Chapter 4

Mangrove Payments for Ecosystem Services (PES): A Viable Funding Mechanism for Disaster Risk Reduction?

Daniel A. Friess and Benjamin S. Thompson

Abstract Mangrove forests provide a multitude of ecosystem services, many of which contribute to Disaster Risk Reduction (DRR) along tropical coastlines. In the face of rapid deforestation, Payments for Ecosystem Services (PES) schemes such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) has been heralded as a potential avenue for financing conservation, although PES schemes remain in an embryonic state for mangroves. Several challenges must be overcome if mangrove PES is to advance. Firstly, challenges exist in quantifying multiple ecosystem services, especially those that contribute to DRR, such as wave attenuation and the control of coastal erosion. Secondly, the permanence of quantified ecosystem services is a central tenet of PES, but is not guaranteed in the dynamic coastal zone. Mangroves are affected by multiple stressors related to natural hazards and climate change, which are often outside of the control of a PES site manager. This will necessitate Financial Risk Management strategies, which are not commonly used in coastal PES, and introduces a number of management challenges. Finally, and most importantly, PES generally requires the clear identification and pairing of separate service providers and service users, who can potentially overlap in the context of DRR. This chapter reviews and discusses these emerging issues, and proposes potential solutions to contribute to the more effective implementation of mangrove PES. Ultimately however, difficulties in pairing separate and discreet service providers and users may render PES for DRR unfeasible in some settings, and we may need to continue traditional modes of DRR finance such as insurance and donor support.

Keywords Blue carbon • Coastal erosion • Permanence • REDD+ • Valuation • Wave attenuation • Wetland

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D.A. Friess (✉) • B.S. Thompson
Department of Geography, National University of Singapore, 1 Arts Link, 117570 Singapore, Singapore
e-mail: dan.friess@nus.edu.sg; benjamin.thompson@u.nus.edu

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4.1 Introduction

With high population densities in the coastal zone, hundreds of millions of people are currently exposed to coastal hazards such as storms, cyclones and sea level rise. Over 789,000 people were killed by tropical cyclones between 1970 and 2009 alone (EM-DAT 2011). The number of people exposed to coastal hazards is expected to rise substantially according to future climate change scenarios. In particular, future increases in both cyclone frequency/intensity and coastal population densities could lead to an extra 149.3 million people in the tropics being vulnerable to coastal hazards, with 90 % of exposed people found in Asia (Peduzzi et al. 2012). Based on some sea level rise forecasts, the population exposed to a 1-in-a-100 year flood event is projected to increase to 350 million people by 2050 (Jongman et al. 2012). Reducing vulnerability to threats such as sea level rise will require increasing the height of coastal defences by up to 1 m across the globe (Hunter et al. 2013).

Due to the future expense of more hard coastal defences, attention has turned to potential ecological engineering solutions (see van Wesenbeeck et al., Chap. 8 and David et al., Chap. 20). Coastal mangrove forests are an important halophytic vegetated ecosystem found throughout the tropics and subtropics. Mangroves provide a multitude of ecosystem services, tentatively valued at US$239 to US$4185 per hectare in Southeast Asia (Brander et al. 2012). These ecosystem services provide a range of biophysical and ecological benefits, and include fisheries, timber, pollutant assimilation, carbon storage, and DRR services such as hydrodynamic energy attenuation and shoreline erosion control (Barbier et al. 2011; Lacambra et al. 2013). Despite their importance, mangroves are experiencing rapid and sustained decline globally due to deforestation for new land uses such as aquaculture, agriculture and urban development (UNEP 2014). Deforestation is resulting in the loss and possible extinction of mangrove vegetation species (Polidoro et al. 2010), and is reducing the provision of ecosystem services upon which hundreds of millions of people depend across the tropics.

Mangroves – like many forested ecosystems – have been managed and conserved under traditional government-led protected area approaches. However, recent years have seen a move towards neoliberal conservation instruments that attempt to balance conflicts between conservation and economic growth priorities. Payments for Ecosystem Services (PES) is one instrument with which to balance such conflicts, and is broadly defined as "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management" (Wunder 2015). While serious issues relating to social equity, governance and commodification exist with PES (Phelps et al. 2010; Pascual et al. 2014), this instrument has been touted as, "probably the most promising innovation in conservation since Rio 1992[1]" (Wunder and Wertz-Kanounnikoff 2009:576). PES has several key tenets that must be satisfied (Fig. 4.1).

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[1] The 1992 Earth Summit in Rio de Janeiro, Brazil, instigated the Convention on Biological Diversity (CBD) and United Nations Framework Convention on Climate Change (UNFCCC), which later spawned the Kyoto Protocol.

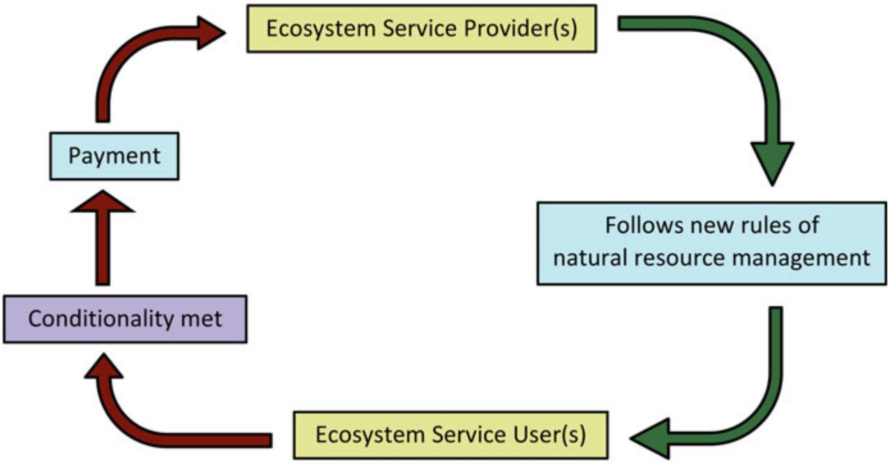


Fig. 4.1 The key tenets of PES showing: ecosystem service flows (*green arrows*), payment flows (*red arrows*), key players (*yellow boxes*), key voluntary transactions (*blue boxes*), and key criteria (*lilac box*) (Based on Wunder (2015))

PES is a concept that has been discussed for decades, with Costa Rica's adoption of PES at a national scale in 1997 viewed as a key moment that instigated new research and policy directions (Chaudhary et al. 2015). Focusing on the tropics, PES schemes that pay for stored carbon, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) have been discussed at the international level for almost a decade, with several operational schemes now in place throughout the tropics and a large number in the proposal stage. Explicit PES in mangroves, however, remains in an embryonic state. Few examples have been communicated (Fig. 4.2), though efforts are beginning in Kenya (Huxham et al. 2015), Madagascar, Vietnam (Hawkins et al. 2010) and Thailand. This leads to the question: "why is mangrove forest PES lagging so far behind other forest PES initiatives?" This question is particularly pertinent because of the broad range of ecosystem services that can be valorised within a PES scheme: mangrove PES has been proposed primarily to conserve carbon stocks (through "blue carbon" initiatives). Other ecosystem services related to recreation, hydrodynamic flow and wave attenuation for the purposes of disaster risk reduction (DRR) have not yet been an explicit focus of PES discussions, but may also be relevant in the mangrove context.

The aim of this chapter is to identify the key challenges and solutions to implementing PES for mangrove forest ecosystem services, with a particular focus on services related to DRR. Firstly, we discuss the broad range of ecosystem services provided by mangrove forests. Then we highlight three key challenges to the implementation of mangrove PES; (i) how to quantify DRR ecosystem services in a robust manner for PES transactions; (ii) how to ensure long-term permanence of DRR ecosystem services in the dynamic coastal zone; and (iii) how to identify and pair key actors in PES, especially ecosystem service providers and users. A critical and honest discussion of the issues will allow us to identify solutions to

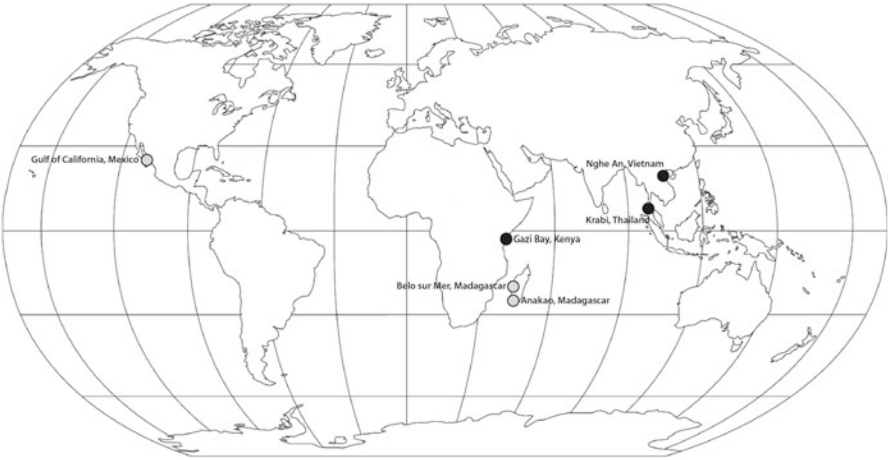


Fig. 4.2 Proposed (*grey*) and pilot (*black*) PES schemes based in mangrove ecosystems across the tropics. Currently, none of these schemes are designed to promote DRR ecosystem services

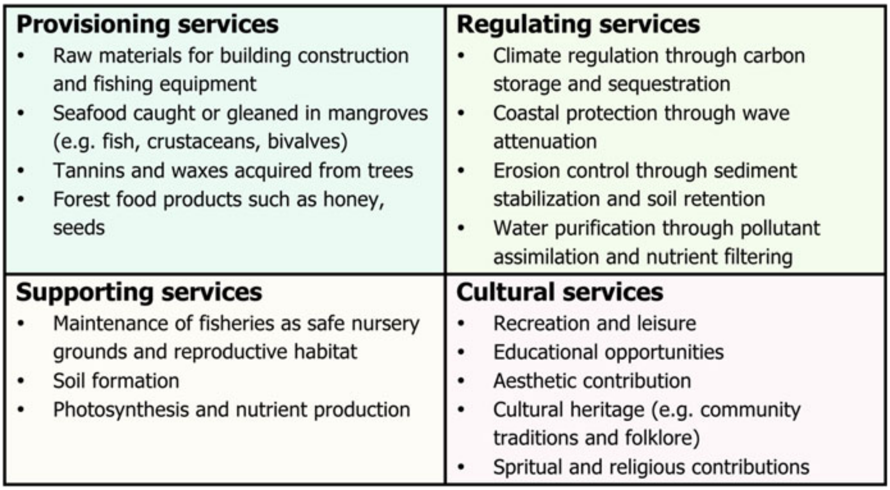
overcome these challenges and realise the benefits of ecosystem services for DRR for coastal populations that rely on mangroves throughout the tropics.

4.1.1 Mangrove Forests Provide a Multitude of Ecosystem Services

Researchers have described and quantified ecosystem services for decades, although the ecosystem service concept gained wide prominence with the publication of the Millennium Ecosystem Assessment (MA) in 2005. An international effort involving 1300 contributors from 95 countries, the MA (2005) categorised ecosystem services into four major categories:

(i) Provisioning services – products obtained from an ecosystem;
(ii) Regulating services – benefits obtained from the regulation of ecosystem processes;
(iii) Supporting services – processes necessary for the production of all other ecosystem services;
(iv) Cultural services – primarily non-material benefits people obtain from ecosystems through spiritual enhancement, cognitive development, reflection, recreation and aesthetic experiences.

A large literature has now formed around research on the broad range of ecosystem services that mangrove forests in particular provide to coastal populations (Fig. 4.3). Below, we describe particular ecosystem services that are of most relevance to mangrove PES for DRR. Supporting ecosystem services may



Provisioning services

- Raw materials for building construction and fishing equipment
- Seafood caught or gleaned in mangroves (e.g. fish, crustaceans, bivalves)
- Tannins and waxes acquired from trees
- Forest food products such as honey, seeds

Regulating services

- Climate regulation through carbon storage and sequestration
- Coastal protection through wave attenuation
- Erosion control through sediment stabilization and soil retention
- Water purification through pollutant assimilation and nutrient filtering

Supporting services

- Maintenance of fisheries as safe nursery grounds and reproductive habitat
- Soil formation
- Photosynthesis and nutrient production

Cultural services

- Recreation and leisure
- Educational opportunities
- Aesthetic contribution
- Cultural heritage (e.g. community traditions and folklore)
- Spritual and religious contributions

Fig. 4.3 A summary of the various ecosystem services provided by mangroves, as classified by the MA 2005 (Based on Barbier et al. 2011; Lacambra et al. 2013; Lau 2013)

either not be of direct relevance to DRR, or are not currently considered for PES, so are not described here.

4.1.1.1 Hydrodynamic Attenuation (Regulating Service)

Mangroves are now well known to interact with and ameliorate incoming hydrodynamic forces such as waves and currents. Hydrodynamic attenuation is equal to the proportion of wave height/current flow reduction per meter of land traversed (Mazda et al. 2006) in a non-linear relationship, and is caused by flow resistance, drag forces, friction and turbulence caused by above-ground vegetative structures. The importance of vegetation in hydrodynamic attenuation means that the magnitude of energy absorption strongly depends on tree density, stem and root diameter, forest width, presence of offshore habitats (e.g. reefs), shore slope, bathymetry, and tidal stage upon entering the forest (Alongi 2008; Koch et al. 2009).

The wave attenuation service of mangroves may be considered the most important in a DRR context, and has been highlighted by recent natural hazards. The role of mangroves in DRR gained the most prominence in response to the 2004 Southeast Asian tsunami. Preliminary surveys after this event suggested that villages behind mangroves suffered less damage and loss of life compared to exposed villages on the coast (e.g. Danielsen et al. 2005; Kathiresan and Rajendran 2005). Mangrove coastal defence services have been calculated at US$ 672/ha/year in the Philippines (Samonte-Tan et al. 2007) and US$ 1879/ha/year in Thailand (Barbier et al. 2008). That said, such findings may have been due to statistical correlation and inference rather than hydrodynamic processes, and the mechanisms contributing to tsunami hazard mitigation by mangroves still need more research (Kerr et al. 2006).

Regardless, the perceived importance of mangroves for hazard mitigation has resulted in huge interest in mangrove restoration and their incorporation into coastal defence design throughout the tropics (see Bayani and Barthélemy, Chap. 10). Academic and decision-making contexts are now awash with terms such as "ecological engineering", "building with nature", "nature-based solutions" and "blue/green infrastructure" (see van Wesenbeeck et al., Chap. 8), which all to varying degrees refer to the incorporation of mangroves into coastal engineering design.

4.1.1.2 Shoreline Erosion Control and Adaptation to Sea Level Rise (Regulating Service)

Mangroves have the capacity to reduce shoreline erosion and adapt to sea level rise through two mechanisms. Firstly, mangroves trap and consolidate sediments through their roots, as attenuated water flows encourage sediment to settle out of suspension (Krauss et al. 2003). Roots also contribute to binding the soil and increase soil shear strength. However, the ability of mangroves to encourage deposition, bind sediments and control shoreline erosion may also be species-specific, and mangrove coastlines themselves can erode once species-specific hydrodynamic thresholds are surpassed (Friess et al. 2012).

Secondly, mangroves have the ability to adapt to changing sea levels, if surrounding geomorphological and sedimentological conditions are suitable. Mangroves can increase their surface elevations to potentially keep pace with sea level rise through multiple processes such as sediment trapping and consolidation, and belowground organic matter production (Krauss et al. 2014). Thus, in comparison to traditional hard engineering structures that are fixed at a static elevation, mangroves and other coastal ecosystems may provide an adaptable and flexible coastal defence in some conditions under uncertain sea level rise scenarios (see Whelchel and Beck, Chap. 6). In minerogenic coastal settings,[2] this is reliant on the continued input of sediment into the coastal zone.

4.1.1.3 Carbon Storage (Regulating Service)

The important role of mangroves in carbon production, transport and storage has been known for decades, with mangroves in the United States a particular focus of research. Early research focused on particular processes in the carbon cycle, such as litterfall dynamics (Twilley 1985), aboveground biomass dynamics (Day et al. 1987) and tidal carbon fluxes (Twilley et al. 1986). However, early studies also put carbon into a broader global carbon cycle and climate change perspective (de la Cruz 1982, 1986; Twilley et al. 1992).

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[2] Made up of mineral materials as opposed to biogenic, i.e. organic, material.

Fig. 4.4 Conducting a standardized carbon stock assessment for a mangrove in northeast Singapore (Photo by DM Taylor, reproduced with permission)

These early research contributions focusing on the role of mangrove forests in climate change mitigation are in some cases forgotten, though are mirrored by similar recent studies that have explored the contribution of mangroves to regional and global carbon budgets (e.g. Bouillon et al. 2008; Donato et al. 2011; Siikamäki et al. 2012). Such studies, bolstered by clear carbon quantification and accounting protocols (e.g. Kauffman and Donato 2012; Fig. 4.4) and new international initiatives (e.g. The International Blue Carbon Initiative) have driven a recent surge in mangrove carbon stock assessments across the tropics (e.g. Donato et al. 2011; Adame et al. 2013; Jones et al. 2014; Thompson et al. 2014). Recent studies are now beginning to extend carbon stock assessments to also incorporate coastal ecosystems adjoining mangroves, providing us with an understanding of where mangrove carbon stocks sit within the broader coastal landscape (Phang et al. 2015). Carbon storage and sequestration is not directly relevant to DRR, but it is a popular mangrove ecosystem service that is the focus of several ongoing mangrove PES proposals. Thus, carbon could be stacked alongside other ecosystem services – such as DRR – to make a potential PES scheme more economically viable (Thompson et al. 2014).

4.1.1.4 Forest Products and Fisheries (Provisioning Services)

Provisioning services relate to products that can be extracted from the mangrove ecosystem. Many products are derived from the vegetation, including timber,

Fig. 4.5 A local fisherman catching mud crabs to sell to a local 5 star hotel, Ouvea atoll, New Caledonia (Photo by DA Friess)

fuelwood, charcoal, and non-timber forest products such as honey and waxes. Several correlative analyses also suggest that mangroves play an important role in the provision of fisheries (Manson et al. 2005). Although dependent on factors such as geomorphological location and vegetation density/type, mangroves can play a role as a nursery for juvenile fish, or may provide nutrients that are exported to offshore fisheries. Provisioning services can be economically important at multiple scales. Locally, provisioning services can provide subsistence for local coastal communities, or can be sold to local businesses to make small profits and improve local livelihoods (Fig. 4.5). The selling of fish and fuelwood extracted from the mangrove can account for as much as 30 % of a household's income in villages along the east coast of India (Hussain and Badola 2010). Across larger scales and extraction intensities, the value of provisioning services can be considerable; for example, the value of timber extraction, fisheries and other provisioning services across the Sundarbans may reach US$744,000 per year (Uddin et al. 2013).

Unlike hydrodynamic attenuation and shoreline erosion control, provisioning services are not directly related to DRR. However, provisioning services can contribute to a coastal community's adaptive capacity, which may increase its resilience to natural hazards and climate change impacts. Factors such as wealth, health and education are key contributors to adaptive capacity, and a recent global analysis suggests that in general coastal communities have higher levels of all of these factors, compared to communities living inland with less access to the coast and the provisioning services it provides (Fisher et al. 2015). Several reasons account for this. Firstly, coastal fishing as a form of livelihood presents a relatively low cost barrier compared to inland forms of agriculture (Daw et al. 2012). Secondly, coastal communities may (but not always) have easier or closer access to ports and markets for trade (Fisher et al. 2015). Thus, DRR activities (whether or not they are related to PES) would benefit greatly from the incorporation of management interventions that also improve provisioning service usage.

4.1.1.5 Spiritual, Cultural and Heritage Values (Cultural Services)

Cultural values encompass a broad range of ecosystem services that vary greatly in their tangibility and ability to be quantified (Pleasant et al. 2014). Cultural ecosystem services can include clearly tangible and quantifiable recreational and educational values. Spiritual, aesthetic and heritage values are substantially more abstract and intangible, but could have significant value for local coastal populations (Thiagarajah et al. 2015).

At first glance, cultural ecosystem services may not seem directly relevant to DRR. However, local or indigenous knowledge can make a valuable contribution to DRR, although it is often missing from DRR planning, or marginalized in favour of expert scientific knowledge (e.g. Mercer et al. 2010). Marginalization of local knowledge arises due to a perception from some stakeholders of the “unrigorous nature” of local knowledge, or due to unequal power relations between local communities and scientists and decision makers, which come to the fore when knowledge is produced and used (Bohensky and Maru 2011). Cultural value can decrease vulnerability to hazards through inter-generational learning related to warning signs of hazards and how to respond to them (e.g. Furuta and Seino, Chap. 13). For example, indigenous communities in coastal Southeast Asia, such as the Moken sea communities in Thailand, were aware of the warning signs of an impending tsunami, so during the 2004 tsunami they were able to evacuate more quickly than foreign tourists and migrant workers (Mercer et al. 2012). In this example, local knowledge can be regarded as an important, but potentially underappreciated source of resilience. While substantial challenges may be faced when integrating local and scientific knowledges into decision making, steps in this direction will improve our response to complex socio-ecological challenges (Bohensky and Maru 2011) such as ecosystem-based DRR. The incorporation of cultural ecosystem services into DRR generally is a key research area to pursue in the future.

4.2 Challenge 1 – How to Quantify ‘Invisible’ DRR Ecosystem Services?

While mangroves provide a variety of ecosystem services, only shoreline protection (wave attenuation and dissipation functions) can be considered directly linked to DRR. Many of the other services described above may contribute to DRR by increasing the adaptive capacity of mangrove-dependent coastal communities, but these may not be suitable for mangrove PES with a focus on DRR, since PES requires a direct ecosystem service that can be explicitly commodified and traded. Tradeable assets require clear quantification and clear ownership rights – traits that are not always possessed by certain ecosystem services. Unlike carbon storage and sequestration, for which clear quantification protocols and market prices exist, it is relatively difficult to commodify shoreline protection services, since (1) very few economic studies have estimated values for them (Barbier 2015); (2) shoreline protection (e.g. wave attenuation) is site-specific and dependent on the local ecological and geomorphological setting; and (3) the amount of attenuation is event-specific, e.g., the amount of hydrodynamic input energy to be attenuated. Yet, despite the difficulties outlined above, several quantification and valuation methods do exist for shoreline protection services, which are discussed in this section.

The first stage in any ecosystem service assessment is to quantify the PES-relevant service in order to establish a baseline against which future performance measures can be compared. Determining wave attenuation involves measuring the current velocity and water level along a cross-shore profile – typically at the open tidal flat, the mangrove fringe, and at systematic points within the mangrove vegetation (Quartel et al. 2007). These hydrodynamic measurements can be taken using pressure sensors and electromagnetic flow devices (such as Acoustic Doppler Velocimeters) that can be mounted on tripods, while bed level height and gradient can be measured at each sample station using a levelling instrument. Wave attenuation is calculated by the difference in initial and final wave height over a specified difference (Mazda et al. 2006). This hydrodynamic data can be combined with biophysical parameters (e.g. stem density, bed roughness, bed gradient), spatial data (shoreline profile, settlement proximity), and data on past events, in order to conduct scenario modelling of hazards such as storm surges (Lau 2013). The outputs are spatial predictions of flood occurrences and hazard levels for each scenario. Such assessments would indicate the current level of shoreline protection services that a particular mangrove provides, where and to whom that service is provided, and how the provision of that service would change with increased or decreased mangrove coverage. This collection of quantitative data and model output can then be subjected to valuation techniques in order to valorise the shoreline protection service – usually an essential step in PES scheme design.

Two cost-based methods can be used to value the shoreline protection service of mangroves: damage costs avoided and replacement costs (Table 4.1) (see Emerton et al., Chap. 2). The former usually requires geographic outputs from scenario models. The method involves estimating the costs of repairing the damages that would be incurred following a reduction in mangrove area, which is used as a proxy for shoreline protection value (Turpie et al. 2010). Damage costs include damage to physical capital such as property, fishing gears, infrastructure (oftentimes the water supply is salinized), and aquaculture/agriculture (e.g. loss of standing crops, fish stocks, or livestock). In addition, more nuanced human capital metrics could be incorporated into the damage cost analysis such as medical expenses or lost household income as a result of injury. The cost of repairing damage sustained

Table 4.1 Advantages and disadvantages of the damage costs avoided and replacement costs methods for valuing the coastal protection service of mangroves

Method	Advantages	Disadvantages
Avoided damage costs	Quantifying wave attenuation can be conducted accurately	Quantifying wave attenuation requires expensive equipment and technical expertise
	Valuation is based on actual market prices	Valuation is based on costs, not benefits
	Not overly data/resource intensive	Very difficult to predict the levels of damage sustained under a particular scenario since values are strongly influenced by the geographic and social (land/property value) context
	An option for locations that are challenging to value by other means	Data on past events is required
	Generally viewed as a better option to replacement costs and contingent valuation	Technical skills (e.g. environmental modelling) is required
		Intra-settlement damage levels and costs could vary greatly
		Land values can change quickly over time as regions gain prosperity or industries go bust
		Difficult to relate damage levels to ecosystem quality and area since there are many other factors
Replacement costs	Quantifying wave attenuation can be conducted accurately	Quantifying wave attenuation requires expensive equipment and technical expertise
	Valuation is based on actual market prices	The valuation is based on costs, not benefits
	Not overly data/resource intensive	Few ecosystems have commensurate artificial substitutes
	An option for locations that are challenging to value by other means	Tends to overestimate actual value of the individual service
		Tends to underestimate actual value of the entire ecosystem since other services that would not be replaced by a manmade alternative are not valued
		Limited application since few environmental actions are based only on cost-benefit comparisons
		Requires strong evidence that the public would demand a manmade alternative if the ecosystem was lost

Based on Pagiola et al. (2004), Turpie et al. (2010), Lau (2013) and Waite et al. (2014)

during past disasters could be used if available (see Bayani and Barthélemy, Chap. 10). Alternatively, if such data were unavailable and modelling was not feasible, the damage costs avoided method can be based on the financial investments that landowners have made in order to protect their assets from possible flood damage (e.g. insurance purchases or spending on anti-flood modifications to their property); this may work better in developed rather than developing countries. The damage costs avoided approach is strongly linked to the geographic (intensity of disaster) and social context (land value, land-use, building type) (Turpie et al. 2010). These values vary greatly both between and within different locales; for example, within the same Bangladeshi village, Hossain (2015) found that poorer residents owned property made out of bamboo with thatched roofs, while high-income earners owned houses made out of bricks with corrugated iron roofing. In this case, both the likelihood of destruction and the rebuild costs of individual buildings will vary greatly. Measurement uncertainty depends partly upon the availability of data on past disasters, but is generally high because it is difficult to model scenarios accurately, and the trajectories, frequencies, and severity of future storms are difficult to predict (Marois and Mitsch 2015). Regardless, this method is generally preferred over the replacement costs method (Lau 2013; Barbier 2015) (see Senhoury et al., Chap. 19).

The replacement costs method estimates the cost of replacing an ecosystem service with an artificial substitute (Pagiola et al. 2004); in the case of mangroves this could mean a groyne or seawall. In order for the valuation to be valid, the man-made alternative must (a) provide a commensurate level of storm protection service, (b) be the cheapest option capable of performing the same role, and (c) society must be willing to incur the cost rather than forgo the service (Pagiola et al. 2004; Waite et al. 2014). Market data are typically available for this method (e.g. an engineer could quote a price for the alternative). However, it has been argued that the replacement cost method overestimates the value of the storm protection services for individual sites, because the approach involves estimating the service benefit primarily by using the costs of constructing groyne or seawalls. Moreover, the artificial substitute is rarely the most cost-effective means of providing the service (Barbier 2007, 2015). In a mangrove storm protection study in Thailand, Barbier (2015) calculated annual welfare losses of US$ 4,869,720 when using the replacement cost method, which were over an order of magnitude higher than the US$645,769 calculated when using the avoided damage costs method.

More broadly, however, approaches to quantify and value DRR-related ecosystem services (such as storm protection) risk undervaluing the ecosystem as a whole. Artificial substitutes such as sea walls will typically only replace one service (e.g. storm protection), while all other benefits provided by the natural ecosystem will remain lost (Thampapillai and Sinden 2013). For example, in a study conducted by Gunawardena and Rowan (2005) in Sri Lanka, coastal defence was calculated to contribute just 27.6 % of the purported 'total economic value' which also included benefits to the fishery and wood used for building materials.

Recently, choice experiments have been used to value the multiple coastal ecosystem services provided by marine protected areas (Christie et al. 2015).

Coastal protection was one of six services that were used in the experiment, which presented respondents with different combinations of improved, current, and reduced service provision; these service packages were coupled with a hypothetical tax payment that gauged their willingness to pay and allowed the value of each service to be determined (Christie et al. 2015). Similar contingent valuation methods could be suitably applied to mangrove ecosystems, using hypothetical scenarios of declining or increasing service provision. However, contingent valuation can be expensive to implement, requires careful survey design, and is vulnerable to many sources of bias; meanwhile, choice experiments are considered to be technically difficult to implement (Waite et al. 2014).

4.3 Challenge 2 – How to Ensure DRR Service Provision and Permanence During a Disaster?

Once a DRR ecosystem service has been quantified, payments for such a service are dependent upon an agreed level of ecosystem service provision over a specified timescale. The maintenance of ecosystem service provision is related in a non-linear fashion to ecosystem quality, the maintenance of higher trophic levels and species richness (Duarte 2000; Dobson et al. 2006). However, a multitude of anthropogenic and natural stressors can reduce habitat quality and extent, thus impairing sustained ecosystem service provision. Such stressors on mangrove ecosystems may include agricultural land cover change (Webb et al. 2014), land reclamation (Wang et al. 2010), typhoons (Aung et al. 2013) and sea level rise (Krauss et al. 2010), and can have varied impacts from direct habitat conversion and destruction to cryptic declines in habitat quality, while the areal extent of habitat remains the same. In theory, many types of PES should require the reduction or cessation of direct anthropogenic stressors, such as harvesting or land cover conversion. However, many stressors in mangrove ecosystems either cannot be meaningfully reduced due to their process, magnitude and scale (e.g. tropical cyclones), and/or because they originate from a location external to the PES site (e.g. sea level rise), and are thus outside the control of a PES site manager.

External stressors such as tropical cyclones and sea level rise are important in a DRR context as we may promote mangroves to protect coastal communities against their impacts, although these external stressors themselves may have an impact on the mangrove system. An increasing literature exists on the impacts of tropical cyclones and storms on mangrove structure and functioning, especially in the wake of hurricanes, such as Hurricanes Andrew and Mitch, in the Neotropics. Some research has also been conducted in Asia after events such as Cyclone Nargis (Myanmar) and Typhoon Haiyan (Philippines). This body of research has described a number of tropical cyclone and storm impacts on mangroves, which may be immediate or delayed:

- *Defoliation:* species-specific defoliation is a common impact of high winds associated with large storm events, with mangroves in the eye of Hurricane Andrew consistently experiencing 100 % defoliation (Doyle et al. 1995).
- *Tree and branch damage:* strong winds can lead to branch and trunk damage, although damage may be species-specific: in one case study, *Rhizophora mangle* mostly suffered less than 50 % crown damage, while *Laguncularia racemosa* trees suffered 75–100 % crown loss (Sherman et al. 2001).
- *Tree mortality:* tree damage can be so great that mass tree mortality occurs. Mortality can be spatially variable due to species composition, geomorphology, elevation and storm track; in a study in the Dominican Republic after Hurricane Georges, mortality reached 100 % in some plots, with an average of 47.7 % (Sherman et al. 2001).
- *Peat collapse:* tree mortality leads to root death and the cessation of below-ground organic matter production. The peat soil may oxidise and collapse until such time when/if surviving trees and newly recruited individuals begin to produce below-ground organic matter to replace what was lost (Cahoon et al. 2003).
- *Sediment burial:* sediment eroded during a typhoon can be deposited within the mangrove. Such deposits can equal as much as 17 times the annual accretion rate experienced in the mangrove (Castaneda-Moya et al. 2010), which may suffocate the aerial roots of some species.

Sea level rise can also impact upon mangrove habitat quality and extent, with knock-on impacts for ecosystem service provision. Mangrove species distribution is controlled to a large extent by surface elevation and relative tidal inundation (e.g. Watson 1928), which can distribute species according to their tolerance to tidal flooding. Sea level rise – if not matched by similar increases in mangrove surface elevation (Krauss et al. 2014) – can increase tidal inundation beyond species-specific thresholds of tolerance, leading over time to a conversion to more tolerant pioneer mangrove species, and eventually to bare mudflat (Friess et al. 2012).

Thus, tropical cyclones, storms and sea level rise present a particularly interesting quandary: almost by definition, the locations most in need of ecosystem-based solutions for DRR are those that are heavily exposed to hazards. Thus, PES for DRR would provide funding for mangrove conservation to protect populations against short term events such as storms and long term events such as sea level rise, although these very same events can substantially damage the ecosystem in question and impact the provision of the required ecosystem service.

While the presence of external stressors may reduce ecosystem service provision and the effectiveness of PES, this does not mean that PES is untenable in such situations. Friess et al. (2015) describe a number of approaches to deal with external stressors in a PES context. While they vary in design and process, all of these approaches focus on siting a PES scheme in the most suitable biophysical location or reducing the risk of external stressors to financial assets. A three step, hierarchical strategy is proposed (Friess et al. 2015):

(i) *Stressor evaluation.* Ecosystem service provision models (e.g. Villa et al. 2014) must be combined with external stressors models in order to evaluate the risk they pose to a PES scheme. Environmental Impact Assessments on developments surrounding the PES scheme could also be mandated. In theory, these steps will ensure that a PES scheme is located in the most suitable location, for example away from neighbouring human developments, or along a sheltered coastline that is at less risk of storm damage (though this suggests that there could be less need for DRR measures in these areas). However, locating PES schemes in the most suitable locations from an ecosystems service and stressor point of view may not always be feasible, as it neglects political and social imperatives for PES scheme location.

(ii) *Stressor mitigation.* Once a PES scheme is located in an area that gives it the best chance of success, attempts can be made to mitigate the negative impacts of remaining identified external stressors. For anthropogenic external stressors this may require landscape planning and cross-sectoral cooperation. However, it is difficult to mitigate external stressors linked to natural hazards and climate change. For example, tropical cyclones and sea level rise are processes that operate on large scales that cannot be meaningfully mitigated by management interventions.

(iii) *Stressor accommodation.* Under the assumption that natural hazards and climate change stressors cannot be meaningfully mitigated, PES schemes must instead incorporate measures that allow the accommodation and management of risk. Such measures revolve around concepts of Financial Risk Management, particularly reducing uncertainty and investing in insurance measures. These may include third party ecosystem service insurance to pay for unexpected reductions in DRR ecosystem service yield. Bell and Lovelock (2013) propose insurance for mangroves damaged in storms, so that they can be restored and continue to provide DRR ecosystem services. Credit buffers and precautionary savings have also been used in some terrestrial PES sites (e.g. Phelps et al. 2011); more credits are created than are sold, so that there is a buffer to refund credits if the expected ecosystem service provision is not reached.

In summary, when planning a PES scheme to deliver DRR ecosystem services in a location heavily threatened by natural hazards and climate change impacts, scheme locations should ideally be determined through the use of ecosystem service and external stressor evaluation models. This will allow schemes to be situated in locations that maximize ecosystem service provision, while minimizing service impermanence. Once a PES scheme is located correctly, PES scheme planning must incorporate Financial Risk Management measures from the very beginning in order to reduce uncertainty and risk to ecosystem service investors, as natural hazards and climate change-related external stressors may never be fully mitigated.

4.4 Challenge 3 – Ecosystem Service Providers and Users Overlap

PES requires a quantified ecosystem service to be traded. PES involves a transaction between at least one service provider (seller) and service user (beneficiary/ buyer) (Wunder 2015). Arguably the most important PES precondition is for a ready user to exist. Potential users include insurance companies, government agencies, NGOs, and local communities (Table 4.2). Providers will likely be local landowners/managers or the local community that implement new management approaches (e.g. mangrove restoration or preservation) in exchange for payment from the ecosystem service user. Thus in the case of local communities, there is the potential for the provider and user to be the same group or stakeholder, which invalidates PES. Additionally, the suitability and structure of mangrove PES for DRR, the types and suitability of users and providers, and their degree of overlap will likely differ between developed and developing economic settings.

Table 4.2 The suitability of different potential PES buyers in developed and developing country settings

Potential buyer	Developed	Developing
Insurance company	Coastal residents likely have property insurance; insurers will need to be convinced that more mangroves means less damage and ultimately less pay-outs (saving them money)	Coastal residents seldom have any insurance cover due to either financial constraints or a deficit of insurers
Government agency	Government may have financial capacity to pay	Government may not have the financial capacity to pay
	Would have to identify situations in which PES would be favoured over command-control regulation and public spending on artificial coastal defences	PES may be more cost-effective than investing in expensive artificial coastal defences
		May be an alternative approach to command-control regulation if compliance is a problem
NGO	Would likely prefer to give financial aid which does not require a return on investment	Would likely prefer to give financial aid which does not require a return on investment
Local community	Potentially could afford payments	May be unable to afford payments
	Potentially overlapping as service users and providers	
Private landowner	Possible that the landowner and land manager may be separate entities. If so, the owner could pay the manager to implement better mangrove restoration/preservation to safeguard the asset being managed	Will likely be unable to afford payments

Insurance companies may have a vested interest in DRR since better-protected coasts will mean less damage and lower pay-outs following a disaster (Forest Trends and The Katoomba Group 2008; Dunn 2011; Lau 2013). The feasibility of insurance companies as users is greater in developed countries in which an established array of insurers and insurance policies exist for property owners to choose from. In developing countries however, coastal residents seldom have insurance cover. This is particularly true for poorer households that will typically own property constructed out of weaker materials (Kolinjivadi et al. 2015), which will therefore be more prone to damage. An insurance company is unlikely to seek improved coastal protection services for coastal settlements that it is not insuring, so in this regard poorer communities may be excluded. Insurance is typically provided on an individual basis and therefore equity issues could arise (in both developed and developing settings) since poorer residents may be priced out.

Government agencies and municipalities responsible for disaster management have also been suggested as potential coastal protection service users (Forest Trends and The Katoomba Group 2008; Lau 2013). In developed countries with ample public spending budgets, it is difficult to see how PES would be a more rational option compared to command-control coastal regulations (that are generally effectively enforced in the developed world) and direct public spending on artificial coastal defences. However, some developing countries will likely have lower public spending budgets, and also more pressing problems to solve – i.e. investing in basic needs such as infrastructure, health, and education. Hence, in such settings, the restoration/conservation of natural barriers may be considered by governments to be more cost-effective than constructing artificial substitutes, which often come at huge installation and maintenance costs. It is feasible that governments may utilise a PES approach to pay local communities that live adjacent to mangroves to reduce mangrove cutting or engage in restoration activities, which can reduce disaster risk in their jurisdiction. This is based on the notion that governments have a duty to ensure the safety of their people.

NGOs can be buyers of ecosystem service credits, particularly to try and nurture carbon-markets. However, in the context of coastal DRR, where a future return on investment is highly unlikely (i.e. climate change exacerbating extreme weather events and sea level rise, thus reducing service provision e.g. *Challenge 2*), it is difficult to see how PES would be favoured over direct aid for which no justification is required other than philanthropy. This is true for both developed and developing settings.

Local communities and private landowners have also been cited as potential users (Lau 2013). This is probably more suited to developed, rather than developing nations. Expecting local communities in developing countries to finance PES seems unfeasible and unjust, because local communities will likely be unable to afford such payments, similar to the equity issues surrounding insurance cover. However, the very notion of local communities (if, due to land tenure issues, they even have control of the ecosystem service in the first place) and private land owners using or buying ecosystem services is controversial, since in almost all foreseeable cases, local communities will also likely be the most suitable service providers (i.e. sellers), as they will be responsible for managing the coastline on which they live. PES requires a transaction to take place between two separate parties, and as such, thinking of local communities as ecosystem service users creates a contradiction, since these beneficiaries would be buying a service that they (in most cases) would also provide.

4.5 Alternatives to PES for DRR

This chapter has described three important issues facing coastal PES as a means of funding ecosystem-DRR activities. All of these issues challenge the fundamental tenets of PES: how can we sufficiently and accurately quantify DRR service provision?; how do we ensure permanence and long-term provision of DRR services in a dynamic coastal environment?; and how do we identify suitable services users and providers, and make sure they are distinct and do not overlap? Ultimately, due to the nascent state of PES for DRR, in many circumstances existing financial mechanisms may be deemed more suitable for DRR and associated disaster relief in mangrove systems, compared to PES. Other financial mechanisms for DRR do exist, although these also tend to vary between developed and developing countries. Three types of mechanisms are primarily relevant to developed countries: compensation, subsidized insurance of assets, and ecosystem service insurance. Within the developing world, financial support for DRR generally comes from a fourth mechanism, donor aid.

Compensation Disaster compensation is a response predominantly confined to the developed world, but is also used increasingly in developing and emerging economies. In considering how socially just such compensation schemes really are, Cooper and McKenna (2008) note that while coastal property owners face a direct financial loss from coastal disasters, compensating them creates accompanying costs to society since the state will use taxpayer's money. It is argued that public interventions are more justifiable at local and short-term scales, but less justifiable at larger geographical and longer time scales since the societal costs to non-coastal tax-paying residents increase due to larger payouts (Cooper and McKenna 2008).

Subsidized Property Insurance Subsidized private insurance offers an alternative to public compensation schemes, especially since private markets are showing an increasing reluctance to underwrite catastrophic risks such as floods (Jaffee and Russell 2006). For example, the US Federal Flood Insurance program subsidizes private insurance premiums to make coastal development more affordable to property owners, and the risks more acceptable to insurance. Similar to compensation, however, this financial benefit for a small group of coastal property owners comes at significant cost to the taxpayer. This approach also perversely encourages development in higher-risk areas (Bagstad et al. 2007). The perverse incentives of subsidized insurance has prompted some economists to question whether governments should be involved in catastrophic risk insurance at all, and have called for private markets to be more robust and take a longer term view of risk and capital (Jaffee and Russell 2006).

State-subsidized insurance is a predominantly developed-nation approach to disaster relief, and potentially for funding DRR activities. However, some have argued for insurance and other public-private programmes to plug the gap between donor pledges and disaster losses. Insurance mechanisms suggested for developing nations include catastrophe insurance pools, catastrophe bonds and risk transfer instruments and derivatives (Linnerooth-Bayer et al. 2005; Linnerooth-Bayer and Mechler 2007).

Ecosystem Service Insurance Payouts from ecosystem service insurance contribute to ecosystem restoration in the event that the ecosystem itself is degraded from an external event (e.g., *Challenge 2*). Bell and Lovelock (2013) proposed a mangrove DRR insurance product focused on protecting coastal land from the impacts of storms. Uptake of such a scheme would rely on property owners understanding that a mangrove forest provides coastal defence for their property. The idea stems from forest carbon credit insurance, wherein buyers can take out insurance as a form of protection for their valuable investment in the event that, for example, the forest is destroyed (Phelps et al. 2011). Premiums could be incorporated into existing property insurance. In designing an ecosystem insurance policy for the DRR services of mangroves, Bell and Lovelock (2013) note the need for: clear specifications of what insured events are covered and excluded; estimates of how much it would cost to rehabilitate the DRR value of mangroves; a prediction of the likely frequency and severity of weather events in the region which will assist with setting the insurance premium; and a protocol for actions the insurer will perform if an insured event occurs. Due to the payments and financial networks required, this is ultimately another financial mechanism most suited for developed countries.

Donor Support State intervention (i.e. compensation) in the aftermath of a disaster is often insufficient in developing nations. Hence, these countries often rely on donor aid for disaster relief, which may be a small percentage of total disaster losses (Linnerooth-Bayer et al. 2005). This is not without major equity issues. For example, international donors contributed US$662.9 million of aid within 3 months after Typhoon Hainan (Philippines), but international assistance still had not reached some affected areas (Lum and Margesson 2014). Much of the aid went to the devastated city of Tacloban which received the most media attention, and assistance was substantially slower to reach rural and small island areas throughout the rest of the archipelago.

4.6 Conclusions

Both coastal populations and mangrove forests continue to face an uncertain future in a coastal zone that is undergoing huge development pressures, exacerbated by the coastal impacts of climate change. PES may be a novel and important instrument to conserve mangroves for their benefits to DRR, but only if current challenges can be overcome. Our ability to quantify DRR ecosystem service provision is lagging behind our knowledge of other ecosystem services such as carbon storage, although several direct and indirect methods of quantification and valuation do exist. Future efforts could focus on how to valorise direct measurements of hydrodynamic attenuation, or how to combine direct measurements with indirect measures of coastal protection such as replacement costs and avoided damage valuation. Ensuring long-term ecosystem service provision is also a challenge in coastal ecosystems that are affected by a host of external stressors that differ markedly in their process, origin, magnitude and scale. These challenges are in no way insurmountable; a series of tools exist to quantify some DRR services, and external biophysical stressors may be mitigated or accommodated in some circumstances.

In addition, some situations may best be tackled through donor support since there are no expectations of a return on investment, which may be unlikely in a dynamic coastal environment. However, at this embryonic stage, we need to take a critical look at PES as an instrument for DRR in mangrove systems. In particular, the mechanics of PES schemes for DRR are uncertain – particularly with regard to the buyer-context and whether these entities overlap or are distinct – as outlined in challenge three. Understanding the three challenges posed in this chapter will ensure that PES is the right funding model to pursue, and will allow us to be more strategic in selecting sites where mangrove ecosystem service delivery, governance and funding arrangements will be most effective over the long term.

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