Journal of Environmental Management 197 (2017) 694–705

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Strengthening governance for intertidal ecosystems requires a consistent definition of boundaries between land and sea

Stefanie M. Rog*, Carly N. Cook

School for Biological Sciences, Monash University, 25 Rainforest Walk, Melbourne 3800, Australia

ARTICLE INFO

Article history:
Received 28 February 2017
Received in revised form
5 April 2017
Accepted 16 April 2017
Available online 22 April 2017

Keywords:
Classification
Legislation
Mangrove
Taxonomy
Tidal lines
Jurisdiction

ABSTRACT

The protection of intertidal ecosystems is complex because they straddle both marine and terrestrial realms. This leads to inconsistent characterisation as marine and/or terrestrial systems, or neither. Vegetated intertidal ecosystems are especially complex to classify because they can have an unclear border with terrestrial vegetation, causing confusion around taxonomy (e.g., mangrove-like plants). This confusion and inconsistency in classification can impact these systems through poor governance and incomplete protection. Using Australian mangrove ecosystems as a case study, we explore the complexity of how land and sea boundaries are defined among jurisdictions and different types of legislation, and how these correspond to ecosystem boundaries. We demonstrate that capturing vegetated intertidal ecosystems under native vegetation laws and prioritizing the mitigation of threats with a terrestrial origin offers the greatest protection to these systems. We also show the impact of inconsistent boundaries on the inclusion of intertidal ecosystems within protected areas. The evidence presented here highlights problems within the Australian context, but most of these issues are also challenges for the management of intertidal ecosystems around the world. Our study demonstrates the urgent need for a global review of legislation governing the boundaries of land and sea to determine whether the suggestions we offer may provide global solutions to ensuring these critical systems do not fall through the cracks in ecosystem protection and management.

1. Introduction

Intertidal ecosystems occur at the interface of land and sea, encompassing environments such as sandy beaches and rock platforms through to vegetation communities like mangrove and saltmarsh. Intertidal ecosystems provide important ecosystem services (e.g. coastal protection and carbon sequestration) and critical habitat for a wide range of both marine (Nagelkerken et al., 2008; Yates et al., 2014) and terrestrial biodiversity (Rog et al., 2017). Despite their ecological importance, globally intertidal ecosystems are in decline due to increasing anthropogenic pressure on coastal areas, including development, climate change and sea level rise (Giri et al., 2011; UNEP, 2014). However, the ability to effectively conserve these ecosystems is currently hampered by the complexity of managing intertidal ecosystems due to uncertainty around land-sea boundary definitions (Clemens et al., 2014; Harris et al., 2014; Tagliapietra et al., 2009).

A large source of complexity in defining the boundaries of intertidal ecosystems lies in the multitude of legislative land sea boundaries based on tidal lines (e.g. seaward between land and sea generally the Low Tide, and between land and intertidal generally the Astronomical High Tide or Mean High Water Mark), which are fuzzy and dynamic (Friess et al., 2016) and difficult to accurately locate. Unambiguous boundaries of ecosystems are vital to enforce legislation, as demonstrated for example in Indonesian rainforests where poorly defined protected forest area boundaries have enabled illegal logging (Sahide and Giessen, 2015). Uncertainty around the boundaries between land and sea has also led to inconsistency in how these boundaries are applied both within and between countries (Abdullah et al., 2013; Day et al., 2012; Liu et al., 2014). This can have serious implications in the many cases where the national and international legislation that overlaps in the intertidal zone has inconsistent laws and regulations (Cao and Wong, 2007) and competing and unclear objectives (Friess et al., 2016) leading to ineffective protection of this zone.

The inconsistent definition of the land-sea boundary creates challenges for broad-scale analyses and global assessments of

* Corresponding author.
E-mail address: Stefanie.rog@monash.edu (S.M. Rog).

http://dx.doi.org/10.1016/j.jenvman.2017.04.052
0301-4797/

biodiversity of intertidal ecosystems, generating potentially large mapping inconsistencies (Friess et al., 2012). This inconsistency has been specifically cited as the reason why intertidal mangrove ecosystems have been excluded from global assessments of threatened ecosystems (Chape et al., 2005; Hoekstra et al., 2005) or grouped with tidal marsh ecosystems (Costanza et al., 2014). Likewise, because there is no consistent definition of the bounds of intertidal ecosystems their original global extent is not possible to estimate (Friess et al., 2012). As a result, there is great uncertainty surrounding estimates of the rate of global decline and the adequacy of protection measures currently in place, making it difficult to anticipate future trends on which management actions can be built.

Another major point of uncertainty complicating the management of intertidal ecosystems is whether the ecosystems themselves are characterized as marine or terrestrial environments. Marine and terrestrial ecosystems have been separated historically which is apparent across agencies, NGO's, scientific institutions (Álvarez-Romero et al., 2011) and national policies (Friess et al., 2016). The uncertainty to which of the two intertidal systems belong is exemplified by the variability on how studies on threats to intertidal ecosystems classify them: marine (e.g. Halpern et al., 2008); terrestrial (e.g. Olson et al., 2001); or both (e.g. Joppa et al., 2016). While it is important to take a comprehensive and cross system approach to studying threats to these ecosystems (Álvarez-Romero et al., 2011) as threats to intertidal in many coastal systems can be diverse in origin (Friess et al., 2015), without a cohesive approach there is a risk that some threats are being missed, while others over-emphasized. One practical implication of whether intertidal ecosystems are characterized marine or terrestrial is whether threat mitigation is the responsibility of marine or terrestrial protected areas. This distinction is vital for the effective protection and management because protection for native (terrestrial) vegetation versus the marine environment differs in emphasis, and often in management practices (Adams et al., 2014; Boon and Beger, 2016) and conservation values (Álvarez-Romero et al., 2015). For example, the most significant threat to the marine environment, over-fishing (Halpern et al., 2008), is not the greatest threat to intertidal ecosystems, such as saltmarsh and mangroves, which are most vulnerable to clearing for coastal development (Giri et al., 2011). In recent years increased attention has been given to integrated coastal zone management (Álvarez-Romero et al., 2011; Beger et al., 2010), however as long as separate marine and terrestrial protected area boundaries exist the different focus points need to be considered when aiming to protect intertidal ecosystems.

For vegetated intertidal ecosystems this marine terrestrial distinction is even more complex on a finer scale as vegetated intertidal systems occur along an environmental gradient, where a transition zone can make it difficult to define the boundary of the intertidal ecosystem with adjacent vegetated terrestrial ecosystems (Boon et al., 2014; Duke, 2006a). Vegetated intertidal ecosystems also potentially fall under legislation related to native vegetation management (where native vegetation is generally defined as aquatic or terrestrial plant or plants indigenous to the region of interest under Australian legislation; Table S1), adding a further layer of complexity. The vegetated intertidal ecosystems mangroves and saltmarsh have species within them that can be classified as both marine and terrestrial (Boon et al., 2011), most likely related to their physiological adaptations to exposure to both marine and terrestrial conditions (Tomlinson, 2016). While this taxonomic classification may seem trivial, it can have important implications for how species are managed and conserved (Fraser et al., 2015). Variation in the taxonomic classification of the species within these ecosystems as marine or terrestrial can lead to them being divided between the types of protection, complicating management responsibility, or missing protection altogether (Boon et al., 2011). Indeed, there is concern that intertidal ecosystems are underrepresented in protected areas (Banks et al., 2005), possibly due to this difficulty in determining whether they should be included within marine or terrestrial protected areas. Without a consistent classification of intertidal plant species related to a consistent characterisation as marine or terrestrial, intertidal ecosystems are at risk of a lack of specific management objectives necessary for effective protection (Harris et al., 2014).

The aforementioned inconsistent definition of boundaries, marine or terrestrial characterisation, and confusion around taxonomic classification has set intertidal systems up for poor governance. Recent studies have highlighted the complexity in intertidal ecosystem management and the urgent need to improve their protection (Banks et al., 2005; Friess et al., 2016; Rogers et al., 2016). Our study is the first to consider the drivers of this complexity from an ecosystem boundary perspective. We explore the complexity in how the land and sea boundaries are defined among jurisdictions and types of legislation, the characterisation of vegetated intertidal ecosystems as marine or terrestrial and the taxonomic classification of intertidal plant species, using Australian mangroves ecosystems as a case study. We use these data to evaluate how this complexity affect the protection of intertidal ecosystems, with the goal of identifying how governance structures for these complex ecosystems can be strengthened.

2. Methods

2.1. Study region

We focus on intertidal ecosystem governance within Australia. Australia is a federation of six states and two territories united under a national government, creating nine jurisdictional boundaries. These boundaries mirror the complexity associated with international boundaries that have created significant international transboundary governance issues discussed elsewhere (Liquete et al., 2011; Bartier and Sloan, 2007; Rahibulsadri et al., 2014). More than 85% of Australia's population live within 50 km of the coastline creating increasing pressure on intertidal ecosystems from encroachment by coastal development; the most significant threat to intertidal ecosystems globally (Giri et al., 2011; Foster et al., 2013).

2.2. Study system

Mangroves occur along the coastline of five out of six Australian jurisdictions. Mangrove ecosystems make an ideal case study because they can occur across the full intertidal zone from the lowest tide line to the highest (Astronomical) tide line (Fig. 1), thereby crossing all tidal lines which are potential boundaries used to define land and sea (see Knight et al. (2008) for detail about the more complex relationships between micro-topography and tidal influences). The other two vegetated intertidal ecosystems (saltmarsh and seagrass) generally occur at the extremes of the tidal range. Due to their occurrence across two realms mangroves also play important ecological roles in both marine and terrestrial communities (e.g. their roots can provide refuge for fish (Nagelkerken et al., 2010); and coral (Yates et al., 2014) and their branches and canopy provide habitat for terrestrial vertebrates (Rog et al., 2017)).

2.3. Data collection

To assess the governance structures for intertidal ecosystems, specifically for mangrove ecosystems in Australia, we focused on