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Rehabilitating mangrove ecosystem services: A case study on the relative benefits of abandoned pond reversion from Panay Island, Philippines

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ABSTRACT

Mangroves provide vital climate change mitigation and adaptation (CCMA) ecosystem services (ES), yet have suffered extensive tropics-wide declines. To mitigate losses, rehabilitation is high on the conservation agenda. However, the relative functionality and ES delivery of rehabilitated mangroves in different intertidal locations is rarely assessed. In a case study from Panay Island, Philippines, using field- and satellite-derived methods, we assess carbon stocks and coastal protection potential of rehabilitated low-intertidal seafront and mid- to upper-intertidal abandoned (leased) fishpond areas, against reference natural mangroves. Due to large sizes and appropriate site conditions, targeted abandoned fishpond reversion to former mangrove was found to be favourable for enhancing CCMA in the coastal zone. In a municipality-specific case study, 96.7% of abandoned fishponds with high potential for effective greenbelt rehabilitation had favourable tenure status for reversion. These findings have implications for coastal zone management in Asia in the face of climate change.

1. Introduction

Environmental management is placing increasing emphasis on the services provided by the world's ecosystems (Cardinale et al., 2012). Mangrove forests deliver numerous important ecosystem services (ES) to humans, valued at $194,000 ha^{-1} yr^{-1} (Costanza et al., 2014): food and fuel, nursery habitat, recreation (Barbier et al., 2008, 2011). Mangroves are of particular significance in the context of climate change (Duarte et al., 2013), affording among the largest per hectare global carbon stores and coastal protection from regular waves and frequent tropical storms (Dahdouh-Guebas et al., 2005; Donato et al., 2011). Growing global policy emphasis on both emissions reduction and climate impact mitigation in vulnerable countries (UNFCCC, 2015) places ever higher significance on the climate change mitigation and adaptation (CCMA) properties of mangroves. High susceptibility to anthropogenic activities and climate change impacts (Primavera, 2005; Duke et al., 2007; Lovelock et al., 2015) has, however, led to mangrove areal declines of 30–50% globally (Field et al., 1998; Valiela et al., 2001), with continued losses of 0.16–0.39% per annum (Hamilton and Casey, 2016; Richards and Friess, 2016). 16% of mangrove species are now threatened with global extinction (Polidoro et al., 2010). Extensive loss has left degraded and highly fragmented mangroves in many parts of their global distribution (Giri et al., 2011; Hamilton and Casey, 2016) that may have limited potential to deliver CCMA services into the future (Koch et al., 2009; Barbier et al., 2011; Lee et al., 2014).

To combat mangrove losses, and to enhance CCMA efforts in the tropics, rehabilitation is an essential management tool (Ellison, 2000; Kairo et al., 2001; Lewis, 2005; Primavera and Esteban, 2008; Primavera et al., 2012a). Rehabilitated mangrove blue carbon-based Payments for Ecosystem Services (PES) projects are emerging (Wylie et al., 2016), and governments are increasingly recognising the significance of mangrove coastal protection (Marois and Mitsch, 2015), with national coastal greenbelt replanting programmes now widespread following recent natural disasters (Dahdouh-Guebas et al., 2005; Primavera et al., 2014). Recent studies on potential blue carbon PES schemes have concluded that projects would benefit from inclusion of “bundled services” to offset low voluntary carbon market prices (Locatelli et al., 2014; Thompson et al., 2014), with particular reference to coastal protection (Kairo et al., 2009; Locatelli et al., 2014). However, mangrove rehabilitation efforts have historically seen low successes (e.g. Primavera and Esteban, 2008; Dale et al., 2014; Bayraktarov et al., 2015; but see Arnaud-Haond et al., 2009; Goessens et al., 2014), and where established, longer-term monitoring

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of functionality has been minimal (Bosire et al., 2008). Where this has been monitored, the structure and specific functionality of rehabilitated mangroves can be comparable to adjacent natural stands (Kairo et al., 2001; Bosire et al., 2008; Ren et al., 2010; Salmo et al., 2013; Nam et al., 2016); however, their relative potential for high multiple ES delivery is mostly unknown (but see Rönnbäck et al., 2007 and Nam et al., 2016). We thus currently lack quantitative information on the combined CCMA potential of current mangrove rehabilitation efforts.

There are two major potential sources of variation in the ability of rehabilitated mangroves to deliver high multiple CCMA ES. First, ignorance of or noncompliance to scientific guidelines has driven many rehabilitation efforts to take place in low-intertidal seafront areas where sub-optimal hydrological conditions limit survival and growth of replanted mangroves (Iftekhar, 2008; Primavera and Esteban, 2008; Primavera et al., 2012a, 2012b, 2014). Rehabilitation in such areas may result in low relative mangrove biomass and density, and associated carbon stocks and coastal protection potential, particularly where rehabilitation failure has historically been high. Second, site areal configuration may heavily impact the potential ES delivery of rehabilitated mangroves. Rehabilitated mangrove carbon stocks may be expected to increase linearly with site area, while coastal protection rapidly increases with mangrove greenbelt width (Koch et al., 2009). Indeed, low-intertidal rehabilitated mangroves exist primarily in monospecific narrow-fringing stands (Ellison, 2000; Iftekhar, 2008; Primavera et al., 2012a, 2012b), with potentially severely limited ability to deliver effective coastal protection (Ewel et al., 1998; Barbier et al., 2008, 2011; Koch et al., 2009). Larger rehabilitation sites in the mid- to upper-intertidal zone may thus be expected to deliver much higher multiple CCMA benefits than narrow, low-intertidal rehabilitated mangroves. However, the spatial configuration and area of suitable land for mangrove rehabilitation is often constrained by land tenure conflicts and complexities in the coastal zone (e.g. agri- and aquaculture); often the major driver for prioritizing low-intertidal zone rehabilitation (Iftekhar, 2008; Primavera and Esteban, 2008; Primavera et al., 2012b, 2014). CCMA arguments for rehabilitation actions may be key in future decision-making and spatial planning. To guide effective coastal zone management in the face of climate change, there is thus a need to identify and prioritise rehabilitation locations in which high CCMA gains may co-occur with minimal tenure issues (Locatelli et al., 2014; Primavera et al., 2014; Thompson et al., 2014).

This study examines the CCMA potential of mangrove rehabilitation in abandoned aquaculture ponds relative to low-intertidal, seafront areas across Panay Island, Philippines. We first quantify the relative vegetation and sediment carbon stocks, and coastal protection potential of rehabilitated mangrove areas (mid- to upper-intertidal abandoned fishpond and low-intertidal seafront areas), against mature natural reference mangrove stands, to explore the ES potential of these different rehabilitation strategies. We then conduct a municipality-specific case study to model the potential CCMA benefits of targeted abandoned fishpond reversion, with specific reference to current coastal greenbelt rehabilitation efforts. We conclude by examining the feasibility of prioritising abandoned fishpond reversion for CCMA goals under current fishpond tenure status across the case study.

2. Materials & methods

2.1. Study areas: Panay Island, Philippines

The Philippines is among the most typhoon-ravaged countries in the world (Peduzzi et al., 2012; UNU, 2014). High typhoon-exposure of coastal areas, and the infrastructural and institutional vulnerability to typhoon events (UNU, 2014), has been recently evidenced by devastating impacts suffered during super-typhoon Haiyan (Soria et al., 2015). The Philippines has experienced substantial mangrove loss: approximately 50% of the former 500,000 ha (Spalding et al., 2010) disappeared over the last century, due primarily to shallow brackish-water fishpond aquaculture development in former estuarine, basin and riverine mangroves (Primavera, 2005). Some of the highest fishpond densities occur in the West Visayas Region; e.g. on Panay Island (Primavera and Esteban, 2008). Development is largely unregulated, and despite laws mandating 50–100 m of mangrove greenbelt (Primavera et al., 2012b), fishponds are often built to the shoreline. Abandonment is high (estimates in the thousands of hectares; see Samson and Rollon, 2011; Primavera et al., 2012b), due primarily to bank breaches in sea-facing fishponds over low productivity (Primavera et al., 2014). Fishponds are tenured by among the wealthiest in society, and operated by the poorest. Reversion of abandoned fishponds to former mangroves for greenbelt resurrection could thus benefit coastal community livelihoods through associated fisheries enhancement (Walton et al., 2006).

Philippines' public mangrove land is released by the Department of Environment and Natural Resources (DENR) for aquaculture under multiple tenure arrangements: from titled ownership, to temporary leaseholds under Fishpond Lease Agreements (FLAs) granted under the jurisdiction of the Bureau of Fisheries and Aquatic Resources of the Department of Agriculture (DA-BFAR). Under Philippine law, failure to adhere to FLA terms should preclude FLA cancellation by DA-BFAR, and reversion of jurisdiction to the Forest Management Bureau of DENR for subsequent mangrove rehabilitation. This includes Abandoned (no operational activity, subleasing, or neglect of payments), Underutilised (no commercial production within three years), and Undeveloped (pond infrastructure absent) (AUU) FLA fishponds (see Primavera et al., 2014). Herein, the term 'abandoned fishpond' refers to all AUU fishponds. However, non-coordination between government departments (DA-BFAR and DENR), low institutional capacity, exclusion of local government units (LGUs) and coastal communities from decision-making, and a lack of political will means FLA monitoring is minimal, and cancellation and reversion rarely occurs: large areas of former mangrove lie fallow. Furthermore, cancelled abandoned FLAs are often absorbed and re-tenured under new FLA leases or operated illegally (Primavera et al., 2014).

Due to the challenges of abandoned fishpond reversion, national greenbelt rehabilitation programmes continue to focus on low- and sub-intertidal planting seaward of coastal infrastructure and fishponds ('seafront rehabilitation'). High mortality in plantations of inappropriate species wastes public and international funds, while threatening other intertidal systems (seagrasses, mudflats; Primavera and Esteban, 2008; Samson and Rollon, 2008, 2011). Surviving seafront rehabilitated mangroves are often small areas growing at the limits of their physiological tolerance ranges (Tomlinson, 1986). In contrast, some Non-Governmental Organisation-led projects, in partnership with specific LGUs, have begun to target rehabilitation of abandoned fishponds in the mid-upper intertidal zone where more natural hydrological conditions largely remain (Primavera et al., 2012b, 2014).

This study investigated the relative CCMA ES delivery by rehabilitated low-intertidal seafront and abandoned fishpond areas across Panay Island, with reference to adjacent natural stands. Six mangrove stands from four sites in Iloilo and Aklan Provinces were used (Fig. 1):

1. Bakhawan ecopark, Buswang, Kalibo, a remnant area of a former deltaic mangrove at the mouth of Aklan River (Cadaweng and Aguirre, 2005; Walton et al., 2006). Following over-exploitation of mangrove timber, large portions of the seaward area have been replanted with *Rhizophora* spp. since the early 1990s. A wide band of mature natural *Avicennia marina* and *Sonneratia* spp.-dominated mangrove remains behind the rehabilitated areas. This study focused on (1) a seafront area replanted in 2006 with *Rhizophora apiculata*, and subsequently naturally recolonised by *A. marina*, *Nypa fruticans* and *Sonneratia alba* individuals ("Bakhawan rehab"); and (2) the inland natural mangrove area ("Bakhawan natural").
2. Ermita, Dumangas. A remnant now-fringing area of a former deltaic mangrove cleared inland for fishpond aquaculture, bordered in the landward direction by active fishponds and a coastal road. The site