STRATEGIC COASTAL ASSESSMENTS – EQUIPPING DECISION MAKERS

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Australians are loving their coast to death and putting it under increasing pressure. Effective regional planning to maintain or enhance the utility of our coasts requires a clear understanding of the status quo, a thorough understanding of the drivers and consequences of any change, and most importantly a clear understanding of the cumulative impact of multiple possible developments. Strategic assessments are critical to effective coastal planning. Here we examine some of the major scientific challenges facing strategic regional coastal assessments and look at some advances that will lead to improved data acquisition, more robust interpretation and better planning outcomes.

An effective assessment requires comprehensive baseline data, a calibrated measure of impacts and robust evaluation frameworks that couple biophysical and socioecological model predictions with statistical validation, data assimilation and scenario planning. But data collection is expensive, long term data collection even more so and sensors and analytical methods for the marine environment are limited in their scope and durability. The challenging working conditions means that understanding physical and biological dynamics of coastal systems and their responses to change, let alone the baseline position and ecosystem trajectories, are difficult. Recently, however, there have been changes, and issues are being considered in a whole-of-system approach, not confined to specific sectors; increasingly there is a globalisation of solutions, and these advances will provide the inputs for integrated management tools (e.g. management strategy evaluation) that allow adaptive management practices to be implemented.

Strategic regional assessments can provide confidence and deliver efficiency in coastal management when they are based on good science and provide insights on the trajectories an ecosystem may take that allows a range of acceptable outcomes to be examined. Significant scientific advances in support of a more strategic approach to regional planning have been made. It is clear that presentation of whole-of-ecosystem understanding in a useable and management-relevant form means that our coastal managers, policy makers and decision takers will be better equipped to deliver socially, economically and environmentally sustainable communities.

Introduction

Australia is undertaking large scale coastal development and the need to make wise decisions about our ocean and coastal estate has never been greater. About 85% of the population live within 50km of the oceans and almost six million people live in Australia’s growing non-capital coastal cities, where the rate of growth is more than 60% higher than the national average (National Sea Change Taskforce, 2012). Expectations around sustainable or expanding use of coastal environments are set in the context of multiple, large ports, shipping, oil, gas and mining developments — particularly in northern Australia. Australia still rides on the back of its primary commodities, such as iron ore and coal: as exports of these grow, ports and other coastal uses, such as shipping, grow in step. For example, over the last decade shipping in the Great Barrier Reef region has increased by approximately 1% annually, growing to 4500 transits in 2012 with the number of port calls expected to reach more than 10000 a year by the 2030s (GBRMPA, 2013). Despite such rapid growth, and increasing regulatory demands around development and conservation, planning approaches have largely remained unchanged. In recent times, Commonwealth and state governments have legislated for a series of marine parks around Australia in an attempt to ensure adequate protection of representative regions of the marine estate, unfortunately coastal processes do not adhere to legislative boundaries and marine parks in themselves will not prevent the degradation of Australia's coastal estate.

There is a growing understanding in the community about the complex way in which multiple groups of stakeholders are affected by decisions, and that change can impact social, environmental and economic well-being in multiple ways. A holistic approach to planning may involve a complex web of interactions and may sometimes be messier, but it is less likely to have unforeseen or undesirable consequences. Effective regional planning addressing the complexity of our social and natural ecosystem requires a clear understanding of the status quo and a thorough understanding of the drivers and consequences of any change, as well as the cumulative impact of multiple developments. Strategic regional assessments (SRAs) are, in effect, the critical pathway to successful strategic coastal planning. Here we examine some of the major scientific challenges facing coastal SRAs and look at some advances that will lead to improved data acquisition, more robust interpretation and better planning outcomes.

Background

Coastal SRAs provide an holistic approach to the scientific issues relevant to a large-scale region (catchment/basin/development). They also provide a thorough understanding of the ecosystem (e.g. biodiversity, connectivity, socioeconomic welfare and resilience to change), of anthropogenic pressures (e.g. industry development, population change, food and water security) and the balance between them (e.g. management options and values-based analysis). A widely adopted definition for SRA is the: ‘‘systematic, on-going process for evaluating, at the earliest appropriate stage of publicly accountable decision-making, the environmental quality, and consequences, of alternative visions and development intentions incorporated in policy, planning, or program initiatives, ensuring full integration or relevant biophysical, economic, social and political considerations" (Berube and Cusson, 2002; Partidario et al., 2009). If implemented early and effectively, SRAs represent a very real opportunity to present the community with a view of multiple alternate futures and to move towards the triple bottom line balance that a healthy community must find.

Although Australia became one of the first countries to introduce strategic environmental assessment requirements with the introduction of the Environmental Protection (Impact of Proposals) Act in 1974 (now repealed), Australia's record of a long term strategic approach to assessment and planning in the coastal zone is not particularly good. Thom (2012) noted that he has

> "observed periodic eruptions of interest in coastal issues leading to parliamentary inquires or initiatives" (since the 1970's). But "....in general, the result of these activities has been a stop-start set of programs and policies with many limitations to long-term implementation designed to improve environmental health and minimisation of risk to natural and built assets along the Australian coast."

Furthermore, the cross jurisdictional nature of institutions created by governments to deal with strategic planning within sectorally focused mechanisms has made them unpopular and short-lived, for example the rise and dissolution of the Australian National Oceans Office.

In Australia, both sides of politics recognise the growth potential of Australia's coasts, particularly in the north. They also understand that to balance population, industry, and the environment and deliver a quality of life that is attractive to the majority of Australians, Australia needs to be proactive, rather than reactive, in its strategic planning. Scientists do not make decisions for society, but the scientific data, models and the interpretation that scientists provide as part of the strategic assessment process, allow managers, decision makers and communities to evaluate trade-offs in order to make informed decisions.

The effectiveness of long term and/or integrated assessments

Any effective SRA requires comprehensive baseline data, a calibrated measure of impact and robust evaluation frameworks that couple biophysical and socioecological model predictions with statistical validation, data assimilation and scenario planning. The framework used should ideally integrate the economic, social and environmental elements that drive or are affected.

For example, geomorphological frameworks use variations in geology, seafloor topography and unconsolidated sediment load to identify how change impacts the marine environment regionally. Such a framework is being used by the UK government to outline coastal process and geomorphological features of the open coastline and to predict coastal evolution over the next 100 years (DEFRA 2006). They use the results to define "behavioural systems", so that flood and coastal defence management planning decisions can be placed within a longer-term and wider-scale framework. Similarly, in Western Australia, the government has adopted a geomorphological approach and has defined sediment cells between from Cape Naturaliste to the Moore River with the aim of providing a framework for coastal management by outlining 'natural' management units which link the marine and terrestrial environments (Stul et al, 2012).

By contrast, ecosystem-based planning and management frameworks provide ecological and socio-economic sustainability through minimizing risk of degradation of ecosystems and irreversible change within scenarios based on ongoing human use. Tensions may occur where stakeholders have multiple, complex and often conflicting social, cultural and economic objectives, thus management decisions will always involve trade-offs. This was a key finding of the Ningaloo research cluster and integrated modelling done in support of multiple use management in the Gascoyne (Fulton et al, 2011).

Many assessments combine elements of both. Port Phillip Bay (PPB) is an area of intense anthropogenic pressures and an example where base line assessments (including a major environmental analysis and subsequent targeted studies) have been used to underpin strategic planning at regional and catchment scales. PPB's enclosed nature sets it apart as a geomorphological unit, whilst elevated nutrient and sediment load due to industry, urbanisation and agriculture, means that ecosystem pressures, in particular water quality, are major issues for the bay. PPB is also the entrance to one of Australia's busiest ports, the Port of Melbourne, supports major commercial and recreational fishing activities and is the focus of a growing tourism industry and an important part of the life of many Victorians.

In 1992, intense and growing pressures on the PPB ecosystem led Melbourne Water to commission a 4 year, CSIRO-led, multidisciplinary Port Phillip Bay Environmental Study that assessed the health of the Bay (Harris et al., 1996); effectively an environmental strategic assessment and the establishment of a baseline dataset. The study investigated PPB's ecology, physical processes, and nutrient and toxicant levels. It identified the sources, concentrations and dispersal of pollutants in the bay and importantly, the critical nutrient load which it can tolerate. The results made it clear that understanding the interactions between these processes is crucial to managing PPB in the longer term.

Ecosystem modelling, using the data collected, examined a range of possible nutrient loading scenarios (Murray and Parslow, 1997) which identified a maximum assimilative capacity for nitrogen loads to the Bay. Other scenarios examined predicted effects due to warming and increased benthic filter-feeder biomass. The study established the basis for strategic plans for the various catchments (1997, 2004, 2005/06 and currently under review), and a major Environmental Management Plan in 2002. However, these studies and plans do not include in depth social and economic analysis.

Importantly, the modelling, originally undertaken to provide a predictive tool to support future management of nutrient loads to the Bay, has since proved robust enough to form the basis for subsequent environmental models internationally; today it still sits at the heart of successful whole-of-system models such as *Atlantis* (Fulton et al., 2004) that expanded on the PPB ecosystem representation to include the entire foodweb and an increasing array of the human drivers, activities and pressures in marine and coastal environments.

The scientific needs/questions

Humans will continue to inhabit the coastal zone so, within the context of maintaining an appropriate environment, we must ask: what is a suitable development strategy, both spatially and temporally? Should impact be limited by spatial extent in high use, high impact zones, or spread with a lesser impact per unit area? How will we ensure that the design criteria are met and that we are achieving our pre-determined goals?

In establishing a fully integrated scientific program for strategic assessment we need to develop an overall picture of the ecosystem, find out how vulnerable a region is to natural and anthropogenic change and identify positive and negative feedback loops. For example, which areas need to be protected, which could be developed and which could sustain multiple uses? Which are the threatened and endangered species and what are the appropriate thresholds for concern for those species? Where ecosystems are described as “at risk”, what appropriate monitoring and/or action thresholds should be put in place? The rate and spatial distribution of development is easy to monitor, but the impact on the environment less so. There is a need to find the right indicators with which to monitor the ongoing situation This is probably the biggest area of contention between scientists seeking to increase system understanding and managers wishing to monitor the ongoing situation.

With the baseline established we need to consider how to identify measure and monitor cumulative impacts and risks and how to set trigger points that initiate modified management practices across all sectors. Comprehensive monitoring strategies (as opposed to *ad hoc* strategies designed to address individual issues), need to incorporate randomisation to protect against variables that influence outcomes but are not captured in our existing/new conceptual and/or process models. Managers may choose to monitor areas that have relatively little systemic variability for example, in these areas change is easier to identify, but the hysteresis of the system may show change too late for effective management action. Alternatively “at risk” areas may be monitored, but if these areas show high natural variability it may be difficult to identify the changing signal.

We should also investigate whether natural and anthropogenic drivers and stressors act additively, antagonistically or synergistically on ecosystem structure and function; and thus on the delivery of ecosystem services and associated human welfare. Early work looking at the combined effects of climate, acidification and fisheries is already highlighting the changing nature of interactions under cumulative stressors and how the use of sustainable integrated management can make for more robust ecosystems (Griffith et al, 2012; in review).

Using the information gathered as input into whole-of-ecosystem process models, we can develop formal decision support methods to support management response to ongoing monitoring data and cumulative risk outcomes. We can examine quantitative loss functions (for cumulative risk assessment) for potentially diverse values and determine the metrics by which to measure consequences for diverse value sets. The latter requires an understanding of stakeholders’ (often competing) values and the building of conceptual models to understand the consequences of competing demands on the same resource. From the economic perspective, we must understand how to evaluate options that achieve multi-sector and triple-bottom line outcomes. And finally, given the constraints of budget and time, we should define our measure of success: how do we determine whether the expected outcomes are met or not?

The scientific requirements

The challenges to achieving the goals discussed above focus around data collection, validation, interpretation, modelling and ongoing monitoring. For example: long term observational and monitoring technology (e.g. remote sensing, gliders, sensor networks); robust and practical diagnostic tools (e.g. routine genome analysis); better understanding of system dynamics, and responses to change (anthropogenic and natural; e.g. habitat mapping, cumulative risk assessment); and the development of integrated management tools (e.g. management strategy evaluation) that include quantitative certainty and validation of whole-of-ecosystem process models and which can inform cumulative impact and risk assessment and allow adaptive management practices. Here we briefly touch on some of the greatest challenges and requirements.

Observational and monitoring technology

Australia’s unique problem is the sheer size of marine estate, so the challenge here is to ensure that the large, but relatively easy to obtain datasets, can be fully utilised and that new and emerging technologies are harnessed to provide as much information about the system as possible including geology and habitat, and ultimately to reduce the human overhead in marine observing.

Optical imaging satellites provide fantastic synoptic overviews of Australia’s coastal systems. The 30+ year Landsat archive (describing the seabed in up to 30m in clear water, >6m water depth for 75% or more of Australia’s coasts) held and being added to by

Geoscience Australia, represents a remarkable and under-utilised resource for establishing what is "normal" in the context of extreme events and rates of change in ecosystem structure and system drivers. Offshore the ARGO profiling float program and altimetry satellites give us great insight into the shelf-scale water movements, but closer inshore where coastal processes have shorter time-steps, sampling is less systematic, with many observations collected to answer specific sectoral needs, and in many cases the data held in institutional silos. This situation is changing, slowly, with state governments introducing open data policies (http://data.nsw.gov.au/ and https://data.qld.gov.au/), but there is a long way to go to systemize the delivery of routine monitoring data as data streams and make them routinely available.

Benthic Mapping:

The benthos is an integrator of all that influences it, and, relative to the water column, it is extremely stable, making it a great place to monitor change.

The relative optical opacity of the marine environment has meant that acoustic methods developed for hydrography have been primarily adopted for coastal benthic mapping; however this is changing as these methods do not scale well to whole of regions and ironically become increasingly expensive in shallow coastal waters. Airborne optical mapping methods represent the most cost effective high accuracy mapping tools in intertidal waters out to approximately 20-30m (water depths most relevant to anthropogenic activity) if there is adequate water clarity. These optical methods include both laser-based active ranging and hyperspectral imaging. Hyperspectral data can provide greater information on habitat, but at the cost of reduced depth certainty, whereas LIDAR delivers a highly accurate depth, but only limited habitat data. The two methods are not operationally compatible for simultaneous operations. Space based hyperspectral and multispectral sensors are now providing a remarkable opportunity to map and monitor the change in regional shallow coastal waters at previously undreamt of resolution.

Where optical methods are not viable, acoustic technology continues to be widely used to map seafloor topography and distinguish broad seabed habitats. Multi-beam sonar bathymetry can be used identify the seabed's physical features such as seamounts, canyons, terraces, banks and deep reefs. Acoustic backscatter data is used to classify and predict seabed substrate (hard rock or unconsolidated sediment) and differentiate some sediment types; in some cases it can be used to determine biological character, for example measure marine biomass (including in the overlying water column). Using multi-beam sonar equipment on vessels such as the national research facility, the RV Southern Surveyor, Geoscience Australia has mapped Australia's continental margin seabed: ~7M km^2 has been mapped since 2004. Current research is working to develop image-processing-based classification routines for backscatter data that will improve seabed classification and make it more robust (Collings et al., 2013). A data collection and processing framework is also being developed to provide a national program of backscatter mapping for environmental seabed mapping. Data collected and processed is available for viewing at http://www.marine.csiro.au/geoserver (Keith and Kloser, 2013).

Benthic Observations

Acoustic and optical remote observing methods can be used to infer habitat type , but in-water observations are needed to validate models and provide understanding of actual ecosystem structure. Traditionally, drop cameras and dredges have collected this data at all depths, supplemented by diver observation in shallower waters (<20m). Baited remote underwater video camera systems have been used to estimate fish assemblages and occasionally acoustics have been used to determine shelf-scale fish stocks (Makris, 2006). Increasingly autonomous underwater vehicles (AUVs) are being used to collect routine ground truth data and even long term ecosystem structure data in their own right. Data volumes from these vehicles are massive and, now the platforms are proven and accepted, the emphasis has moved to the development of scalable analysis tools that make sense of these remarkable data sets.

Through Australia's Integrated Marine Observing System (IMOS) the University of Sydney's Sirius AUV, in conjunction with regional researchers, has developed a number of reference sites which are visited on a one to two year cycle to re-map the benthos and determine the changes that can be detected year on year and their significance. CSIRO has focussed its research in a slightly different direction, focusing effort to develop AUVs that boost survey coverage and can be deployed by a small team. Operating systems and operating methods for such systems are necessarily robust and low cost. CSIRO's Starbug AUV concept has now reached its third generation and two Starbugs have successfully been deployed and operated by a single operator.

Pelagic Observations

The temporal and vertical spatial variability of the water column make it difficult to assign value to single point observations in terms of either understanding process or monitoring change. However, platforms, such as profiling gliders, are changing how we look at the pelagic environment. With deployments from weeks to months and the ability to profile through the water column, we are for the first time able to observe the evolution of water masses and observe some of the biological activity associated with them. Whilst we may not fully understand the significance of the longer term changes we may (or may not) see, we are at last collecting data that will help develop that knowledge.

In comparison to land-based sensor networks, the marine environment is still sparsely sensed. Open data and the development of platforms to deliver routine monitoring data as data streams that are discoverable on a machine to machine basis, will significantly increase the volume of data available. Once marine monitoring data is delivered in this manner the advances in sensor informatics that have come from dealing with the large terrestrial datasets can be easily focussed on extracting and distilling this marine data feed.

Robust sensors are key to data acquisition. The ideal marine sensor should use no energy, never foul or degrade, be the size of a grain of sand and communicate on a common interface. These sensors do not yet exist, but by combining operational methods, sticking to mature sensing methods and limited parameters, platforms like the ARGO profiling floats are heading this way, with in-water times now exceeding five years.

Gradually sensors are being developed that increase the breadth of our vision of marine ecosystems. Some tools, such as meta-genomic sensors, promise to deliver snapshots of community structure that can be used for rapid monitoring information. Other observations, for example nutrient concentrations, which in the past required physical samples to be taken to the lab for analysis, are now being delivered real-time in the field and used for immediate management decisions. Similarly, benthic surface metal concentrations can be compared to legacy measurements to detect variation. Importantly, new *in situ* and high density sampling in dynamically changing environments, such as our coastal zones, challenges the representative validity of previous triplicate lab analysis methods.

Diagnostic tools

An array of diagnostic tools are available to assess the ecological health of the system. One area that is showing particular promise is ecogenomics. Ecogenomic techniques have the potential to provide environmental scientists with a tool that rapidly and comprehensively examines the biotic composition and biodiversity of sediments, or the microbial structure of the water column. Major advances in sequencing techniques provide a rapid, low cost and more realistic view of the ecological status of a system than expensive and labour intensive studies such as counting macrobenthic organisms (e.g. polychaetes and bivalves).

Ecogenomic techniques target a single or multiple genes which are present in all the organisms of interest. For example, in eukaryote studies the gene 18S rDNA (or 18S) is often targeted to provide taxonomic information. Recently, a new technology called ‘pyrosequencing’ has emerged which enables all the targeted genes (e.g. 18S) within a complex mixture to be sequenced simultaneously, producing over 1 million sequences in a single analysis run. In addition, unique ‘tags’ can be placed on the front of the DNA extracted from each individual sample, numerous samples (e.g. sites, plots or replicates) can be pooled for a single sequencing run, with each sequence being traceable back to its sample of origin. This makes the procedure practical for complex experimental designs such as environmental monitoring programs. This new ecogenomic approach to assessing and monitoring ecosystem health in marine systems has been demonstrated by CSIRO scientists in Port Jackson (Chariton et al., 2010).

System dynamics, and responses to change

Where monitoring strategies are established how do we identify, measure and monitor cumulative impacts and risks? How do we set trigger points that initiate modified management practices? This is perhaps one of the hardest tasks as we are only just starting to come to grips with how cumulative pressures modify system structure and function. However, by looking back over the last 50 years of ecological literature, resilience theory, sustainability science and newer socioecological initiatives, it is clear that it is possible to get system-level perspectives that provide for more robust decision making under uncertainty and dynamic change.

Successes to date, either when looking across multiple users in related sectors (e.g. recreational, charter and commercial fishing) or across multiple sectors, has shown that planning and management frameworks that provide ecological sustainability through minimizing risk of degradation of ecosystems and irreversible change, that can also identify long term socio-economic benefits, are critical for broad uptake and commitment. Tensions occur where stakeholders have multiple, complex and often conflicting social, cultural and economic objectives. Management decisions will always involve trade-offs, but it is important that communication sits at the heart of the process so that (i) it is as clear as possible what the trade-offs involve and (ii) how the models (conceptual or otherwise) differ between the stakeholder groups (so that it is clear what they are basing their assumptions upon). System tools set within strong participatory and engagement exercises can be very effective means of exploring potential change and planning strategically and pro-actively (Pomeroy et al, 2001). Although how to effectively scale such processes to large regional scales remains an active area of consideration.

Integrated management tools

One useful system tool provides integrated modelling approaches that focus on the adaptive management cycle. This kind of management, also known as evidence-based management, involves actively evaluating management actions and periodically adjusting goals in a dedicated, planned and pro-active way (sometimes even actively doing experiments to see what the effect is). This kind of management is used for natural resource management such as fisheries and forestry, but can be also applied in modified forms to any form of management, including multiple use management (McDonald et al, 2008).

Spatial planning involving at least some consideration of overlapping uses and ecosystem services is happening in many places now. However, the dedicated use of quantitative dynamic systems tools that cover all major industries and support strategic planning at a regional scale is so far restricted to Australia. For example, some of the most detailed and thoroughly executed examples of this approach have been carried out in northwestern Australia in the Pilbara and Gascoyne regions. Global earth system models that attempt to bring biophysical and socioeconomic together in the context of global change are only just beginning to take shape (Gifford et al, 2010).

The Ningaloo Reef region is an exemplar of the application of the approach across all sectors in a tightly interconnected system that has great intrinsic beauty, social and cultural worth and rich potential resources for exploitation. Integrated modeling tools were developed for the region in support of integrated sustainable development of the world heritage listed coastline. A systems approach to research, through the Ningaloo collaboration cluster, collected information across all aspects of the system; which were in turn synthesized in a system-level model that was used to look at alternative futures for the region (Fulton et al, 2011). Multiple models were developed to explore different aspects of the complex system and to help people understand its dynamics and how to manage it. While the degree of detail in the models varied, the core concept was to think holistically about the system, with key components such as climate, oceanography, food webs, industry, infrastructure and the social and economic fabric of the communities, considered (Figure 1). Management relevant components include science and monitoring to inform management policy, management decision processes, stakeholder satisfaction, and natural/anthropogenic catastrophes.

A number of alternative futures were found for the system, all highlighting the socioeconomic need for onshore development to support local communities and the ecological sensitivity of the region. Nevertheless robust compromises that meet the major system objectives were also found. The most important result is that the key pressure points, (e.g. the level of development and visitation and some of the environmental pressures) were all identified by, or are related to issues identified by, people in the system, not the regulatory bodies in Perth. These are not the only important drivers, others like the level of industrial development are clearly important, but without the inclusion of the broader region (Exmouth and the pressure from the Pilbara) as well as finer details (like the utilities, roads, infrastructure and housing) the true system dynamics and trade offs would have been missed.

Summary

In Australia there are increasing numbers of major regional coastal developments - new ports, increased shipping traffic and spreading urbanisation - each of which brings with it a diverse and complex range of social, environmental and economic issues. There is a need to provide pre-competitive, rigorous, robust and effective frameworks and methodologies for SRAs in these domains that can lead to evidence-based, efficient decision-making developments: for example related to mineral and/or oil and gas industrialization in Australian coastal and offshore waters. This is a contentious area of local, state and federal planning – whether it be about the environmental safety of proposed industries, social equity, the cumulative impact of multiple developments and piecemeal decision-making, or the frustration by industry about costly delays in environmental approvals, commonly referred to as "green tape". The *Greentape Reduction Act* in Queensland (2012) and recent federal moves to streamline project environmental approvals reflect some of these tensions.

Coastal SRAs can provide confidence and efficiency in coastal and ocean management if the assessments are based on good science. Input of science produces knowhow that gives us a better understanding of system dynamics and allows us to develop integrated management tools to enable responses to change (anthropogenic and natural) and allows adaptive management practices. It is clear that presentation of whole-of-ecosystem understanding in a useable and management-relevant form means that our coastal managers, policy makers and decision takers will be better equipped to deliver socially, economically and environmentally sustainable communities.

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Figure 1: Schematic diagram of the content of the Ningaloo-Exmouth system model (as of Fulton et al, 2011)