Published in: In Rivera-Monroy, V. H., Lee, S. Y., Kristensen, E. & Twilley, R. R. (Eds.). Mangrove ecosystems: a global biogeographic perspective on structure, function and services ISBN 978-3-319-62204-0.

Chapter 8: Mangroves and People: local ecosystem services in a changing climate.

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There is no wealth but life – John Ruskin

1. Introduction

1.1 The value of local ecosystem services

Mangrove forests are exceptionally useful ecosystems, but understanding the ways in which they improve human welfare and communicating this so that it makes a difference is difficult. A popular approach involves economic valuation. A range of economic tools is used to capture and summarise the value of different services in monetary terms. There are good arguments for this approach; 'money talks' so nature can be heard. However, it risks encouraging partial or distorted views - often to the frustration of economists themselves who do not conflate 'the price' with the value. It is particularly so for ecosystem services of most immediate benefit to local (and often poor) people, the focus for this chapter. An example from Gazi Bay in Kenya helps illustrate the point. Here the value of wood to be used as fuel for cooking is only around 5% of the total economic value of the forest, whilst carbon sequestration makes up 38% (Huxham et al., 2015). This follows the typical pattern in which regulating services such as coastal protection and carbon capture and storage dominate the estimated values of mangrove forests when using economic methods. However 71% of households in the village rely on mangrove firewood and 96% of the individuals responsible for collecting this wood are women (who as a group are poorer than men). Throughout the tropics, it is common for women to carry the burden of fuelwood collection (e.g. in Brazil; Glaser, 2003), hence under-valuation of the ecosystem service of firewood production may marginalise women as well as the poor. In Kenya firewood is used daily in the preparation of food, whilst the value of carbon sequestration to local people is a theoretical one at most sites (although not entirely at Gazi; Plan Vivo, 2015). Hence firewood assumes an immediate and pressing importance in the lives of some of the poorest people associated with mangrove forests, an importance that may be obscured if we only rely on global economic valuations. From the local perspective, the value of mangrove forests in national or global policy may be irrelevant and hence do little to help encourage local action for sustainable management. Social equity and practical conservation demand that we remember the importance of the local.

1.2 Defining local services

Ecosystem services are those contributions to human welfare made by the natural world. As such all human beings are stakeholders in ecosystem services, if we follow Hein et al. (2006) in defining stakeholders in this context as 'any group or individual who can affect or is affected by the ecosystem's services'; ultimately all of us depend on ecosystems. However different services are generated and used at different spatial scales. In defining here what we mean by 'local' ecosystem services we focus on the social rather than ecological characteristics, since these two elements might differ. For example services might be generated at very small ecological scales (such as truffle fungi growing in a few patches of a forest) but enjoyed over large or distant scales (in exclusive restaurants gracing distant capitals). In economic language, the 'distance decay' of a service might be fast (the shade provided by a tree?) or non-existent (the value of Antarctic wilderness, as perceived by Europeans). Hein et al. (2006) use international, national, state/provincial, municipal, family and individual levels in their analysis of the institutional scales pertinent to ecosystem services. Our definition of 'local' incorporates their individual to municipal levels. Figure 1 summarises the spatial extent of key ecosystem services provided by mangrove forests. It is based on the usual and maximum distances recorded in the literature over which the benefits of a service from a specific mangrove site were spread; for example, the distance to market of a product such as charcoal or the area of coastal land protected from storm surges. Hence the ecosystem services considered in this chapter are primarily those of most benefit to people living in close proximity (from zero to tens of kilometres) of mangrove forests. This definition excludes services such as carbon sequestration and storage that benefit all humanity, since these benefits do not accrue more locally than internationally. In an increasingly globalised and interconnected world making such distinctions between 'local' and 'global' scales of impact and benefit has become harder. A striking example is the inequality in the distribution of costs borne and benefits realised from intensive shrimp aquaculture in mangrove swamps. High income groups (the global rich) are responsible for 44% of the estimated costs of this destructive practice but suffer <0.5% of the damages (mainly because they usually live at a great distance from the affected sites); the equivalent data for low income groups are 29% and 54% (using 'equity weighted' sums that correct for poverty; Srinivasan et al., 2008). One complication here is the existence of a range of market and policy mechanisms that may help transfer these global benefits (or compensation for costs) back to local levels, creating real income for local people. Examples include payment for ecosystem services (PES) schemes in which local stakeholders are paid for protecting and enhancing services enjoyed by others (Locatelli et al., 2014; Plan Vivo, 2015). Whilst acknowledging their potential for helping to 'make the global local', such schemes are still rare in mangrove areas and are beyond the scope of this chapter.

The local mangrove services we consider here include provisioning (fuel wood and charcoal, fodder, timber, crabs and fin-fish) and regulating (coastal protection and fisheries nursery functions) services. We chose these because the literature emphasises their local importance and because there is information to explore general trends; other services, such as water filtration, may be vital locally but are poorly studied. The forests that deliver these services range in size from a few hundred trees to thousands of hectares, may consist of just one or dozens of tree species and may grow in vast deltas or on tiny over-wash islands; but the diversity of our subject matter is not limited to the biological and geographical. The types of human communities contiguous to these forests range from megacities to tiny villages and consist of some of the poorest and the wealthiest people on the planet. Any general patterns that emerge in the face of such variety are likely to be imprecise and to ignore multiple exceptions. This does not mean that attempts to classify mangrove forests and their ecosystem services at the global scale are doomed to lack utility. For example a scheme based on only three variables – soil organic matter, suspended particles and tidal range – provides a useful indication of the likely best approaches to mangrove restoration across the tropics (Thorsten and Friess, 2015). Two guiding and interacting themes inform the approach taken in this chapter: the roles of biological diversity and of poverty. For each of our local services, we consider whether patterns of usage – involving for example particular species or families of mangrove trees– are consistent between biogeographical regions. We examine the role of biological diversity in determining local use and value of mangrove forests, asking whether people exploit a wider range of species, which provide a wider range of services, in forests with higher levels of floral diversity? We also explore the social factors, and in particular poverty, that may determine forest use. Finally we conclude with thoughts on the future. Mangrove ecosystems face numerous challenges, not least from climate change; are there biological or social factors that are likely to make the provision of local mangrove services more or less vulnerable in the face of these stresses?

2. Fuelwood and Charcoal

Mangrove trees are used for fuelwood and charcoal production throughout the tropics, making this ecosystem service one of the most widespread (Walters et al., 2008). Many studies report that mangrove wood is highly prized as a fuel. In Pakistan, about 0.1 million people use 18,000 tonnes of mangrove firewood each year (Vannucci, 2002). In the Philippines, 'mangrove wood is unanimously viewed as superior for firewood to non-mangrove wood' (Walters, 2005). This preference may reflect the ease of access to the wood, or the fact that it is not owned or actively managed at some sites, i.e. that it is an open access resource in contrast to wood from trees deliberately cultivated. Thus, forests that are adjacent to settlements and are easy to reach are likely to experience higher rates of exploitation. This can sometimes reflect seasonal differences in accessibility; for example flooding permits easier access to mangrove firewood by canoe in Cameroon (Munji et al., 2014). However the superior qualities of the wood, such as its ability to burn for a longer time and at high temperatures and the production of particular flavours of woodsmoke may also be important. Walters (2005) describes how the use of mangroves as firewood increases dramatically during fiestas in the Philippines, when even households that do not routinely use it prefer it for roasting pig. Because species in the family Rhizophoracea (such as *Rhizophora* spp. and *Ceriops* spp.) produce particularly dense wood that sustains hot fires, some literature identifies them as preferred sources of fuelwood. Less desired species, such as *Avicennia germinans,* may be left untouched as part of a management strategy (for example in the Caribbean; Smith and Berkes, 1993), since maintaining canopy cover can help prevent deterioration of sediment quality and help ensure natural regeneration (Huxham et al., 2010). More commonly, however, other species are also exploited if the preferred sources are depleted. The tendency for communities to prefer Rhizophoraceae (and specifically *R. mangle)* is most pronounced in the Atlantic- East -Pacific region (Table 1), which is also the region with the lowest overall species richness of mangroves. With increasing availability of different species (or perhaps decreasing dominance of one or two key species) there is less evidence of a clear preference. Hence communities in Asia are recorded as utilising a wide range of different species with no clear preferences (Table 1). For fuelwood this broad comparison suggests that increasing biological diversity (that is, increasing numbers of mangrove species) generally correlates with increasing diversity of human use and perhaps greater flexibility in provision of this ecosystem service.

Wood is the main source of domestic fuel throughout the tropics, although rates of use vary widely between countries. Much of this variation is driven by climate, with desert and dryland nations having much lower wood resources than those in wetter areas. For example people in Chad use an estimated 0.3 kg/cap/day compared with 1.5 kg/cap/day in wetter Nigeria (Yevich and Logan, 2003). However social factors exert at least as strong an influence as climate. Africa has the lowest global per capita use of fossil fuels because of its relative poverty. Hence most people, and especially those in rural areas, rely heavily on biofuels, principally wood and charcoal. For example, rural households in Kenya consume an average of 2.14 kg/cap/day of fuelwood, more than 15 times the average used in urban areas (Kituyi et al., 2001). Urban dwellers have a higher reliance on charcoal, at 0.37 kg/cap/day, than rural users (0.26 kg/cap/day), which partly compensates for this lower fuelwood use (Kituyi et al., 2001). Rates of fuelwood use are even higher in other African countries where relatively abundant supplies of wood combine with poverty and lack of access to fossil fuels; thus, Zambia tops the per capita consumption rates at 3.24 kg/cap/day (Yevich and Logan, 2003). Mangroves provide an interesting case study of how poverty and social factors influence the use of natural wood resources; most users of mangrove fuelwood are collecting under *de facto* open access conditions from unplanted forests growing close to their homes. Reviewing the literature for case studies that identify proportional reliance (the percentage of households using mangrove wood for fuel) in communities living adjacent to mangrove forests shows a strong influence of average income (as reflected by GDP per capita for the country) on the proportional use, with wealthier countries showing less reliance (Figure 2). However the considerable scatter in this relationship also reflects the importance of local conditions including governance and access regimes; for example, the data from Tanzania represent an outlier, with unexpectedly low percentage use, because of the effective regulation in force in the area of the case study (McNally et al., 2011).

Just as mangrove wood is considered a superior fuel, charcoal derived from mangroves is also highly prized as long burning, with a low ash and moisture content and resistance to spitting. Whilst exploitation for fuelwood and charcoal often co-occur and share some of the same driving factors there are significant differences in the socio-economic characteristics of these two related services.

In particular, charcoal is often produced for sale to markets that may be at a great distance (more than 2000 km) from their source (Figure. 1). Hence its definition as a local ecosystem service is less consistent than for firewood. Although there are cases of large scale cutting of mangrove forests to supply commercial markets with fuelwood (for example in Cameroon, where mangrove wood is also used for smoking fish; Atheull et al., 2009), most exploitation for fuelwood is artisanal, unmanaged and outside formal markets. In contrast, some mangrove forests are planted and managed specifically for commercial charcoal production. For example plantations of *R. apiculata* have been managed for charcoal in Thailand for fifty years (Kridiborworn et al., 2012), whilst the Matang mangrove forest reserve in Malaysia has been a model of mangrove silviculture, producing commercial charcoal and poles for timber, for more than a century (Goessens et al., 2014).

3.Timber, thatch and fodder

Mangrove wood is used for a range of timber products, from small household items, to fish traps through to large beams for construction (Walters et al., 2008). Harvesting for timber is often species and size specific. For example, in Kenya poles with diameters of 8-13 cm are preferred for construction and *R. mucronata* has been the main species targeted for these. This has in some areas led to shifts in forest composition towards less valuable species such as *C. tagal* (Kairo et al., 2002). In Colombia, *R. mangle* is targeted for poles whilst *A. germinans* is preferred for planks, and this selective extraction have led to shifts towards *L. racemosa* dominance (Blanco et al., 2012). Whilst a general preference for Rhizophoraceae is recorded in the literature, and is reflected in the deliberate cultivation in managed forest (Goessens et al., 2014), it is not universal (Table 1). As with firewood, the largest number of exploited species is recorded from Asia where the largest number of available species grows.

The mangrove palm *Nypa* is often highly prized. The fronds of this plant are used as thatch for houses and outer boundary walls. One hectare of *Nypa* plantation provides about 15,300 palm leaves each year. In addition, mats, baskets, hats and rain caps are also woven from leaf fibers. Young leaves are used as wrappers for food, while the ribs are used as fuel. The sap of young inflorescences is tapped for sugar production, alcohol distillation and vinegar production. The soft endosperm of fruits is edible and highly esteemed in Thailand, Indonesia and Philippines. The hard shells of the ripe fruits are used to make buttons.

Some mangrove species, particularly *Avicennia* spp, provide cheap and nutritive feed for buffaloes, sheep, goats and camels, and this use is common in arid areas of India, Pakistan and the Persian Gulf region. It is believed that cattle feeding on mangroves yield highly nutritious milk. Camel herding is one of the activities practiced by the pastoral communities known as 'Maldharis' in Gujarat, India. The maldharis are in the habit of shifting along with their livestock to distant areas in search of fodder for their cattle and degradation and restrictions of access to mangrove forests have critically impacted their livelihoods (Kathiresan, 2015).

4. Mangrove Crab Fisheries

An abundant and diverse fish, mollusc and crustacean fauna inhabit mangrove forests and estuaries. Many species are exploited by small-scale and artisanal fisheries (sensu FAO http://www.fao.org/fishery/topic/14753/en) for subsistence and income. These fisheries deliver the major value of marketed mangrove resources (Walters et al., 2008). We focus on the fishery of crabs here, a key faunal component of mangrove ecosystems around the globe, playing important functional roles whilst also delivering significant provisioning services and being culturally important. In northern Brazil, for example, the obligate mangrove forest dweller *Ucides cordatus* is the most frequently used mangrove resource and supports a valuable market-driven yield of up to 7 tonnes per km^2 *Rhizophora mangle* forest yr^{-1} (Diele et al., 2010). About 60% of interviewed households indicated its use for subsistence and 40% for marketing (Glaser, 2003). In Asia, mud crabs (i.e. *Scylla* spp.) reached a production value of US$ 252 Million in 2004 (FAO, 2006; cited after Ellison, 2008). Mangrove crabs were probably already harvested in pre-historic times in the Americas, as suggested by a richly ornamented clay artefact of *U. cordatus* (Figure 3), dating back to the Marajó culture (approximately AD 400 to 1350) (Diele et al., 2010). Coastal villages in northern Brazil have retained a strong cultural relation to the fisheries resources provided by adjacent mangrove ecosystems, exemplified par excellence during annual thanks-giving festivals when dancers dress in beautiful 'natural costumes', such as those made entirely from crab shells (Figure 4).

Table 2 summarizes a literature search for mangrove and mangrove associated crabs fished for subsistence and/or commercial purposes. The harvested crabs include supratidal species of the family Gecarcinidae, intertidal forest-dwelling grapsid, ocypodid, sesarmid and ucidid crabs foraging at low tide, as well as mostly subtidal/mangrove-estuarine families (Calappidae, Matutidae, Menippidae, Oziidae, Panopeidae, Portunidae and Varunidae). The list is not exclusive, particularly for species captured for subsistence that are unlikely to be adequately documented in the scientific literature. They are also not included in fisheries statistics that typically focus on marketed species only, despite the fact that local communities may harvest significant amounts of these non-marketed fisheries resources. In Micronesia for example, the proportion of non-marketed catch to total catch was estimated at 90% (Naylor and Drew, 1998). Clearly, for obtaining a realistic view of livelihood dependencies on mangrove forests, of fishery impact on the full range of harvested species (including the delivery of functional roles of the targeted species) and of economic valuation of mangrove ecosystems, these non-marketed resources need consideration. The poorest and less educated parts of coastal populations often harvest supratidal and forest dwelling intertidal crabs, since their capture does not require costly equipment. These species are mostly burrowing and can be caught with relative ease (yet requiring professional experience) during low tide, e.g. by digging them out by hand, grabbing them carefully with a hooked stick or with simple baited traps (e.g. Brown, 1993; Rodriguez-Fourquet and Sabat, 2009; Diele et al., 2005). The relative "affordability" of this fishery permits self-employment, so harvesting supra- and intertidal mangrove crabs holds an important poverty alleviation function for those with few or no other income options. Harvesting subtidal mangrove-associated species such as portunid crabs, e.g. *Callinectes* in the Neotropics and

Charybdis in the Paleotropics, generally requires more financial input such as nets, and often involves trawling from smaller boats, resulting in a lower number of self-employed fishers. Crabs are also targeted by recreational fisheries in some countries, e.g. *Scylla serrata* in Australia.

Two main patterns emerge from the literature review regarding the identity and diversity of the targeted species (Table 2). First, targeted species are mostly mid (4-5 cm carapace width) to large-sized (>> 7 cm carapace width). Eating crabs is a laborious task due to their hard carapace and small specimens may not contain enough meat to make the effort worthwhile. This also explains why the number of supra- and intertidal species that are fished is only a small proportion of the much larger number of crab species associated with these habitats globally (about 300 mangrove species of brachyuran crabs reported; Ellison, 2008), since few of these species grow large e.g. crabs of the genera *Cardisoma* and *Ucides*. The size-selectivity of crab fisheries further explains the globally much higher number of targeted subtidal crabs compared to the intertidal ones. The portunid swimming crabs for example include the large and fast growing species of the genera *Callinectes*, *Charybdis* and *Scylla*, representing over half of the species listed in Table 2. The size selectivity of mangrove crab fisheries, however, only accounts for the yield directed to live-crab and meat-processing markets. In contrast, large numbers of megalopae and small juveniles ("crablets") of mud crabs, *Scylla* spp., are collected as seed stock to supply crab farms in many Asian countries. The continuous capture of these early life stages due to expanding export markets is threatening wild populations (Quinitio et al., 2001).

The second pattern emerging from the literature review is that the number of recorded species that are harvested is by far largest in Asia. This probably reflects the overall higher faunal (and floral) diversity in this region (e.g. Ellison 2008), rather than simply being a function of a possibly higher number of fishers. For example, the number of medium-sized "fishable" sesarmid species is much higher in this region than in the Americas (Lee, 2008). Overall, the literature review yielded 27 exploited mangrove crab species in the AEP and 40 in the IWP. This divergence matches the global pattern observed for the use of mangrove fuelwood, charcoal and timber.

5. Mangrove fin-fisheries

Fish may utilise different habitats at different life stages (Nagelkerken et al., 2000, Kimirei et al., 2013) and mangrove forests often act as important nursery habitats for marine fish (e.g. Nagelkerken, 2009). Local households often depend directly on mangrove forests for fish, deriving their income and subsistence from fishing practices within and around forests (Barbier, 2006). There can be serious social and economic consequences for local people if this fisheries function is impaired. For example, mangrove-rich areas in India provide up to 70 times more catch and income than similar mangrove-poor areas (Kathiresan and Rajendran, 2002). This service is often well understood at a local level. Mangrove forests are described as 'the roots of the sea' in Asia; their loss would leave no fish and the sea would behave like a tree without roots.

Whilst fin-fish can be vitally important for individual households and whole communities adjacent to mangrove forests there is wide variation which cannot simply be explained by crude measures of poverty. In contrast with fuelwood, there is no clear relationship between the GDP of the country and reported local reliance on mangrove forests for fish (Figure 5). Fishing is often an occupation of the poor, but it can also secure high and stable incomes and may be central to cultural identity. Furthermore, recreational fisheries are important in many countries with a high GDP. Hence in contrast to fuelwood this local service may not decline in importance with increasing wealth.

Many of the world's commercial fish species rely on mangrove areas during their life cycle (FAO, 2006). Table 3 shows the main mangrove fish taxa caught by artisanal fishers in the AEP and IWP, identified in a literature search of studies looking at artisanal mangrove fisheries; 'key species' (or taxa) were defined as those cited from more than one study in any one region. Fish from the families Lutjanidae and Gerridae are the most prevalent species and both commercial and artisanal fishers target these.

6. Coastal protection

The idea that mangrove forests can act to protect the shoreline is old. Saenger and Bellan (1995) describe misguided advice to stabilise the banks of the Suez Canal by planting mangroves and report official calls in 1911 to protect the coastline of Cameroon using mangroves. Some local communities have also long recognised this function; for example Fijians traditionally maintained mangrove forests for coastal protection, and areas that have continued this tradition suffer less erosion now (Mimura and Nunn, 1998). Both the profile and the understanding of this service have developed rapidly in the past two decades, driven by dramatic events (such as the Asian tsunami) and impending sea level rise. Mclvor et al. (2012) summarise the evidence for protection against major events (storm surges) whilst Thampanya et al. (2006) present a clear demonstration of how mangrove forests control erosion; forested sites across Thailand suffered over the past 30 years significantly less (or no) loss of shoreline compared to sites where mangrove trees had been cleared.

The shoreline protection service often features prominently in official government and NGO campaigns and in estimates of the total economic value of mangrove forests. It may, however, be of less immediate concern to local people than provisioning services, since its benefits can be subtle (gradual erosion) or demonstrated during relatively rare events (such as storm surges), and the poor may not have the luxury of privileging such longer-term considerations over more immediate subsistence. It is certainly harder to find examples in the literature where this service is the main incentive for local communities in their use, management and restoration of mangrove sites than for other services (Table 4). However, knowledge of the ability of mangrove forests to protect the coast is widespread and is often reported as an additional benefit in projects and surveys focused on other services such as fish and timber. This is particularly true in Asia, where some of the worst tropical storms occur and where recovery from the 2004 tsunami continues. Barbier (2006) reports how communities in Thailand that are most dependent on mangrove fish are most likely to invest time in restoration, whilst also being aware of the protective function of the forests. Dangerous storms provide tragic demonstrations for local people to see for themselves the protective functions of mangrove vegetation, and local anecdotes are supported by wider surveys and theory. For example cyclone 'Nargis' caused in 2008 the deaths of over 30,000 people in Myanmar, with mortality worst in areas with no or degraded mangrove forests (Kathiresan, 2015). Mangrove vegetation is often surprisingly resilient in the face of extreme events, in sharp and visible contrast to human infrastructure and artificial coastal protection (Figure 6)

Theoretical and empirical studies have identified some of the mangrove characteristics most likely to reduce the depth of storm surges, the heights of waves and to ensure surface elevation in the face of sea level rise. The clearest (and most obvious) is the size of the forest. Wave heights during a typhoon were reduced by 50% after passage through ~380 m of *K. candel* forest, and by ~90% after 1 km (Barbier et al., 2008). The density of forest is also important (Kumara et al., 2010; Thampanya et al., 2006). Some species are more effective than others in reducing wave energy, in particular those with denser aerial roots (hence *S. caseolaris* is three times better than *K. candel*; Barbier et al., 2008), and some (such as *R. mangle* compared with *L. racemosa)* are better at recovering after storm damage (Mcivor et al., 2012 and refs therein). Experimental work suggests that mixing species with different root profiles may boost forest productivity and therefore resilience (Lang'at et al., 2013). However, where coastal protection or storm shelter are the key objectives of restoration or management the species of tree used are normally not selected specifically or exclusively for their ability to stabilise and protect shorelines. The planning and implementation of such work is rarely sophisticated enough to utilise such knowledge, but must focus instead on considerations of ensuring successful planting and growth and appropriate local tenure and governance (Primavera and Esteban, 2008). As with other services, Asia supports more species providing coastal protection than in other regions (Table

4). This probably reflects the greater range of species available at individual sites rather than any deliberate attempt to utilise different ecological or hydrological properties.

7. The vulnerability of local mangrove services to climate change

Mangrove forests face a wide range of stressors and threats. Any of these – such as aquaculture, coastal development, diversion of freshwater and silt by dams and agricultural conversion – can undermine the provision of their local services and require urgent amelioration (Lavieren et al. 2012). Here, we focus on the possible impacts of climate change for two reasons. First, this growing global threat is relevant to all mangrove forests regardless of their location. Second, the factors that make local mangrove services at any given site particularly vulnerable to anticipated climate change tend also to reduce their resilience to other threats. Hence, considering climate change vulnerability helps clarify general points about the resilience and fragility of local mangrove service provision and can thus inform management. The combination of potential climate change impacts and vulnerability of individual species will help guide the type of management needed. For example, when both variables are high a more active and directed management approach (e.g., habitat re-creation, species translocations) may be required, while passive management (e.g., monitoring, ecosystem-based management) would suffice when both are low (Koehn et al. 2011).

7.1 Mangrove forests and sea level rise

The positioning of mangrove forests at the interface of land and sea makes them directly susceptible to sea level rise. Higher sea levels result in extended exposure to seawater reducing growth, survival and reproduction (Kraus et al. 2008). The degree to which any given forest is affected by sea level rise largely depends on local physical processes, coastal geomorphology, interactions with other environmental factors and ecosystem interdependencies (Mcleod et al. 2010, Alongi 2015). The balance between sediment accretion rate and sea level rise is critical in determining whether mangroves drown, persist, or expand at their seaward and landward edges. Mangrove forests will be more resilient where sediment sources are plentiful and unobstructed (Field 1995). Rivers are important sources of freshwater and sediment for riverine mangrove forests and their natural setting within the seascape is therefore important. However, human activities modify freshwater and sediment loads of rivers systems in many ways (Davis et al. 2015). For example, alterations to river flows due to construction of dams and channels, and extraction of freshwater, have consequences for the influx of freshwater and sediment into tropical river deltas. The degree of rainfall also regulates the magnitude of freshwater and sediment flow, and climate change is predicted to alter regional precipitation patterns, most likely leading to less rainfall in dry regions and more rainfall in wet ones (Alongi 2015).

Mangrove forests may adapt to sea level rise by extending landwards (Di Nitto et al. 2014), but the degree and type of coastal development at the landward fringes will determine how likely this is. Where mangrove forests occur next to coastal developments, their extension to higher elevation is prevented and forests are squeezed in the coastal zone. Topography also plays a major role as steep slopes prevent horizontal extension, while mangrove forests on flat, low-lying islands quickly run out of space at higher elevations. For example, shoreline retreat in Gambia has been predicted to be 6.8 m in cliffy areas and ~880 m in flat, sandy areas, and most areas lost to inundation will be associated to wetland and mangrove ecosystems (Jallow et al. 1996). Ecosystem interdependencies may further alter the impacts of sea level rise. In cases where coral reefs or seagrass beds occur close to mangrove forests, the wave energy is usually reduced by these more seaward located ecosystem structures (Gillis et al. 2014). However, coral reefs are unlikely to keep up with the rate of sea level rise leading to more wave energy moving into back reef areas (Saunders et al. 2104). This effect will be further exacerbated by direct destructive impacts of local communities on reefs, and reduced reef calcification due to ocean warming and acidification. Whilst elevated CO_2 can lead to enhanced mangrove primary productivity, this may only occur at low salinity and high humidity (Ball et al. 1997). Hence, the combination of higher aridity (from global warming) and salinity (from sea level rise) might counteract any positive effects of elevated CO_2 on mangrove growth. Thus, climate change will most likely cause multiple stressors to interact (see Chapter 7).

The degree to which local mangrove ecosystem services are affected by climate change will depend on local environmental and geomorphological conditions and whether humans exacerbate or mitigate climate change effects. For example, the way in which river flows are modified can alter the responses to sea level rise. Some mangrove forests will increase in surface area in response to sea level inundation (Traill et al. 2011) and may provide more opportunities for harvesting wood and forest products by local communities, whereas in other parts of the world mangrove areas might quickly decline (Saleem Khan et al. 2012) leading to lower primary and secondary productivity. Higher sea levels can also have positive effects such as better access by canoe to forest areas otherwise inaccessible to harvest mangrove wood (Munji et al. 2014). Altered inundation patterns of mangrove wetlands may also change their nursery function and alter fish community structures (Igulu et al., 2014; Hylkema et al., 2015) and may affect local harvests. Not all ecosystem services will be equally affected by climate change. In a case study in India, agriculture, aquaculture, and mangrove forests were the three natural resources most at risk of inundation from sea level rise (Saleem Khan et al. 2012). Aquaculture in this area is based on brackish water farming of prawns leaving this industry and the communities that depend on this prone to salinization from seawater intrusion.

7.2 Range extensions of mangrove forests

Mangroves are limited at their high-latitude ranges by low winter temperatures. Climate change is facilitating range extensions of various mangrove species to higher latitudes (Osland et al. 2013, Saintilan et al. 2014). Modelling studies suggest that Central America and the Caribbean will lose relatively more mangrove cover than elsewhere in the world due to regional decreases in rainfall (Record et al. 2013). Because saltmarshes occupy a similar ecological niche to mangrove forests, this often leads to invasion of salt marshes by mangroves. In cases where they already co-occur, mangrove forests have been observed to extend their ranges landwards and invade salt marshes (Saintilan et al. 1999).

Whilst mangrove forests and salt marshes are both highly productive and support fisheries they harbour very different biological communities and therefore changes in coastal vegetation due to climate change may have large consequences for local marine fauna and for the people that depend on it. We know very little about the response of associated marine species to mangrove range extensions, or range contractions of salt marshes. As a potential analogue to range extensions, one study found that introduced mangrove forests in Hawaii did not have a negative effect on local fish communities and may act as nurseries for local as well as exotic fish species (MacKenzie and Kryss, 2013). Although the ultimate effects are still difficult to predict, range extensions of mangrove forests will lead to losses as well as gains for local human communities.

7.3 Range extensions of fisheries species

As the oceans warm and foundation species like mangroves extend their ranges so will those species that depend on them. Many of these mangrove-associated species are of high value to local fishers. Various marine species have already extended their ranges to higher latitudes (Poloczanska et al., 2013) and this is an ongoing process driven by ocean warming. Most emphasis on marine range extensions has been on ecosystems and species from coastlines or the open ocean, with barely anything known about inshore ecosystems or mangrove-associated fauna like fishes, crabs, shrimp, and bivalves. It is very likely that these taxa will also extend their ranges, but we know little of the rate at which this might occur and the species that will respond fastest. Mangrove-dependent species might be limited by the rate at which mangrove habitats move, while others may outpace mangrove movement and utilise novel habitats they encounter (Riley et al. 2014). Because many species that live in mangrove forests and estuaries are more tolerant to fluctuating environmental conditions than oceanic species (Gillanders et al., 2011), their responses might differ from the latter. Life history strategy will also determine how fisheries species are impacted, because some species use mangrove estuaries during their entire life, some for part of their life, and some as transient areas to move between the ocean and freshwater systems (Crook et al., 2015). Because the rates of community response to climate change will vary with habitat type, species with the most complex life history dependencies might be particularly vulnerable (Nagelkerken et al., 2015). These include species that require mangroves, seagrasses and coral reefs in close proximity, such as various species of Haemulidae, Lutjanidae and Scaridae (Nagelkerken et al., 2001).

The impact of species range extensions and changes in species assemblages due to climate change on local communities will largely depend on the specific species that are targeted by artisanal mangrove and estuarine fisheries. In addition, local environmental factors and geomorphology will play a role, with (partially) enclosed mangrove estuaries perhaps being less prone to range-extending species than ocean-facing mangrove forests, and mangrove forests along continental coastlines being more likely to experience range extensions by post-settlement movement of marine species than oceanic islands surrounded by deep waters.

7.4 Effects of ocean acidification, warming, salinity, and hypoxia on fisheries species

Elevated CO_2 and temperature can have positive effects on primary producers, thereby enhancing benthic and pelagic marine primary production and increasing food availability for consumers (Roessig et al. 2004), although this is more likely to be the case for temperate rather than tropical species. Higher temperatures elevate metabolism usually leading to a greater demand for food (Roessig et al., 2004). In cases where food is not limiting, growth rates of some mangrove and estuarine fauna may therefore increase with temperature leading to higher reproduction and secondary productivity (Hare et al., 2010). However, global meta-analyses suggest that although primary production might increase in some regions this does not translate to higher (fisheries) productivity of most consumer species (Nagelkerken and Connell, 2015). Moreover, elevated CO_2 can have detrimental effects on species survival rates through altered animal behaviour (Nagelkerken and Munday 2016) and reduces the growth of calcifying organisms (Fabry et al. 2008). Mangrove forests harbour various calcifying species such as oysters, mussels, and various species of crustaceans, and ocean acidification is likely to have large impacts on such seafood species (Branch et al., 2013).

The degree to which mangrove fisheries species are affected on a local scale will depend not only on species identity, but also on also multi-stressor effects. For example, many shallow coastal areas and estuaries are increasingly turning into hypoxic 'dead zones' due to human eutrophication, exacerbated by ocean warming (Altieri and Gedan, 2015), whereas artificially drained mangrove wetlands can be sources of highly acidic sulphate soils (Sammut et al., 1996). Furthermore, because climate change is predicted to either increase or decrease rainfall (and therefore river flow and salinity of estuaries) depending on region, and because many species have life cycles driven by temperature and salinity gradients, climate change will have consequences for many species using estuaries (Gillanders et al., 2011, Igulu et al., 2014). This will be particularly evident for fish species from freshwater and marine environments that temporarily move into and utilise (mangrove) estuaries as spawning grounds or nurseries (Boucek and Rehage, 2014), as well as on offshore fisheries that are often positively correlated with freshwater runoff and rainfall (Meynecke et al., 2006). How such local and global stressors interact at levels relevant to local communities, in combination with local hydrology and geomorphology, will determine the impact on local fisheries. Little is known about multi-stressor effects on mangrove fisheries species specifically, but due to different species sensitivities to such stressors (or their interactive effects) there is the potential that local fisheries might need to adjust the species they target in the near future.

7.5 Socio-economic implications and climate adaptation options

The impacts of global change on mangrove fisheries will vary among different types of fishers (Roessig et al., 2004). Commercial fishers can often adapt to changes in the range and season of fish stocks since their large boats can stay at sea for long periods. They have also access to storage facilities and more distant markets. Artisanal fishers are usually restricted to areas close to their homes and have fewer financial resources for adaptation. Changes in fish species, abundances, migrations, and body sizes may therefore have a stronger impact on local communities, and artisanal fishers may need to adjust the species they target and the gear they use. For example, modelling studies have forecasted smaller fish body sizes and lower catchability in the tropics (Rashid Sumaila et al., 2011). Recreational fishers are also likely to be affected at local scales. A narrow range of fish species form the basis of the recreational fishing industry in various countries. Some of these are associated with mangrove estuaries, e.g. tarpon (*Megalops atlanticus*), bonefish (*Albula vulpes*), grey snapper (*Lutjanus griseus*), and barracuda (*Sphyraena barracuda*) in the Caribbean, and barramundi (*Lates calcarifer*) in Australia. Recreational fishing can especially in westernised countries be a large industry with significant financial flow-on effects to supporting businesses (e.g. hotels, restaurants, car rentals, boat charters, sale of fishing gear and bait). For example, the annual recreational fishing industry in Australia is worth $1.8 billion based on 3.36 million fishers (Stephan and Hobsbawn, 2014). In Queensland alone, the recreational fishery is worth ~ $320–400 million annually, based on 700,000 fishers. About 43% of this state's recreational catch is from mangrove estuaries, with the main target species being yellowfin bream (*Acanthopagrus australis*), sand whiting (*Sillago ciliata*), trumpeter whiting (*Sillago maculata*), dusky flathead (*Platycephalus fuscus*), pikey bream (*Acanthopagrus pacificus*) and barramundi (Taylor et al., 2012). Range extensions of highly esteemed recreational species will probably have strongest effect on local businesses that cannot move as easily as the moving species, whereas the fishers themselves could more easily target the species in their new ranges. The aquaculture sector will also feel the impacts of climate change. Sea level rise and increased storm frequency can lead to salinization of inshore areas, having a negative effect on local communities that culture fish in freshwater ponds close to shore, but potentially having a positive effect on shrimp farming (Ahammad et al., 2013).

Local communities most at risk from sea level rise are those living in low-lying flat coastal areas where risk and extent of inundation will be largest. Sea level rise and any increase in the intensity of storms following climate change will exacerbate the risks of coastal erosion and storm damage. Hence, the value of coastal protection provided by mangrove forests is likely to increase, provided the forests can adapt to the new conditions. Healthy forests with adequate sediment supply should be able to track sea level rise, and management that encourages dense growth may help (Kumara et al., 2010). Modelling on saltmarsh carbon burial suggests that initial responses to increased CO_2 may be an increase in organic matter accumulation (Kirwan and Mudd, 2012); if mangrove forests respond similarly then there may be initial positive impacts for this service. Also at risk are communities that rely heavily on local resources (e.g. recreational fishing tourism, specific local fisheries species, nearby fishing grounds) and cannot adequately adapt, i.e. diversify livelihoods, migrate, change to alternative fishing areas, change to alternative forms of protein, have insufficient capital to switch gear (Ruckelshaus et al., 2013). Reliance on mangrove fisheries varies considerably (see Figure 5) with economic fisheries values ranging from 0.2–12,305 US$/ha/yr (Hutchison et al., 2014), showing that local communities will not be affected to the same extent. Fishers that depend on traditional knowledge (rather than technology), using weather and tidal patterns to predict abundance and catch potential of fisheries species, are at high risk (Marschke et al., 2014).

Options for climate adaptation by local communities include switching gear and fisheries target species, mangrove reforestation, fish species and habitat protection, and greater reliance on ecotourism (Roessig et al., 2004). Ecotourism can provide a buffer against further decline from exploitation and create income for local communities (Marschke et al., 2014). Likewise, mangrove habitat protection and reforestation can buffer mangrove loss due to climate change and provide people with access to a more diversified range of products making them more resilient to climate change (Pramova et al., 2012). Another option for climate adaptation involves changing from wild-caught fisheries to aquaculture, because the latter has higher control over water quality (Richards et al., 2015). The early life stages of fish are particularly sensitive to global change stressors, and in aquaculture these early stages are often kept in culture environments where water quality can be monitored and adjusted. While global stressors like warming and acidification are difficult to halt, appropriate actions toward local stressors, such as eutrophication, acid soils and river flow alteration, can mitigate cumulative stressor effects (Gilman et al., 2008) and provide opportunities for species to acclimate. Climate change presents a major threat to many oceanic habitats (and their services), but mangrove forests are by nature amongst the most resilient to the anticipated impacts. For example, whilst risk of impacts on warm water corals of an increase in sea surface temperature of 1.5 - 2°C is predicted to be high or very high, the direct risk to mangroves of a similar change is undetectable or moderate (Gattuso et al., 2015). Hence, there is hope that careful management of local stressors could allow mangrove forests to flourish under the less extreme climate predictions. Severe concurrent impacts on more sensitive ecosystems such as corals, and the predicted loss of their services, may make those provided by mangrove forests even more important to many local communities.

8. Conclusions

We should do what we can to conserve and restore the world's mangrove forests; that is a general message that ecologists, economists, political scientists and mangrove-dependent communities agree on (see Chapter 10). But the urgency of this message, the chances of its success and the winners and losers from sustainable mangrove management vary greatly from one place to another. As this chapter shows, biological and socio-economic factors work together to determine the degree of reliance of people on particular local mangrove services and species, and their options in the face of decline or change in these services. In general, higher biological diversity translates to a wider range of exploited species, and therefore greater possible redundancy (or 'insurance') in the event of the loss or decline of any particular species. Similarly, greater wealth brings more options for fulfilling some needs; fossil fuels and electricity, protein from farms instead of the sea, land that is less vulnerable to salinization and flooding. Similar conclusions are likely to apply to climate change impacts. Hence, forests with many tree species may have the biological resources to allow shifts in species composition in response to changes in rainfall and salinity, whilst those with fewer species may not achieve this. Wealthy communities can also invest in methods of fishing and storing fish that allow adaptation to changing fishing locations, species and times. Put crudely, vulnerability to current and predicted future stresses increases as we move from diverse and lush mangrove locations to biologically depauperate and economically poor ones. Of course such a simplification ignores important caveats and may mislead thinking, particularly where there are complex dependencies between these variables. For example, mangrove forests that are biologically productive and diverse may be so because of their place in a complex connected sea-scape of other forests and related habitat (Brander et al., 2012). Their higher diversity may thus be a sign of a broader vulnerability to environmental damage in fragile neighbouring habitats such as coral reefs.

There is a general trend of greater variety of exploited fuelwood, timber, crab species and coastal protection in the IWP (and particularly in Asia) than in the AEP. This probably reflects the higher floral and faunal diversity of mangrove forests in this region presenting a greater range of options for harvesting and planting. Alternative explanations are possible; for example, sites with higher population densities and greater anthropogenic pressure may see people forced into the use of a wider range of less preferable species. However, this is unlikely to explain the broad pattern, since many sites in the AEP region report intense use of all the available, but limited, pool of species (for example for fuelwood in West Africa). Finfish are an exception to this pattern and provides support for this opportunistic explanation, since we are not aware of higher diversity of mangrove-related fish species in Asia compared with other regions.

Income is a key predictor of the dependence on some local mangrove services. Firewood is the best example here, with people changing to alternative fuels when they can afford them. The use of less desirable (smaller) crab species is also probably closely linked to wealth. But this pattern, of ‘liberation’ from use of the local forest, is not seen for other ecological services such as fisheries and coastal protection. Whilst wealth may bring a broadening of options, these often include an increased expenditure on desirable fish protein or investment in infrastructure that is sheltered by mangrove forests. Hence, economic development may increase local resilience to environmental change, but does not imply a reduction in the value, economic or ecological, of mangrove forests. It will rather result in a shift in importance, often from provisioning towards regulating services and from less preferred to higher valued products. Whilst the world as a whole benefits from mangrove forests, it is local people, rich or poor, who are the key beneficiaries and who can best act as their champions and protectors.

9. Acknowledgements

Thanks to Sarah Murray for help with Figure 1 and to Victor Rivera-Monroy for his help with editorial work. Essam Mohammed and an anonymous reviewer provided helpful comments on an earlier draft.

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Table 1.Mangrove species used for fuelwood and timber in the Atlantic-East-Pacific (AEP) and Indo-West-Pacific (IWP) regions. Species in bold are those highlighted in studies that report more than one species being used but identify those species as of particular importance. Information here and in subsequent tables was taken following a literature search for detailed case studies of particular sites as well as more general overviews of countries and regions. Full references and more methodological information for Tables 1-4 are available as supplementary material.

AEP region			IWP region		
Americas	Caribbean	W Africa	E Africa	Asia	Oceania
Fuelwood					
R. mangle *A. germinans*	*R. mangle*	*A. germinans* *C. erectus* *L. racemosa* *R. racemosa* ***R. mangle***	*A. marina* *B. gymnorrhiza* *C. tagal* *R. mucronata* *S. alba*	*A.officinalis* *A. corniculatum* *A. marina* *B.cylindrical* *B. gymnorrhiza* *B. parviflora* *C.decandra* *E. agallocha* *H.fomes* *L. racemosa* *R. apiculata* *R. mucronata* *S. apetala* *S. caseolaris* *X. granatum*	*B. gymnorhiza* *R. apiculata*
Timber					
A. germinans *L. racemosa* ***R. mangle***		*R. harisonii* *A. germinans* *R. mangle*	*B. gymnorrhiza* *C. tagal* ***R. mucronata***	*A. marina* *A. officinalis* *B. cylindrical* *B. parviflora* *E. agallocha* *H. fomes* *R. apiculata* *R. mucronata* *S. alba* *S. apetala* *X. granatum* *B. gymnorrhiza*	*B. gymnorhiza* ***R. apiculata***

Published in: In Rivera-Monroy, V. H., Lee, S. Y., Kristensen, E. & Twilley, R. R. (Eds.). Mangrove ecosystems: a global biogeographic perspective on structure, function and services ISBN 978-3-319-62204-0.

Table 2. Mangrove crabs harvested for subsistence or commercial use in the AEP and IWP regions. The list is not exclusive, particularly for species harvested for subsistence, which is often not reported in the scientific literature.

	AEP region			IWP region		
	Americas *	Caribbean	W Africa	E Africa	Asia	Oceania
Supra/Intertidal (most active in air)	■ Gecarcinidae *Cardisoma guanhumi*[WA] *C. crassum* [EP] ■ Grapsidae *Goniopsis cruentata*[WA] ■ Ucididae *Ucides cordatus*[WA] *U. occidentalis*[EP]	■ Gecarcinidae *Cardisoma guanhumi* ■ Ucididae *Ucides cordatus*	■ Gecarcinidae *Cardisoma armatum* ■ Grapsidae *Goniopsis pelii* ■ Sesarmidae *Sesarma angolense* ■ Ocypodidae *Uca tangeri*	■ Gecarcinidae *Cardisoma carnifex* ■ Sesarmidae *Neosarmatium meinerti*	■ Gecarcinidae *Cardisoma carnifex* ■ Sesarmidae *Episesarma chentongense* *E. mederi* *E. palawanense* *E. singaporense* *E. versicolor*	
Subtidal *Also occurring in the lower intertidal, but most active in water	■ Portunidae *Callinectes bocourti* [WA] *C. danae* [WA] *C. exasperatus* [WA] *C. marginatus*[WA] *C. sapidus* [WA] *C. arcuatus* [EP] *C. bellicosus*[EP] *C. toxotes* [EP] **Total: 13 species** [WA] Western Atlantic, [EP] Eastern Pacific	■ Menippidae *Menippe mercenaria* ■ Portunidae *Callinectes bocourti* *C. danae* *C. exasperatus* *C. marginatus* *C. rathbunae* *C. sapidus* **Total: 9 species** (of which 7 also occur in continental Americas)	■ Menippidae *Menippe nodifrons* ■ Panopeidae *Panopeus africanus* ■ Portunidae *Callinectes amnicola* *C. marginatus* *C. pallidus* *Cronius ruber* *Portunus hastatus* *Sanquerus validus* *Thalamita sp.* **Total: 13 species** (one occurring in Americas/Caribbean)	■ Matudidae *Ashtoret lunaris* ■ Portunidae *Charybdis feriata* *C. natator* *Podophthalmus vigil* *Portunus pelagicus* *P.sanguinolentus* *Scylla serrata** *Thalamita crenata* ■ Varunidae *Varuna litterata* **Total: 11 species** (8 of them occurring in Asia also)	■ Calappidae *Calappa lophos* *C. pustulosa* ■ Matudidae *Ashtoret lunaris* *Matuta planipes* ■ Menippidae *Myomenippe fornasinii* *M. hardwickii* ■ Oziidae *Baptozius vinosus* *Epixanthus dentatus* *Ozius guttatus* *O. tuberculosus* ■ Portunidae *Charybdis affinis* *C. feriata* *C. granulata* *C. helleri* *C. lucífera* *C. miles* *C. natator* *C. orientalis* *C. rostrata*	■ Portunidae *Charybdis natator* *Portunus pelagicus* *Scylla serrata** **Total: 3 species** (all fished in Asia also)

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					C. truncata *C. variegata* *Portunus pelagicus* *P. sanguinolentus* *Scylla olivácea** *S. paramamosain** *S. serrata** *S. tranquebarica* *Thalamita crenata* *Thalamita danae* ▪ Varunidae *Varuna litterata* *V. yui* **Total: 37 species** (8 of them occurring in E-Africa also)	

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Table 3. Key fish species and families utilising mangrove estuaries caught by artisanal fisheries in the AEP and IWP regions.

AEP region			IWP region		
Americas	Caribbean	W Africa	E Africa	Asia	Oceania
Anchoa spp. *Centropomus undecimalis* *Eugerres spp.* *Diapterus spp.* *Lutjanus griseus* *Mugil spp.* *Cynoscion spp.* *Stellifer spp.* *Bairdiella spp.*	*H. flavolineatum* *H. sciurus* *H. parra* *L. apodus* *L. griseus* *L. analis* *Negaprion brevirostris* *Gerres cinereus* *Sphyraena barracuda* *Scaridae spp.* *Epinephelus itajara*	*Ethmalosa spp.* *E. fimbriata* *llisha Africana* *Liza grandisquamis* *Lutjanus spp.* *Pseudotolithus spp.* *P. elongates* *Elops lacerta* *Tilapia spp.*	*Chanos chanos* *Gerres filamentosus* *G. oyena* *Lethrinus spp.* *L. harak* *L. fulviflamma* *Lutjanus spp.* *Mugil spp.* *M. cephalus* *Siganus spp.* *S. canaliculatus* *Sphyraena spp.* *Tylosurus spp.* *Valamugil seheli* *Lutjanus argentimaculatus*	*Chelon spp.* *Gerres spp.* *G. oyena* *Liza spp.* *Scolopsis spp* *Sillago sihama* *Lates calcarifer* *Tenualosa ilisha* *Sardinella spp.* *Megalops cyprinoides* *Rastrelliger spp.*	*Acanthopagrus spp.* *Liza spp.*

Table 4. Species of mangroves recorded as planted or managed specifically or primarily for the purposes of coastal and storm protection. This includes 'storm holes' for sheltering boats from cyclones in Australia and the Caribbean.

AEP region			IWP region		
Americas	Caribbean	W Africa	E Africa	Asia	Oceania
Avicennia germinans *Laguncularia racemosa* *Rhizophora mangle*	All species available	*Rhizophora sp.*	*Sonneratia alba*	*Avicennia spp.* *A. marina* *A. officinalis* *Kandelia spp.* *K. candel* *Sonneratia spp.* *S. apetala* *S. caseolaris* *Rhizophora spp.* *R. apiculata* *R. stylosa*	All species available

Figure legends

Figure 1 . Mangrove ecosystem services by category range. Range refers to the maximum distance over which the benefits of the service are spread, as recorded in a review of relevant literature. For example honey and wax are utilised and sold immediately adjacent to forests and in global markets hundreds of kilometres away. In contrast, commercial pharmaceuticals serve only global or distant markets. Our definition of 'local services' are those of most benefit to people in close proximity to mangrove environments. Whilst payments for ecosystem services schemes can make distant services of local benefit we exclude them from this review. Full details of the methodology under-pinning Figures 1, 2 and 5 are provided in supplementary materials.

Figure 2. Local dependence on mangroves fuelwood vs national average per capita GDP. Dependence data come from case studies of communities living adjacent to forests, and show the percentage of households reported using mangrove fuelwood. GDP per capita are in international dollars (adjusted for spending parity) taken from IMF 2014. Linear regression R^2 =0.63, P<0.001. Countries are BR Brazil, CM Cameroon, GM Gambia, ID Indonesia, IN India, KE Kenya, LK Sri Lanka, MM Myanmar, MX Mexico, PH Philippines, TH Thailand, TZ Tanzania, VN Vietnam and ZA South Africa.

Figure 3. 1,000 to 3,000-year old clay artefact of the mangrove crab Ucides cordatus (Museo Forte do Castelo, Belém, Pará). Excavated at Marajó Island near the mouth of the Amazon river, Brazil (Museo Forte do Castelo, Belém, Pará, personal communication). Photo credit: Karen Diele.

Figure 4. Girl dancing at thanksgiving festival in Acarajó, north Brazil. Her dress is made entirely out of the shell from Ucides cordatus legs. Photo credit: Karen Diele

Figure 5. Local dependence on mangrove fish species vs national average per capita GDP. Dependence data come from case studies of communities living adjacent to forests, and show the percentage of households reported as being reliant on fishing in and around mangrove waters as their main household income. GDP per capita are in international dollars taken from IMF 2014. Countries are BD Bangladesh, BR Brazil, CM Cameroon, KH Cambodia, SV El Salvador, FJ Fiji, GM Gambia, ID Indonesia, KE Kenya, MZ Mozambique, NG Nigeria, TO Tonga and TZ Tanzania.

Figure 6. A jetty in south east India destroyed by the 2004 tsunami, in contrast to the resilient adjacent mangroves (Photo credit: K.Kathiresan)

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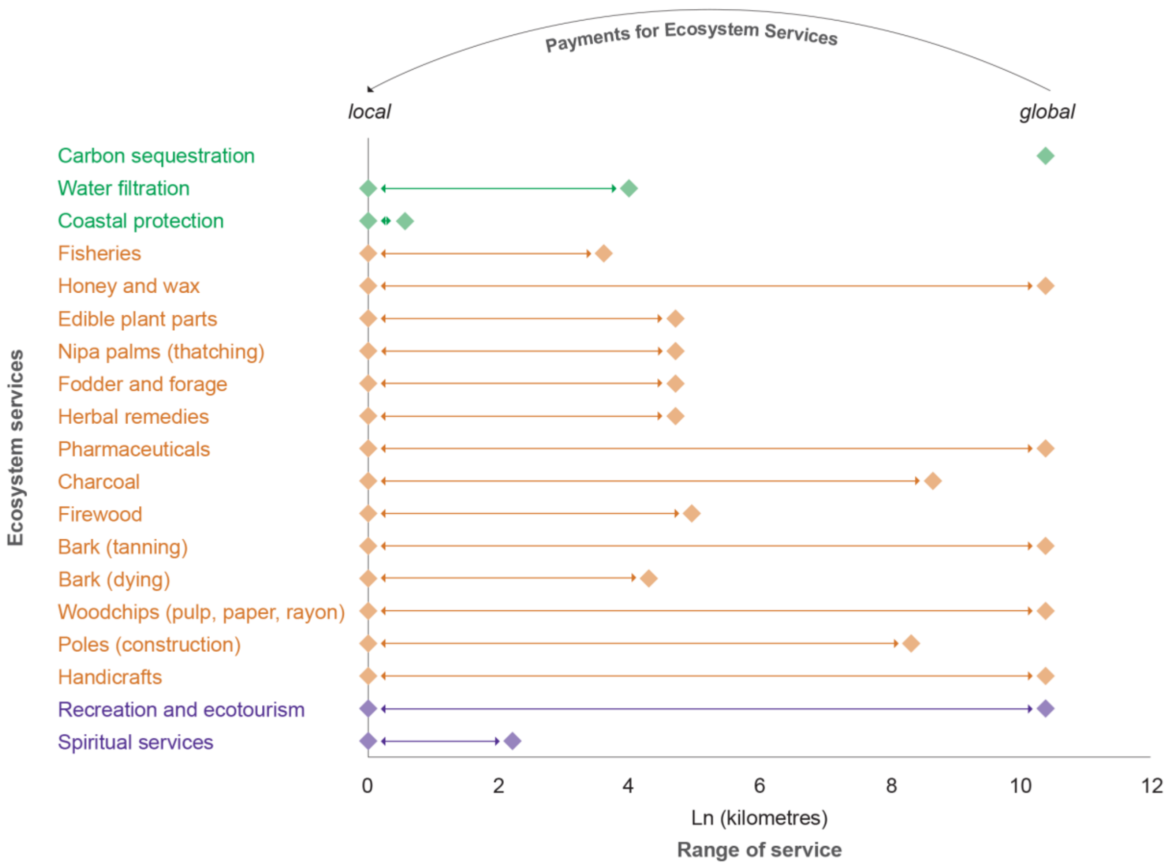
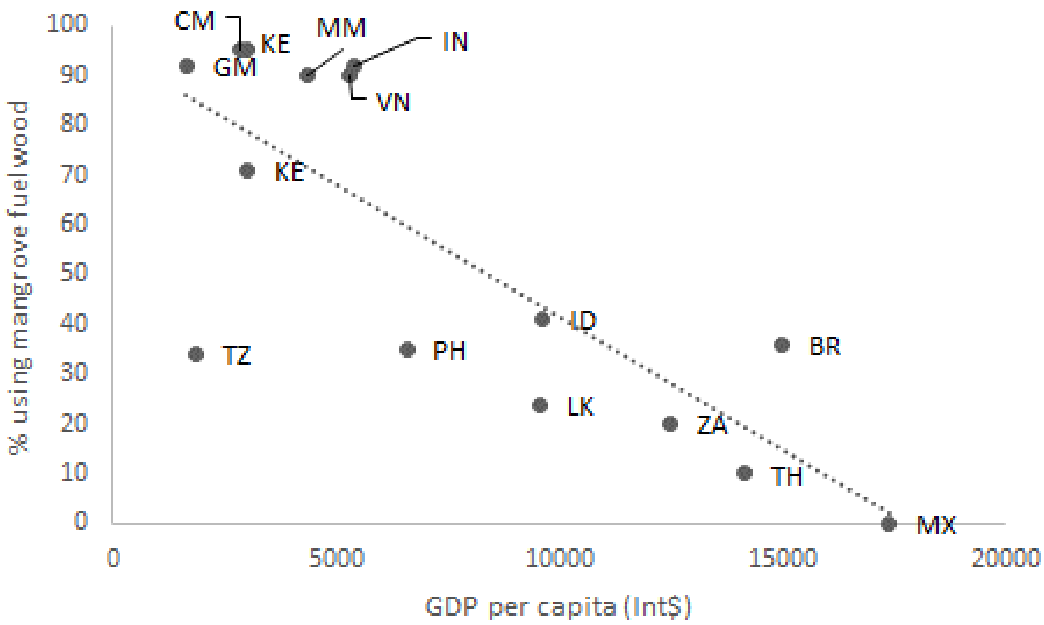


Regulating, provisioning and cultural services of mangroves with range Ln(km); from local to global services



100
90
80
70
60
50
40
30
20
10
0
% using mangrove fuel wood
0
5000
10000
15000
20000
GDP per capita (Int$)
CM
KE
GM
MM
IN
VN
KE
ID
TZ
PH
BR
LK
ZA
TH
MX

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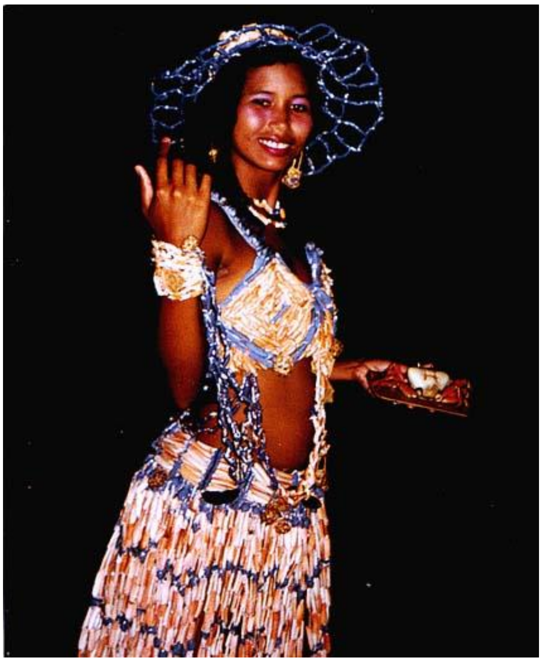
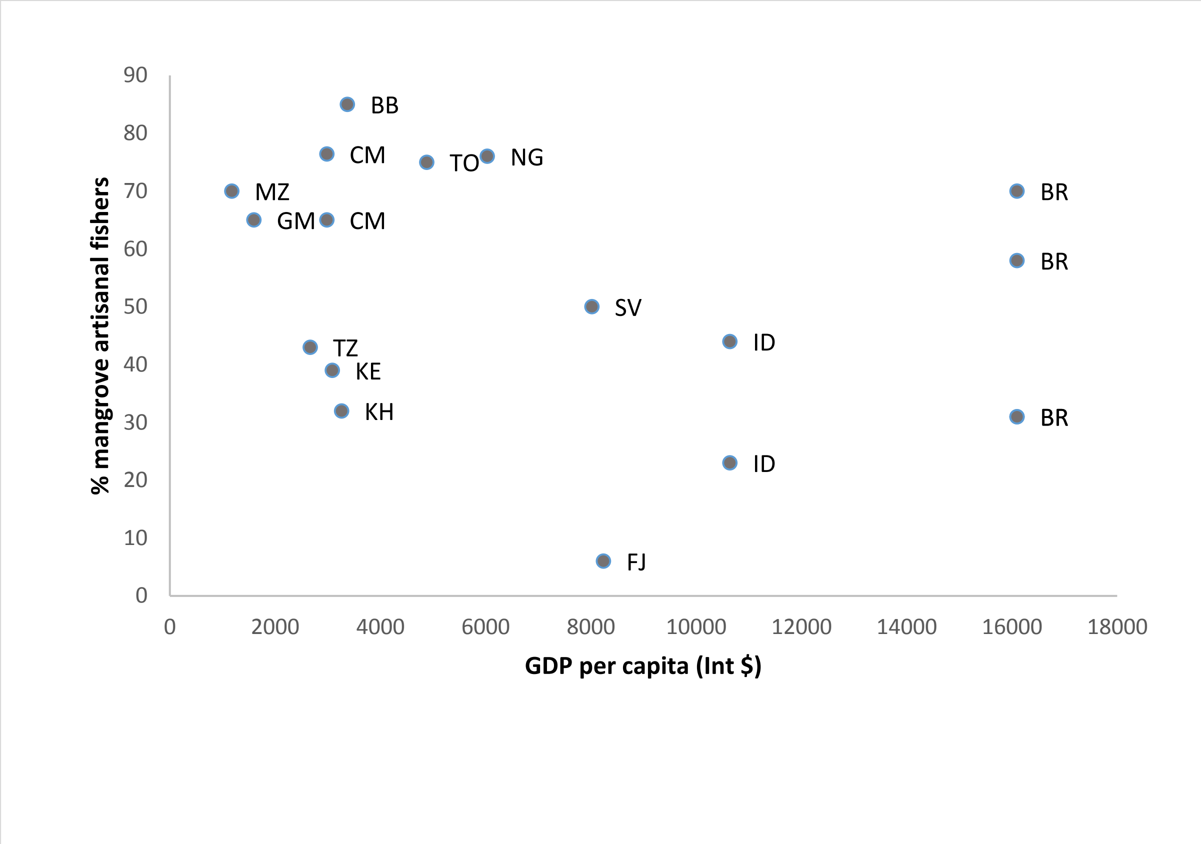
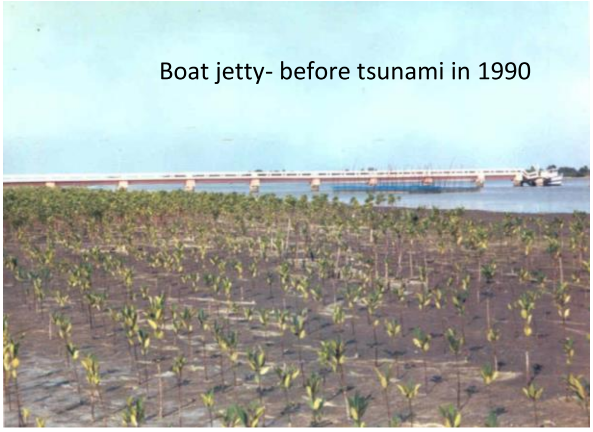



90
80
70
60
50
40
30
20
10
0
% mangrove artisanal fishers
BB
CM
TO
NG
MZ
GM
CM
BR
BR
SV
ID
TZ
KE
KH
BR
ID
FJ
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
GDP per capita (Int $)


Boat jetty- before tsunami in 1990


Boat jetty- after 2004 tsunami