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Science, biodiversity and Australian management of marine ecosystems

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Introduction

As signatory of the UN Convention on the Law of the Sea (LOSC) Australia has accepted environmental and natural resource management obligations for the third largest area of responsibility for Territorial Waters and Exclusive Economic Zone, in the world.

These obligations include Article 61: Conservation of living resources and Article 62: Utilization of living resources, including provisions for access to resources not utilized by the coastal state. These are additional to and complementary with obligations under other UN Conventions including the UN World Heritage Convention and the UN Convention on the Conservation of Biological Diversity.

The Australian area of responsibility under UNCLOS covers an area of 11 million sq km. It is 2.5x the size of the national landmass and there are linked responsibilities for an estimated further area of 5.1 million sq km of contiguous continental shelf. This encompasses a tremendous range of habitats and associated biota of large areas of the Indian, Pacific and Southern Oceans, a lengthy coastline and many offshore territories from the subantarctic to the tropics (from 10^{o}S to 48^{o}S and 110^{o}E to 160^{o} E) from intertidal to abyssal. Not surprisingly given the great size of the area of responsibility, knowledge of the biota is patchy and heavily biased towards temperate and shallow water areas and commercial or potentially commercial seafood species (for a review see Ponder et al., 2002).

In 1992 Australia completed a consultative process to develop a National Strategy for Ecologically Sustainable Development (Commonwealth of Australia, 1992). The core objectives of this Strategy were: to enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations; to provide for equity within and between generations and to protect biological diversity and maintain essential ecological processes and life-support systems. The strategy specifically addressed the issue of marine resources, ecosystems and biological diversity and led to development of an Oceans Policy (Commonwealth of Australia) to address obligations under the United Nations Convention on Law of the Sea. The Oceans Policy established regional marine planning as the way to advance the development of integrated and ecosystem-based management of Australia's oceans. "Our goals for regional marine plans are to determine the conservation requirements of each marine region, including the establishment of marine protected areas, prevention of potential conflict between sectors in relation to resource allocation and provision of long-term security to all ocean users"(Commonwealth of Australia, 1992).".The Oceans Policy envisaged that each marine plan would deal with the following issues, relating to conservation of biological diversity:

- setting out what is known of ecosystem characteristics and a broad set of objectives for those systems;
- identifying the requirements and priorities for environmental baseline and basic biological inventory and other surveys;
- identifying priorities and putting in place measures to meet conservation requirements and determining those areas that should be assessed for marine protected area declaration;

Marine Bioregions

While there were many local data sets from fisheries and museum taxonomic cruises these did not generally provide a coherent framework for understanding ecosystem scales and characteristics, planning conservation requirements or determining areas for protection at the scales required. A workshop in 1994 was the first step in a long-term research program to develop a national marine and coastal regionalisation for Australia. The initial outcome was an evolving synthesis of diverse existing datasets that led to an Interim Marine and Coastal Regionalisation of Australia (IMCRA 3.3,) to provide a basis for initial planning. This identified 60 meso scale coastal, continental shelf and offshore marine regions through a process based on fish biodiversity, climate characteristics and water mass types augmented where possible by other biological data (Commonwealth of Australia, 1998).

Ponder et al. (2002) stressed that much of Australia's marine biodiversity is undescribed and many habitats poorly sampled especially among many of the invertebrate groups. They considered this to be a critical data need for management to conserve marine habitats, ecosystem processes and the associated biodiversity, much of which is endemic to the EEZ. More recently, Butler et al. (2010) have reiterated the need to address the lack of broadly based data on the composition and distribution of species other than those of recognised or potential commercial value as seafood species. The food chain linkages between demersal fish species and benthic communities are not well understood. The lack of such information is particularly challenging in the context of predicted changes in marine species and community distributions as a consequence of ocean warming, acidification and other effects of climate change.

Studies following IMCRA 3.3, produced improvements through further synthesis and the results of research targeted to address prioritised gaps. This led most recently to the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4.0, Commonwealth of Australia, 2006).

IMCRA 4.0 was underpinned by a substantial research program of seabed and sub-seabed description made possible by swathe mapping. It developed a National Marine Bioregionalisation (NMB) based on descriptions of seabed geomorphology and provincial bioregions described largely on the basis of patterns of bottom-dwelling fish diversity and on the apparent distribution of habitats in very deep water. The NMB differs from IMCRA v3.3, in that the continental slope is divided into biomes, which are depth-related areas derived from the distribution of demersal fish species. Geomorphic units are also described based on clusters of identified geomorphic features of the sea floor. Associated but relatively limited biological and seabed sampling, particularly of tropical seabed sponges, described habitat characteristics and indicated the scope of the large fauna and geological resources. Very little sampling and analysis of epifauna and infauna was possible. The report (Commonwealth of Australia, 2006) identified the need for data to enable further revisions in ecosystem understanding and ecosystem surrogates, data coverage; and conceptual classification models.

Ecosystem understanding and surrogates

Our knowledge of offshore and deep water ecosystem functioning is still extremely limited. Benthic communities contain organisms with a diversity of life strategies and spans and so they may be far more responsive to environmental changes than others. Some advancement has been made in understanding the impact of introduced species in nearshore shallow water environments (Galluci et al., in press; Gribben and Wright, 2006; Gribben et al., 2009) but we know far less about the impacts of introduced species in deeper water. Deeper water benthic communities are almost completely unstudied and even benthic communities closer inshore are poorly studied especially with regard to natural pertubations over time (Stephenson et al., 1970; Hutchings and Jacoby, 1994). Far less is known about how increasing water temperatures and ocean acidification are affecting benthic communities although we know that species distributions are changing (Ling et al., 2009) and that changes in ocean acidification are impacting on survival of larvae (Byrne, 2011; Byrne et al., 2009, 2011; Preslawski et al., 2008; Ross et al., 2012).

IMCRA 4.0 has provided a useful basis for initial planning to address the biodiversity conservation objectives of Australia's Oceans Policy. This has been achieved through linked double surrogacy based on substantial seabed data, with limited and selective fauna data. In the longer term managing biodiversity in the contexts of changes in climate, and the impacts of human activities on marine ecosystems requires capacity to monitor and understand changes in distribution and abundance of indicator species or ecological communities in space and time. This presents substantial data and information challenges.

All marine ecosystem management is largely based on the use of surrogacy, for example the zoning plans for Port Stephens Marine Park, New South Wales (NSW) were based on habitats characterised by sediment and species of seagrasses. The validity of the assumption that this would adequately cover the diversity of this region by Marine Parks. has recently been tested. Dixon et al. (in prep.) sampled the infauna in each of the habitats and found a reasonable correlation with the abundant and diverse polychaetes and concluded that the current zoning plan adequately protected the benthic diversity of the region. A study by Shokri et al. (2009) in Brisbane Waters, NSW, of all benthic macro-infaunal communities suggested how this data could be used to identify areas in estuaries which should be protected, although to date this has not been used to establish marine protected areas in this region.

These two studies of invertebrate benthic communities were conducted in restricted localities and highlights the usefulness of invertebrate benthic communities in defining habitats but because of their scale they cannot necessarily be extrapolated to larger areas. This raises the issue of the need to compare the distribution of such communities with studies of more mobile fauna such as fish. Similar sandy sediments will have different benthic communities in tropical to temperate areas and also vary according to depth and exposure. Studies of infaunal composition of benthic communities in Jervis Bay at three monthly intervals over three years have shown the natural variation in species composition over time with little evidence of seasonality, indicating the variation in recruitment success over time (Hutchings and Knott, in prep.).

A further example of the need for understanding of ecosystem processes underlying possible surrogate utility is provided by studies of benthic infaunal communities of *Posidonia* beds along the NSW coast which found that these varied significantly with factors such as exposure and sediment type being critically important (Collett et al., 1994).

The limitations of the current fauna data reflect the expense and logistic challenges of marine biological field studies. The predominance of data on demersal fish reflects the fact that most of the data that is available comes from broad scale surveys and studies of species of actual or potential commercial interest. There is taxonomic and ecological data on non-commercial, cryptic and infaunal marine species from research field station and expeditionary vessel studies and from predictive environmental impact studies for major developments. Where accessible, such data is important but it is often very localised and collected for a specific purpose that limits its value for understanding the distribution and abundance of species in space and time. There has been very little sampling beyond 1,000 to 2,000 m in depth (Butler et al., 2010).

The spatial and temporal limitations of data on non-commercial species are of particular concern in the case of soft bodied, cryptic and infaunal species which can have significant roles in food webs.

A recent survey of the seafloor of the Great Barrier Reef lagoon was undertaken before the new rezoning plan for the GBR was implemented (Pitcher et al., 2006; Pitcher and Doherty, 2008). This Seabed Biodiversity Programme undertook extensive trawls, epibenthic sled and video transects throughout the region, however no sampling was undertaken of the benthic infaunal communities. Detailed benthic maps based on depth, sediment and major groups of epifaunal assemblages have been prepared and are available in various departmental reports and websites but to date no peer reviewed papers have been published. Much of the epifaunal data is identified to major groups and awaits identification to species in museums. More than 7,000 species/species-equivalent OTUs (operational taxonomic units) were identified. The dataset comprises 79,173 site by- species records (Butler et al. 2010). While this program increases our knowledge of the diversity, the absence of information on infauna prevents a complete analysis of the functioning of this system. A further impediment is that many of the epifaunal species are only identified to OTU's which makes comparison of this fauna with other coral reef systems difficult. The infauna includes a broad array of taxonomic groups exhibiting a diversity of feeding, and reproductive strategies, specific habitat requirements and multiple roles within the food chain (see eg. Hutchings, 1998 for polychaetes). While the adults of this fauna are generally sedentary most have a pelagic larval stage and species may be impacted in different ways at different points during their life cycles and therefore may be good indicators of change.

Data coverage

Robust data on species occurrence and distribution are fundamental for ecosystem understanding and management. It is impossible and unnecessary to undertake complete faunal analysis at all sites so surrogacy is essential but it is important to have sufficient analyses to understand the constraints of surrogacy and which species or conditions are valid surrogates for understanding and managing ecological regions.

The development of bioregional data for ecological studies and biodiversity management at the scale of Exclusive Economic Zones presents substantial logistic challenges. The first is availability of specialist vessels with capacity for offshore benthic infauna sampling such as substantial winches, station keeping or mother ship capacity for remotely operated vehicles with grab sampling. The second is technical capacity to sort and preserve samples in a state suitable for identification and the third is expert professional capacity for identification.

Taxonomic collections will record the identification and generally collection date and location of specimens but may not have a context of relative abundance or variation over time. For most faunal groups data can only be interpreted over a limited area (Butler et al., 2010). For specific collections, areas or locations data may be limited to taxonomic groups for which the institution has resident expertise or has been able to arrange identification by specialists from other institutions.

Since IMCRA, 4.0, additional benthic sampling has taken place especially in deeper water (Bax et al., 2001) and at selected coral reef sites (http://www.creefs.org; Knowlton et al., 2010). This material has largely been deposited in museums and is gradually being worked up but the selection of taxa is largely dependent upon the expertise of the personnel involved in these studies. Similarly GeoScience Australia has been undertaking extensive surveys in northern Australia and extensive collecting has been funded by mining companies in the North West Australia as part of mining and gas exploration but in both cases limited resources have been available to describe and document the biodiversity. While it appears to be relatively easy to obtain funds to charter vessels and collect samples, which is very costly especially in remote locations, often such expeditions fail to include funds for identifying the material collected and incorporating them into museum collections and databases. Australia's state museums where the majority of systematists reside are all state funded with limited research funds and declining taxonomic expertise and increasingly are unable to provide identification services without funding. Ironically the funds required are far less than the cost of actually collecting the material but perhaps lacking the high public profile of sampling in remote locations.

Butler et al. (2010) drew on five electronic data bases in their review of marine biodiversity in the Australian region:

- the Ocean Biogeographic Information System (OBIS);
- the Codes for Australian Aquatic Biota (CAAB);
- the Australian Faunal Directory (AFD);
- the Online Zoological Collections of Australian Museums (OZCAM); and
- the National Introduced Marine Pests Information System (NIMPS)

Most of the participants in the Online Zoological Collections of Australian Museums (OZCAM) contribute some but not necessarily all of their marine taxonomic data. In part this is due to the backlog in databasing old collections, for example less that 40% of the Australian Museum enormous mollusc collection is data based and while all new material is databased, it will take time to incorporate the important time series data from older collections which extend back to the mid 1860's.

Butler et al. (2010) noted that other data exist in the digital form of unpublished database records and non-digital forms of published records and survey records such as field data sheets and referred to the CSIRO MarLIN data base which as of 16 November 2011, had 2677 datasets with 56 meta data entries to address of varying levels of accessibility and, in the context of this paper, relevance to biodiversity/habitat surrogacy and modelling. The situation is confused as to variety, forms and availability of relevant data collected for a wide range of research objectives but given the logistic and challenges of collection and analysis to produce new field data there are clear incentives to identify, evaluate and develop metadata to make fullest use of available materials. Obviously such an evaluation should include some indication of the reliability of the data especially with respect to observations for which no specimens have been lodged in a museum for verification. While an evaluation of existing data is obviously far cheaper than collecting new material it is typically more difficult to find funding to undertake this.

Conceptual Classification Models

A Marine Biodiversity Research Hub has been established by Australian Commonwealth Government to support marine environmental management through research on surrogacy and methods for prediction of marine biodiversity. The limitations and variability of objective, methodology and form of the available data present fundamental difficulties for robust conceptual classification modelling.

Taxonomic collections record the identification and generally collection date and location of specimens but may not have a context of relative abundance or variability. For most faunal groups data can only be interpreted over a limited area (Butler et al., 2010). For specific collections, areas or locations data is often limited to taxonomic groups for which the institution has resident expertise or has been able to arrange identification by specialists from other institutions. Some groups of invertebrates lack resident Australian experts eg. ascidians, oligochaetes, enteropneusts. .

Museum datasets in part reflect the research interests of the specialists and changes in conditions and patterns of use. For example the flow of data on molluscs has declined as a consequence of restrictions on collecting from marine reserves and a declining number of naturalist shell collectors who can no longer collect shells without permits. Also such databases fail to capture nil records, an area may have been well studied but absences are not recorded. Hooper and Ekins (2005) have been collating databases related to the distribution of marine sponges in northern Australia and they recognise 3,800 species (where a species is defined as a distinct operational taxonomic unit). But many of these remain to be formally described.

Over the past few years, a potential source of benthic data has been available which could help in refining IMCRA regions. Data from selected benthic polychaete families exhibiting different life styles and reproductive strategies has become available based on records of material housed in the various Australian state museums which has been checked for identification. This material exceeds more than 17000 latitude and longitude point records covering 275 species in two families the Nereididae and Terebellidae. While there are some obvious hotspots around research stations and near capital cities there is good coverage around the coast although it is biased towards the intertidal and shallow water communities down to depths of about 30 m (unpublished data of Hutchings; and Wilson and Glasby). A similar comprehensive data set on benthic ophiuroids also exists based on re-examination of museum deepsea collections (O'Hara et al., 2011). The value of these datasets which complement each other is the quality of the data because all the records have been checked by re-examining the actual specimens, rather than just relying on the variable quality of datasets available from museums.

Regional reviews of the distribution of echinoderms and decapods have been undertaken by O'Hara and Poore (2000) and floral and faunal assemblages of temperate rocky shores by O'Hara (2001) but much more needs to be done. While detailed surveys of infaunal benthic communities have been undertaken of selected locations such as Port Phillip Bay (Hewitt et al., 2004 and refs therein , Jervis Bay (Hutchings & Jacoby, 1994), Upper Spencer Gulf (Ward and Hutchings, 1996), Moreton Bay (Stephenson et al., 1970), Darwin Harbour (Northern territory Government, 2003) , the results have not been synthesised to consider the distribution of these shallow water communities and how they can be related to those communities just derived from sediment data. Last decade a series standardised port surveys were carried out to document native and introduced species, however the standard of the surveys varied (Bishop & Hutchings, 2011) and an important opportunity to document the biodiversity of Australian ports was lost

Increasing digitisation of Museum records and their incorporation into the publicly available Australian Faunal Directory (http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/index.html) provides the capacity to plot faunal records using the Atlas of Living Australia (ALA). In the wrong hands this can lead to erroneous conclusions being drawn from very few records plotted against the IMCRA regions. Most IMCRA regions cover several thousand square kilometers and a single record of a species or a species known only from a very restricted area or sub-region can be shown as occurring throughout that entire IMCRA region. For example the coastal polychaete species Hadrachaeta aspeta (Hutchings, 1977) is implicitly represented in AFD figures as occurring in an IMCRA bioregion that encompasses approximately 2,400 kilometers of the south east coastline of Australia(ABRS, 2009). However the text records that the species has been identified from only three locations in the northern half of the region with the northernmost and southernmost separated by approximately 1000 kilometers. Repeated for many species such data representations may generate a false understanding of the biodiversity of that region. This reinforces the need to thoroughly understand the limitations of the data being interrogated to describe species distributions and the importance of collaboration with the relevant specialists working on those species.

Discussion

There are three challenges in the development of conceptual bioregional habitat classification models. The first is the extent to which the physical data on the water column and seabed explains the distribution and function of biological communities this still needs to be tested. The second is understanding the ecological roles and functions of particular species that may enable them to serve as useful surrogates or indicators of change in the ecological communities within which they occur. The third is that the dwindling number of Australian experts in systematics (ABRS, 2006, FASTS 2007) and the situation has almost certainly deteriorated since then and increasingly limits capacity to identify substantial and growing collections from field surveys. It also limits the capacity to link morphological taxonomy and gene sequence signatures and thus to develop more rapid molecular techniques for extent of species identification needed to develop community scale marine ecosystem classification models.

For most nations management responsibilities that flow from the LOSC concern very large areas of 200 nautical mile Exclusive Economic Zones and associated continent shelf. The logistic challenges and costs of obtaining and analysing relevant biological data are so substantial that surrogacy and classification modelling approaches are needed to develop management responses. This is particularly the case for Australia which has responsibilities for an area more than 2.5 times its land mass extending from tropical to sub Antarctic latitudes and covering three oceans.

Much of the Australian benthic marine fauna is new or represents cryptic species which need to be separated using both morphological and molecular techniques. While molecular techniques hold the promise of more rapid identification through gene sequence signatures these need to be properly grounded in relation to morphological taxonomy and environmental variability.

High technology instrumentation including vessel towed and satellite remote sensing have provided a reasonable description of oceanography and at least shallower seabed topography and surface geology. IMCRA 4.0, has developed a bio-regionalisation based largely on the association of demersal fish species, water masses and seabed characteristics. This has provided a basis for establishment of ecosystem management but in the context of changes in human uses, impacts and the expected effects of climate change it raises issues of the nature of the food chain association between mobile demersal predatory species, the water column and the seabed. Seabed sled imagery and trawl sampling can provide data on the biological communities on the seabed and this has enabled the development of national scale analysis of distribution of sponges, decapod crustaceans and brittle stars which have distinctive skeletal structures (Butler et al., 2010).

The development of means for identifying and monitoring benthic infauna is a substantial issue for the development of robust surrogacy. The biogeographic relationship between the geology and topography of the seabed surface and cryptic burrowing and soft- bodied species presents a particular challenge. Such species can represent substantial food chain elements of demersal fish and they may thus be significant factors in the distribution of more easily observed groups.

Butler et al. (2010) comment that the museums of Australia and the world are building significant collections of Australian specimens from depths as great as 2,000 m but the ABRS Survey of Australian Taxonomic Capacity (2006) commented that Australia would face a crisis in chronic lack of taxonomic capacity by 2011.

Nations that are signatories of the United Nations Convention on the Law of the Sea have accepted obligations for understanding and managing marine ecosystems. A framework for addressing these obligations was clearly stated in Chapter 17 of Agenda 21 which was adopted at the United Nations Conference on Environment and Development (UN 1992) and reiterated at the World Summit on Sustainable Development (UN 2002) and Rio +20 (UN 2012). In recent decades the range and capacity of uses of marine space have increased with greatly increased shipping capacity and infrastructure requirements, offshore oil and gas, wind and other alternative energy installations. At the same marine capture fisheries have plateaued and the issue of climate change and its implications for changing distribution of marine species and ecosystems has emerged. Our understanding of the nature, interactions and distribution of marine species and their distributions is inadequate for properly informed response to the issues. Australian experience demonstrates that surrogacy based on remote sensing studies of seabed and water masses and fishery related data can provide an important working baseline. However in the longer term progress towards understanding and managing the interaction of environmental and human induced change and uses will require a clearer understanding of the relationships between species within food webs and in relation to the properties of benthic and water column habitats. This will depend on our capacity to analyse the composition and interactions of invertebrate species in the water column, on the seabed surface and within seabed sediments.

Conclusion

The use of oceanographic, seabed and demersal fish data augmented with very limited additional biological data provided a basis for surrogacy which developed a bioregionalisation of substantial areas of Australia's marine jurisdiction (IMCRA 4.0 2006). This has provided a systematic basis for approaching the management of marine biodiversity. The rationale for management is maintaining the health, biodiversity and productivity of the ecosystems of marine bioregions in the face of increasing human uses of marine space and the changes that are expected to flow from those and from climate change. Our understanding of the relationships between species within food webs and in relation to the properties of benthic and water column habitats is limited. This is likely to present increasingly important information constraints for effective management.

Further development of classification models for refinement of understanding is increasingly constrained by lack of data. There is a clear constraint in that collection of new marine data particularly in offshore areas is costly. There are certainly major gaps in survey and collection coverage that should be addressed by new field studies. Butler et al. (2010) have identified the need and priorities for new data collection and sampling but if only on grounds of cost and efficient use of vessels and analytical capacity there is good reason to consider whether some of the requirements might be addressed by addressing existing un-analysed material.

A further constraint is the considerable variety of form, quality and accessibility in data bases. There is a substantial amount of existing data in 5 sometimes overlapping databases (OBIS, AAB, AFD, OZCAM and NIMPS) and in the developing CSIRO MarLIN data base (Butler et al., 2010). and clear scope for further data discovery and for metadata analyses and classification in relation to format, methodology, authority and constraints. This would improve the availability and understanding of confidence levels of existing data for use in analysis and modelling.

Whether for new collections or for the steadily accumulating unsorted, and unidentified collections in museums and research centres in Australia there are increasing constraints because of the dwindling number of specialist researchers skilled in taxonomic analysis.

However the history and the form of the biological data available for planning for management of marine biodiversity reflects that there is an urgent need for funding to address the growing shortage of taxonomic expertise and technical support for time consuming and specialist studies needed to identify existing collections, to explore and develop the potential for molecular techniques for identification of key taxonomic components in monitoring the effectiveness of management of marine biodiversity.

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