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Review

Assessing risk of estuarine ecosystem collapse

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ABSTRACT

Estuarine ecosystems are increasingly threatened by coastal development and climate change. The large number of estuaries globally necessitates risk assessment to prioritise conservation efforts. Schemes for assessing risk of ecosystem collapse have been designed around terrestrial ecosystems, often defined by a single characteristic vegetation type, with their applicability to estuaries unclear. Here we consider the causes and symptoms of estuarine ecosystem collapse and assess, using a case study of the Chesapeake Bay, the applicability of ecosystem-level risk assessments to estuarine ecosystems, typified by mosaics of habitats. Functional estuaries are characterised by habitat heterogeneity and connectivity, maintenance of constituent habitats through recruitment, and a complex trophic structure including apex predators. Additionally, primary production and biomass are dominated by benthic, as opposed to pelagic, species. Hence, homogenisation of habitat types, decreased connectivity, recruitment failure, loss of apex predators and a decreased ratio of benthic to pelagic biomass may be symptoms of a trajectory towards collapse. In terrestrial ecosystems, criteria used for assessing risk of ecosystem collapse include declining or restricted distribution of ecosystems, degradation of the abiotic environment, changes in species composition and declining ecological function. As the boundaries of estuaries are typically defined by topography, rarely do significant changes in the area of the ecosystem occur. Furthermore, because the extent of estuaries is typically small, assessments based on area of occupancy may over-inflate risk. Instead, criteria based on abiotic and biotic changes, many of which are documented through monitoring programs, may be most useful for risk assessments of estuarine ecosystems.

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1. Introduction

As ecotones at the interface of the terrestrial, marine and fluvial environments, estuaries support unique species assemblages and ecological interactions (Remane, 1934; Elliott and Whitfield, 2011). Estuaries serve as vital nursery areas for many species of commercial importance provide food and raw materials, maintain clean water, sequester carbon, protect shorelines, control erosion, and provide recreational and aesthetic amenity (Barbier et al., 2011). However, due to their high value, estuaries are often under intense pressure from human populations (Hughes et al., 2005; Worm et al., 2006; Halpern et al., 2008). Conservation strategies are required to maintain estuarine biodiversity and important ecosystem services.

With thousands of estuaries globally and limited conservation funding available, mechanisms are needed to triage potential conservation efforts (Brooks et al., 2006). Biodiversity risk assessments allow decision makers to prioritise critical species and/or areas of need. Risk assessments have traditionally been focussed at the species level (Rodrigues et al., 2006). However, many researchers have suggested that risk assessment at the ecosystem scale may be more efficient than a species-by-species approach and also capture the loss of important functions often not visible in species-based assessments (Nicholson et al., 2009; and Keith et al., 2013). Because of the ease of defining their spatial boundaries, estuaries are commonly used as management units (Imperial and Hennessy, 1996; Elliott and McLusky, 2002) and may provide a suitable scale for risk assessments.

Several schemes have been advanced for assessing risk of collapse at the ecosystem-scale (Nicholson et al., 2009). The most recent such scheme is the International Union for the Conservation of Nature (IUCN) Red List of Ecosystems. Launched in 2013 (Keith et al., 2013), the Red List of Ecosystems has been widely adopted across continents and ecosystem types (e.g. Keith et al., 2013; Payet et al., 2013; Auld and Leishman, 2015; Clark et al., 2015; Murray et al., 2015). Risk assessment criteria utilised by such schemes include declining or restricted distribution, degradation of the abiotic environment, changes in species composition and declining ecological function as predictors of ecosystem collapse (Nicholson et al., 2009; Keith et al., 2013). For the purpose of risk assessment, the distribution of an ecosystem is usually defined by the area of occupancy of a dominant group of foundation species, for example a vegetation type (Keith et al., 2013). This approach works well for terrestrial ecosystems where vegetation maps are available to define and track the borders of ecosystems. This approach may also be applicable to other ecosystems such as coral reefs, which are dominated by a single group of foundation species. However, its applicability to estuarine ecosystems that are often constrained by topography and/or bathymetry, encompass mosaics of different habitat types (e.g. sedimentary bottoms, vegetation patches, shellfish beds) and have upper boundaries defined by the extent of tidal influence (Cameron and Pritchard, 1963), is uncertain. In estuarine ecosystems, the connectivity and persistence of multiple types of habitat patches may be particularly important as many species utilise multiple habitats within a landscape throughout their life history to obtain different resources (Jackson et al., 2001).

Here we consider the applicability of the IUCN Red List of Ecosystems risk assessment criteria to estuarine ecosystems. We examine common causes of decline in estuarine ecosystems and suggest a suite of indicators that are predictive of collapse and that may be used by conservation managers. A retrospective risk assessment of the estuarine ecosystem of Chesapeake Bay, in the eastern United States, conducted for the year 1980, is presented as a proof-of-concept for the proposed indicators. We identify incongruities in applying the proposed indicators to the IUCN Red List of Ecosystems risk assessment criteria, as being representative of the most common criteria proposed in risk assessment schemes, and discuss potential solutions to these incompatibilities.

2. State change in estuarine ecosystems

Effective risk assessment of ecosystem collapse requires knowledge of the range of conditions across which ecosystems may be considered functional as well as a defined end-state, beyond which they are no longer functional and collapse has occurred (Keith et al., 2013). An understanding of both functional and collapsed states allows patterns of change that are predictive of collapse at the scale of whole estuaries to be identified.

2.1. Features of functional estuaries

Functional estuaries contain a mosaic of distinct habitats, each of which is of sufficient area, complexity and number to support characteristic biota and key ecosystem services and to resist disturbance (Simenstad et al., 2006). Among and within habitat types there is connectivity of resources and species. Functional biogenic habitat patches are maintained by successful recruitment over time, facilitated by connectivity among habitat patches (Fig. 1).

Functional diversity in estuarine landscapes is a product of both species diversity within habitats (alpha diversity) and the variation present across the entire habitat-mosaic (beta diversity) (Whittaker, 1960). Alpha diversity is maximised where total habitat area is large and habitat is complex (Hewitt et al., 2005). The majority of physically complex habitat in estuaries is biogenic, such as seagrass meadows, oyster reefs or mangrove forests (Hewitt et al., 2008). These ecosystem engineers modify the abiotic environment by providing substrates, creating habitat and/or altering the flow of nutrients and energy through the system (Jones et al., 1997; Worm et al., 2006). Beta diversity is driven by the level of differentiation between the habitats present. Different habitat types maintain diverse ecological functions by supporting either different species or differing densities of taxa representative of functional groups (Hewitt et al., 2008). The presence of multiple patches of each habitat type provides potential sources of recolonisation as insurance against environmental perturbations (Loreau et al., 2003).