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Prioritising catchment management projects to improve marine water quality

Jutta Beher[a,*], Hugh P. Possingham[a,b], Sean Hoobin[c], Cameron Dougall[d], Carissa Klein[a]

[a] Centre of Excellence for Environmental Decisions, Centre for Biodiversity and Conservation Science, The University of Queensland, St Lucia, QLD 4072, Australia
[b] Imperial College London, Department of Life Sciences, Silwood Park, Ascot SL5 7PY, Berkshire, England, United Kingdom
[c] WWF Brisbane, Level 1, 17 Burnett Lane Brisbane QLD 4000, Australia
[d] Department of Natural Resources and Mines, Rockhampton, QLD 4700, Australia

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ABSTRACT

Runoff from human land-uses is one of the most significant threats to some coastal marine environments. Initiatives to reduce that runoff usually set runoff reduction targets but do not give guidance on how to prioritize the different options that exist to achieve them. This paper demonstrates an easy to interpret economic framework to prioritise investment for conservation projects that aim to reduce pollution of marine ecosystems caused by runoff from agricultural land-uses. We demonstrate how to apply this framework using data on project cost, benefit and feasibility with a subset of projects that have been funded to reduce runoff from subcatchments adjacent to the Great Barrier Reef. Our analysis provides a graphical overview of the cost-effectiveness of the investment options, enables transparent planning for different budgets, assesses the existence of trends in the cost-effectiveness of different categories, and can test if the results are robust under uncertainty in one or more of the parameters. The framework provided solutions that were up to 4 times more efficient than when omitting information on cost or benefit. The presented framework can be used as a benchmark for evaluating results from a range of prioritisation processes against the best possible conservation outcomes.

1. Introduction

Runoff carrying pollutants from the land is one of the most significant threats to coastal marine ecosystems globally (Richmond et al., 2007; UNEP, 2012), including the Great Barrier Reef in Australia (De'ath et al., 2012). Pollutants carried in agricultural runoff from the land into the ocean are often classified under three main forms: nutrients, sediment, and pesticides. However, runoff from industrial or urban sources can carry additional pollutants. The impact of runoff varies with the marine ecosystem it affects through changes in water quality (Schaffelke et al., 2005). In tropical coastal marine ecosystems, for example, nutrient runoff has been linked to crown-of thorns starfish outbreaks that increases coral mortality substantially (Fabricius et al., 2010), toxic phytoplankton blooms, and the reduction of oxygen (i.e., hypoxia) required for life (Rabalais et al., 2009); pesticide runoff can exacerbate dieback of mangroves and coral bleaching (Shaw et al., 2010); and sediment runoff reduces light availability to corals and seagrass meadows (Brodie et al., 2012). Runoff with particulate and dissolved pollutants that reaches waterways can be generated through different processes of soil erosion, mainly described as hillslope, gully or streambank erosion (Merritt et al., 2003). The different suspended pollutants in waterways are further referred to with the simplified term "runoff". The form of runoff and the erosion processes that generate it are influenced by land-use and type (e.g., agriculture, urbanization, forestry). Runoff related degradation not only affects marine ecosystems, but impacts millions of people that rely upon them as a source of income and livelihood (Burke et al., 2011). Still, the most prevalent marine conservation interventions are reducing overfishing through the establishment of marine protected areas and the regulation of fisheries. Integrated land and sea planning that takes the full range of stressors into account is still in its infancy, and no method or strategy on how to best link data of landbased mitigation actions into marine conservation plans has been agreed upon as a successful example of best practice yet (Álvarez-Romero et al., 2011; Cicin-Sain and Belfiore, 2005; Makino et al., 2013; Stoms et al., 2005).

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* Corresponding author.
E-mail addresses: J.beher@uq.edu.au (J. Beher), h.possingham@uq.edu.au (H.P. Possingham), Shoobin@wwf.org.au (S. Hoobin), Cameron.dougall@dnrm.qld.gov.au (C. Dougall), c.klein@uq.edu.au (C. Klein).

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Several national and international water quality improvement initiatives have been recently established to reduce runoff and improve marine water quality, but further substantial investment in management interventions is still urgently required in most places. Examples of the already established initiatives are the European Water Quality Directive in Europe (European Parliament and Council, 2000), the Total Maximum Daily Load Initiative in the USA (USEPA, 2011), and the Reef Water Quality Protection Plan in Australia (Australian Government, 2013, 2009a). These initiatives typically include targets for improving water quality (e.g., reduction of 20% of sediment by 2020 from receiving catchments) but do not provide detailed guidance on which actions to take. Depending on the existing land-use (e.g., grazing, conservation, cropping) and erosion processes (e.g. gully, stream bank) a range of different strategies could achieve a given water quality target. As funding for achieving water quality targets is limited, an efficient approach is to prioritise projects that reduce the maximum amount of runoff per dollar spent. Furthermore, information on socio-economic and biophysical context, such as different cost factors or spatial location of ecological assets and sources of pollution can improve the prioritisation. Depending on the objective, other variables can gain influence in the prioritisation process, such as equity, minimization of opportunity costs, or technical or social aspects. In most circumstances, the prioritisation that optimizes one objective fails optimization for other objectives and different trade-offs between efficiency and other variables of importance become necessary (Wilson et al., 2009). For example, fair and equal distribution of costs among different stakeholders or regions is most desirable and is often incorporated into policy decisions to support implementation and uptake by stakeholders. However, planning for equity usually compromises the benefit for conservation for a given budget (Halpern et al., 2013).

Conservation focused planning that is based on costs and conservation benefits can demonstrate best possible outcomes for conservation objectives and provides at the same time a measure for the loss of possible conservation benefits when factors other than cost-efficiency have to be considered. Investment in conservation actions where the rates of return on investment are forecast to be highest is therefore an approach that is increasingly being applied in conservation decision making (Ando et al., 1998; Armsworth and Roughgarden, 2001; Joseph et al., 2009; Murdoch et al., 2007; Polasky et al., 2008; Possingham et al., 2001; Wilson et al., 2006). Several approaches have been developed to inform terrestrial investment decisions to improve water quality, which all have advantages and disadvantages in different contexts. For example, Klein et al. (2012, 2010) focus on avoiding additional runoff through implementation of terrestrial protected areas and provide a connection between land and sea planning, but their framework does not allow for a comparison of best options to reduce existing runoff from highly intensified land-uses, which is important across more developed landscapes. Other studies have developed approaches to identify and evaluate cost-effective strategies across intensively used land (Star et al., 2013; van Grieken et al., 2013), but focus on management strategies to minimize opportunity costs within a specific land-uses and/or land types across an entire catchment from the perspective of the landholder. Implementing a particular strategy homogeneously across an entire catchment may often not be the best option, as it requires the cooperation of the land manager/owner, which will vary from property to property, similar to benefit and cost between properties (Kancans et al., 2014; Pannell et al., 2006). Planning over larger regional scales has to deal additionally with differences in size and applicable land-uses. Finally, INFFER, a very detailed framework for assessing the cost-effectiveness and feasibility of different options exists (Doole et al., 2013; Pannell, 2013; Pannell et al., 2012; Roberts et al., 2012), but it can be time-consuming to apply in its full extent and is mostly used for assessing specific local projects with a limited number of alternative options or scenarios.

Usually either price-based or quantity-based mechanisms are used to address water quality issues within implemented conservation programs (Rolfe and Windle, 2011). In Australia, the Queensland government has implemented a price-based approach where land managers bid for a specific amount of funding to implement water quality improvement projects on their land (Australian Government, 2013, 2009a). However, little guidance on how to prioritise projects for investments has led to the use of a range of different approaches across the Great Barrier Reef (GBR) catchments. While catchments and land-uses have been assessed for their contribution to the total amount of runoff to the GBR lagoon (Waters et al., 2014; Table S1), the cost-effectiveness of proposed projects are not considered in some GBR catchments. Furthermore, options are usually not compared across catchments or land-uses, although such comparisons could optimise the investment decisions within the whole auction mechanism for possible conservation achievements (Rolfe and Windle, 2011). Thus, decision makers are in need of a prioritisation approach that considers the benefits, costs, and feasibility of multiple options of specific management projects (where a project is defined as a specific action in a specific place) across a catchment, and allows for a transparent, quick and quantitative comparison in order to support investment decisions for improving water quality. Ideally, this approach is flexible enough to incorporate different level of detail in the data, can be modified with additional variables under different objectives, and can be linked into integrated and spatial explicit land-sea planning.

Here, we develop an approach to identify the most cost-effective catchment management projects for reducing runoff to the ocean with a limited set of data. We (1) demonstrate that it is possible to develop a simple economic prioritisation framework based on information that is already available in the existing auction mechanism that can compare cost-effectiveness of a large quantity of projects across spatial units such as catchments and land-uses, political categories of land-management standards or more detailed project categories in a transparent and quick way, (2) compare the cost-effectiveness of our prioritisation with the commonly applied prioritisation methods of targeting least cost, largest benefit, or largest area to be covered (3) test the robustness of the results under uncertainty of the used information. In particular, we use information about the benefits, costs, and feasibility of a range of management projects to inform the prioritisation. Our approach can be adapted to inform water quality improvement decisions at a range of scales, including within a catchment and between catchments, for any pollutant categories (sediment, nutrient, and pesticide) that are caused by runoff from different land-uses as well as a combination of these categories.

2. Methods

2.1. Case study data

There are local government bodies (aka Natural Resource Management groups) in Queensland and each is responsible for the assessment and implementation of management projects within their boundaries, which align with hydrological catchment boundaries (Fig. S1, Supplementary material S1 and S2). Six of these groups receive funding under the Reef Plan program which aims to reduce run-off to the GBR. We apply our framework within two catchments adjacent to the GBR, Fitzroy and Mackay–Whitsundays, using data on sediment reduction projects on individual properties in two different land-uses that were