National Marine Science Plan White Paper

Urban Coastal Environments: Coastal Contamination

Abstract

(100 words)

The potential for contaminants to impact on coastal ecosystems will grow in concert with industrial and urban development, the intensification of agriculture and as the number of industrial chemicals in common use continues to increase. There will be an increasing need to balance the social and economic benefits associated with development activities with appropriate management that protects estuarine and marine ecosystems. For future research to be successful, a transdisciplinary approach involving close integration of relevant disciplines (e.g. chemistry, ecotoxicology, ecology) with key stakeholders will be essential in order to evaluate the impacts of a complex cocktail of contaminants on marine ecosystems, develop mitigation strategies and establish regulatory limits that are appropriately protective without unnecessarily restricting coastal development.

Background

Coastal ecosystems are under threat worldwide from chemical contaminants released through anthropogenic activities such as agriculture, aquaculture, mining, industrial development, dredging, large-scale manufacturing, and urbanisation. Such contaminants may comprise naturally-occurring constituents such as metals/metalloids, nutrients or man-made chemicals (e.g. industrial chemicals, pesticides and pharmaceuticals). Compounding the impact of chemical contaminants on marine ecosystems are additional stressors such as climate change and ocean acidification which increasingly need to be taken into account. Environmental Report Cards which have been used across Australia to increase community awareness and understanding of local issues in coastal environments, cards consistently flag poor water quality as a consequence of environmental contamination.

The predicted expansion in coastal industries over the next 20 years and beyond has the potential to increase contaminant loads and consequently intensify pressures on already impacted coastal ecosystems. In response to these growing pressures, there has been increasing community expectation that valuable ecosystem resources be protected through the sound management and regulation of contaminant issues.

Research therefore focuses on understanding the risks posed by contaminants on ecosystems, understanding their interactions with marine organisms, underpinning guideline development, predicting future impacts and developing mitigation options.

Australian research into the occurrence and impacts of environmental contaminants in marine systems dates back to the 1970s as concerns grew around the contamination of various estuaries through metal mining and smelting when regulatory controls were poor or non-existent. Examples include the lead/zinc smelter at Lake Macquarie (New South Wales), lead smelting at Port Pirie (South Australia), zinc refining in Hobart (Tasmania), and copper mining and processing at the Mt Lyell mine, near the King River and Macquarie Harbour in western Tasmania. These extreme cases had serious impacts on aquatic ecosystems, for example, in the 1970s; oysters from the Derwent River, Tasmania were grossly contaminated with zinc discharged from a local smelter and were unfit for human consumption (Bloom and Ayling 1977). Other more recent examples include dioxins/PCBs in Homebush Bay, resulting in consumption bans for fish caught west of the Sydney Harbour Bridge (NSW Food Authority 2013); PAHs and hydrocarbon oil/tar contamination preventing port expansion in Newcastle Harbour until major remedial actions were undertaken (CH2MHill,2014).

Marine contaminants research in Australia has grown considerably over the last 40 years to include a number of research groups across the country. Key institutions in this area are: CSIRO, AIMS, ANSTO, ERISS, NSW Office of Environment and Heritage, Victorian EPA/Melbourne Water (CAPIM), Queensland Government (Entox) and research groups within many universities such as: Canberra, Curtin, Griffith, Wollongong, Sydney, CDU, SCU, JCU, CQU, UTS, UQ, UNSW and UWA. Based on membership of professional organisations, the cohort of scientists working in this area is around 100 (not including students). Contaminants research in Australia is a success story in terms of the level of collaboration and co-operation between the research and regulatory communities. This is illustrated by the history of environmental guideline development in Australia which has involved deep collaboration across professional and institutional boundaries. This is one of the reasons behind Australian research in this field being highly regarded internationally. Professional societies such as the Australasian branch of the Society of Environmental Toxicology and Chemistry (SETAC) have played an enormous role in developing these linkages and promoting Australian science on an international stage.

Work is currently funded directly by Federal and State Governments and research agencies with some investment from the private sector.

Sources of contaminants to the Australian Coastal Zone

The United Nations Environment Programme estimates there are around 50,000 industrial, agricultural and household chemicals that are commercially-available (UNEP 2013). These can enter waterways through diffuse source inputs such as agricultural runoff, stormwater runoff and atmospheric deposition, or by direct discharge of treated wastewaters from sewage treatment plants and industry.

Toxicologically-based guidelines are in place for a limited number of priority metal and organic contaminants that are discharged in high volumes, or are particularly toxic;

however for most contaminants the guidelines are unreliable or non-existent. The key issue is that we are introducing 100s of new chemicals annually yet we have only 38 high reliability and 65 moderate reliability water quality guidelines in places. Thus, we are unable to reliably determine the risks posed from a very large percentage of the chemicals that may contaminate our coastal waters, either individually or in mixtures, nor do we know about their persistence or the impact of their degradation products.

There are legacy contamination issues in many industrialised Australian estuaries. For instance, to protect human consumers, commercial fishing has been banned in areas of Sydney Harbour since 2006 due to the detection of toxic organochlorine chemicals in fish and prawns. These contaminants originated from former industrial sites, as discharges or leached from contaminated soils, ultimately accumulating in bottom sediments. They are subsequently taken up by sediment-dwelling organisms and passed on via the food chain to fish, crustaceans and marine reptiles/mammals.

The polluting effects of acid sulfate soils were realised when fish kills due to hypoxia and fish disease (e.g. red spot ulceration) were observed in estuarine waters. Acid-forming soils can be found at many coastal locations and are particularly prevalent in northern New South Wales, SA, WA, Queensland and around Darwin NT. The cost of managing acid sulfate soils, including the replacement of damaged infrastructure can be significant. In Queensland alone, the cost is approximately $189 million per year not including direct losses to fisheries and agriculture (Ozcoasts 2010). The acid can dissolve metals, such as aluminium and if discharged to rivers and estuaries the combination of metals and acidity can kill plants and animals.

Antifouling paints may also degrade water quality in harbours or marinas where there is a high density of shipping. Tributyltin has been phased out globally as a result of its devastating effects on the oyster industry, however legacy contaminant problems still exist owing to the presence of TBT and its breakdown products in sediments and also on the hulls of boats that have been 'overpainted' with other antifoulants. Replacement antifoulants such as copper-based formulations are also likely to impact on estuarine and coastal systems particularly in busy harbours and marinas. Rocky foreshore communities and harvested shellfish are particularly vulnerable to antifoulant contaminants.

While new chemicals are introduced continually, only a small proportion of these chemicals are regularly considered in assessments and even fewer routinely monitored in water. An emerging contaminant can be broadly defined as any synthetic or naturally occurring chemical that is not commonly monitored but has the potential to enter the environment and cause known or suspected adverse effects. The release of emerging chemical or microbial contaminants may have gone unrecognised for long periods until new, more sensitive analytical detection methods were developed. The contaminants detected include human and veterinary drugs, natural and synthetic hormones, personal care products, detergent metabolites, plasticisers, insecticides, fire retardants and microplastics. Work on the environmental fate of organic contaminants has progressively shifted from pesticides to organic micropollutants, such as pharmaceuticals and personal care products, endocrine-disrupting chemicals and manufactured nanomaterials.

Plastic pollution in the oceans is a global issue which is receiving increasing attention. Plastic production has increased 560-fold in the last 60 years and will continue to increase exponentially (PlasticsEurope 2012). Globally, one third of marine turtles and two thirds of seabirds have ingested anthropogenic debris (Hardesty et al. 2014). The greatest number of seabirds affected globally is in the Tasman Sea, south of Australia (Hardesty et al. 2014). It is predicted that 95% of seabird species will have ingested plastic by 2050 (Hardesty et al. 2014). Effects on marine life include entanglement, physical effects from ingestion, and transmission of toxic chemicals (Reisser et al. 2013).

Sources of contaminants to the Australian Coastal Zone

- Urbanisation
- Stormwater runoff
- Industrialisation (e.g. coal-fired power stations, mineral processing, chemical manufacturing, pulp mills)
- Offshore oil and gas industries
- Ports/marine harbours (bulk commodity loading spillage)
- Dredging
- Desalination plants
- Mine effluent disposal
- Sewage and wastewater disposal
- Runoff from agriculture (fertilizers, pesticides)
- Marina's/Shipping traffic (including antifouling paints)
- Acid sulfate soils
- Aquaculture
- Air pollution
- Aeolian dust
- Intensive animal production

Relevance

There are a large array of stakeholders in this area: the general public who wish to see their coastal environments managed responsibly, State and Federal governments who have regulatory responsibilities, and private industry who aside from compliance are increasingly driven by ethical considerations 'corporate social responsibility' in order to demonstrate their commitment to coastal environmental management (e.g. aquaculture, oil and gas industry).

The end-users of the research are many. The primary users are generally the regulatory agencies and the industries involved. However, a substantial indirect benefit of research and sound environmental management flows onto other users of the waters and its resources, such as fishermen, oyster farmers, recreational users and the tourism sector whose activities are dependent on the good health of marine ecosystems.

Science needs

The science needs are grouped below into the following categories: detecting contaminants in the environment, understanding contaminant fate and effects on specific biota and, translating these findings into a credible assessment of the risk to whole ecosystem health, which will inform management actions. This last step is termed: 'integration science'.

Detecting contaminants in the environment

The determination of exposure concentrations is a critical step in risk assessment and many of our current analytical methodologies are inadequate. The development and application of state-of-the-art measurement capabilities that can track the behaviour of contaminants in all environmental compartments at concentrations that are environmentally relevant, can measure those forms that are important biologically are required. In addition, for routine application there is a need to develop new tools that are sensitive, robust, rapid and cost effective.

Advances in analytical techniques have opened up new opportunities to study contaminant behaviour at time and spatial scales not previously possible. These include X-ray (synchrotron science), isotope tracing, coupled speciation and spectrometric instrumentation, passive samplers and sensors amenable to field deployment. In the area of biological assessment, the '-omics' revolution has provided an exciting array of new techniques for quantifying ecosystem diversity and function. In particular, ecogenomic approaches have already shown great promise in detecting changes in community structures that are associated with contaminant gradients (Chariton et al. 2010).

Environmental monitoring programs are often criticised as they do not provide adequate information on exposure to environmental contaminants or the status of impacted biological communities. In particular, establishing baselines (i.e. natural chemical concentrations and ecological states) is a key issue particularly in the context of preparing environmental impact statements and monitoring changes with time. Very often the baseline data used is inadequate or relies on extrapolation from other systems. Considerable expenses are outlaid on sub-standard chemical measurements that frequently do not meet assessment needs. The issue here is ensuring that consultants and environmental analytical laboratories adopt best practice methods that have appropriate performance characteristics for monitoring purposes.

The scientific challenges in this area are:

- Developing multi-residue methods in marine biota (including bioanalytical tools) for trace level residue analysis (ng/L and below) of micropollutants, including contaminants of emerging concern (endocrine disrupting chemicals, pharmaceuticals and personal care products, nanoparticles and microplastics).
- Development of new techniques/approaches for elucidating monitoring contaminants concentrations in situ and elucidating contaminant bioavailability in sediments and waters.
- Techniques to quantify concentrations of 'new'contaminants such as microplastics, personal care products, antibiotics and endocrine-disrupting chemicals.
- Development of ecogenomic techniques for measuring biodiversity and ecosystem function in marine systems.
- Assessing the environmental exposure, transformation and fate of organic micropollutants in marine waters, (e.g. hormones, pharmaceuticals, personal care products).
- Measuring solid-phase speciation of contaminants in sediments to aid predictions of bioavailability.
- Monitoring the amount and forms of plastic in the environment using low cost means. Such as biomonitoring or opportunistic use of remote sensing from ships, and new analytical approaches for assessing type or source.
- Cost-effective monitoring –application of proxies/surrogates and use of remote sensing.
- In situ and continuous measurement of contaminant concentrations (or surrogates).
- Developing a comprehensive and accurate database of baseline contaminant concentrations in Australian coastal waters to help define the reference condition.
- Development of reliable, accessible integrated databases on contaminant distributions in marine systems (environmental information systems).
- Defining best practice monitoring and measurement protocols for use in Australia.

Effects of contaminants on biota

As environmental regulations have become more sophisticated, research has evolved from studying the acute effects of single toxicants to characterising more subtle, sub-lethal and chronic effects of mixtures of chemicals. The latter is a scenario more representative of actual environmental conditions. A major challenge in this area is to understand how very dilute mixtures of contaminants interact with living organisms, and how interactions between contaminants may magnify biological effects. Importantly, organisms will be subjected to additional multiple stressors such as climate change, habitat modification and ocean acidification which may enhance the impact of contaminants.

In terms of ecological risk assessment, a common limitation is the inappropriate ecotoxicological tests that are applied in environmental impact assessments that frequently do not meet assessment needs, e.g., direct toxicity assessments (DTA) for waters which utilize insensitive test organisms or use acute tests instead of sub-lethal chronic tests. Australia still lacks standardised ecotoxicological tests for the assessment of marine contaminants.

The scientific challenges in this area are:

- Development of sensitive marine ecotoxicity tests for assessing the toxicity of contaminants in waters and sediments.

- Understanding the toxicity of mixtures of contaminants to marine organisms at acute, chronic and sub-lethal concentration ranges and developing theoretically sound predictive models.
- Understanding the effects of pulses of contaminant exposure on marine organisms.
- Determining the impacts of terrestrially-derived pesticides on marine organisms.
- Understanding relationships between exposure and effects in contaminated sediments, encompassing a range of organism types and feeding behaviours.
- Improving the environmental relevance of laboratory toxicity testing to better mimic field exposures.
- Developing methods and guidelines to assess short-term exposures (pulses) to contaminants in waters and sediments.
- Utilising molecular biology tools to understand the mechanisms behind contaminant toxicity and detoxification processes in aquatic organisms.
- Developing assessment approaches that take into account multiple stressors such as the effects of climate change, hypoxia, flow and salinity.
- Understanding the use and ecological relevance of total and functional microbial diversity as indices of environmental change, ecosystem function, ecosystem resilience, contamination/perturbation and remediation.
- Biomarkers as an additional line of evidence in weight-of-evidence assessments.
- Increased contaminants inputs into coastal ecosystems have been identified as a potential cause of higher disease incidence in marine species. However, so far, no environmental studies have addressed whether the increased disease incidence can be due to natural reservoirs of pathogenic bacteria responding positively to contaminants.
- Impact of antibiotics (e.g. from aquaculture) on marine organisms and the development of antibiotic resistance.
- Quantifying the impact of plastics on marine organisms. This includes their role as a vector for hydrophobic organic contaminant exposure.

Integration science

A critical step is the translation of effects observed on individual organisms (the cornerstone of ecotoxicology) to ecosystem level impacts and assimilation of exposure and effects data into regulatory frameworks. Current state of the art approaches involve the use of multiple lines of evidence (chemistry, ecotoxicology and ecology) to better regulate and manage contaminants in aquatic systems.

The risk assessment of contaminants in the environment increasingly requires sound underpinning science directed specifically at understanding the fate, transformations and ecosystem impacts of existing and emerging contaminants. This approach is by its nature transdisciplinary, necessitating an integration of chemical, ecotoxicological and ecological assessment capabilities, along with strong bioinformatics to analyse complex data streams.

A significant challenge in integration science is to develop models that can predict the concentration and biological effects of exposure to contaminants at variable scales temporally (e.g. hours to decades) and spatially (e.g. site, landscape, regional), in different environments (high energy sandy coastlines, low energy upper estuaries), and scenario analysis to determine different intervention strategies.

In addition there is a need to improve our ability to assess risks from multiple contaminants and how this is influenced by multiple stressors in estuarine and marine ecosystems. This challenge also incorporates the development of regulatory guidelines that are adequately protective without placing unnecessary constraints on coastal development. The guidelines need to be 'living' documents that can be regularly updated without need to political intervention (a fundamental tool, not a political pawn)

Specific challenges include:

- Increasing the understanding of ecological risks associated with emerging contaminants (e.g. endocrine-disrupting chemicals, pharmaceuticals and personal care products) in marine systems.
- Improving the statistical and biological robustness of methods (e.g. species sensitivity distributions) used to determine 'safe concentrations'.
- Developing better spatial and biogeochemical models to link landscape management, changes in land condition (both inland and coastal), and changes in anthropogenic inputs to allow prediction and protection of marine resources.
- Improving bioinformatics pipelines for dealing with complex 'omics-derived' data sets and new statistical approaches for interpreting effects thresholds such as tipping points for community health impacts.
- Integrating mixture toxicity, hormesis and bioavailability (incorporating site-specific physicochemical properties) into ecological risk assessment methods.
- Improved linkage of catchment-to-coast evaluations: specifically for contaminants – better tools for catchment signatures; improved understanding of remobilisation and transport from catchments; estuaries as filters.
- The inclusion of climate change and multiple stressors on contaminant bioavailability and toxicity.
- The development of predictive models of contaminant mobility, transport and toxicity.
- Merging of localised knowledge of contaminant distribution and behaviour with reconfigurable/relocatable coastal environmental models.
- Integration of ecogenomic, metagenomic and transcriptomic information in risk assessments
- Establish water quality guidelines for sediment, nutrients, pesticides and other contaminants in marine environments, in particular northern Australia.
- Ensure learnings from disturbed/polluted coastal catchments in the south and east of Australia are applied to the more pristine catchments in the north, in the context of proposed development of agricultural land uses.
- Establish baselines for the more pristine catchment-to-coast systems in northern Australia, including water quality and native biodiversity.
- Improved spatial and temporal understanding of the contribution of pollutants by point sources to the Great Barrier Reef lagoon, in particular for pollutants other than total suspended solids, nutrients and photosystem II inhibiting herbicides that may pose a high risk to Great Barrier Reef ecosystems.
- Development of integrated GIS databases with contaminant monitoring information from Government, research organisations and industry.
- Development of indicators of coastal and marine ecosystem health/disease, using a variety of trophic levels, from microbes to megafauna.
- Improve understanding of cumulative impacts of contaminants, including interactions with climate change factors (temperature, ocean acidification).
- Integrated whole-of-system models to test different management scenarios and interventions
- Understanding the relationship between human behaviour, incentives, infrastructure, and attitudes in determining human behaviours that affect the environment.

Perspective

Key drivers setting research priorities

The research agenda will be set by both national and international pressures, as dictated by government, community and industry needs. Several national and international drivers provide impetus for research. Internationally, these include recent initiatives such as the European Union's Water Framework Directive, the European Union's REACH program and the Global Harmonisation System for chemicals, UNEP's Strategic Approach to International Chemicals Management (SAICM) and the Stockholm treaty on persistent organic pollutants. National drivers include the ongoing revisions to the National Water Quality Management Strategy and the Australian and New Zealand water and sediment quality guidelines which occur on a 10-15 year cycle.

International best practice standards are also a driver. There is also the expansion of 'best practice' global codes that pressure industries to meet strict environmental standards. Examples include: the Aquaculture Stewardship Council's certification scheme (ASC 2014) and the Global Sustainable Seafood Initiative (GSSI 2014). These are not national regulations, but influence the local industry by regulating access to certain markets through the need to adopt best practice codes.

Why does this work need to be done in Australia?

Australia's coastal environment is unique in many respects (e.g. geomorphology and biodiversity) and consequently large components of overseas research are not directly applicable to the Australian situation. Australia has a wide range of ecoregions ranging from polar (Antarctic Territory), temperate to tropical. The diversity of coastal systems in Australia (macro-, micro-tidal systems, coastal lagoons, coral reefs, estuaries, salt marshes, mangroves, etc.) means that science for our coasts needs to be flexible and tailored to requirements. It is therefore vital that Australia maintains its investment in marine contaminants research.

A number of current burning issues illustrate this point:

- For the proposed development of northern Australia and the need prevent ecosystem degradation that has occurred elsewhere.
- Protection of the GBR: understanding the impacts of sediment, fertilizers, and herbicides and pesticides that are present in runoff from agricultural areas (e.g. sugar cane plantations) on reef ecosystems
- The tensions around dredging - Gladstone Harbour: are released contaminants responsible for fish disease?
- Poor water quality in over half of the estuaries in NSW. Many have double the natural levels of sediment and nutrient inputs, and around one-third of catchments have lost over 50% of their natural vegetation through land clearing (SOE 2011).

- Given the drivers to further develop northern Australia, special emphasis needs to be placed on improving our understanding of tropical coastal ecosystems. Tropical regions have unique ecosystems comprising sensitive habitats, unusual taxa and greater biodiversity than temperate regions. The direct application of ecological risk assessment (ERA) tools to tropical regions may not be appropriate due to differences in geochemistry, organic matter, climatic conditions (including higher temperatures and suspended solids loads, seasonal rainfall and the ephemeral nature of local water bodies) and differences in biota physiology. Specific tropical habitats most at risk include marine and estuarine mangroves, coral reefs, seagrass communities, and pelagic and benthic marine ecosystems. Very limited exposure or effects data currently exists to appropriately assess the risk of multiple stressors in these tropical systems.

Realisation

The unmet needs in this area are identified below. Note that many are common to other areas of marine science. We see knowledge transfer as a critical activity to attain maximum impact in this research area. This would build on the networks that already exist in the contaminants area and will result in research translating into management practice.

Key infrastructure, funding and capability requirements

- National core funding (e.g. all government and industry) to achieve research outcomes on the many contaminant issues without borders, including consistent regulations.
- Maintaining national research expertise in marine contaminants analysis, ecotoxicology and ecology.
- Coordinated funding on coastal zone issues focussing on sustainable ecosystem management which enhances collaboration across University and Government Institutional boundaries.
- University training need to be boosted in the area of ecotoxicology, risk assessment and environmental omics. It is noted that the parallel growth of environmental bioinformatics as a discipline will be necessary to realise significant advances.

Enhancing cross-disciplinary research

- Funding initiatives that favour interdisciplinary and cross-disciplinary team approaches
- The designation of demonstration sites to encourage researchers to work on the same sites and share their data. Not only would this result in enhanced science impact but also value for money for the funding agencies.

Knowledge Transfer

- Significant impact would be achieved by providing 'how to' guidance to the

environmental consulting and analysis sectors. Very often this sector which provides services to a wide range of coastal industries uses sub-optimal methods. Interactions with the research community resulting in a transfer of knowledge and expertise would improve this situation.
- A facilitated exchange program of short-term secondments and other constructive interactions between providers of research on coastal contaminants and environmental managers in coastal facilities and infrastructure (e.g. ports, coastal industry, wastewater treatment plants, environmental departments for all levels of government, EPAs, planning authorities) to improve an understanding of knowledge needs among the former and science capability and capacity among the latter.
- Regular workshops to inform regulators and industry of knowledge advancements that are transforming guidelines and assessment frameworks (i.e. to increase the rate of adoption of best practice)

Impediments

- Lack of regulatory pressure at both Federal and State level on industry to fund research on contaminant impacts and their mitigation.
- Inconsistent application of guidelines and frameworks across 'borders' (federal/state, state/state), despite the same fundamental contaminant issues
- Lack of funding to develop new or improved marine water and sediment quality guidelines for contaminants.
- No formal programs/initiatives to promote international collaboration in the marine contaminants area.
- Lack of funds to support national collaborative projects of the type regularly supported in North America and Europe. The CRCs provide an opportunity but there is a trend away from public good CRCs.

List of contributing authors and affiliations

Simon Apte CSIRO Land & Water Flagship, Lucas Heights, Sydney

Graeme Batley Land & Water Flagship, Lucas Heights, Sydney

Anthony Chariton Land & Water Flagship, Lucas Heights, Sydney

Edward Butler, Australian Institute from Marine Sciences, Darwin, NT

Denise Hardesty, CSIRO Oceans & Atmosphere Flagship, Hobart, TAS

Rai Kookana Land & Water Flagship, Lucas Heights, Sydney

Frederieke Kroon, Australian Institute from Marine Sciences, QLD

Stuart Simpson Land & Water Flagship, Lucas Heights, Sydney

Jenny Stauber Land & Water Flagship, Lucas Heights, Sydney

Peter Teasdale Griffith University, QLD

Chris Wilcox, CSIRO Oceans & Atmosphere Flagship, Hobart, TAS

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