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Assessing risks to marine ecosystems with indicators, ecosystem models and experts

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ABSTRACT

Assessing risks to marine ecosystems is critical due to their biological and economic importance, and because many have recently undergone regime shifts due to overfishing and environmental change. Yet defining collapsed ecosystem states, selecting informative indicators and reconstructing long-term marine ecosystem changes remains challenging. The IUCN Red List of Ecosystems constitutes the global standard for quantifying risks to ecosystems and we conducted the first Red List assessment of an offshore marine ecosystem, focusing on the southern Benguela in South Africa. We used an analogous but collapsed ecosystem – the northern Benguela – to help define collapse in the southern Benguela and derived collapse thresholds with structured expert elicitation (i.e. repeatable estimation by expert judgment). To capture complex ecosystem dynamics and reconstruct historical ecosystem states, we used environmental indicators as well as survey-, catch- and model-based indicators. We listed the ecosystem in 1960 and 2015 as Endangered, with assessment outcomes robust to alternative model parametrizations. While many indicators improved between 1960 and 2015, seabird populations have suffered large declines since 1900 and remain at risk, pointing towards ongoing management priorities. Catch-based indicators often over-estimated risks compared to survey- and model-based indicators, warning against listing ecosystems as threatened solely based on indicators of pressure. We show that risk assessments provide a framework for interpreting data from indicators, ecosystem models and experts to inform the management of marine ecosystems. This work highlights the feasibility of conducting Red List of Ecosystems assessments for marine ecosystems.

1. Introduction

Marine ecosystems around the world face degradation and collapse as a result of diverse threats (e.g. overfishing and environmental change), with potentially catastrophic consequences for biodiversity, ecosystem functions and ecosystem services (Barange et al., 2014; Reid et al., 2016). Many offshore marine systems have undergone regime shifts in recent decades and reductions in commercial fishing have not always triggered reversals to antecedent ecosystem states (Frank et al., 2011; Roux et al., 2013). Understanding the risks of such outcomes is a fundamental requisite for marine conservation planning and ecosystem-based management aimed at avoiding ecosystem collapse. Yet the development and application of quantitative risk assessment methods for marine ecosystems have lagged behind those for terrestrial ecosystems.

Many risk assessment protocols for terrestrial ecosystems only consider declines in spatial distribution (Nicholson et al., 2009), which can be inadequate for marine ecosystems that have highly uncertain or variable spatial distributions or show functional rather than spatial symptoms of degradation (Bland et al., 2017). Qualitative and semi-quantitative risk assessment protocols (e.g. Fletcher, 2015; Hobday et al., 2009) and maps of cumulative threat impacts (e.g. Sink et al., 2012) have been developed for marine ecosystems, but these methods may not fully characterize ecosystem dynamics and pathways towards

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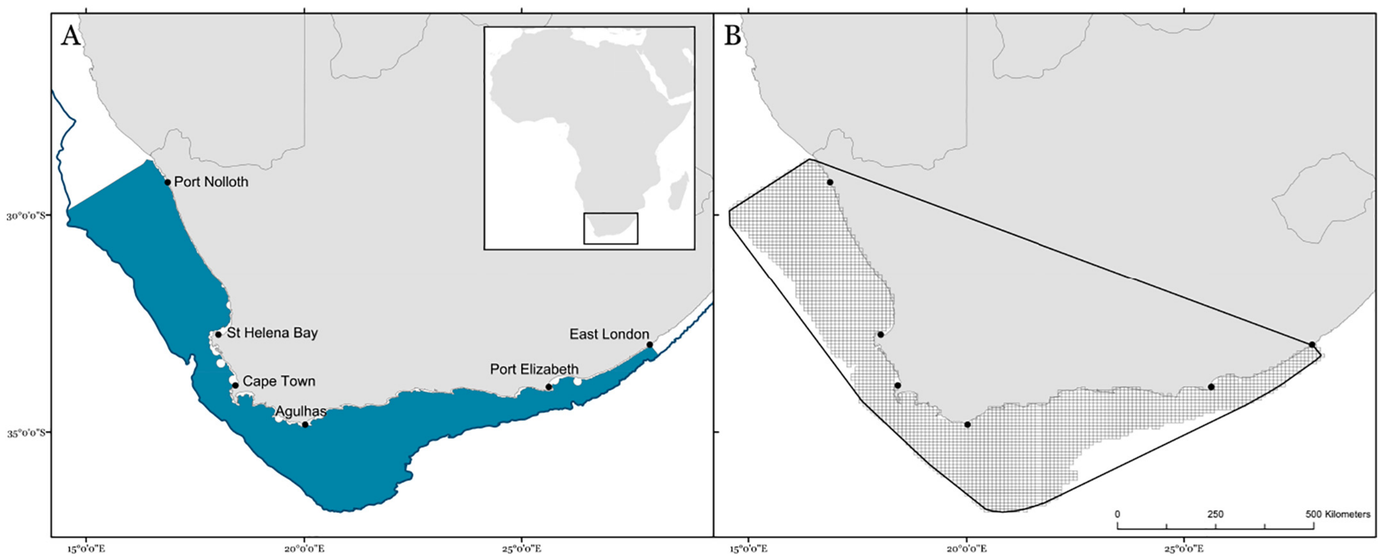

Fig. 1. Spatial distribution of the southern Benguela and assessment under criterion B of the IUCN Red List of Ecosystems. A) Spatial distribution of offshore areas within the South African exclusive economic zone from the 30-m to the 500-m isobath (dark blue line). B) The thick black line indicates the minimum convex polygon enclosing all ecosystem occurrences (extent of occurrence). The small grey squares indicate grid cells occupied at a 10 × 10-km resolution (area of occupancy). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ecosystem collapse. The IUCN Red List of Ecosystems explicitly accounts for complex ecosystem dynamics and is designed to be globally applicable to terrestrial, marine and freshwater ecosystems (Bland et al., 2016; Keith et al., 2013). Despite the growing use of the IUCN Red List of Ecosystems protocol, only 10% of ecosystems (7 out of 71) on the global Red List belong to the marine realm and the protocol is yet to be tested on offshore marine ecosystems (Rowland et al., 2018).

Defining ecosystem collapse, identifying suitable indicators and quantifying long-term ecosystem changes are three central requirements of ecosystem risk assessment (Bland et al., 2016; Bland et al., 2018). Ecosystem risk assessments rely on explicitly identifying the endpoint of ecosystem degradation (i.e. ecosystem collapse), defined as a transformation of identity, a loss of defining features and/or replacement by a novel ecosystem (Keith et al., 2013). In marine ecosystems, complex changes in multiple functional groups, trophic pathways and environmental drivers can be symptomatic of ecosystem collapse, challenging the quantification of collapse thresholds (Bland et al., 2018). The large amounts of data available globally on marine regime shifts and trophic cascades could inform the delineation of collapsed ecosystem states for risk assessment but currently remain under-used (Bland et al., 2018). Quantitative techniques have been developed to identify regime-shift thresholds (i.e. thresholds marking sudden, non-linear changes in ecosystem indicators triggered by small changes in pressures; Foley et al., 2015; Tam et al., 2017) and to characterize ecosystem trophodynamics under perturbation and recovery (Link et al., 2015). These techniques may identify ecological thresholds that could inform the delineation of collapsed ecosystem states. However, in some cases, ecological thresholds may be difficult to quantify for risk assessment either because they require large amounts of data that are not readily available (e.g. structural equation modelling) or because they can only be calculated retrospectively (e.g. some regime-shift indicators) (Tam et al., 2017). Some ecosystems may undergo large transformational changes that do not involve non-linear thresholds. In any case, careful derivation of collapse thresholds based on available evidence is necessary to ensure a repeatable analysis of state change (Bland et al., 2018).

In the IUCN Red List of Ecosystems, measuring transitions to collapse requires assessors to select ecosystem-specific indicators, rather than generic indicators (e.g. species richness; Keith et al., 2013). This promotes the comparison of indicators based on a mechanistic understanding of ecosystem dynamics, but detailed guidelines are currently lacking for selecting indicators in different ecosystems (Bland et al., 2016). Marine ecosystems are dynamic by nature, with complex trophic links and environmental drivers that shift in space and time, so multiple indicators are required to quantify different dimensions of change (Coll et al., 2016; Shin et al., 2010). Catch-based indicators (e.g. fishing pressure), survey-based indicators (e.g. biomass, size and trophic level), and model-based indicators (e.g. model-derived trophodynamic indicators) all provide complementary views of ecosystem responses to fishing and environmental change (Coll et al., 2016; Shin et al., 2010). Recent work has focused on constructing empirical indicators for management, conservation and communication of ecosystem state and change for multiple marine ecosystems (Boldt et al., 2014; Coll et al., 2016), but these indicators remain unevaluated for use in ecosystem risk assessment.

The limits of modern time series for monitoring present a further challenge for ecosystem risk assessment. Many marine ecosystems show distinct intra-annual and decadal variability, for example linked to species recruitment and climatic oscillations such as El Niño or La Niña events. Distinguishing short-term changes from directional long-term trends towards collapse can be difficult with time series of indicators spanning only a few decades (Coll et al., 2016). Mass-balance ecosystem models rely on biomass, diet and catch estimates from a few species to reconstruct complete foodwebs and are useful tools for historical reconstruction of marine ecosystems before the onset of systematic surveys or for groups with inconsistent surveys (Coll and Lotze, 2016). These ecosystem models have revealed drastic patterns of marine ecological change over historical timeframes (Ainsworth et al., 2008; Watermeyer et al., 2008b) that could affect the resilience of modern ecosystems to upcoming threats. A historical approach is essential to reduce the impacts of shifting baselines on the estimation of risk and to track the status of ecosystems through time with sequential Red List assessments.

The southern Benguela is a biodiverse and dynamic upwelling ecosystem located off the coast of South Africa (Fig. 1a) and it has been home to valuable and large-scale pelagic and demersal fisheries since the 1950s (Griffiths et al., 2004). The southern Benguela upwelling ecosystem shares many ecological features with its northern neighbour located along the Namibian coast, the northern Benguela (Hutchings et al., 2009). The northern Benguela underwent a regime shift in the