, particularly slower growing bottom species such as groupers, is therefore necessary. While long-lining continues to require careful management Australia does have a commendable record for reducing potentially harmful by-catch from long-line fishing and by-catch reduction devices and practices are mandatory in most fisheries for which they are relevant.

Commercial hand-line fisheries in NSW and throughout Australia are all small-scale activities with relatively selective targeting of premium market species. They produce relatively small catches of extremely high quality with limited incidental impacts. Hand-lining is amenable to precise management through the many forms of traditional fisheries management.

7.2.3.6 Commercial hand-gathering

Numerous commercial fisheries are based on the hand-gathering of individuals of selected species. Prominent examples include abalone, pipis and beach worms. The techniques used are all amenable to precise management, however, when individual specimens can bring high monetary returns, for example large abalone, the incentives to work outside regulations are considerable. When these incentives are aligned with the ease of overexploitation of relatively slow growing, sedentary and highly visible individuals resource collapses can occur. For example bêche-de-mer stocks have been over-fished in most countries, including Australia and several of Australia’s abalone stocks have been overexploited. In NSW these stocks have been the subject of recovery plans and numerous recoveries have been reported (Fisheries NSW unpublished data).

7.2.3.7 Recreational fishing

The number of Australians involved in recreational fishing is high; almost 20% of the Australian population fished at least once in the year to May 2000 (Henry and Lyle, 2003) and inclusion of other family members, friends or neighbours who may benefit makes the total number of people with an interest in inputs or outputs considerably higher. The great majority of participants are anglers who use a wide variety of line-fishing equipment and techniques to take a significant percentage (approximately 25%) of Australia’s total fish catch (projected from data in Henry and Lyle, 2003). Other interest groups include spear-fishers and those who use small nets and traps for prawns, crabs and lobsters in the limited places where such activities are permitted and productive.

The impact of an individual angler is usually very small, especially when compared, for example, with the potential impact of a large bottom trawler. It is, however, the large number of participants and the extreme variety of techniques coupled with the rapid development of technology for locating and capturing selected species that has led to greatly increased collective impact. In combination with the extensive areal coverage, these attributes makes angling at least a potential threat to other beneficiaries of marine resource use and even to some species and habitats. Recreational catches of many species have continued to increase in NSW and total landings now exceed commercial catches of numerous key species, such as mulloway (Rowling et al., 2010).

Skilled anglers can be very specific in what they target and catch but many anglers are simply 'fishing' for whatever comes along. By-catch by anglers, particularly of undersized individuals that may be killed or injured in the fishing process requires ongoing, adaptive management and education programs. For species where recreational catches dominate total landings and in areas where recreational activities and incidental impacts, such as from bait gathering, exceed those from commercial exploitation it is logical that concerns over the maintenance of optimum abundance levels of some species and management of incidental impacts of fishing should be focussed on recreational activities.

Recreational targeting of particularly large, long-lived species can be of considerable importance for conservation and wise management of those species. When abundance levels of deep-water species such as the large groupers fall below the levels that are necessary to support commercial targeting, commercial fishing for them will usually be curtailed. The ongoing and cumulative catch of single specimens by anglers can, however, remain relatively rewarding for individual anglers and be potentially damaging to remnant fish populations. Recreational fishing for bottom-dwelling species in deep waters is a particular threat for some species because of the relative size and longevity of individuals of those species, the elevated vulnerability of some to modern fishing technology and techniques and the high mortality of captured individuals due to barotrauma (the result of being brought quickly to the surface from considerable depth). The increased efficiency of recreational fishers since the explosion in the availability of sonar-based fish-finders and GPSs has made precise management of recreational effort on deep-water species in particular, more necessary. The advent of electric reels to facilitate fishing in very deep water has further increased the potential impact from, and hence the need for management of, effective recreational fishing effort on long-lived species.

Recreational fishing can be managed relatively precisely by traditional fisheries management techniques including bag and size limits, gear limitations and seasonal and area closures to specific gear types. Recreational fishers need to ensure that these specific and targeted techniques work and can be demonstrated to be effective. **If specific and targeted management is not effective or perceived not to be so, pressure will mount for blunt and inefficient management measures such as total 'no-take' zoning of large areas that are not selected to address specific threats.**

Spear-fishing and underwater collecting by hand are extremely selective harvesting strategies that, as for angling, have benefits to participants beyond the harvest of seafood. Opposition to spear-fishing is frequently emotive and/or ideological. It is commonly based more on animal-rights issues, direct allocation conflict with non-extractive underwater enthusiasts and highly visible competition with anglers than with evidence-based assessment of impact on the total resource or marine biodiversity. However, as species targeted by some individuals can include those that are relatively resident, highly visible and vulnerable to spearing, such as blue groper, careful identification and adequate description of threats that might be posed by spearfishing are high priorities. **As spearfishing commonly targets**

species that are visibly prominent and as a result disproportionately dominate the popular indicators of marine environmental health used by other divers and many scientists the overall impact can be easily distorted. It is imperative that impacts are accurately assessed and management priorities are aligned with evidence-based assessments of impacts on broad ecosystem sustainability and use and including the impacts of alternative resource allocation decisions.

7.2.3.8 Indigenous fishing

Indigenous impacts on marine system functionality were traditionally minimal compared to the contemporary threats to the marine environment and fisheries resources. Fishing in marine environments prior to European settlement was based on relatively benign practices that harvested small fractions of total resources and caused very little ancillary damage to associated environments. Fishing was not a significant threat to marine systems or fisheries resources. However, indigenous fishing in the form of customary fishing practices is itself threatened greatly by a variety of pressures resulting from the collective impacts of numerous modern changes. These pressures include the very complex array of social, cultural and physical change discussed in this report and competition for resources associated with the extensive changes to the population and industrialisation of Australia. **The collective result of these impacts is such that indigenous fishing, as traditionally practiced in Australia, is now virtually impossible (Australian Law Reform Commission, nd).** This is obviously a major cultural issue for indigenous Australians and as a consequence, a significant social issue for all Australians.

Virtually all of the threats to marine systems and fisheries resources considered in this study would be threats to traditional indigenous fishing, if such fishing were still possible. There can be no doubt that most of these threats will continue to have impacts on indigenous utilisation of marine resources. However, indigenous fishing has also been severely and more directly impacted by access to what were traditional resources by other users, most directly non-indigenous commercial and recreational fishers.

Increased efficiency of fishing resulting from technological development in boats, motors and gear has resulted in the total resource available to indigenous fishers in NSW being greatly expanded. However, the degree to which the catch that has resulted from a greatly reduced share of an expanded total available resource has compensated indigenous fishers for the loss of exclusive use of a much less vulnerable or available resource is not well described. But regardless of the magnitude of the resulting catch the cultural change resulting from effectively removing customary fishing techniques and curtailing associated social practices must be considerable (see for example Schnierer, 2011).

It is outside the scope of this report and the qualifications and experience of the authors to comment on how the threats to indigenous fishing, traditional cultures and food use practices might be prioritised beyond stating the obvious: **all threats to marine systems and fisheries resources in NSW are threats to indigenous use of these resources, as are outcomes of resource allocation decisions, specifically those impacting allocation to non-extractive users and between commercial, recreational and indigenous fishers**. Whether allocation is based on deliberate decisions or the mere failure to address the pressures of competing uses of resources does not impact the conclusion that the culture of indigenous use of marine systems and fisheries resources has been, and continues to be, seriously impacted.

7.2.3.9 Aquaculture

The major persistent threats to the marine environment and fisheries resources from aquaculture in Australia are from the increase of nutrients from feed and waste, the translocation of species and the exclusion of habitat to local species. Amplification of pathogenic disease organisms has the potential to negatively impact fisheries resources and even the well-being of species, particularly where wild stocks of the same or similar species as those farmed co-exist. The translocation of micro-organisms and pathogens in feeds is also an issue that requires constant vigilance. Reduction of visual amenity and exclusion of areas used for fishing and tourism is cited as a major public concern, particularly in highly populated areas.

The escape and subsequent establishment of species introduced for aquaculture is a potential threat but it is largely restricted to the culture of aquarium species and not aquaculture for seafood. Food species were deliberately introduced into NSW as far back as the late 1800s but with the exception of the Pacific oyster, deliberately introduced marine food species have not become a major issue and the importation of food species for aquaculture is no longer permitted.

7.3 Alterations to Physical Habitats

7.3.1 Terrestrial Mining

Land clearing for terrestrial mining can, in addition to the obvious removal of native vegetation, result in water-shed change, affect rates of erosion and increase sedimentation. Mining operations can lead to leaching of toxic and acidic materials from exposed excavations and tailing dumps, and from the disposal of tailings and overburden. Toxicants, including heavy metals may enter waterways especially during flood conditions and leaks and spills of processing chemicals including cyanide and sulfuric acid can occur. Secondary impacts arise from transport of ore both overland and by sea, caused by ship activities, port development and use, and from road and rail infrastructure construction and use (ABS, 2003).

New technologies and methods to exploit resources such as horizontal drilling and the expanded use of hydraulic fracturing (fracking), to recover coal seam gas (CSG) and shale gas can constitute new threats to marine environments and fishery resources by impacting ground water and surface water quality, flow and abundance. Economic recovery of CSG, for example, requires the establishment of numerous wells within a relatively small area that each initially need between 0.2 and 0.6 ML of water mixed with particulate matter and a variety of chemicals to facilitate the fracking process (Batley and Kookana, 2012). During the gas production phase, that may last up to 10 years, formation water is released from the fractured structure at an initial rate of up to 100kL per day (Batley and Kookana, 2012). In NSW, regulations have been introduced that ban the use of *"harmful chemicals"* (NSW Government, 2013a) in fracking operations, stop new operations within 2km of present and known future residential areas, and, prevent operations in the *"Upper Hunter equine and viticulture Critical Industry Clusters"* (NSW Government, 2013a). Stringent standards also exist regarding the isolation of geological layers from one another and the ground surface in drilled wells to prevent aquifer contamination and the uncontrolled release of hydrocarbons. While regulation of fracking in Australia and NSW may be of a higher standard than in other countries, it is important to note that environmental damage and human health impacts from coal seam and shale fracking have been reported in other locations, particularly the USA. Reported and potential problems include air, soil and water contamination from hydrocarbons and from heavy metals and radiation contained within drill cuttings (Finewood and Stroup, 2012, Finkel and Law, 2011) and 'produced' water (Orem et al., 2007). In addition, a range of serious acute and chronic health effects from introduced and released chemicals and compounds have been reported, some of which have been identified as being carcinogenic or as endocrine disruptors (Finkel and Law, 2011). Like many potentially high-impact human activities, strict monitoring of fracking is needed in the broader context of effective environmental management and sustainability of both ecosystems and resources.

7.3.2 Ocean Mining and Oil and Gas Extraction

Wide-scale mining of minerals from the ocean floor, with the exception of sand and gravel for the construction industry, is not commonplace although it has been touted since the 1970s when resource scarcity was regarded as being a threat to sustained global economic development. Papua New Guinea has approved the mining of polymetalic-sulfide deposits within parts of its EEZ that have some similarities to Australia's Coral Sea zone and other countries are assessing opportunities to exploit ocean based deposits. In addition to sand and gravel, deposits of interest can produce manganese, zinc, tin, copper, silver, gold, base metals and, diamonds (Halfar and Fujita, 2002, Parr et al., 2009). These may be spread over large areas of ocean floor or concentrated near geothermal vents.

Oil and gas extraction poses well publicised threats to the marine environment. In addition to widely publicised pollution events caused by oil rig accidents such as BP's Deepwater Horizon explosion and subsequent spill in the Gulf of Mexico, normal oil and gas extraction activities can involve the release of large volumes of wastes to marine waters. These include produced formation water (water released from the reservoir and water pumped into and released from the reservoir), drilling-fluid chemicals, oil and water based drilling-muds, cuttings, metals, crude oil, and fuels and lubricants from a wide variety of transport vessels, structures and equipment (Holdway, 2002). Both acute and chronic impacts to marine biota have been recorded (Holdway, 2002).

Accessing mineral resources within a water oriented environment is likely to lead to environmental change that is difficult to contain. Beyond the obvious and immediate damage and loss of habitat in the mined benthic zone, increased turbidity and toxic levels of metals and other elements may cause severe impacts. Nutrient balances within the water column can also be affected creating changes in primary production, leading to eutrophication events and subsequent changes in species diversity. In addition, the disposal of unwanted material can cause further habitat destruction through increased turbidity and smothering (Halfar and Fujita, 2002). At present, Australian marine mining, other than oil and gas production, is largely limited to operations commenced in the 1970s dredging carbonate sand for industrial use offshore from Fremantle and utilising dredge by-products from channel deepening operations in Moreton Bay for construction (Parr et al., 2009). There is currently no commercial mining in NSW marine waters.

7.3.3 Dredging

Dredging is used to create or keep shipping and boat access channels navigable, to collect construction materials and ores, to translocate sand to areas where it is considered more necessary and to remove previously contaminated sediments (see case studies, particularly Cudgen Creek and Port Hacking).The removal of sediments can destroy benthic habitat and biota, create turbid conditions, re-suspend previous contaminants and alter current flow and direction. The dumping of dredged material in adjacent areas can smother habitats and biota, spread contaminants and also create unfavourable turbid conditions. Impacted areas can at times be disproportionately important habitats, such as spawning grounds or important food sources for fish and seabirds (Clark, 2001). Dredging sediments previously contaminated by persistent pollutants such as PCBs poses further problems. The renewed bioavailability of the contaminants and the lack of suitable facilities for cleaning, decontaminating and storing sediment and associated water are threats that need to be prioritised in the context of effectively managing deliberate changes to marine systems that involve negative consequences for the living components of those systems (Clark, 2001).

7.3.4 Connectivity, Flow-Regime and Salinity Change

Flow regime changes have occurred in many areas of Australia since European settlement; the multitude of dams and weirs on the Murray-Darling River system is a prominent example. Specific examples relating to NSW estuaries are described in the case studies, particularly Cudgen Creek and Richmond River. Clearing native vegetation for logging and agriculture use alters the dynamics of catchment behaviour and typically results in increased average waterway flows and more extreme pulses of flow during rainfall events.

Drainage, infrastructure development, flood mitigation, and land use changes for agriculture and settlements all tend to impinge upon a waterway system's stability and connectivity. This changes habitat structure and restricts habitat access. As a result of flow, drainage and connectivity changes, normal tidal flushing may also be impeded and impacts on salinity, both upward and downward, can result. These impacts change habitats and can restrict their suitability for a variety of flora and fauna. They can also change the timing and magnitude of chemical cues used by migrating or resident species.

7.3.5 Watershed Alteration

Linked to the category above, watershed alteration is a typical effect of European-type land management practices. As detailed in the case studies, alteration follows a typically similar pattern of logging, farming, drainage, flood mitigation, settlement expansion, infrastructure development and industrialisation. Each and every aspect of these changes impacts the functionality of a waterway's catchment. Clearing, draining and storing water result in changed flow patterns, higher peak flows, increases in sediment and changed chemical and thermal properties of water entering streams and rivers. The suite of human activities and infrastructure associated with modern living such as industrialised agriculture, settlement for habitation, industry and transport result in wastes and toxicants entering waterways.

7.3.6 Watercourse Change

Watercourse changes of different types have been and continue to be made for a variety of reasons. Within the case study areas, drivers have included the creation of permanent navigational access to rivers from the sea through the construction of training walls e.g. Cudgen Creek and the Richmond and Clarence Rivers; control of beach erosion through the construction of sea walls or groynes e.g. Botany Bay, facilitation of bridge construction economically and logistically, e.g. Cudgen Creek; prevention of riverbank erosion especially after land clearing by concreting river banks e.g. Cooks River that flows into Botany Bay; reclamation of land for development such as the Cooks River diversion and changed location of the entrance some 1.5km south of its original point to facilitate runway construction at Sydney's airport; 'reclamation' of land for agriculture and urban development e.g. Richmond and Clarence catchments; and, instigation of flood prevention measures in many northern NSW estuaries.

With such changes, many environmental and ecosystem effects are immediate, or quickly apparent; habitats can be lost, saltmarsh areas reduced, seagrass beds destroyed or moved, and flow regimes and tidal flushing changed. There are also longer-term effects that result: erosion and deposition patterns along rivers are altered, beach sand is removed and deposited in different places and at different rates and the viability of wetland habitat is impacted and usually reduced. Increased siltation and deposition of estuarine material may also facilitate mangrove encroachment into other habitats.

The artificial opening of intermittently closed and open lakes and lagoons (ICOLLs) is also a form of watercourse change (for example Cudgen Creek). Artificial opening may be performed to alleviate flooding of low lying agricultural land and developments or to facilitate uninterrupted access, but current practice is to allow openings to follow natural patterns where possible. Opening typically results in the immediate exit of large fish and prawns and may result in renewed larval recruitment. However, estuarine systems are complex and deliberately changing flow regimes for fishery benefit or increased amenity, as is often suggested by interested parties, needs to be based on a level of knowledge and precise understanding of consequences that is essentially, currently unavailable.

Impacts from changing watercourses are sudden and may effectively be permanent. Longer-term biotic changes also occur as ecosystems attempt to adapt to the altered physical conditions. For fishery resources, the largest impacts are likely to come from habitat loss, reduced access for fish and other living organisms and reductions in water quality.

7.3.7 Coastal Development

Coasts and particularly estuaries are centres of human economic and recreational activity. Coastal locations are favoured for industrial and power generation sites, ports and for lifestyle and recreational opportunities. These forms of use impact water quality and availability, lead to increased pollution, noise and disturbance, and restrict or reallocate access to previously important habitats. Major impacts stem from deliberate changes to waterways (for example for airport runway or port development (see Botany Bay case study)), industrial waste discharges and outputs from sewage treatment plants. Inappropriate and/or excessive coastal development results in hydrological changes, loss of habitats, and an excessive influx of pollutants and toxicants. These impacts can affect the productivity of fisheries, reduce the effectiveness of other ecosystem services and reduce the environmental and aesthetic standing of an affected area (Ofiara and Seneca, 2006).

7.3.8 Tourism

Alongside the general impacts from an increased human presence, added impacts from tourism include the development of hotels, recreation facilities, jetties, harbours and airports. Tourist visits result in increased use of fresh water, food and power and there are increases in sewage and other waste for disposal. Tourists may also directly damage ecosystems such as reefs and wetlands and cause damage to seagrass and other vulnerable habitats particularly if they have no experience or understanding of their importance and propensity to be damaged. Cruise ships with their large passenger numbers produce much rubbish, estimated to be in the order of 2kg per person per day (Clark, 2001). This can overwhelm port facilities particularly in developing countries and may, at least in part, find its way into the marine environment. In addition, visits by large numbers of tourists particularly over short periods of time may cause ecological damage to visited sites.

7.3.9 Recreational Use

Water based activities are increasingly popular and over the last few decades new forms of water based recreation have become available. Many of these can impact aquatic environments. Marinas, boat moorings, slipways, jetties and boat ramps physically alter and damage habitats while motorised boats and jet skis cause noise, disturbance, bank erosion from wash and pollution from oils and fuels. Changed hydrodynamics, sediment characteristics and the build-up of antifoulant compounds and other chemicals used to maintain watercraft can adversely affect marine species (Rivero et al., 2013). Windsurfing, sailing and kite surfing, if practiced with a high density and frequency effectively excise areas of surface marine habitat from some surface dwelling species. Species that use this habitat and their predators may be dislocated leading to severely depleted localised numbers at least during periods of high usage. The knock-on ecosystem effects of such changes are little known.

7.4 Invasions of Exotic Species

Various human assisted vectors exist that enable the invasion of alien species and organisms (Hewitt and Campbell, 2010). Biofouling of vessels (including hull boring of wooden vessels) that traverse non-connected aquatic environments regionally and across the globe is a major means by which organisms can be translocated. This means of translocation has been associated with human movements over thousands of years and increased with global exploration and trade that has accelerated since the 16th century. It has become increasingly recognised as a problem and with current high and growing levels of international ship movements, management of its impact warrants greater priority. In NSW a risk assessment approach has identified the most likely vectors and species to arrive and become established in Sydney ports (Glasby and Lobb, 2008).

With the advent of ships designed to utilise ballast tanks in the late 19th century, further opportunity for invasion was afforded as water was routinely taken on board in one location and released in another, complete with its contents, including various living organisms. Globally it has been assessed that biofouling can be associated with 55% of invasive species and ballast water with 31%; the figures for Australia are estimated to be 60% and 24% respectively (Hewitt and Campbell, 2010). Other vectors of transport include, the use of dry and semidry ballast; the transport of organisms associated with aquaculture and mariculture (including farmed species feed stock and associated pathogens); the transport and distribution of species (and associated pathogens) for the aquarium trade; the transport of contaminated packing materials; the movement of species for research; the translocation of maritime equipment, fishing gear and bait; and, the movement of live seafood (Hewitt and Campbell, 2010). Within Australia, 429 non-indigenous marine species had been identified by 2008 (Hewitt and Campbell, 2010). In the context of conserving biodiversity this number is of great significance to the interaction and balance of organisms within Australia’s varied aquatic habitats. Official government statistics indicate that not a single marine species has been reported as extinct in Australia (Dept. SEWPaC, 2009). So for consideration of the conservation of biodiversity based on just numbers of species, introduced species are an immense (arguably infinitely more, 429:0, than extraction) problem for marine conservation.

Invasions can also cause declines and regional displacement of native species through exclusion or by disease and result in far-reaching and essentially permanent ecosystem and biodiversity changes. The impacts of introduced marine species and the way they are managed in Australia, with an emphasis on NSW, is provided by Glasby & Creese (2007).

Introduced species can compete with and even out-compete native species and change ecosystem functionality (Pimentel et al., 2005). The Pacific oyster provides a pertinent example for NSW. Introduced to Australia deliberately in the 1930s the species is now actively cultivated in most southern states, where it is the basis of a large aquaculture industry, including in NSW. It has displaced native oysters from foreshores to varying degrees throughout its range, particularly effectively in Tasmania. In South Australia the Pacific oyster's habit of settling on other members of its species has resulted in oyster-based reef development that is changing local shallows and coastal wetlands. In NSW the Pacific oyster is well established in the wild and it has been demonstrated that "*at Port Stephens, spawning and larval development of the* [introduced] *Pacific oyster does not appear to occur over a wide range of temperatures and is confined to the period in which increasing seasonal mean water temperatures exceed approximately 21 ˚C*" (McOrrie, 1995 p.23). In contrast "*at Port Stephens, spawning and larval development of the* [native] *Sydney rock oyster occurs over a wide range of temperatures, with the major reproductive period occurring at mean water temperatures above approximately 19˚C*" (McOrrie, 1995 p.23). As oyster spawn is a major food item for many estuarine species the alteration in the seasonal availability of food that results from Pacific oysters displacing Sydney rock oysters could be expected to be a disadvantage for local species that have evolved in an environment dominated by endemic oysters. Conversely it could be to the advantage of introduced species, discussed below. This could be expected to be a more significant issue in those states or regions where Pacific oysters have more completely displaced local species.

The recent discovery of Tilapia *sp*. in Bogangar canal and in waterways adjacent to Cudgen Lake in NSW (see Cudgen Creek case study) is a pertinent example of the threat to NSW ecosystems represented by introduced species. It has set in place a response from the NSW DPI seeking the public's help to control its spread (NSW DPI 2014). Eradication appears unlikely under current levels of knowledge and management capability. Tilapia is described as being "one of the world's most invasive fish species" (NSW DPI 2014). The presence of Tilapia has been confirmed in several locations that flow into Cudgen Creek with the fish apparently thriving even in water with low dissolved oxygen and low pH. Its ability to establish itself and potentially out-compete native species, particularly in less than ideal conditions, raises concerns about the level of long-term impacts it will have on all of the systems it invades (Creese 2014 pers, comm.).

The altered environments created by introduced species, including the seasonal availability of food they represent or produce, could be expected to be advantageous for other species, including introduced ones that are more amenable or accustomed to the seasonality of the introduced species. **The impact of introduced species can be much greater than their obvious physical presence and the control of introductions is a high priority for ongoing management.**

7.5 Global Climate Change

7.5.1 Temperature Change

Sitting on top of many marine environment and fishery resource impacts is climate change. The associated rise in ocean levels, increasing temperature and changes to ocean acidity and currents (IPCC, 2007) are global in nature. Temperature changes can have multiple impacts on marine organisms. Prominent reported changes include the skewing of sex ratios of turtles, shifting seabird, seaweed and fish distributions (southwards in the southern hemisphere) and affecting symbiotic balance in coral reefs. These changes are expected to impact established food webs (CSIRO, 2006). If global temperature does change in accordance with IPCC predictions, or more, there will undoubtedly be many obvious changes to marine systems that will represent very serious threats to human expectations of global stability as reflected in the desire to maintain the *status quo*. But the degree to which these changes represent threats to the sustainability of a total marine ecosystem as productive or as species rich as the one that would exist without climate change, is less certain.

7.5.2 Sea Level Rise

Between 1971 and 2000, observations show that the global mean sea level (GMSL) rose by 2.0 mm yr^{-1} (Church et al., 2013). Future predictions suggest that it is "very likely" that this rate of increase will be exceeded, even under modelled conditions with the lowest future increase in radiative-forcing linked to the most controlled scenario of atmospheric greenhouse gases emissions (Church et al., 2013). Regional effects, including those driven by rise and fall in land masses as large as tectonic plates, impact the actual rise in sea level experienced in different locations and since 1993 north and northwest Australia have experienced increases three to four times the global average; NSW increases have been similar to the global average (CSIRO, 2012). Approximately 85% of the Australian population lives in the coastal zone and consequently sea level rise has the potential to cause great impact to infrastructure and lifestyles (Ozcoasts, 2013c). The existence and probable future enhanced protection of built environments alongside the preservation of current land usage has the potential to put pressure on the relative availability of certain important habitats such as salt marsh and mangrove and increase pressures from flood mitigation and flow control activities. **With reduced capability to adapt to rising sea levels, particularly in and around urbanised estuaries, aquatic habitats that are important to maintain current systems must be expected to be reduced in both quality and extent.**

7.5.3 Ocean Acidification

Industrial activities, such as fossil fuel burning and cement production alongside land use change have caused an increase in atmospheric CO_2 (IPCC, 2007). Some 500 billion tonnes of CO_2 have been released through human activity since the industrial revolution with about 30% of this being taken up by the world's oceans (Friedrich et al., 2012).

The marine environment is impacted not only by absolute levels of atmospheric CO_2 but by the rate of change experienced over the last century that is some 100 times faster than changes over the previous few hundred thousand years (Fabry et al., 2008). Hoegh-Guldberg et al. (2007) have suggested that this will push natural adaptation beyond its limit. But there is no unequivocal evidence that there is a knife-edge limit to adaptation. The history of evolution would suggest that at least some adaptation will continue and that modified mechanism or even novel ones may arise to facilitate adaptive responses. The outcome of these responses is unknown but it is unlikely to be beneficial to many aquatic ecosystems that are important to the current human population.

It must be assumed that there will be extremely wide spread change resulting from ocean acidification and other impacts of climate change and much of this change is likely to not be to the liking of the human population. The degree to which this change represents harm to the future of the total marine environment and the total quantity and diversity of the resources therein is, however, not well understood.

7.5.4 Extreme Weather Events

Weather events, such as extreme storms and floods threaten the short-term well-being of many marine systems and the availability of some fisheries resources. According to recent IPCC assessments, the frequency of extreme weather events is likely to increase over the coming decades (IPCC, 2007). Changes are expected to include an increased number and magnitude of storms, and more periods of drought and flood. Increases in wave-energy and storm events are likely to alter habitats such as coral reefs and adversely affect the reproduction rates of some animals such as turtles (CSIRO, 2006). There is also the potential to redistribute contaminants from sediments and increase their availability. The longer-term and accumulated effects of such secondary impacts are likely to exceed the direct and immediate impacts.

7.5.5 Changes to Ocean Currents

As for weather events changes to ocean currents must be anticipated but their impact cannot be accurately predicted. Changed currents and associated wind patterns coupled with a greater number of extreme weather events have the potential to impact many marine environments and fisheries resources. There will almost certainly be implications for various aspects of lifecycles, including the distribution and behaviour of plankton, fish and seabirds but the end result of all such changes on Australia's marine systems and fisheries resources, other than redistribution, while anticipated, can only be surmised.

7.5.6 Mitigation Activities (Marine Energy, Offshore Wind Farms, Carbon Sequestration and its Associated Infrastructure)

To combat increased atmospheric greenhouse gas concentrations, several methods of carbon sequestration utilising the ocean have been suggested. These include deep ocean storage of liquefied CO_2, storage of CO_2 in geological structures beneath the ocean floor, the promotion of phytoplankton growth via iron fertilisation, and the farming and use of algae for bio-fuel production. In addition, certain forms of renewable energy such as offshore wind, that has been utilised since the 1990s and wave, current and tidal power, if implemented, do and will change habitat structure and dynamics. Consequences include disruption to interrelated ecosystem functions, reduced connectivity and restricted access to forage areas, spawning grounds and aggregation sites etc. for marine biota, fishers of all persuasions and others that need or enjoy marine access. In addition to the installation of generating equipment, there is likely to be disruption from associated water and land based infrastructure developments; purposeful changes to tidal flows; increased human activity to construct, access and maintain infrastructure; the introduction of various chemicals and toxicants; and, increased dredging activity. Currently there are "*over 100 conceptual and early-stage designs for harnessing and converting the energy of ocean waves, tides and currents into electricity*" (Copping et al., 2013) and the marine energy industry is expected to grow rapidly from its present early stage of development. New and novel uses of aquatic environments and resources should be assessed in the interests of ensuring that new technologies do indeed deliver the benefits predicted and that new threats to marine ecosystem and fishery sustainability are effectively investigated, managed and ameliorated where and when necessary.

7.6 Ocean Based Activities

7.6.1 Ship related Accidents Waste and Debris

In addition to mechanical damage to marine environments from grounding of shipping, especially structured benthic areas including reefs there is also vulnerability to more regular shipping activities such as aggregations of anchoring off ports, accidents involving the loss of cargo, and chemical and oil releases. Oil spills and discharges can kill or damage both plants and animals through smothering and preventing respiration, reducing light levels, damaging thermal insulation and waterproofing and through direct and indirect toxicity effects. The toxic effects of oil and other chemicals may be lethal or cause behavioural changes, physiological damage to individuals and systems, and cause reproductive problems (as discussed under several individual threats).

The volatile content and molecular weight of petroleum and petroleum products influences the level of impact on marine organisms; highly volatile and middle molecular weight fractions being the most toxic (Clark, 2001). As a result of spills, habitats may be lost or damaged and the loss of key species may result in the opportunistic dominance of different, including invasive, organisms. In addition, the excessive or inappropriate use of oil dispersants can lead to considerable ecological damage (ITOPF, nd-b).

Oil contamination in the marine environment may also affect fisheries resources and/or mariculture facilities by directly contaminating seafood or tainting it. Fishing gear or cultivation equipment may become oiled, necessitating cleaning or replacement and consumer confidence may be reduced if oil spills are known to have occurred within fishing grounds or production areas.

Sedentary inter-tidal species such as edible seaweed and shellfish are particularly vulnerable. Fishing and harvesting restrictions imposed after oil spill incidents cause economic losses and food supply and security problems. These effects may be more critically experienced in developing country situations amongst subsistence producers but can also impact production and producers in market based environments such as Australia (ITOPF, nd-a).

Ballast water discharges are a vector for invasion by alien species. To combat this, new standards are being introduced to underpin the disinfection of ballast water before it is discharged to the environment. However disinfection by-products including low molecular weight halogenated substances, are themselves recognised to pose potential threats to marine environments (GESAMP, 2012).

7.6.2 Bilge Water, Tank Washing, Antifoulants, Criminal Activity and War-time Destruction

Wastes and discharges stem from the pumping out of contaminated bilge water; the disposal of water, oils and chemicals from tank washing; the disposal of general waste; and, the loss of cargo during heavy seas. The chemical and mechanical effects associated with these events can cause damage to habitats and the loss of or changes to biota.

Antifoulants are used to prevent the unwanted build-up of marine organisms on ship and boat hulls and other structures immersed in seawater. Coatings containing organo-tin and copper that leach and are toxic have been widely used. These compounds, however have serious effects on target and non-target organisms residing in the broader marine environment and have subsequently been subject to restrictions and bans. Tributyl tin (TBT) has numerous impacts, including the masculinisation of female shellfish, preventing their reproduction (Sharpe and Irvine, 2004) while "[l]*onger term effects in crabs, starfish and whelks include shell abnormalities, reduced body weight, limb deformities, and anomalous sexual characteristics. In some areas species have been lost*" (Howells et al., 1990). The European Union restricted (TBT) use in 1989 and the International Maritime Organisation (IMO) proposed the 2003 global ban of its use (van Wezel A. P. and van Vlaardingen P., 2004). The now restricted TBT remains in sediment for some 160 days after exposure so contamination levels do reduce when active usage is stopped. By design, however, effects are longer lasting when treated craft and structures are present.

New substances are becoming available to prevent fouling but many of these may also lead to environmental degradation (Feng et al., 2009). Antifoulants do not work unless they have some level of impact on at least some marine organisms. Impacts may be due to individual compounds or may result from combinations that are present in busy areas such as harbours, marinas and estuaries (van Wezel A. P. and van Vlaardingen P., 2004). In the UK, local restrictions have already been imposed on some replacement antifoulants and at least one compound has had its approval as an antifoulant revoked (Feng et al., 2009).

Further marine environment threats stem from criminal activity, smuggling and wartime destruction which can variously affect marine ecosystems and access to marine resources in different parts of the globe. Such activities have been recognised by the UN as an ongoing threat (Ban, 2009). It is assumed in this report, however, that this sub-category does not currently represent a significant threat to NSW's or Australia's marine systems or fisheries resources.

7.7 Ill-informed Perceptions/Ideologies

7.7.1 Biased/Misguided Human Perceptions

While it is recognised that many members of civil society justifiably desire or even demand greater levels of marine conservation, it is evident that conservation efforts and the debate on their appropriateness have favoured simplistic actions that have not always represented solutions. These tend to circumvent comprehensive understanding of the complexity of marine ecosystems and human interactions with them. A transposition of terrestrial management techniques that focus on a network of protected areas, ideally with some form of connectivity, has uncritically been given disproportionate priority as the preferred solution in marine waters (Kearney et al., 2013). A sanitised and neatly wrapped paradigm of human interaction with parts of marine systems has prevailed at the expense of management that effectively and efficiently addresses at least the prominent threats to all major components of the total marine environment in proportion to the severity of the threat. The public continues to be told that an adequate and representative sample of marine biodiversity has been, or is being, encased in selected areas that are then termed 'protected'. The resulting MPAs are espoused by governments and their supporters to provide adequate or even total and permanent protection (for example by the relevant Commonwealth Government Minister (Burke, 2012a, Burke, 2012b)), even though Australia's system of marine parks, the NRSMPA, is not based on addressing threats.

The very basis of the word 'protect' is that there is a threat. The provision of 'protection' requires the addressing of that threat or threats. The use of the term 'protected' implies that the threat(s) has/ have been addressed. The Australian Commonwealth Government has adopted an extremely optimistic assumption in relation to the fundamental platform for the provision of protection. It has assumed that 'marine parks' and 'marine reserves' are automatically 'marine protected areas': the three terms are described as synonymous (Australian Government, 2014). This assumption is then used as the fundamental justification for the declaration of marine parks even though the process for determining these parks and the management within them is not based on addressing threats (Marine Protected Areas Working Group, 2007). In reality, most threats are not managed adequately even in marine parks, and some remain not managed at all. The impacts of this inadequate management continue: for example, the Great Barrier Reef Marine Park Authority acknowledges in its most recent review that in Australia's oldest, most expensive and most intensively researched marine park the "*long-term outlook for the Great Barrier Reef is poor, has worsened since 2009, and is expected to continue to deteriorate in the future*" (GBRMPA, 2014 p. vi). The case studies presented in this report provide compelling evidence of similarly unsatisfactory outcomes that have resulted from the continuing failure to adequately identify and manage effectively the major threats to estuarine and marine systems in NSW.

7.7.2 Social/Political (Mis-use of Evidence)

Many of the threats to marine systems discussed in this report are not being effectively managed in NSW or in Australia more generally (as discussed above and demonstrated by RIS, 2012 and the subsequent action taken). Some are not included in assessments of environmental conditions while the management of others is ignored in favour of concentration on more visibly obvious activities, the threat from which has not been adequately assessed and prioritised. While the difficulty, or even impossibility, of adequately managing all threats must be acknowledged the failure to appropriately prioritise threats should be avoidable in a country that has significant scientific assessment capacity and sole sovereignty over its marine systems and responsibility for their protection.

That improvements in the alleviation of environmental degradation have occurred over the last 40 or so years, including in the marine environment, must not be ignored. The early 20th century witnessed the formation of numerous community and science-based groups that aimed to tackle issues that are now known to be formidable regional and even national environmental issues. In the late 20th century global directives promoting sustainable development spawned at least some government action worldwide. Australia has been at the fore in introducing regulation and legislation to ensure that sustainable practices underpin commercial and other activity; this is particularly evident in state and federal fisheries management legislation. Awareness, scientific assessment and management have all improved, albeit from a very low base, and fundamental conservation principles are now embodied in many of civil society's accepted practices and expectations. Management actions have not however, mirrored the assessed severity of each and every major threat in proportion with their relative capacity to cause impact.

8 Assessment of Risk

Assessing risk from threats involves consideration of global, regional, national and local components. The often highly publicised global components are documented in international literature and are variously promoted by large international conservation NGOs. Global issues also underpin the far reaching and all-encompassing agreements, concepts and treaties that attempt to focus development on generalised sustainable outcomes and aim to achieve international cooperation in managing biodiversity (1992 UN Convention on Biological Diversity (CBD, 1992)), the climate (1992 UN

Framework Convention on Climate Change (UNFCCC, 1992)) trans-boundary pollution ((1979 Long-Range Transboundary Air Pollution Convention and its numerous updates (UNECE, n.d.)) and stratospheric ozone loss (1987 Montreal Protocol (UNEP, 2011)) amongst others. As such they form an important aspect of global geopolitics and expectation both between nation states and by the citizens of individual countries, particularly in so far as they relate to issues such as human induced climate change for which global solutions are essential. Local components may be lesser known, attract much narrower publicity and their management may not be associated with high-profile kudos. Management of locally oriented issues, however, is likely to produce more tangible benefits and be more focussed and hence demonstrably cost effective while being more amenable to amelioration of problems within human scales and understanding. Furthermore focussing on management in the local context may actually underpin the more grand internationally promoted ideals and provide a more rational path to their objectives while also increasing society's appreciation of their importance. This report adopted the perspective of identifying threats as outlined in international and national literature and subsequently applied these to an Australian and particularly NSW context to detail the magnitude of threats, the effectiveness of management and the focus for future interventions.

8.1The implications of the scoring of threats and the management of their impacts (Table 1 (expanded in Appendix 1)).

The subjective nature of the scoring of each threat within each category in Table 1 is obvious and acknowledged. But what is not obvious is the degree to which each threat is currently having an impact in NSW, and the magnitude of that impact if it does occur. This makes the scoring of several characteristics of threats even more open to interpretation. For example the accuracy of an interpretation can be drawn into question when something is having intense impact in other areas (or countries) but is reasonably effectively managed in NSW and therefore the threat is assessed to be minimal. A relevant example is Destructive Fishing Practices: several forms of this, particularly dynamiting and cyaniding of reefs, can have intense impact if not managed but both are illegal and not practiced in NSW. Fish trawling and scallop dredging over vulnerable benthos can be destructive and so the use of both in NSW is tightly managed, scallop dredging being possible only after the issue of a special permit. The intensity of these threats is high but the impact is localised and managed. As such, impacts, although ongoing in some areas, are contained.

When considering the priorities for future management many combinations of the scores in Table 1 are possible and different combinations can lead to alternative priorities. Managers will obviously need to set their own priorities based on the criteria that determine their responsibilities. However, it is suggested that a combination of the intensity and duration of the impact with the likely cost-effectiveness of management (feasibility and cost) is an appropriate starting point for generalised prioritisation of threats.

The comments below on the prominent categories expand on those aspects of earlier comments that relate to how individual threats have been scored in Table 1 and priorities for management have been derived.

8.1.1 Land-based pollution and eutrophication

The first five threats (1 – 5) in this category are prominent forms of chemical pollution that are documented as representing current or potential problems for marine systems. These five by no means constitute an exhaustive list of the relevant forms of pollution. Furthermore, the intensity (short-term) and accumulated (long-term) effects of even the most prominent forms of pollution in NSW are not well understood. Most impacts are not clearly visible and not adequately researched. As a result, the combined impacts of all forms of pollution must be assumed to be broader and almost certainly greater than publicly acknowledged.

Pollution is a threat throughout NSW but the impacts of the threat from the many forms of pollution are far from uniform in space or time. There are instances of very high concentrations of pollutants in some areas, particularly in the proximity of industrial development e.g. Homebush Bay in Sydney Harbour, to the extent that they have been assessed to be a significant threat to human health (commercial fishing has been prohibited in the area to prevent sale of the inhabiting species and advisories issued for recreational fishers). Even in much less impacted estuaries, for example Port Hacking, very high concentrations (more than 20 times background levels) of several heavy metals have been documented in sediments in poorly flushed reaches. Even though the impacts of high levels of these pollutants have not been accurately described it would be most unlikely that they would not be a significant threat to some marine organisms, at least in the immediate vicinity of the original discharge or deposition of the pollutants.

The Port Hacking example is pertinent as this is an estuary that is generally regarded as being in good condition. There is no major industrial activity in the area and the primary source of pollutants is assessed to be run-off from roads and houses of the type that is common to most urbanised areas in NSW. It could be expected that the greatly elevated heavy metal levels reported in parts of Port Hacking would be prevalent in many similar estuarine situations that have not been sampled. It could also be expected that at the levels recorded in Port Hacking these pollutants would be impacting biota in at least localised areas and may have more wide-spread impacts, particularly if the impacted sediments are resuspended or even gradually translocated.

The total impact of this type of pollution is not well known, is extremely difficult to measure or even estimate but is likely underestimated by governments. Even the types of impacts that the pollution may have can only be surmised. For example fish, particularly larvae, that are infirmed by any cause, for example by the impact of pollutants, can quickly become prey for other fish and birds and thus their plight is seldom detected by humans. Non-extractive impacts are usually only observed when mortality is ubiquitous and widespread (such as occurs episodically in the Richmond and Clarence rivers; see case studies). **There is inadequate monitoring of the lower trophic levels of marine ecosystems and assessment of anthropogenic and natural factors that may cause fluctuations in their abundance.**

The localised impact of many forms of pollution is not well described but is likely to be higher than has been reported to date in NSW. As remediation of many forms of pollution is rudimentary across much of NSW the likelihood of the seriousness of their individual impact increasing as they continue to be discharged or recycled is high, resulting in an accumulation score of 4 for each of them (Table 1 Threats 1 to 5).

A large number of pollutants impact ecosystem health in a variety of ways and it is probable the impacts are at least additive or possibly magnified by synergistic effects or collective exposure; a fish or aquatic plant infirmed by one pollutant may be rendered more vulnerable to others. Furthermore, pollutants can impact many trophic levels simultaneously or serially if they magnify through trophic structures. For example, a pesticide such as DDT could kill or infirm zooplankton and larval fish that are present in an area at the time of initial impact and then magnify in larger more mobile fish or other creatures that eat the resulting carrion.

The collective threat from the many forms of chemical pollutants must be considerable (likely underscored in this assessment!), however from Table 1 it is apparent that the ease, feasibility, cost and time required to redress even a single threat is such that effective management of the suite of problems they cause is likely to remain elusive, even if conscientiously attempted.

The sixth form of terrestrial derived pollution, eutrophication and resulting algal blooms and deoxygenation, can result in far more intense (score of 4 which may understate its effect) though relatively localised, impacts. It is a particular problem in NSW and it is discussed in some detail in the case studies of the Richmond and Clarence Rivers and Baragoot Lake. Attempts to manage this particular threat can be rewarding (aggregate management score of 15) with results obvious in the immediate vicinity of manifestation of the impact of the threat. **This is a tractable threat and its remediation must be a high and immediate priority for NSW and other parts of Australia where the problem is significant.**

In several major NSW estuaries the problems of deoxygenation are confounded with impacts from the drainage, exposure and subsequent breakdown of acid-sulfate soils (threat 8). The intensity of the major episodes of discharge of low pH deoxygenated water commonly results in catastrophic impact (impact 5) including the death of all marine organisms over large reaches of river systems. These events are popularly referred to as 'fish kills' but this title seriously understates the significance of such events. It also demonstrates the bias towards responding to the visibly obvious impact of the event; the presence of dead large fish. **These mortality events should more correctly be termed 'total biota kills' or 'ecosystem kills'**. **The combination of extreme impact (score 5), localised cause and relative ease and cost of management of the problem (score 15) confirms a very high priority for its management throughout the NSW marine estate.**

Ocean dumping (10) and tailings disposal (11) both have relatively high impact if not tightly managed and both have very specific and easily identified causes. Neither is currently a major issue for marine systems in NSW. Both could be afforded greater priority for Australia more generally and both are relatively easily managed by strict controls on infrequent events. However, the relative value of the mining industry in Australia could be expected to skew estimates of the ease and feasibility of future effective regulation. Recent actions and decisions concerning the dumping of dredge spoil at Abbot's Point in the GBRMP are examples of both the magnitude of the possible threat and the compromises that can be expected in attempting to manage it.

Noise and disturbance (13) can have rather intense local impacts and because of their easily identified cause the threat can be usually attributed to individual operations, activities or even individual people. Furthermore, the impact usually diminishes very quickly after the activity ceases. Thus they would appear, superficially at least, to be relatively easy to manage. However, because of the popularity of some of the activities and sports involved it may not be feasible to adequately regulate the use and impacts of all sources, for example, fast, small, water craft that are the cause of considerable disturbance to surface dwelling marine organisms in numerous bays and inshore areas.

Thermal pollution (14) in estuarine NSW is dominated by power stations. In individual estuaries this can be a significant issue but on the scale of state-wide impacts it is not a major problem and having such a limited number of individual sources it would be technically relatively easy to fix. However, noting the social and political importance of the generation of electricity it may not be feasible to adequately address this issue in the short to medium term. **It is nonetheless a threat that needs ample consideration when approving future development and/or modifying existing activities.**

8.1.2 Overfishing, destructive fishing and illegal, unreported and unregulated fishing

Over-fishing (over-harvest and over-exploitation (17)) is repeatedly stated to be one of the major, if not the major threat to marine systems globally (for example Greenpeace International, 2014, WWF Australia, nd). This level of threat is commonly seriously overstated, even on the global scale (Hilborn and Kearney, 2012), but it should be afforded at least a moderate score (2 – 3) for intensity on a global scale and an even higher score (4) for accumulated impact in areas or regions where it remains unmanaged or continues to be inadequately managed. However, in this report it is accepted that over-fishing is much less a threat in NSW and Australia generally than it is in many other parts of the world (for example Pitcher et al., 2009). Since about 2000 over-fishing has been increasingly effectively addressed in Australia (for details see Kearney, 2013, Rowling et al., 2010) demonstrating that when problems are identified they can be effectively managed and that impacted resources do recover relatively quickly. As this report is NSW centric overfishing has been scored in the context to which it is relevant to NSW, i.e. as specific to an individual fish stock, to a particular by-catch issue or to an individual fishery and not as a generic or unmanaged threat. It is also unlikely that serious over-fishing would be allowed to continue and therefore its accumulated impact should be considerably less than in numerous other countries that do not have Australia's singular competence for the management of its fisheries resources.

Destructive fishing practices (18) are usually an intense threat (score 5) to the area in which they occur and if allowed to continue they could be expected to lead to very considerable accumulated localised impacts. The most damaging threats reported in other countries, dynamite and cyanide 'fishing' on reefs have, however, been banned for years in Australia and unless there is a fundamental breakdown in governance in NSW they can be considered to have been eliminated. Scallop dredging was considered to be unacceptably damaging to benthic communities in the areas in which it operated in NSW but it has now been so strictly limited in this State (a special permit is required) that no commercial scallop fisheries are currently permitted.

Bottom trawling over vulnerable benthic habitats is accepted to be damaging and if continued without control it can be termed a destructive practice. However two major issues impact the classification of bottom trawling in Australia: first, trawling is not allowed indiscriminately and where it is permitted it is tightly regulated, for example bottom trawling for Orange Roughy was deemed to be damaging to some marine ecosystems, particularly on fished sea-mounts and to the localised abundance of Orange Roughy. It has now been banned in 97% of the known distribution of the species in Australia (there is currently no trawling at all for Orange Roughy off NSW even though commercial catches were taken in the late 1980s); second, the type of trawling and the substrate over which it operates is of critical importance to the assessment of both the intensity and accumulated impact of its effect. In the only estuary in NSW where the immediate impacts of prawn trawling over the bed of a river, the Clarence, have been investigated it was found to be relatively benign (no impact on bottom benthos from individual trawls could be detected (Underwood, 2007)). This result surprised many, including the trawl-fishers. Underwood suggested however, that in an estuary subject to the major impacts of floods and other disturbances that were common in the Clarence River this result should not surprise. The other recent study of the impacts of trawling in NSW looked at fish-trawling in oceanic waters and even though lacking in compelling evidence it also failed to find a seriously damaging impact. In fact even though abundance of target species was, as expected, reduced by trawling biodiversity was, contrary to the expectations of most, found to be higher in the trawled compared to the untrawled areas (Savina et al., 2009).

For the reasons given above great care must be taken in scoring destructive fishing practices in NSW in relation to the priority for future management. The impact of the uncontrolled threat can be locally intense (4 – 5) if not managed and if allowed to go unmanaged it could have considerable accumulated effect (4 – 5), however it is being effectively managed in NSW and is most unlikely to be a significant threat in the foreseeable future; this is acknowledged in the scores of 2 for intensity and 2 for accumulated impact. The legislative requirements for sustainable fisheries and the relative ease and success already achieved with the management of over-fishing are reflected in the composite management score of 16.

Poorly managed aquaculture can represent a serious threat to marine systems and fisheries resources primarily through the inadvertent introduction or enhanced incubation and/or concentration of diseases and inappropriate use of feeds. The discharge of excess nutrients, escape of cultured individuals, particularly if of introduced species and damage to substrates below cages can also be problems if not adequately managed. Many complaints are made about the visible, or even potential, presence of aquaculture in an area (in the form of floats, moorings, cages etc.) but these are largely expressions of personal preference of individual human inhabitants of areas where aquaculture may be allowed than assessment of a threat to marine systems. NSW has very little intensive estuarine or coastal aquaculture other than the open farming of oysters and there is tight regulation of all forms. The only impact likely to represent a major accumulative threat is that from the introduction of foreign organisms (particularly for the aquarium industry or in feeds used in seafood production) that may prove difficult to control and impossible to eradicate. The aggregate score (13) of the characteristics of management is influenced by the priority given to this one potential threat from aquaculture.

Discarded or lost fishing gear is in NSW more an expression of undesirable or anti-social behaviour by fishers, both commercial and recreational, than a major threat to the sustainability of marine systems. Drift netting, the major cause of ‘ghost fishing’ globally, is not permitted in NSW. Entanglement and/or entrapment in other forms of lost netting, in particular lost or abandoned recreational crab dillies and traps, do occur and are problems. The threat is not major for the total ecosystem but its visual impact in particular, is considerable. It is of sufficient impact that it does need to be monitored and adaptively addressed.

Managed fishing only becomes a significant threat if management fails. The NSW Fisheries Management Act (New South Wales Government, 1994) stipulates strict conservation of marine systems above sustainable extraction of fisheries resources. However, vigilance is necessary to ensure the short-term interests of individuals in pro- and anti-fishing groups do not dominate the long-term interests of wise conservation of marine systems and sustainable seafood supply. Commercial fishing is more consistently monitored, in the form of catch returns and Government surveys (which are less numerous and intense than would be ideal), than are most other threats to marine systems, including recreational and indigenous fishing. Consequently there is relatively routine monitoring of the impacts of commercial fishing and as a result it is technically feasible to identify management options. The total costs of rectifying problems that might be detected are also reasonable and often negligible at the level of total government expenditure, even though the impact on a relatively small number of operators may be personally extremely significant.

Recreational catches in NSW represent an increasing fraction of total fishing activities and fish-landings and incidental by-catch of some key species (e.g. Greynurse Sharks). Accordingly the relative prominence given to the management of recreational fishing and the monitoring of the success of this management should be continually increased. **The legislative procedures are in place to ensure effective management; inadequate management of fishing of any form in NSW would be an expression of governance failure rather than the intractability of the problem**.

Illegal fishing does occur in NSW but it more an issue of compliance at the edges of legislation and regulations, such as exceeding quotas or bag limits and poaching of high priced species such as abalone, than the blatant and deliberate disregard for conservative management explicit in the claimed "*rape and pillaging*" (Grenpeace, 2011 p.10) of resources by foreign fleets that has engendered public outrage, influenced perceptions and made elimination of IUU fishing an international priority.

8.1.3 Alterations to physical habitats

Mining is one cause of prominent alteration of terrestrial and marine areas. Terrestrial mining is mainly an issue in NSW for aquatic environments in inland areas and the upper reaches of a small number of estuaries. It is still a threat that demands careful management. Sand mining, primarily for rutile and zircon, was a major issue adjacent to ocean beaches extending into local waterways (see Cudgen Creek case study) but such mining is no longer practiced and this particular threat (to be distinguished from ongoing impact) from mining has largely been removed.

There is currently no commercial mining of marine areas in NSW that is not more accurately described as dredging (25), but **if mining in marine environments is to occur it could represent an intense threat to local habitats that would need precise management.**

The fundamental characteristics, including salinity, of many NSW estuaries have been altered by watershed alterations (27), primarily in the form of dams, weirs, barrages, flood gates and drains. There has been some success with the management of the impacts of some of the smaller structures (see Richmond River case study) but removal of major structures, such as Warragamba Dam (that has had a major impact on the Hawkesbury River and likely the subsequent abundance of key species such as mulloway) in the interests of restoration of marine environments is fanciful.

Similarly, other forms of watershed alteration, such as housing and agricultural development, and deliberate watercourse changes resulting from training walls and bridges (28), and coastal development have all had intense impacts that will not be undone in the interests of restoration of pre-existing environments. The priority for management needs to be focussed on the control of future activities. Here it must be acknowledged that many coastal zone management bodies (for example Clarence Valley Council, 2010, Richmond Valley Council, 2007) have improved considerably their understanding of the impacts of terrestrial activities on marine systems and progress is being made in taking a more holistic approach to management that acknowledges the importance of marine systems and their vulnerability to terrestrial based influences.

The difficulty in managing the threats from tourism and recreation highlights the dilemma facing coastal zone managers. Specific threats, such as those posed by increased use of waterways, boat moorings and antifoulant paints, are increasingly well described and the need for a solution recognised. One solution for each is obvious (less watercraft of all sorts, less moorings and antifoulant paints that don't kill marine organisms or at least do not accumulate in the marine environment) and technically possible and not particularly costly to implement. The bad news is that in spite of these attributes they are extremely unlikely to be adequately implemented in the foreseeable future. **The social implications of drastic actions (too many people would be upset) and economic losses from the highly promoted and increasingly important tourism sector are such that the additional restrictions necessary to fully address the problems are not a political reality for the foreseeable future (currently not feasible in total).**

8.1.4 Invasions of exotic organisms

Introduced organisms represent a category of threats with high impact and potentially extreme accumulated effect on biodiversity. With increasing shipping to support growing global trade and the current failure to adequately control live imports, both unintentional (e.g. ballast water) and intentional (live aquarium species), coupled with the extreme difficulty in eradicating introduced organisms this threat is clearly worthy of greatly increased priority. **It is of great and immediate interest to NSW and even though the regulations and commitments that are necessary must be national if NSW is to effectively address the conservation of biodiversity in marine environments this threat must be regarded as a high priority**.

8.1.5 Global climate change

Changing or increasing average land and sea surface temperatures, sea level rise and ocean acidification are all realities, regardless of to what degree they are the result of industrial development, urbanisation or agriculture. They are all likely to cause great changes to marine systems and the distribution of fisheries resources. Temperature change and sea level rise will impact the distribution of marine organisms which will represent changes that humans do not like. However, they may not necessarily represent great threats to the continued existence of functional marine systems, albeit in somewhat modified forms, or the total abundance of fisheries resources. There may well be secondary effects of temperature change, such as increased absorption or impact of chemicals or increased virulence of pathogens that could be extreme but have not been adequately predicted or described.

The impact of sea level rise will be more acute in those estuaries of NSW where human development has changed land forms and water courses such that inundation of new areas to replace lost wetlands has become increasingly difficult or even impossible. While it will be impracticable to restore many reclaimed areas to wetlands, particularly in metropolitan areas, it would not be impossible to facilitate the inundation of more new wetlands in at least some areas as sea level rises. It will not be feasible for NSW to prevent sea level rise (feasibility score 1.5) or even to allow the inundation of sufficient new wetlands in all estuaries to locally compensate for the losses that will occur. However**, the feasibility**

of facilitating inundation of at least some areas in many NSW estuaries, particularly in less densely urbanised areas, and the consequences of not doing it wherever possible, make it a high priority for future management. The scoring of this threat in Table 1 highlights the difficulty in determining the appropriate priority for a threat that cannot be fixed by actions in NSW but for which NSW can take actions that will ameliorate to at least some degree the impact on this State.

Ocean acidification is in itself an impact of chemical pollution (predominantly CO_2) and should possibly be considered more in the context of other chemical threats than the physical threats from climate change. Acidification is anticipated to cause particular problems for marine systems and fisheries resources predominantly because the increased levels that are predicted are anticipated to impact the ability of numerous marine organisms to form exoskeletons and/or other essential body parts. Noting the prominence within the marine realm of organisms such as crustaceans and corals and in particular larval forms of these and others that are dependent on calcareous body parts, the potential impact of increased acidification on marine life as we know it may be extreme. It must also be noted however, that beyond laboratory based experiments that do not fully replicate aspects including seasonal cycles and an organism's adaptive capacity, such extreme impacts have not yet been apparent (for example Courtney et al., 2013) and it is possible actual impacts may be less than currently feared. Therefore the scoring of the threat from ocean acidification is very much based on the potential of the threat to have impacts. As such the score of 4 for accumulated impact may well be an aberration.

Change to ocean currents is also effectively a hypothetical threat in so far as its occurrence and impact are unknown; ocean currents do change. Increased change could be expected to have considerable impact on the distribution of species but the chances of impacting total fisheries productivity negatively (a threat) are not necessarily different to the chances of a positive (benefit) response.

Extreme weather events create changes, often intense, that marine systems have evolved to deal with; they will continue to do so. But more frequent and severe change will tax many systems and represent a threat to the lifestyles that many people have become accustomed to. It is reasonable to assume that the impact on land of extreme weather events will be more influential on human attempts to counter this threat. The threat of the change to marine environments is, on the basis of current information, unlikely to be sufficient in itself to provoke the effort, including expenditure and level of international cooperation, necessary to prevent the change.

Activities, such as carbon sequestration in marine systems, that may mitigate climate change can be expected to have unintended impacts, at least some of which could be expected to be negative. For example massive algal culture could impact ecosystems in the areas in which it operates. However, as all such activities are at this time totally hypothetical for NSW at least, it is debatable if they should be considered as more than possible threats.

Any future plans to develop marine energy facilities that utilise wave energy, tidal movements or currents should be individually, carefully assessed. Such projects would inevitably cause at least some direct change to habitats and local connectivity and also have associated impacts from supporting land based infrastructure and other increased human activities. Harnessed energy is no longer available to perform its normal and expected environmental functions and while the fraction of total energy that is harvested is usually extremely small, when coupled with associated infrastructure development the end result could change environmental characteristics and hence ecosystem functionality, even if only locally.

8.1.6 Ocean-Based activities

In view of the continuing increase in boating and shipping, accidents and incidental issues related to shipping could be anticipated to increase. However, improvements in navigational and avoidance technologies may well be such that negative impacts from accidents will decrease. Many of the likely impacts are covered under other threats, such as pollution and introduced organisms; these have accumulating impacts that are difficult to manage. Others, such as bilge-water discharges and tank washings (discussed separately, for example 7.6.2 and 8.1.4) are technologically manageable and it is feasible to expect them to be managed as problems are identified and prioritised. It is important, however, to effectively monitor new practices and technologies as they are introduced. By-products from new technologies to sterilise bilge water, for example, may themselves be found to be unacceptably damaging to marine environments where ships congregate.

8.1.7 Perceptions and ideology

There is a multitude of threats to marine systems and few of them are adequately managed. Some, such as introduced organisms, are technologically extremely difficult to manage once established while for others such as dams on rivers, management is feasible based on technological capability but not likely to occur because of the number of people unwilling to accept the sacrifices necessary. Consequently the political reality is that many impacts will remain inadequately managed for the foreseeable future.

In order to disguise the failure to address threats that the available evidence indicates should be high priorities, governments worldwide maintain the practice of overselling the benefit of what actions they are prepared to take. They also tend to exaggerate the benefits of minimalist actions which can be portrayed as addressing grand and general problems. International agreements that have extremely lofty goals, such as alleviation of poverty or climate change, but do not in themselves constitute compelling commitments to major and immediate expenditure, are extremely popular. Nurturing the shallow perception that a very public, but only partial commitment to a laudable international or national objective will result in an adequate response to pressing local problems is unfortunately a strategy common to many governments.

The nurturing of public misconception is also fostered by advocacy groups such as those NGOs who benefit from public support for campaigns consistent with the exaggerated projection of gloom and doom from not restricting fishing beyond the legislated requirements for sustainable fisheries (Hilborn and Kearney, 2012). Many of these NGOs do not base their ‘call to arms’ (the case for donations) on evidence-based evaluations of cost-effectively addressing cause and effect of threats to marine environments and fisheries resources.

Some misconceptions, such as a general unsustainability of Australia’s fisheries, are also encouraged as they support the rent-seeking activities of those who aim to benefit from the implementation and management of seafood certification schemes (Kearney, 2013). In Australia, with federal and state regulations applied to all fisheries through fishery management acts and with the additional conservation requirements of the overriding Environment Protection and Biodiversity Conservation (EPBC) Act (EPBC Act, 1999), such third party assessments of sustainability should not be necessary.

They can add to confusion amongst consumers and also result in a further layer of cost of seafood supply (Kearney, 2013).

Public perception is also swayed by the expressed opinions of scientists. There is therefore a considerable responsibility resting with scientists to ensure that opinions put to the public are soundly researched and objectively presented. The moral obligation of scientists as custodians of the investigative capabilities of society is to look beyond the obvious, particularly in pursuit of determination of cause and effect and the promotion of solutions to community-wide problems. In matters that impact the well-being of society, such as the pursuit of protection of ecosystems, logic dictates that the process should begin with probing investigation of the causes of the known and anticipated problems (discussed in section 7.7.1), i.e. the threats to existing components of ecosystems (biodiversity) and the composite ecosystems themselves. The public profile of Australia's approach to the protection of marine ecosystems has been disproportionately based on a commitment to a national system of marine parks that continues to not be based on identification and subsequent prioritised management of threats. Yet this system of parks continues to receive voluminous support from many Australian scientists that is all too commonly uncritical of the limitations of the actions taken to address the major threats to marine environments. This support is often in the form of consensus statements that generalise a call for more protection without first identifying priorities for actions on those activities that most threaten marine environments. Unfortunately the resulting generalisation can be at the expense of accurate and precise presentation of scientific assessment of what action is necessary in specific situations to provide effective protection. Consensus statements are driven by agreed advocacy for a particular position and their intent is to sway public perception. When accompanied by media campaigns that are well-funded, often by NGOs, they tend to have the intended impact. To protect public perception of the general effectiveness of science for addressing problems, such as the provision of effective protection of ecosystems, it is imperative that the content of consensus statements is scientifically precise and their message unbiased.

An example of imprecise presentation in a consensus statement relevant to this review of the management of the threats to marine environments and fisheries resources of NSW is provided by the 'Science statement on marine park zoning in New South Wales' of January 13, 2014 from 222 marine scientists (Statement of 222 Marine Scientists, 2014). This statement criticises specific NSW Government policy and actions in relation to recreational fishing on ocean beaches and headlands. It begins with acknowledgement of the variety of marine life that contributes to the value of the NSW marine environment. A list of species, which is selectively dominated by the icons of marine environments, such as turtles, seals and whales, then provides an emotive introduction to the need for conservation. The imprecision and bias in the 'Science statement' is immediately evident in that recreational fishing in sanctuary zones on ocean beaches and headlands, the subject of the statement, is not a recognised threat to the conservation of these highlighted species.

The key claim in this 'Science statement' relating to the role of science in the development of the relevant components of the marine parks process in NSW misrepresents reality in relation to ocean beaches. The "extensive scientific research" that was claimed to precede the declaration of fishing closures in NSW marine parks, even if it was extensive, did not include appropriately scientific research on ocean beaches. The 'Science Paper' used by the Government of the time as the justification for these closures broke fundamental principles of scientific enquiry and reporting. It misquoted and misrepresented numerous papers to repeatedly exaggerate possible benefits of marine parks, particularly as they related to fishing closures on ocean beaches (Kearney, 2007). The number of distortions of the available science, the way in which these distortions were presented and their consistency towards exaggeration of the asserted benefits of fishing closures were such that the bias could not be accepted as accidental. They were clearly the result of advocacy and not evidence-based science (Kearney, 2008a).

Exposure of the errors in this ‘Science Paper’ resulted in its withdrawal by the Government of the time and subsequent replacement by an updated version (MPA NSW, 2008). References to papers which, when accurately interpreted, refuted the original conclusions were removed, but the conclusions were not corrected. Selectively mis-using data to bolster a preferred position while deliberately deleting that which is known to be contrary, is abuse of science. In this instance it was tantamount to scientific fraud.

The seminal concluding comment in the 2014 ‘Science statement’ that, “Sanctuary zones free of extractive activities, such as recreational fishing i.e. ‘no-take’, must be the corner stone of marine conservation” displays advocacy for recreational fishing closures, but it does not confirm the presence of evidence-based science related precisely to the subject in question.

As discussed above, there was not appropriate scientific research to justify the original recreational fishing closures on ocean beaches. No new evidence is provided in the ‘Science statement’ to support the inference that ‘no –take’ zones as declared and managed in NSW marine parks will make a significant contribution to the provision of adequate protection of NSW beaches and headlands against the major threats to marine environments. Recreational fishing closures on ocean beaches will be singularly ineffective against virtually all of the major threats. In fact recreational fishing on ocean beaches is such a minor threat to marine conservation in NSW that its impact has not been the subject of ‘extensive scientific research’: the most recent review concluded “The review of the literature found no studies that specifically address the impact of recreational shore-based fishing at the amnesty sites or similar sites in NSW” (NSW Marine Estate Expert Knowledge Panel 2013).

The ‘corner stone of marine conservation’ should not be determined by inadequately evaluated assumptions but by the evidence-based determination of threats and management options in each situation. The Australian Intergovernmental Agreement on the Environment (Commonwealth of Australia, 1992) mandates such a priority-based approach.

For as long as governments can use imprecision in scientific statements they will continue to take the populist and usually the cheap, way out. In so doing they will continue to ignore the real cornerstone of sound marine conservation; the effective management of clearly identified threats in proportion to the severity of the threat in each situation.

8.2 Summary of Priorities

The implications of each and all of the various factors that have been scored in Table 1 would perhaps best serve the purpose of this project if they could be combined to provide a single quantitative ranking of priorities for future management, including addressing key gaps in knowledge. However, great caution is necessary when attempting to assign such definitive quantitative value to the assessments or discussions. Obviously there is great disparity between the dimensions described for the different factors and to manipulate the subjective scores of them as mathematically rigorous entities would be inappropriate. Uncritical acceptance of the scores themselves would be exacerbated by implying statistical rigor to combinations of them. However, it would be similarly misleading not to acknowledge that the relative importance of many variables should be taken into account when identifying management priorities. Obviously factors such as the likelihood of a particular threat, the intensity of its impact, the history of its impact in NSW, the ease with which it can be managed, and the performance of management to date should be considered in combination when determining priorities for future management. Accordingly some combination(s) of the grades and scores provided in this report should be useful for informing the debate on management priorities. Scores for individual threats and management implications are likely to be more informative for the priority setting process for specific situations once threats are identified for each circumstance.

9 Management Efforts

Overarching management responses that can improve marine environments and result in improvements to fishery resources have evolved over time. Some responses are targeted directly at natural resource management within marine systems such as the Food and Agriculture Organization guidelines (for example FAO, 1995, FAO, 1996) and Australian state and federal fishery management acts (for example Commonwealth of Australia, 1991, Government of NSW, 1994, Government of South Australia, 2007). Others are not primarily aimed at protecting marine resources but have significant flow-on effects. As a result, from a marine conservation perspective, management is susceptible to being fragmented both in its approach and through the allocation of responsibility (Thom, 2002).

There are many international agreements and treaties of significance to the marine environment. These include the 1979 Long-Range Transboundary Air Pollution Convention that has been repeatedly extended with protocols aimed at abating impacts such as acidification, eutrophication, persistent organic pollutants and heavy metals (UNECE, n.d.); the 1985 Vienna Convention for the Protection of the Ozone Layer (UNEP, 1984) (and particularly the associated 1987 Montreal Protocol) (UNEP, 2011); the 1972 London Dumping Convention coming into force in 1975, aimed to control dumping in and pollution of seas (UNEP, nd); the 1982 UN Convention on the Law of the Sea (UN, 2012); the 1992 UN Convention on Biological Diversity (CBD) (CBD, 1992); and, the 1992 UN Framework Convention on Climate Change (UNFCCC) (UNFCCC, 1992).

The success of these and other international conventions and agreements has been varied. Radiation is one highly regulated area where significant achievement has been made globally in understanding, managing and controlling radioactive substances especially since the 1955 establishment of The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The Montreal Protocol to the Vienna Convention formalised the reduction in manufacture and utilisation of stratospheric ozone depleting substances. This has impacted the marine environment by affecting the amounts of exposure to UV-B radiation. Primary production can be reduced as UV-B radiation increases while breakdown of some pollutants may benefit from increased exposure.

Global efforts to reduce atmospheric carbon dioxide via the United Nations Framework Convention on Climate Change (UNFCCC) are primarily aimed at preventing anthropogenic impact to the climate system. In a marine context, benefits may arise from improved energy efficiency and resource use resulting in lower levels of waste entering the marine environment, the reduced risk of extreme weather events and a slowing of ocean acidification. Some adverse effects on marine environments may also occur through the enhanced use of aquatic systems for renewable energy production.

The Convention on Biological Diversity (CBD, 1992) was developed to pursue the objective of "*the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources…*" (CBD, 1992 p.3). Various measures to maintain biological diversity and protect habitats in the context of individual nation state's various environmental policies and development agendas are stated. In-situ conservation in the form of "*protected areas or areas where special measures need to be taken to conserve biological diversity*" (CBD, 1992 p.6) is detailed with the purpose of conserving biological diversity and promoting its sustainable use "*as far as possible and as appropriate*" (CBD, 1992 p.6).

Other environmental initiatives aimed at efficient resource use, energy efficiency and cleaner production that may even be promoted as medium or long-term cost saving measures benefit marine environments by reducing waste streams that enter aquatic environments both directly and via polluted air. The 'cleaner vehicles and fuels strategy' (NSW Government, 2011) is an example of a programme that can indirectly, but significantly, benefit the condition of waterways and the marine environment.

While some local efforts have flowed from international declarations that were aimed at highlighting significant or high profile environmental and conservation issues most are more direct responses to Australia specific and localised impacts, as is the case with acid sulfate soil management. Acidification associated with drainage and excavation of acid sulfate soils is a widespread problem along the east Australian coast (Dove and Sammut, 2013, Sammut et al., 1996). In addition to the case study estuaries discussed in this report, in the Manning River an estimated 1000 t of sulfuric acid is released into the estuary annually from rural runoff, impacting on estuarine ecology, fisheries and oyster production. Most acid discharge results from early drainage schemes that have disturbed acid-sulfate soils.

Since the 1980s the Manning River acid sulfate management programme has involved improving understanding of the issue. Remedial work by Greater Taree City Council since 2003 has involved land acquisition at Cattai and the Big Swamp totalling 1200 Ha. Drain management to restore tidal inundation, raise water tables and encourage vegetation recovery is improving water quality, with total expenditure to date of $3.58m. The programme and remediation works have also promoted community understanding of the importance of wetlands and acid sulfate soil remediation more generally (Greater Taree City Council, nd).

In addition to the direct management of Australia-wide impacts, the management of locally known problems can also be bolstered by globally promoted umbrella causes; "*more recently, the need for remediation of former wetland areas has been furthered by the opportunities for carbon sequestration in the context of global warming. Sea level rise may also affect remediation strategies at some sites in the medium to long term*" (NSW Government, 2013c).

In Australia, a far reaching community-based initiative to reduce environmental degradation from agriculture is the Landcare programme that has been active since 1989. By providing a sustainability framework, it underpins the management of agricultural impacts including sediment and nutrient loading of waterways, pesticide runoff and riparian damage (Landcare NSW, 2014).

Local councils, through the grant of building and other development approvals as detailed in documents such as Richmond Valley Council's '*Guidance for Construction Activities*' provide management of ASS areas to ensure "*long term sustainability of the land and water systems in the area*" (Richmond Valley Council, 2007).Through this process, future disturbance is managed but amelioration of existing problems is not completely addressed.

Invasive species are also recognised as being a threat to native ecosystems and the NSW Government aims to prevent, or at least effectively manage the introduction and spread of invasive species so that this significant threat is minimised (DPI, 2008). While this strategy has a terrestrial focus, there are overlaps with management needs applicable to marine environments. The example of the recent discovery of the noxious introduced fish, '*Tilapi*a *sp,* in the case-study Cudgen Creek, and consideration of its possible eradication or containment is relevant.

In fulfilment of Australia's obligations under the London Protocol to prevent marine pollution by dumping of wastes and other matter, waste dumping and pollution discharges in Australia's marine environment are regulated by the *Environment Protection (Sea Dumping) Act 1981*. Permits are required for all ocean disposal activities, which include dredging operations, the creation of artificial reefs, dumping of vessels, platforms or other man-made structures, and burials at sea. Water quality impacts from sewage treatment plants, primarily aimed at human health risks, particularly for beach users, and in some areas for mariculture such as oyster cultivation, have resulted in numerous sewage treatment plant upgrades (as detailed in the case studies, especially Lake Conjola). These upgrades benefit the broader marine environment. The environmental performance expectation within civil society of industrial facilities has also grown, particularly since late 20th century. Waste streams entering the atmosphere and waterways are, on average, better managed and regulated. Environmental management systems within individual organisations, partly in response to tightened legislation and partly to appease societal demands promote a process of continual improvement in environmental performance and continual reductions in toxic waste discharges. These advances benefit estuary and ocean conditions although legacy impacts, particularly those within estuary sediments are present and are at risk of causing renewed harm if disturbed. **Marine system impacts that are noteworthy for not being well managed at present include agricultural chemicals: stormwater runoff, particularly that affected by road vehicles; pharmaceutical residues in sewage; endocrine disruptors; marine invasive species; and climate change.**

It is apparent that much of the Australia-wide and even local effort in ameliorating environmental impacts and managing threats is based on international actions and obligations that arise in response to those actions. While this form of response has certainly heightened public awareness of the issues and resulted in numerous high profile actions intended to improve the marine environment, the global approach is commonly deficient in that it is not adequately cognisant of locally specific impacts and conditions. It also suffers from a lack of performance indicators that are appropriate for each situation and binding public accountability against relevant indicators. Some NGO campaigns, especially those that are internationally orchestrated, lobby governments into generalised actions favoured by individual NGOs that civil society has been led to believe are of paramount importance. As a consequence more locally relevant aspects of international agreements and sustainable development more generally can be overlooked. The CBD, for example notes that "*conservation and sustainable use of biological diversity is of critical importance for meeting the food, health and other needs of the growing world population*" (CBD, 1992 p.2) while "*protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources*" was a stated outcome of the 1992 UN Conference on Environment and Development (UNCED, 1992). As such, these statements lend support to the sustainable and equitable utilisation of natural resources and while promoting conservation to underpin ongoing access to ecosystem services, as discussed in section 10 they do not advocate the excising of large productive areas from human interaction as advocated by many NGOs.

The relatively recent decisions by the NSW Government to take a more evidence-based approach to marine conservation that gives priority to the identification of threats to marine environments no matter where they arise (MEMA, 2013) stands out from the more loosely defined international perspective and national perception of how marine environments and resources should be managed.

10 Marine Parks: their role in addressing threats to NSW marine environments and fisheries resources (expanded comment specifically requested by the NSW FRAB in the context of the current review of the role of marine parks in the management of the NSW marine estate)

10.1 The role of representative areas in the management of threats

Marine environments and fisheries resources are constantly changing. The rate of change has increased greatly in many global locations in the last 200 years. Many threats to a huge variety of marine environments have been identified, with examples given in this report. The vast differences between the different threats dictate that different approaches would be required to efficiently address each of them. It is readily apparent from the case studies considered in this report and from other relevant literature that many threats have not been adequately described or quantified and are not currently being adequately investigated and then appropriately managed. This conclusion must be considered in the context of marine parks being the prominent marine environment management paradigm currently promoted in most of Australia's waters. The threats based approach identified for NSW under the Marine Estate Management Authority (MEMA) (MEMA, 2013) is a notable exception.

Australia's approach to marine conservation has been very publicly centred on a national system of marine protected areas, the NRSMPA, that relies disproportionately on the regulation of fishing. This preoccupation with additional controls on fishing is usually at the expense of identification of threats and management tailored to address each in proportion to its severity. That governments continue with this approach is understandable when their own research and management departments and agencies provide documentation that supports the case that marine parks represent the most appropriate cost-effective conservation (for example RIS, 2003, RIS, 2012). This approach is the more questionable given that they are not based on addressing identified threats or guided by adequate cost-benefit analyses and appropriate performance indicators (Kearney and Farebrother, 2014). Marine parks as implemented in Australia are certainly cheaper than effectively addressing the prominent threats and when supported by well-funded advocacy campaigns they foster the public misconception that appropriate action is being taken. Advocacy for uncritical support for more fishing closures in marine parks has been funded by many NGOs who benefit from public support for laudable concepts, such as the conservation of environments, without providing critical evaluation of how appropriate goals can actually be achieved. The continuing decline in the condition of Australia's most iconic marine park (De'ath et al., 2012, UNESCO, 2014), the Great Barrier Reef MP, provides compelling evidence of the consequences of not addressing threats in accordance with their assessed priority. The case studies considered in this report provide further evidence of the need for management that is targeted as threats that are specifically identified for each location.

From an examination of marine environment threats, such as detailed in this report, it becomes apparent that zoning in marine parks is seldom an appropriate strategy for addressing impacts, particularly those from invasive threats such as pollution and introduced organisms that have no respect for boundaries of zones (Kearney et al., 2013). Such vectors are now recognised to be the major threats to the ecological integrity of coastal Australia, including even the Great Barrier Reef (as summarised in Brodie and Waterhouse, 2012) which is much more remote from terrestrial-based impacts than the coastal regions of NSW. In spite of the increasing recognition of the impacts of these threats, accurate measures of their impacts and performance indicators on the effectiveness of management efforts are not commonly the priority in Australia's marine management. Again the strategy proposed for NSW under MEMA stands out as a more rational approach.

The primary, or at least initial, impact of invasive threats such as pollution on coastal areas is commonly on the lower trophic levels of marine systems, such as phytoplankton and zooplankton, and the building blocks of living reefs, for example corals. But measurement of impacts on lower trophic levels is not routine and certainly not comprehensive; in NSW the monitoring of impacts that does occur is disproportionately concentrated on the visibly obvious, for example marine mammals, large fish species and sea grasses as evidenced by aerial images of change. Many of the agents of major change to marine systems, such as pollution, are commonly invisible and few of the primary or initial changes they cause are readily detectable by the non-expert. These changes are also usually less intensely researched than their more obvious counterparts.

The failure to identify and use appropriate indicators of ecosystem well-being has contributed to seriously disproportionate use of the relative abundance of larger, more visible species in different areas as measures of ecosystem health and the effectiveness of its management. In the case studies for this report it is detailed that the impacts of pollution from deoxygenated water and acidic soil runoff have commonly only become the subject of management when they reach such catastrophic levels that even the apex predators, large fish, are killed and problems become visibly so obvious they cannot be ignored (see the Richmond River case study). The relative abundance of apex predators within what are complex ecosystems has become a totally distorted indicator of the health of Australia's marine systems. This is exemplified in the marine parks process. The many claims that marine parks work (e.g. Possingham (2011) reports there are more than one hundred examples) are dominated by reports of the elevated relative abundance of large, visibly prominent, fish or crustacean species in 'protected' versus fished areas.

Undetected change remains a particular problem at lower trophic levels where the first, and often the greatest, primary impacts of invasive vectors such as pollution commonly occur. Unfortunately few studies have used primary indicators of ecosystem health or biodiversity conservation from the trophic levels most impacted by pollution as descriptors of the effectiveness of marine parks. The use of the relative abundance of fished species that have in many cases previously been deliberately 'fished-down' to levels that optimise productivity and that quickly and directly respond to changes in fishing pressure as indicators exaggerates the conservation outcomes of fishing closures. It distorts the relationship between fishing and true ecosystem well-being. Detecting higher abundance of selected species in an area closed to fishing does little more than confirm that abundance of target and associated species can be regulated by changing catch. It is not a robust measure of holistic conservation outcomes. Its preferential use is to the detriment of accurate evaluation of the effectiveness, or lack thereof, of protection for the individual components of different levels of the system (i.e. biodiversity) and of net benefit to broader ecosystems.

The dominant threats, such as climate change and pollution in many forms are now accepted to result in ocean acidification and other forms of deterioration of water quality. Changes to water quality are in effect changes to the basic marine environment that supports ecosystem health and subsequently fish abundance. Gilbert (1997) highlights the impact of environmental variability on one key component of this ecosystem, spawning bony fish stocks. Periods of low recruitment of bony fish appear to be in the main environmentally driven and the lower limit of stock size that is capable of producing reasonable recruitment is in fact a very small fraction (much smaller that minimal stock size permissible under good fisheries management) of the maximum stock. Others project from this that low environmentally driven recruitment reduces spawning stock size to a greater extent than the spawning stock size determines recruitment (Szuwalski et al., 2014, Vert-pre et al., 2013).

To the extent that environmental variability can determine recruitment at most trophic levels and that anthropogenic activities influence environmental quality, it is evident that the impacts of pollution in its many forms are more likely to be the primary drivers of ecosystem health, including the recruitment of fish species. Regardless of the cause of change in environmental health, indicators of it from lower trophic levels, or larval forms of higher levels, are more likely to represent real-time and more direct descriptors of change and the causes of it than are the numbers of large apex predators. To this end the reported declines, for example, of approximately 50% of the coral cover in the GBR (De'ath et al., 2012) are providing more timely and direct measures of the status of the Reef and its surrounds, the threats to it, and the influence of current management, than is the change in abundance of lightly exploited and alternatively managed reef fish (further discussed in Kearney and Farebrother, 2014). The same principle applies to all Australia’s marine waters with even greater need for lower trophic level indicators of ecosystem health and the impacts of specific threats in the more anthropogenically impacted areas, such as the estuaries and coastal ecosystems of NSW. This further questions the current predominance of estimates of visible abundance of previously targeted species as indicators of the effectiveness of marine parks for providing comprehensive, or even appropriate partial, protection of marine environments, particularly in inshore areas such as estuaries and ocean beaches.

An alternative perspective of marine environmental management can be based on the increasingly accepted concept that in a changing global environment more holistic management of total ecosystems is necessary. More comprehensive indicators of ecosystem health are necessary and active management of the total ecosystem and its living resources is increasingly accepted as preferable to ‘setting aside’ part of it (IUCN WCPA, 2005, IUCN WCPA, 2010). It is argued that for terrestrial environments some exploitation, or intermediate disturbance (Krohne, 2001), is beneficial for total ecosystem management (Götmark, 2013, Leopold et al., 1963). For marine systems with their greater inter-connectivity and mobility management of the total system, including its exploitation, is a preferable option (for example Buxton et al., 2006). Such holistic management is consistent with the previously suggested benefit of intermediate disturbance even in offshore waters of NSW (Savina et al., 2009). Careful control of exploitation over the whole area of impact and targeted management of specific threats wherever they occur is more likely to provide effective conservation outcomes than closure to well managed exploitation within pre-determined subsets of areas in regions that are interconnected and subject to multiple agents of change. Again the relevance of the threats-based approach proposed for NSW under MEMA is prominent (MEMA, 2013).

Noting that at least most of the agents of change identified in this report and elsewhere are likely to have greatest impact, at least immediately, on lower trophic levels, it would follow that not only would apex predators not be the most appropriate primary indicator of the success of ecosystem conservation, but they are also unlikely to be the most appropriate trophic level at which to target management. Depending on the relationship between different trophic levels it is likely that controlled exploitation of carefully targeted predator species (well-managed fishing) would, by impacting predation, be beneficial for those lower trophic levels that are being independently more heavily challenged. Well managed fishing across the whole region could well be more beneficial for the protection of biodiversity and the resilience of the total ecosystem than setting areas aside from all fishing. This would not preclude the allocation of selected areas of appropriate type for research or for the benefit of non-extractive users, such as underwater observers (for further discussion see Kearney and Farebrother 2014). Acceptance of more precise objectives for areas closed to fishing would also greatly facilitate assessment of the size of the area of closure that would result in cost-effective management, rather than adherence to pre-determined closure targets for all types of areas and environments.

Rather than basing marine conservation on addressing clearly identified threats, Australia has given disproportionate priority to the concept of identifying a sample of all types of habitats and their contents, asserting it to be adequate (CAR (comprehensive adequate and representative)) and subsequently claiming it to be protected. While the simplicity of this approach is seductive the available evidence is progressively challenging the principles. The continuing decline in even some of the most intensely managed marine parks, for example the GBRMP (UNESCO, 2014, UNESCO, 2013, De'ath et al., 2012) progressively questions the likelihood of achieving appropriate conservation through a system of marine parks as currently designed and managed in Australia. Nonetheless Australian governments have continued to roll out marine parks that prioritise further restriction of fishing, usually to the detriment, or even exclusion, of addressing other threats. This is primarily because it is relatively easy to do so and much cheaper than preventing the impacts on marine environments of climate change, industry, agriculture, coastal development and introduced organisms and the plethora of other threats identified in this report. The electoral rewards of nurturing the biased perception that effective management of marine environments is being provided at limited expense to interested parties are considerable (Kearney et al., 2012).

11 Conclusions

11.1 Evaluating the impact of threats

Collectively the reviews of the seven case study estuaries paint a picture of dramatic change and continuing problems. Previous assessments of the state of all NSW estuaries (for example Roper et al. 2011) indicate that the seven selected here are representative of this State's estuaries, thus confirming great changes to the coastal ecosystems of NSW. There is undoubtedly increased awareness of the plight of aquatic ecosystems and considerable effort is being made by numerous state and local government agencies and independent interest groups (such as OceanWatch and Landcare) to address at least some of the issues. However, the collective evidence leaves little doubt of great change having been made to the State's coastal ecosystems and a level of remedial action that is slowing the rate of change but not by any means addressing all major threats or compensating for all past and numerous continuing actions.

The rate of change caused by deliberate destruction of aquatic habits in the name of development is slowing and remedial actions to address past excesses are increasingly evident (for example in the Cooks River (Botany Bay case study) and Richmond River). However, the available evidence, albeit unfortunately scant, suggests that the collective impacts of more insidious changes resulting from population growth and technological development, such as result from pollution and introduced organisms, are continuing to accumulate. New threats are appearing, many threats have not been accurately described and numerous known threats are not being adequately addressed, for example agricultural chemicals and introduced organisms. In fact the lack of description of all threats and assessment of how each could be cost-effectively addressed is an unfortunate feature of the available documentation.

11.2 Indicators of the effectiveness of the management of the NSW marine estate

The priority given to identification and management of threats to the total marine estate in NSW through the creation of the Marine Estate Management Authority and the objectives given it are refreshing expressions of intent based on a holistic approach. Hopefully they will be followed up with thoroughly researched objectives and performance indicators that truly reflect the effectiveness of management in protecting the total estate, including the fisheries resources it supports. At present there is a serious lack of assessment of the health and productivity of the total aquatic ecosystem and also a lack of appropriate performance indicators of the effectiveness of management attempts.

Fisheries catch statistics remain a primary indicator of the productivity and well-being of the State's fisheries resources. For all their serious limitations they remain one of the best available data sets that can be related to the total impact on the higher trophic levels of marine systems. However, they are poor indicators of the cause of problems and they are imprecise indicators of change and the time-scales over which it is occurring. Furthermore, interpretation of them as descriptors of cause and effect is commonly distorted. When declines are detected in catches, fishing is usually automatically assumed to be the cause; the common management response is further restriction of fishing. This response creates the impression that corrective action is being taken which in turn masks the need to thoroughly describe cause and effect and develop measures that specifically address the real underlying problems.

Noting the magnitude of the changes to estuaries and the declines in many indicators of ecosystem health it is inappropriate to use the relative abundance of target species that are independently managed by effort and catch controls as indicators of ecosystem well-being. The reported relative stability in catch rates in the fisheries in NSW (Rowling et al., 2010) is likely more attributable to the continuing decrease in commercial fishing effort than excellence in managing sustainable development or the maintenance of total productivity of the NSW marine estate. Even though the catch rates of most individual species have been assessed to be sustainable total commercial catches are declining disconcertingly (derived from Rowling et al., 2010 and Fisheries NSW unpublished data). While a significant part of the decline in commercial catches is due to the continuing allocation of more of the total resource to recreational interests it is difficult to accept that the inshore fisheries resources of NSW are as healthy as the commercial catch data and the available analyses based on them would suggest. There can be no doubt that the total ecosystem that supports fisheries resources has been, and continues to be, seriously threatened. Better primary indicators of the health of marine environments and the impacts on them than the relative abundance of target species in fished and unfished areas is required.

11.3 The effectiveness of marine parks as implemented in NSW in providing marine conservation

It is evident that marine parks as currently implemented in NSW are not an adequate management response to any of the major threats to the ecosystems or fish resources of NSW estuaries and inshore areas, particularly ocean beaches. The available evidence on the nature of the key threats, their impacts and how they could be effectively managed confirms that espousing ‘no-take’ closures as the cornerstone of marine conservation in NSW (Statement of 222 Marine Scientists, 2014) is misguided. Advocacy for imprecisely defined objectives distracts attention from the need for more specific responses to the real threats to the NSW marine estate. Hopefully this will come in response to the expressed intent to managed the NSW marine estate more holistically (MEMA, 2013)

11.4 Threats for priority management

The need to base management of the NSW marine estate on a threats-based approach is logical and appropriate. All of the threats listed in Table 1 and discussed in this report have at least some relevance to the marine systems of NSW and Australia more generally. NSW would benefit if they were all effectively managed. However, the priority given to management by individual management authorities, such as the NSW Government agencies, will be impacted by many factors including, the magnitude of the local impact, the immediacy for a response, the responsibility for a response, the cost of the necessary action and the likelihood of success. Within these constraints and noting the scores given to the selected characteristics of threats and impacts in Table 1, the highest priorities for ongoing management of the marine estate are clearly more accurate description of the threats, most obviously those from pollution and in particular agricultural chemicals, and the management of the perception of the NSW public founded on evidence-based evaluation of actual cause and effect of impacts. A more strategic approach that openly acknowledges the general threat from human population growth, the more direct impacts of increased urbanisation and industrialisation and the limitations of current management actions is clearly necessary. More immediate and specific positive outcomes from management within NSW will come from the following: the remediation of discharges of acidic and deoxygenated water into the estuaries of NSW (threat # 8 and also # 6), restoration of flow regimes and salinity changes (centred around threats 25 – 29), reduction of the impact of boating, including damage from moorings and antifoulant paints (# 31) and more effective management of litter, debris and micro-plastics (# 9). Spanning all of these management efforts, advantage would be gained from an ongoing national program to inform and educate the broad spectrum of stakeholders in the need for and benefits of evidence-based policy guidance and monitoring of environmental conditions that is based on performance indicators that reflect critically assessed impacts. If aligned with ESD principles and correctly interpreted international and national priorities and commitments such a program could alleviate ideological barriers and perceptions that can preclude the timely implementation of scientifically sound priority measures (#42).

11.5 Management of the threat from fishing

Overfishing can represent a threat to at least fisheries resources and some associated ecosystems and that threat must be managed. However, in general the impact from overfishing in Australia is not great and is more easily managed than that from most forms of habitat destruction and pollution. In areas such as NSW where fisheries are actively managed and monitored, overfishing does not usually occur suddenly and its impacts are seldom extreme and usually relatively quickly reversible. However, the public perception of the harm caused by overfishing in NSW and Australia generally currently greatly outweighs the threat that fishing actually represents. As a result reports of overfishing continue to lead to attitudes against fishing that are disproportionate to the relative significance of the actual threat. The resulting management responses are currently likely to include total closures of areas to all forms of fishing at the expense of efficient management of the specific cause of the problems.

Commercial and recreational fishers need to be aware of the likelihood of disproportionate and inefficient responses to reports of overfishing and to minimise the chances of such reports; they need to minimise the chance of serious overfishing and the misreporting of declines in fish population from other sources being attributed to fishing. Obviously they need to support ongoing traditional fisheries management measures that are demonstrably conservative and better integrate the impacts of commercial and recreational fishing, thus minimising the threat that overfishing will occur. However, they also need to actively promote monitoring and assessment of all major impacts on the status of fisheries resources and more holistic approaches to the management of all threats to the underlying resource base (the marine estate).

11.6 International precedents

Australia has been party to many international management arrangements and conventions that impact marine resources, Governments have unfortunately allowed the laudable but generalised global intent of these commitments to distract management efforts from the identification and prioritisation of specific actions to address national and/or more localised problems. The conventions which describe most global initiatives are the result of negotiated compromise that is biased towards acknowledging and accommodating the limited capabilities of at least some signatory nation states, i.e. the principal of accommodating the lowest common denominator. They should not be allowed to distract more advantaged governments from taking the specific actions appropriate to address priority threats.

Australia is blessed with the capability and geographic advantages of a developed and relative remote island state. As such it is able to base its marine conservation and resource use actions on prioritising objectives that are specific to each situation, including cost-effectively addressing carefully identified and prioritised threats to individual marine environments. It must not allow imprecise assumptions, global generalisations or translocation of the implications of other countries' problems and inabilities that are irrelevant to Australia to distract or misdirect management efforts.

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Project materials developed

Two papers related to this work and destined for peer reviewed journals are currently being produced. The first is focussed on the identification and assessment of marine environment and fishery resource threats. The second discusses the interaction of evidence based science and policy development in the sphere of marine conservation and sustainable resource utilisation.

Appendices

Appendix 1 Identified Threats to Marine Environments and Fishery Resources

Full version of Table 1 Identified Threats to Marine Environments and Fishery Resources showing threat categories and descriptions, the dominant scale of each threat, key causes, and management.

	Threat Category and Description			Dominant Scale of Threat				Key Cause			Management of Threat					
ID #	CBD category	Threat Type	Nature of Threat	Spatial Scale	Temporal Scale	Intensity	Accumulation	Urbanisation	Industrialisation	Agriculture	Ease	Feasability	Cost	Time	Total	Performance
1	Land based pollution and	heavy metals	c	local/regional	c-d	2	4	x	x	x	2.0	2.0	1.5	2.5	8.0	d
2	eutrophication	halogenated hydrocarbons PCBs OCPs PBDEs	c	local/regional/global	c-d	2	4	x	x	x	2.0	3.0	1.5	2.0	8.5	c-d
3		polycyclic aromatic hydrocarbons PAHs	c	local/regional/global	c-d	2	4	x	x		2.0	2.5	1.5	2.5	8.5	c-d
4		pharmaceuticals including medical hormones	c	local/regional/global	a-c	2	4	x	x	x	2.0	1.5	2.0	3.0	8.5	d
5		endocrine disruptors including hormones	c	local/regional/global	a-d	2	4	x	x		2.0	1.5	2.0	3.0	8.5	d
6		**eutrophication/nutrients/algal blooms and toxins**	c	local/regional	a-b	4	2	x	x	x	3.5	4.0	3.5	4.0	15.0	c
7		pathogens	o	local/regional	a-d	3	3	x		x	2.5	3.0	2.0	3.0	10.5	b-d
8		**acid sulphate run-off**	c	local/regional	a-b	5	3	x		x	4.0	3.5	4.0	3.5	15.0	b-c
9		**litter, debris and micro plastics**	p	local/regional/global	a-d	2	4	x	x		3.0	3.0	3.0	3.5	12.5	d
10		ocean dumping	p	local/regional	a-d	4	3		x		4.5	3.0	3.5	4.5	15.5	b-d
11		tailings disposal	p	local/regional	a-d	3	2		x		4.0	3.0	4.0	4.5	15.5	d
12		nano particles	p	local/regional/global	d	3	3	x	x		1.5	2.0	1.5	2.5	7.5	d
13		noise /physical disturbance/light	r	local/regional	a	3	2		x		2.0	1.5	4.0	4.5	12.0	d
14		thermal pollution	r	local	a	2	1	x	x		3.0	3.0	4.0	4.0	14.0	c
15		UV-B	r	global	c-d	1	3	x	x		2.5	3.5	3.0	3.0	12.0	b
16		radioactive substances	r	local/regional/global	b-d	1	2	x	x		2.5	2.5	1.0	3.0	9.0	a&d*
17	Overfishing, destructive fishing,	overfishing	e	local/regional	a-b	2 (3)**	2 (3)**		x		4.0	4.0	4.0	4.0	16.0	b-c
18	and illegal, unreported and	destructive fishing practices	d	local/regional	b-d	2	2		x		4.0	4.0	5.0	4.0	17.0	b
19	unregulted (IUU) fishing	aquaculture	o	local/regional	a-c	3	3		x		3.0	4.0	3.0	3.0	13.0	b-c
20		discarded fishing gear	d	local/regional	a-b	2	2				3.5	3.5	4.5	4.5	16.0	d
21		managed fishing	e	local/regional	a-b	2	2				3.5	3.5	4.0	4.0	15.0	a-b
22		IUU fishing	e	local/regional	b-d	2	2				3.0	4.0	4.0	3.5	14.5	b
23	Alterations to physical habitats	mining terrestrial	d	local/regional	a-d	2	2		x		3.0	2.0	3.0	3.5	11.5	d
24		mining ocean inc. oil and gas extraction	d	local/regional	a-d	#	#		x		4.0	4.5	3.5	3.5	15.5	a-b
25		**dredging**	d	local/regional	a-c	3	3		x		3.0	2.5	3.0	4.0	12.5	d
26		**altered flow regimes - salinity change**	d	local	c-d	3	3	x	x	x	4.0	2.0	1.5	2.5	10.0	d-e
27		**watershed alteration**	d	regional	a-d	2	4	x	x	x	3.0	2.5	3.0	3.0	11.5	c-e
28		**watercourse change (inc. training walls)**	d	local/regional	c-d	4	3	x	x		1.5	2.0	2.0	4.0	9.5	c-d
29		**coastal development**	d	local/regional	c-d	3	4				3.0	2.0	2.0	3.0	10.0	b-d
30		tourism	d	local/regional	a-c	2	3				4.0	3.0	3.5	4.0	14.5	c
31		**recreation**	d	local/regional	a-c	3	4				4.0	2.0	4.0	4.5	14.5	d
32	Invasions of exotic species (Organisms)	introduced species and/organisms	o	local/regional	a-d	4	5		x		1.5	2.0	1.5	2.0	7.0	b-d
33	Global climate change	temperature change	d	global	c-d	2	3	x	x	x	1.5	1.5	1.0	2.5	6.5	d
34		sea level rise	d	local/regional/global	c-d	2	3	x	x	x	1.5	1.5	1.0	2.5	6.5	d
35		ocean acidification	c	global	c-d	2	4		x		1.5	1.5	1.0	2.5	6.5	d
36		changes to ocean currents	d	regional/global	b-d	2	2				1.0	1.0	1.0	2.5	5.5	d
37		extreme weather events	d	local/regional	a-c	4	2				1.0	1.0	1.0	2.5	5.5	d
38		mitigation activities (C sequestration algae farming, infrastructure)	d	local/regional	b-d	2	2				2.5	4.5	4.5	3.5	15.0	d-e
39	Ocean based activities	ship related accidents wastes and debris	p	local/regional/global	a-c	4	2		x		3.5	4.0	3.5	4.0	15.0	c-d
40		bilge water, tank washing, fuel use, antifoulants	c	local/regional/global	a-c	2	3		x		3.0	4.0	3.5	3.0	13.5	c-d
42	Perception/ideology	**social/political (mis-use of evidence, biased misguided perceptions)**	m	local/regional/global	a-c	3	3	x			2.0	3.0	4.0	3.5	12.5	d

Bolded "Threat Type"	Priorities for Management in NSW	
Nature of Threat		* 'd' in the case of accidents e.g. Fukushima, 'a' for normal-use management
c	chemical	** 2 NSW, 3 Global
d	destruction (habitats)	# not a current threat but potentially in need of management
e	extraction	
m	misinformation	
o	organism	
p	particulate	
r	radiation	
Temporal Scale		
a	short - years	
b	moderate - a decade	
c	intermediate - decades	
d	long - centuries	
Intensity of Threat		
5	extreme	
4	high	
3	intermediate	
2	moderate	
1	low	
Accumulation Potential of Threat		
5	extreme	
4	high	
3	intermediate	
2	moderate	
1	low	
Management Ease		
5	simple	
4	moderate	
3	intermediate	
2	complex	
1	impossible	
Management Feasibility		
5	likely	
4	moderate	
3	intermediate	
2	unlikely	
1	impossible	
Management Cost		
5	low	
4	moderate	
3	intermediate	
2	high	
1	extreme	
Management Time		
5	short - years	
4	moderate - a decade	
3	intermediate - decades	
2	long - centuries	
Management Performance		
a	managed - essentially solved	
b	good - improving and ongoing	
c	inadequate - attempted with minimal results or stalled	
d	ineffective - insufficient effort and/or little improvement	
e	none - not recognised or not managed	