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Spatially explicit scenarios for conservation planning in the Great Barrier Reef coastal zone, Australia

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Abstract

The Great Barrier Reef World Heritage Area (GBRWHA) borders the east coast of Northern Australia for almost 2000 km. Parts of this coast have been extensively developed with planned and potential further coastal developments, including for mining, ports, agriculture, urban, industrial and tourism. These developments may threaten the health of the GBRWHA through sediment, nutrient and pollutant run-off and habitat loss. In the context of conservation planning, the future must be taken into consideration to understand which ecosystems, species or ecological processes may be at risk and where. However, future coastal development is difficult to predict as it depends on volatile socio-economic factors. With this in mind, we develop a research project that uses spatially explicit scenario planning to identify plausible futures to 2035 for the GBRWHA coastal zone. Land use change modelling to produce eight scenarios is being done with GIS. The resulting maps of scenarios allow for comprehensive conservation planning.

Introduction

The Great Barrier Reef (GBR) and its lagoon, along the coast of northern Queensland, Australia, have been classified as a World Heritage Area (the GBRWHA) since 1981. Most of this WHA (with the exception of small areas reserved for ports) is also protected up to the shoreline as the Great Barrier Reef Marine Park (GBRMP) (Figure 1). Hence, most of the marine part of the coastal zone is protected under federal law and consistently managed. However, neither the GBRWHA nor the GBRMP cover any of the terrestrial or freshwater coastal zone. This part of the coastal zone, however, is the "backbone" of the GBR. The terrestrial and freshwater parts of the coastal zone include substantial areas of forests and woodland, estuarine vegetation, mangroves and freshwater wetlands. These non-marine coastal ecosystems can act as a buffer between the land and the sea and filter run-off from land, limiting the amount of sediment and pollutants reaching the GBR lagoon (Great Barrier Reef Marine Park Authority, 2009). Coastal development has taken place in numerous areas of the GBR coast leading to degradation or loss of coastal ecosystems, increase in run-off (sediments and nutrients) in the lagoon and intensification of dredging in the lagoon, stirring up sediments and pollutants (Wolanski and De'ath, 2005; Brodie *et al.*, 2012). Economic activities in the GBR coastal zone are set to expand and intensify with numerous on-going coastal development projects and further plans to increase export capacity and tourist numbers along with expanding agricultural and urban areas (Waterhouse *et al.*, 2010).

The pressure from coastal development along the GBRWHA led the United Nations World Heritage committee to warn the Australian government that better coastal management and policies are required. The coral cover on reefs in the GBR has declined on average by half over the period 1986-2011 due to the combination of natural and human-induced causes (De'ath *et al.*, 2012). Maintaining functioning coastal ecosystems and limiting disturbance, pollution risks and run-off are some of the main steps that will allow the GBR to recover and be resilient to future climatic events (Brodie and Waterhouse, 2012). Conservation planning determines the best spatial use of limited conservation resources to minimise the loss of valued aspects of the natural world associated with human development (Margules and Pressey, 2000). In the context of coastal development and land use change, conservation planning is faced with a significant challenge. The threats to ecosystems and species are highly uncertain. In Queensland, they mostly depend on volatile foreign economic factors that dictate which development will take place and where. Consequently, conservation planning for the GBR coastal zone requires an understanding of plausible future development and land use change.

Scenario planning is a well-established method for understanding and planning for the future. It has been recently adapted to and used in conservation planning (Pereira *et al*., 2010). For conservation issues where the future is highly uncertain, scenario planning allows consideration of different plausible futures and how current management decisions and policies can be adjusted to ensure persistence of the key natural elements in question (Peterson *et al*., 2003). As conservation planning is inherently spatial, scenarios are spatially represented in the form of land use maps. We use spatially explicit scenario planning to prepare maps of plausible futures for the GBR coastal zone to 2035. The scenarios are designed and used to answer the specific question: How can conservation planning ensure the resilience and health of the GBRWHA and its coastal zone in the light of future coastal development and land use change in the next 25 years? Here, we describe 1) how we define the terrestrial coastal zone in this project, 2) the process used to define and characterise scenarios and, 3) the spatial modelling method used to produce maps of scenarios.

Methods

A combination of stakeholders' working groups and experts' meetings are conducted to determine what the coastal zone should encompass, the main drivers of land use change in the coastal zone adjacent to the GBR and the storylines of scenarios for the GBR coastal zone.

The coastal zone in this conservation planning project has to be delimited and needs to incorporate areas corresponding to intensive coastal agriculture, geomorphologic characteristics, coastal vegetation, human presence, and recreational activities. The coastal zone definition can be summarised as any area within 10km from shore or below the 20m elevation contour continuous with the coastline and any area, and 5km around it, that is covered by either residential, industrial, sugar and horticulture land use found within 1km of the inland boundary created by the two previous descriptors (Figure 1).

Scenarios are built using storylines with varying levels and importance of five socio-economic drivers. These drivers dictate the amount and type of coastal development and land use change in the coastal zone. Four scenario streams are described, each with a different level and type of land use change, characterised by the amount of increase or decrease of the land use classes. The systems of governance (the process of decision-making and implementation), however, can play a significant role in mediating outcomes of the distribution of land use change. Depending on governance, the spatial distribution of land use classes can vary, along with their impacts on species and ecosystems. In order to understand the level of impact of different governances, each scenario stream is modelled in two contexts: with strong and weak governance.

When scenario storylines are finalised, quantitative amounts of change in land use are attributed to each land use class in each scenario based on the current areas, plans, predictions and maximum amounts of space available. Different land use types have various impacts on the GBRWHA and coastal ecosystems. Thirteen land use classes are modelled. These land use classes are extracted from the Queensland Land Use Mapping Project (QLUMP) 2009 data with additional inputs from other sources to obtain more detailed land use classes. The finalised current land use map is transformed in a raster format for the modelling process.

Spatial modelling starts by producing "suitability" and "probability" maps for each land use class in each scenario depending on a set of rules established through the governance effects and the scenario storylines. These maps are created in ArcGIS (ESRI, Redlands, CA). They are all standardized to a range of values. The land use change modelling is conducted in IDRISI using the GEOMOD model, a well-established land use change software (Sloan and Pelletier 2012, Sohl *et al*., 2012) including for scenario modelling (Pontius and Neeti, 2010). Each land use class is run through the model using the current land use map, the "suitability" and "probability" maps and rules for spatial allocation of change. The resulting maps of land use change to 2035 are combined with values, for each scenario, of estimated shipping, dredging, fertilizer use, run-off and tourist numbers to produce the final scenarios.

Results and discussion

The coastal zone covers approximately 47,136 km^2 of land adjacent to the GRBWHA along approximately 2000 km of coastline (Figure 1). Intensive use areas (urban, industrial, mining and transport) cover 9.4 % and agriculture in modified environments covers 13.8 %. Other activities that impact the GBR include ports and associated heavy dredging within the GBR lagoon. These human activities are most often situated near the coastline where habitats such as mangroves and wetlands are cleared or reclaimed to allow development. As shown in Figure 1, areas of intensive uses, urban or agricultural, are also concentrated in specific areas of the coast. The importance of this observation is highlighted by a recent study on coral reef cover decline in the GBR that showed that the majority of coral cover loss occurs near or adjacent to coastal areas with the highest level of intensive uses (in the central section; De'ath *et al*., 2012). Current land use allocation without improvements in management or restoration and/or further development of intensive uses consequently threaten the health of the GBRWHA and could reduce the resilience of coral reefs to climatic change in particular (Wolanski and De'ath, 2005, Brodie and Waterhouse, 2012).

Eight scenarios are produced as maps with associated numerical values. Each scenario represents a plausible future of the GBR coastal zone. Impacts on selected ecosystems, species and ecosystem services are investigated in each scenario using spatial or quantitative modelling or qualitative assessment from experts (Wilson *et al*., 2005). Stakeholders' consultation about these scenarios and their potential impacts refines the identification of qualitative conservation goals (independent of scenarios) and quantitative objectives that are specific to each scenario to reach desired goals (Pressey and Bottrill, 2009). Comparisons of modelled development across all scenarios also identify areas that will likely be at risk in the future regardless of variation in land use drivers. Combined with the impact assessment and the stakeholder-defined objectives, the scenarios will be used to determine where protection and restoration of coastal ecosystems is required to ensure the health of the GBRWHA. Coastal zones around the world are under pressure due to human activities and development. Spatially-explicit scenario planning, exemplified with our GBR example, could help planning for the future. Scenario-based conservation planning brings together socio-economic and environmental factors to allocate development and protection spatially and promote future resilience of ecosystems.

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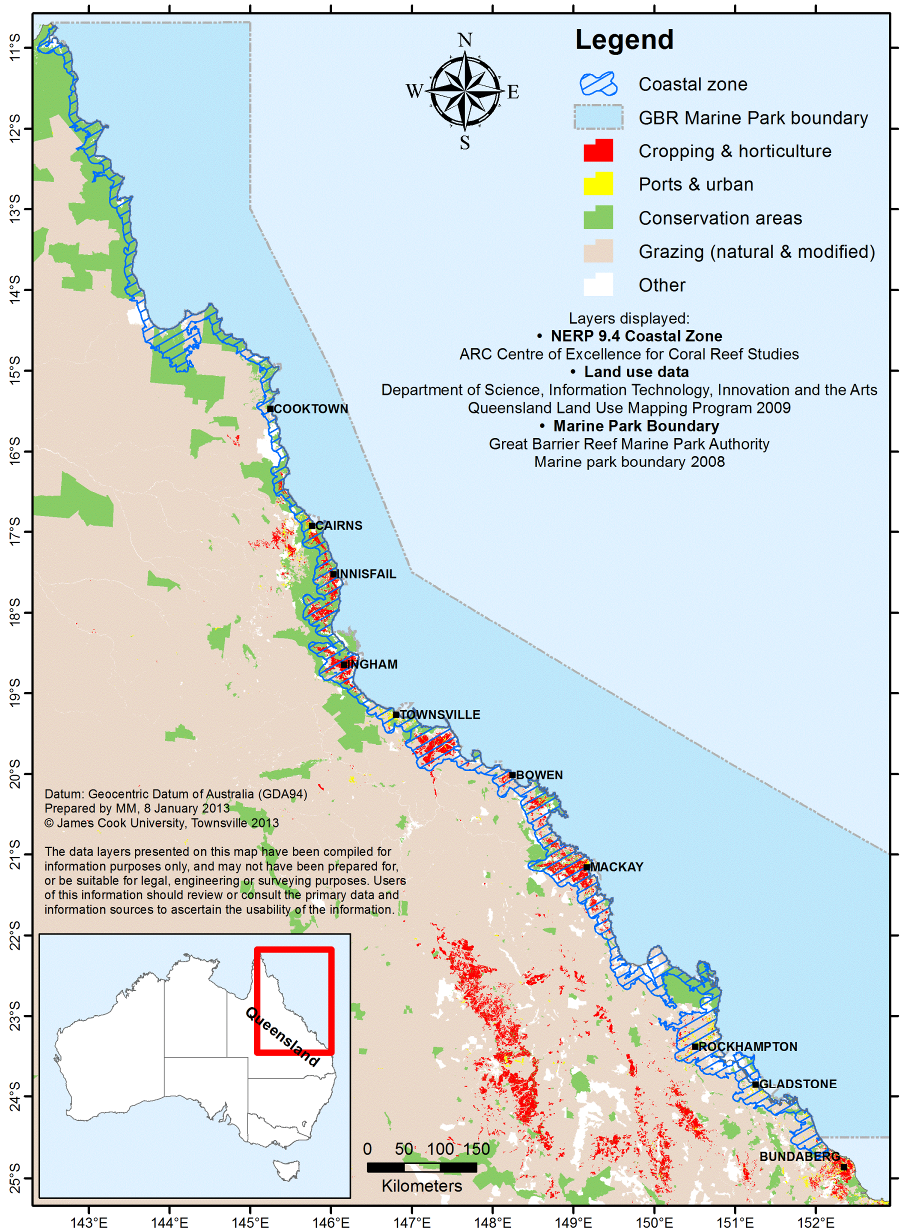

Figure 1. The Great Barrier Reef Marine Park and its coastal zone as defined for conservation planning in Queensland, Australia, with land use classes and major coastal urban centers.