Biological Conservation 203 (2016) 43–54

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/bioc

Improving conservation outcomes for coral reefs affected by future oil palm development in Papua New Guinea

Vivitskaia J.D. Tulloch [a,*], Christopher J. Brown [b], Hugh P. Possingham [a], Stacy D. Jupiter [c], Joseph M. Maina [a,d], Carissa Klein [e]

[a] *ARC Centre of Excellence in Environmental Decisions, University of Queensland, St Lucia, 4072, Australia*
[b] *Australian Rivers Institute, Griffith University, 170 Kessels Road, Nathan, 4111, Australia*
[c] *Wildlife Conservation Society, Melanesia Program, Suva, Fiji*
[d] *Department of Environmental Sciences, Macquarie University, New South Wales, 2109, Australia*
[e] *School of Geography, Planning and Environmental Management, The University of Queensland, St Lucia, 4072, Australia*

ARTICLE INFO

Article history:
Received 19 May 2016
Received in revised form 12 August 2016
Accepted 15 August 2016
Available online xxxx

Keywords:
Oil palm sustainability, land–sea planning
Land-use change
Coral reef degradation
Marine protected area
Ridge to reef
Papua New Guinea
Sedimentation
Marxan

ABSTRACT

Clearing forests for oil palm plantations is a major threat to tropical terrestrial biodiversity, and may potentially have large impacts on downstream marine ecosystems (e.g., coral reefs). However, little is known about the impacts of runoff from oil palm plantations, so it is not clear how oil palm development should be modified to minimize the risk of degrading marine ecosystems, or how marine conservation plans should be modified to account for the impacts of oil palm development. We coupled terrestrial and marine biophysical models to simulate changes in sediment/nutrient composition on reefs as a result of oil palm development in Papua New Guinea, and predicted the response of coral and seagrass ecosystems to different land-use scenarios. The condition of almost 60% of coastal ecosystems were predicted to be substantially degraded (more than a 50% decline from their initial state) after 5 years if all suitable land was converted to oil palm, with only 4% of coastal ecosystems improving in condition as trees matured. We evaluated marine ecosystem condition if the oil palm developments were consistent with global sustainability guidelines and found that there were only slight improvements in ecosystems condition compared to the scenario with complete conversion of forest to oil palm. Substantially reducing the impact of oil palm development on marine ecosystems required limiting new plantings to hill slopes below 15°, a more stringent restriction than currently allowed for in the sustainability guidelines. We evaluated priority marine conservation areas given current land-use and found reef ecosystems in these areas will likely be heavily degraded in the future from runoff. We find that marine conservation plans should be modified to prioritize turbid areas where coral communities may be more tolerant of increased suspended sediment in the water. The approach developed here provides guidelines for modifying marine conservation priorities in areas with oil palm development. Importantly, oil palm development guidelines cannot be truly ecologically sustainable unless they are modified to account for the impacts of oil palm on coastal marine ecosystems.

1. Introduction

Coastal ecosystems are under pressure from a variety of human activities (Jackson et al., 2001). Deforestation has been shown to cause widespread destruction on the land and to downstream marine environments (Rogers, 1990). In the tropics, oil palm agriculture has been identified as a major driver of deforestation and biodiversity loss (Koh and Wilcove, 2008). The impacts of oil palm plantations to terrestrial ecosystems are clear (Fitzherbert et al., 2008), but their effects on marine ecosystems are not well understood. Erosion from new plantations can result in poor water quality from increased sediments, nutrients and pollutants (e.g., agrochemicals) (Ah Tung et al., 2009; Comte et al., 2012). To exacerbate this issue, development of palm oil plantations is occurring upstream of sensitive and biodiverse habitats, such as coral reefs.

The palm oil industry is economically important to many developing nations (Cramb and Curry, 2012), thus solutions that balance the economic benefits of oil palm with its ecological impacts are required. Poor understanding of land-sea linkages, in addition to limited data in affected regions, makes agricultural development and conservation difficult. Coral reefs are vulnerable to increases in runoff that can result from extensive land-use change, due to smothering, light loss from turbidity, eutrophication, and toxicity (Bartley et al., 2014; Fabricius, 2005; Fabricius, 2011). Despite this, the potential impact of runoff from oil palm on these ecosystems is rarely, if ever, explicitly considered during planning processes. Ignoring cross-system interactions at the land-sea interface can hinder effective conservation decisions, and may result

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* Corresponding author.
E-mail address: v.tulloch@uq.edu.au (V.J.D. Tulloch).

http://dx.doi.org/10.1016/j.biocon.2016.08.013
0006-3207/

in suboptimal or perverse outcomes (Álvarez-Romero et al., 2015a). Although guidelines for sustainable oil palm certification have been developed (OPIC, see http://www.rspo.org), the extent these guidelines mitigate the risks to marine biodiversity from increased runoff associated with new plantations is unknown, as cross-system impacts are not explicitly considered in the criteria for sustainability assessment.

Robust decision-making frameworks for data-poor regions that can account for land-use change, predict changes to downstream ecosystems, and identify priorities for management action are urgently needed. There are increasing numbers of approaches to modeling runoff (e.g. N-SPECT: Eslinger et al., 2005; InVEST: Tallis et al., 2013; Sednet: Wilkinson et al., 2004), but rarely do these extend into the sea. Recent studies linking runoff loads to reefs use over-simplified erosion, transport and condition models (Klein et al., 2012), or ignore the spatially and temporally heterogeneous response of different reef ecosystems to changing runoff regimes (Rude et al., 2015). Further, existing efforts to prioritize areas for marine conservation typically use only threat maps, which do not account for the greater tolerance of some ecosystems to threats than others (Tulloch et al., 2015). Importantly, no one has linked reef ecosystem condition to fine-scale land-uses and impacts in a single framework for spatial prioritization for data-limited regions.

Here we create an integrated planning framework that links land-use change under differing scenarios for the extent of oil palm expansion to their impacts on marine ecosystems in the data-limited province of New Ireland, Papua New Guinea. Our framework couples outputs from a terrestrial runoff model, ocean transport model, and ecological condition model, allowing the identification of coastal areas affected by land-use changes. Our approach builds on models of fine-scale regional erosion and coastal transport to predict sediment loads in coastal waters for data-limited regions (Álvarez-Romero et al., 2015b; Rude et al., 2015) by linking sediment loads to marine habitat condition and also accounting for changes in nutrients. We account for heterogeneity in the response of different reef ecosystems across space and time to changes in sediment and nutrient loads. Finally, we use model outputs in a marine spatial conservation prioritization that account for ecosystem condition changes from land-use changes over time. We answer the following questions:

1. How and where do changes in oil palm coverage (including using the global sustainability development guidelines) impact nutrient and sediment discharge and affect reef and seagrass ecosystems over time?
2. How do we plan for marine reserves to account for the likely impacts from expanding oil palm on the land?
3. Does incorporating oil palm development in the planning of marine reserves lead to better condition of marine ecosystems?

2. Methods

2.1. Study area

We chose a case study of the island province of New Ireland in Papua New Guinea where major current threats to marine ecosystems are fishing pressure and logging (and associated runoff), along with potential new threats from oil palm expansion (Nelson et al., 2014). We choose this region because tropical rainforests across Papua New Guinea have undergone high rates of logging and conversion to oil palm plantations in recent decades, and in island provinces, 45% of all rainforest has been logged (Shearman et al., 2009). In New Ireland Province (7404 km^2), oil palm plantations have been established at a relatively small-scale since 1994 (Koczberski et al., 2001). The province receives high levels of annual rainfall (>4500 mm), and is bordered by the Bismarck Sea in the west and the Pacific Ocean in the east, with a narrow (100 m wide), fringing reef extending down much of the northeastern coastline that drops very steeply to depths exceeding 500 m (Fig. 1).

2.1.1. Land-sea model

We applied scenarios for oil palm development to a model that coupled terrestrial processes of soil and nutrient loss with the marine processes distributing sediment and nutrients in adjacent coastal waters (Fig. 2). The models were designed for a data-limited setting with simple marine and terrestrial processes, because most oil palm development is in countries where direct measurements of runoff dispersion and habitats are not available. We predicted coral reef and seagrass condition as influenced by the indirect impacts of watershed-based pollution and direct impacts of fishing. Finally, we used the inverse of predicted ecosystem condition as the probability of degradation to plan for marine reserves that minimize the risk of destruction from different oil palm coverage scenarios, targeting high quality ecosystems for protection across the coast of New Ireland. Inputs and outputs for the model were processed using a combination of ArcGIS 10.1 and the R programming language (R Core Team, 2014) (Fig. 2). Further details for each step are described below.

2.1.2. Step 1: terrestrial runoff model

We used the open-source version of the runoff simulation tool N-SPECT (Nonpoint Source Pollution and Erosion Comparison Tool) (Eslinger et al., 2005) in MapWindow GIS to simulate runoff and sediment discharge from watersheds. N-SPECT combines data on elevation, slope, soils, precipitation, land cover characteristics, as well as surface retention and abstraction (USDA, 1986), to derive estimates of runoff, erosion and pollutant sources (nitrogen, phosphorous and suspended solids) and accumulation in stream and river networks.

Watershed boundaries for New Ireland's main island were delineated using N-SPECT based on a conditioned SRTM derived Digital Elevation Model (DEM) with 90-m spatial resolution (Appendix A). These were checked against global coastline data, and Landsat satellite imagery (2009–2013), and modified in the north-west where flat terrain prevented automatic delineation of smaller watersheds. Coastal drainage points for watersheds were determined based on this delineation and validated using existing coarse-scale stream and river data (Appendix A). Data sources and transformations for N-SPECT parameterization are described below.

2.1.2.1. Soil data. Soil data were downloaded from Version 1.1 of the Harmonized soil database of the world (Appendix A). We derived two variables for the runoff model: (i) hydrologic soil group, where soils were classified into four hydrologic soil groups (A, B, C and D) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting (Nam et al., 2003); and (ii) soil erodibility factor (K-factor), representing soil's susceptibility to erosion by rainstorms as a function of sand, silt, clay and organic carbon concentration (see Appendix B). The average integrated K-factor was determined for each pixel using reclassification processes (Maina et al., 2012).

2.1.2.2. Rainfall data. Annual monthly average, maximum and minimum precipitation data for 2013 were obtained from Worldclim at 30 arc-seconds resolution (~1 km), and resampled to 90 m resolution. These data were used to determine the average erosive force of rainfall for each pixel, calculated from monthly rainfall data using the Modified Fournier Index (Vrieling et al., 2010) (Appendix B).

2.1.2.3. Land-use land-cover (LULC) data. A LULC classification for 2013 was derived by updating the Papua New Guinean Forestry Inventory Management System from 1996 (Appendix A Table 1) with Landsat 7 ETM+ images using on-screen digitization to distinguish forested, urbanized, and cultivated land at 100 m resolution 1 (Hansen et al., 2009), combined with further on-screen classification of oil palm plantations using maps obtained from New Britain Palm Oil. A total of 10 LULC classes were delineated. We classified established palm oil estates, new plantings (within 5 years, not yet mature), as well as independent