Of sets of offsets: cumulative impacts and strategies for compensatory restoration

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Summary
Biodiversity offsets are increasingly advocated as a flexible approach to sheeting home the ecological costs of economic development. Arguably, however, this remains an area where policy making has run ahead of science. A growing number of studies identify limitations of offsets in achieving ecologically sustainable outcomes, pointing to ethical and implementation issues that may undermine their effectiveness. Here, we explore several conceptual issues relating to the effectiveness of alternative biodiversity offsetting approaches, using a marine system as an example. We develop a novel system dynamic modeling framework which integrates key components of the broader socio-ecological system within which offsets operate, and use this model to unpack some of the key drivers identified in the empirical literature as determining the potential success or failure of offsets.

Introduction
Biodiversity offsets are increasingly considered as an option to compensate for the ecological costs of development, with 72 countries identified as having some form of legislative requirement for compensatory biodiversity restoration either already in place or under development (Madsen et al. 2011). They may include a wide range of interventions, at species, community or whole-of-ecosystem levels, which can be carried out as part of voluntary or mandatory regimes, with the aim to compensate for on-going or anticipated ecological loss. While often vaguely defined, the objective of "no net loss" (Gordon et al. 2011, Gardner et al. 2013) is central to offsets and increasingly offset policies require demonstration of the equivalence between what is created and what is lost. Despite their increasing popularity as a flexible approach to the reconciliation of economic development with biodiversity conservation, a number of studies have pointed to the potential limitations of offsets in achieving ecologically sustainable outcomes (Morris et al. 2006, Maron et al. 2012). Here, we explore several conceptual issues relating to the effectiveness of alternative biodiversity offsetting approaches, using a marine system as an example.

Materials and methods
We propose a modelling framework to assess stylized offset management strategies under alternative scenarios relating to (i) ecological response to the implementation of multiple developments and offset actions, in particular the time delays involved in ecological recovery, and (ii) societal response to the damages caused by development, determining the objectives for compensatory restoration actions.
The biophysical component of the model is adapted from the formal representation of habitat – species interactions proposed by (Foley et al. 2012). The model captures four main processes spanning both the physical and human components of the system within which offsetting occurs: (i) a biological resource which provides a range of ecosystem services, (ii) a habitat which supports the biological resource and is negatively impacted by economic development, (iii) a management body which assesses the level of restoration required for a development proposal to be approved and (iv) a social process which determines the permitted extent of ecosystem service loss over a given time horizon.

Our management strategies capture differences in the way in which the "no net loss" objective is interpreted, including restoration scaling approaches that rely on habitat-to-habitat modelling, and value-to-value methods that explicitly account for the value to society of ecosystem changes. The management strategies considered in this analysis also capture contexts in which developments are assessed and approved, and offsets determined, on a project-by-project basis despite being components of a regionally-based strategic approach.

Results and discussion

Although stylized, the model allows exploration of key issues which may arise from the cumulative impacts of approved developments under alternative offset management strategies. Our results confirm that, when it comes to offsets as a conservation tool, the devil lies in the details. Approaches to determining the magnitude of restorations required, as well as their timing and allocation among multiple developers, can result in potentially complex and undesired sets of economic incentives, with direct impacts on the ability to meet the overall objective of ecologically sustainable development. The approach and insights are of direct interest to conservation policy design in a broad range of marine and coastal contexts, where the abundance and hence utility of a biological resource is dependent on a habitat that is affected by development or exploitation. This is representative of many marine examples involving fish and shellfish species of commercial interest, and their dependence on, for example, seagrass, mangrove and coastal marshes, coral reefs, freshwater bodies or seafloor habitat. The modeling framework can also readily be adapted to account for alternative ecosystem structures, and for cases in which the value of ecosystem services may not be strictly related to extractive resource harvesting.

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