



Mangrove Restoration Potential

A global map highlighting a critical opportunity

Thomas Worthington, Mark Spalding



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With:

Kate Longley-Wood (The Nature Conservancy, Boston), Ben Brown (Charles Darwin University), Pete Bunting (Aberystwyth University), Nicole Cormier (Macquarie University), Amy Donnison (University of Cambridge), Clare Duncan (Deakin University), Lola Fatoyinbo (NASA), Dan Friess (National University of Singapore), Tomislav Hengl (EnvirometriX Ltd), Lammert Hilarides (Wetlands International), Ken Krauss (U.S. Geological Survey), David Lagomasino (University of Maryland), Patrick Leinenkugel (German Aerospace Center), Cath Lovelock (The University of Queensland), Richard Lucas (Aberystwyth University), Nick Murray (University of New South Wales), Siddharth Narayan (University of California, Santa Cruz), William Sutherland (University of Cambridge), Carl Trettin (USDA Forest Service), Dominic Wodehouse (Bangor University), Philine Zu Ermgassen (University of Edinburgh).

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FOR FURTHER INFORMATION:

<http://oceanealth.org/mangrove-restoration/>

CONTACT:

Dorothee Herr | Manager, IUCN's Oceans and Climate Change programme | Dorothee.HERR@iucn.org
Kathryn Longley-Wood | Ocean Mapping Coordinator, TNC | kathryn.longley-wood@tnc.org

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Fishing with a spear in the shallow coastal mangroves of Kimbe Bay, Papua New Guinea. © Mark Godfrey/The Nature Conservancy

Executive summary

Rapid losses of mangroves over the past 50 years have had negative consequences on the environment, the climate, and humanity, through diminished benefits such as carbon storage, coastal protection and fish production. Restoration of mangrove forests is possible, and has already been undertaken in many settings, but such efforts have been piecemeal, and many have failed. The current work describes the findings from an entirely new effort to locate and map, on a global scale, the places where mangroves can be restored, and to calculate the potential benefits from such restoration. The work has generated the Mangrove Restoration Potential Map, which provides a critical tool for encouraging restoration and enabling robust, data-driven policy changes and investments.

Key findings include:

- Global statistics on mangrove extents, gains and losses developed by our partners show the global extent of mangroves in 1996 was some 142,795 km², but by 2016 had reduced to some 136,714 km², a net loss of over 6,000 km².
 - In a first ever review of mangrove degradation, we have mapped some 1,389 km² of degraded mangrove as found within the latest (2016) mangrove cover map.
 - A new global “typology” of mangroves has been developed: all mangrove areas have been classified into deltaic, estuarine, lagoonal and fringing systems, and subsequent analyses are based on the resulting 6000 typological units.
 - In total, some 8,120 km², or 6%, of former mangrove area are considered restorable. In addition to these statistics, an expert-derived model for ‘restorability’ has been developed based on key environmental components that influence the ease of restoration. Using this model, some 6,665 km² are considered highly restorable. Degraded areas are independent of this.
 - The work overlays current and potential mangroves areas with models of ecosystem services to assess potential benefits. Full restoration of the areas identified could enable:
 - Carbon sequestration in aboveground biomass amounting to 69 million tonnes of carbon, equivalent to annual emissions from 25,000,000 US homes;
 - The saving of 296 million tonnes of soil carbon stocks through a combination of avoided emissions and sequestration emissions, equivalent to annual emissions from 117,000,000 US homes;
- The addition of commercial fisheries species in mangrove waters totalling 23 trillion young-of-year finfish and 40 trillion crabs, shrimp and molluscs; and
 - Protection from annual coastal flooding for hundreds of thousands of people.
- These ecosystem service benefits are based on restoring areas of loss. Restoring degraded areas would yield further benefits.
 - Our estimates for restoration areas are based on changes since 1996. Considerably more areas could be restored from areas converted and lost prior to this data, notably in Asia where large-scale losses to aquaculture began much earlier.
 - Worldwide there are some 2500 protected areas, which include mangrove forests within their boundaries. These include some 54,000 km², or over 39%, of the world’s remaining mangroves. Levels of degradation within protected areas are less than half those recorded from outside protected areas.
 - In an entirely new global synthesis and review of mangrove restoration efforts, we have developed data on over 160 mangrove restoration efforts worldwide covering 2,000km².
 - The end-product of this work, the Mangrove Restoration Potential Map, has been released as an online tool to allow users to explore these findings at global, regional and national levels and to generate numbers for individual typological units: maps.oceanwealth.org/mangrove-restoration/.



Mangrove restoration is widely used to control erosion and reduce storm damage risk along the low-lying, heavily populated barrier islands in Florida.

1. Introduction

Healthy mangroves are a precious, almost priceless, resource, and yet the world has witnessed staggering levels of mangrove loss and degradation, particularly over the last 50 years – faster than any other forest type. Mangroves can quite literally save lives during storms, but losing mangroves also means losing livelihoods, food security, valuable timber production, coastal defence, and one of the most efficient carbon stores on the planet.

This economically and socially illogical destruction of a key natural asset has been called out many times before, and there are already growing efforts to protect some of the world's remaining mangroves. Indeed, the losses are such, and the opportunities sufficiently great, for mangrove restoration to be seen as a critical component of both conservation and shrewd coastal management.

Mangrove restoration can be strategic, fundable and achievable. Methods have been greatly refined over recent years and, properly applied, they rarely fail. Successful restoration can support local communities; help countries to achieve targets for conservation and carbon emissions; and even help in the urgent fight to slow climate change.

In a review we assessed about 160 well-documented mangrove restoration efforts in 24 countries and included a total extent of some 2,000km²¹ planted over the last 40 years. Not all such efforts, particularly the earlier efforts, have been successful, but nevertheless these numbers represent an already significant contribution to mangrove restoration – covering between 1% and 2% of mangrove extent and over 10% of the extent of losses over the last 20 years. The potential for mangrove restoration is thus already well understood, and the approaches for restoration are increasingly well refined. What is needed, however, is a large-

scale understanding of the scope and potential benefits of mangrove restoration, together with a more localised sense of the opportunity. This work provides such information.

Outline and approach

Our work on the Mangrove Restoration Potential Map (MRP Map) began with the utilisation of the very latest mangrove extent maps, derived by Global Mangrove Watch (GMW)², which for the first time provide a globally consistent picture of mangrove change. These were used to derive maps of mangrove losses, a key component of determining areas for restoration. The same maps, in combination with other remote-sensing derived indices, were used to develop a model, and then to map mangrove degradation in remaining mangrove areas – the first time such an approach has been used at a global level for mangroves.

Mangrove scientists have often described broad classifications or typologies of mangroves, recognising that both physical and ecological conditions are strongly influenced by their geomorphological settings. For various elements of our subsequent work it was felt necessary to utilise this knowledge and so we developed the first-ever global classification of mangroves by type, recognising four broad classes of mangrove:

- Deltas
- Estuaries
- Lagoons
- Fringing.

These mangrove types represent very different ecological and oceanographic settings, affecting delivery of ecosystem service benefits and approaches to restoration.

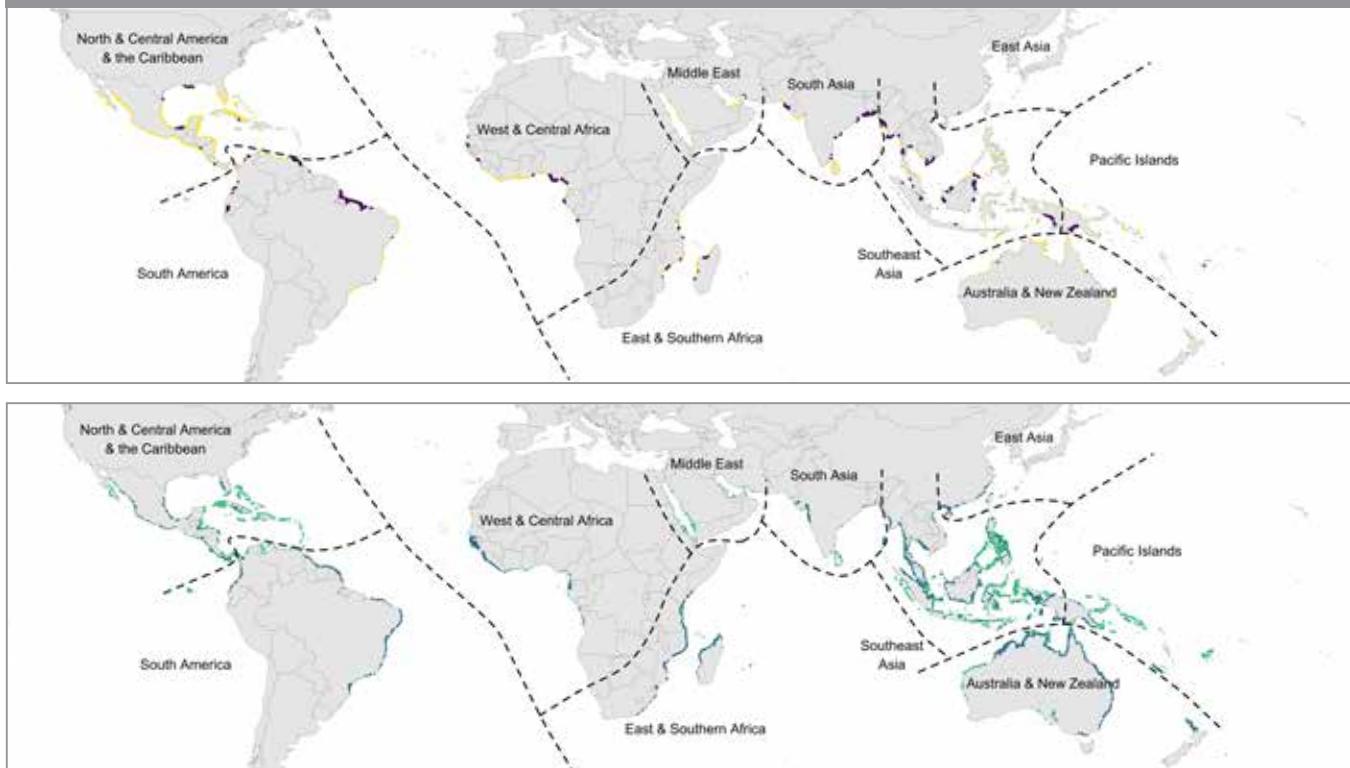
Table 1.1: Area of mangroves in 2016 by typological units.

Region	Total area km ²	Deltaic km ²	Estuarine km ²	Fringing km ²	Lagoonal km ²
Australia & New Zealand	10,037	214	5,803	3,685	335
East & Southern Africa	7,329	2,499	3,306	1,079	444
East Asia	159	1	131	27	1
Middle East	319	12	-	224	82
North & Central America & the Caribbean	21,072	1,957	2,676	4,479	11,960
Pacific Islands	6,327	2,605	700	2,688	334
South America	19,063	13,041	3,177	2,165	680
South Asia	8,492	7,101	524	654	213
Southeast Asia	44,060	16,634	13,616	13,219	591
West & Central Africa	19,857	11,228	7,720	623	286
Total km²	136,714	55,291	37,654	28,844	14,925

¹ Such figures may sometimes include a proportion of non-mangrove habitat

² Global Mangrove Watch – www.globalmangrovewatch.org

Map 1.1: Mangroves of the world, with faint outline showing major mangrove regions. Upper map: Deltaic (purple) and lagoon (yellow) mangroves. Lower map: fringing (green) and estuarine (dark blue) mangroves



The world's mangroves were then grouped based on these typological units, giving over 6000 units (including 95 deltaic units, 965 estuarine units and 644 lagoonal units³). The type of mangrove unit has relevance in a number of ways, mostly stemming from their physical features: estuarine and deltaic systems typically have higher levels of freshwater and sometimes nutrient and sediment supplies; fringing systems are more saline and sometimes more exposed to waves. Productivity is influenced by this, and from that comes many of the human benefits from mangroves. For this reason, the typological units defined here also form the basis of our subsequent analyses and reporting in the MRP Map.

Areas of mangrove loss based on GMW data gave us a working map of potential areas for restoration, however clearly not all such areas are restorable. For the MRP Map we modified these areas of loss, removing areas that had been converted to urban uses and areas that have become, through erosion or inundation, non-tidal open water. This provided our base map of restorable areas.

Working with an expert advisory team we then developed a model for likely ease of restoration in each of the typological units in the MRP Map. It was assumed that mangrove restoration would be unlikely in places where mangroves had been converted to urban landscapes, or

where they had been inundated or eroded to become open water, but for the remaining areas of mangrove loss, "restorability" would be influenced by various conditions such as tidal range and sediment supplies. We therefore devised a model to score restoration potential based on these conditions in different places. The scores do not account for the local challenges – such as physical modification of the site, or legal and land tenure challenges – as these are particular to each location and cannot be mapped at global scales. Nevertheless, the restoration score gives a pointer towards the general opportunity for restoration in different locations.

Finally, using our maps of restorable mangrove areas, we applied a series of models of ecosystem service values relating to carbon storage and sequestration, fisheries value, and coastal protection. These enable us to project a likely potential value for each mangrove unit in our typology. These values are estimated as if the mangrove was fully restored to a near-natural system, and such restoration takes time. By mapping such potential we can show what could be achieved and provide a target and a vision.

The value of mangrove restoration may be immense in terms of local and global benefits. Mapping potential value is a means of raising awareness as well as promoting new and large-scale restoration efforts and locating these in the right places.

³ The largest deltas were split into several units; estuaries and lagoons are typically single features, but in some cases may include two or more adjacent or adjoining systems; fringing systems were grouped based on proximity, amalgamating scattered mangrove patches into larger tracts.

2. Loss and degradation

Bottom Line:

Since 1996 Global Mangrove Watch data show that a total area of some 9,736 km² of mangrove has been lost worldwide, or some 6.6% of the 1996 cover of over 146,000 km². In addition, an estimated 1,389 km² of remaining mangrove areas has been identified as degraded.

Mangrove loss

Mangrove forests are found in almost every warm coastal region of the world, but vast areas have been lost or degraded. The conversion of mangrove areas to coastal aquaculture ponds traces back many decades, particularly in Southeast Asia. This is now a global phenomenon, often supported by government-backed incentives. Conversion to agriculture, including rice paddies, and to pasture has been widespread, and the growing demand for palm oil has led to new waves of clearance, particularly in Southeast Asia. Mangrove clearance for urban expansion and for the development of coastal infrastructure, including roads and ports, has added to losses, particularly in places where coastal populations are rapidly expanding. There are also areas where initial mangrove reduction or degradation has, over time, led to continuing losses as the coastline is no longer protected by a living wall of mangroves and erosion takes away both mangroves and the coastal land on which they once grew. Their loss is also our loss. The profits and benefits from loss and degradation are typically short-term, and often only flow to a small number of people. These profits are dwarfed by the losses as coastal communities



Many areas converted to aquaculture ponds become unproductive in just a few years and remain as barren areas with no human or ecological value.



Large-scale conversion of mangrove areas in the Philippines has largely been for aquaculture development but also for urban expansion.

lose one of the most productive ecosystems on Earth. In 2018 the Global Mangrove Watch team released the latest and most detailed maps of current mangrove distribution⁴, and with this a time-series on mangrove extent change, going back to 1996 and covering all of the major mangrove nations of the world⁵. Even in natural settings, mangrove forests can be opportunistic and dynamic, and so any time-series will show areas of expansion as well as loss. From this work we developed a map showing the maximum extent of mangroves over this time, which includes areas recorded as mangrove in any part of the 20-year timeframe as some areas have gained and lost mangrove over time. This map showed a largest extent of mangroves of some 146,451 km², an estimate very close to that developed in the *World Atlas of Mangroves* published in 2010⁶.

Using the time-series from GMW we calculated and located mangrove losses and gains worldwide. Net worldwide losses total over 6,000km², or over 4% of the 1996 coverage: further statistics by major mangrove region are provided in Table 2.1.

Mangrove losses continue on every continent, although rates of loss have declined considerably. Earlier records showed 1.04% annual losses worldwide in the 1980s, and 0.72% annual losses in the 1990s. The current data suggest an average loss rate from 1996 to 2016 of 0.21% annually.

⁴ Global Mangrove Watch - www.globalmangrowewatch.org

⁵ GMW maps include 108 countries and territories. They do not include a small number of mangrove jurisdictions that have small mangrove extents. These include: Bermuda, British Indian Ocean Territory, Congo, Guam, Kiribati, Maldives, Marshall Islands, Mauritania, Montserrat, Peru, Réunion, Togo, Tokelau, Tuvalu. Without mangrove maps for these nations we were unable to model restoration potential, but would note that for a number of these there are considerable additional restoration opportunities

⁶ Spalding, M. D., M. Kainuma, and L. Collins. 2010. *World Atlas of Mangroves*. Earthscan, London.on.

Mangrove degradation

In many locations mangroves remain in place, but have been impacted and changed with lower stature trees and shrubs, sometimes with broken canopy cover or bare areas where continuous forests were once present. Perhaps the most widespread causes of this degradation are intensive harvesting of timber and fuelwood, and changes to riverine inputs, with falling levels of freshwater flows, or nutrient and sediment loads as a result of upstream water abstraction and dams. For example, freshwater abstraction from the Indus River has led to a collapse in water flows into the Indus Delta, with dramatic effects on mangroves – even where mangrove cover remains, there has been a change in the species and biomass⁷. Other causes of degradation can include pollution events such as oil spills, changes in sea level leading to drying out or flooding of mangroves, or the impact of extreme events such as hurricanes and flooding.

Using the 2016 GMW base maps we have been able to develop a unique global assessment of mangrove degradation. We looked at changes in key vegetation parameters to predict areas that have been degraded since 1996. We also modelled the rate of change and the trajectory, with areas classified as degraded, declining or recovering. This method is likely to be conservative as it is unlikely to detect minor changes in condition. The areas are also likely to include some areas of near-complete clearance. The results show that, in addition to losses, some 1,389 km² of mangroves are degraded (Table 2.2).

Where mangroves are degraded rather than lost they present an opportunity for rapid and effective intervention. Restoration of such areas may require little more than a reduction or cessation of damaging actions such as timber



Coastal villages take a toll on local mangroves through overharvest of timber and fuelwood.

exploitation. Some ecosystem services are still maintained by degraded mangroves, albeit at lower levels. Allowing trees to recover to full diversity and stature will safeguard and enhance these services and prevent the consequences of full loss, such as subsidence and erosion, which can make recovery challenging and costly.

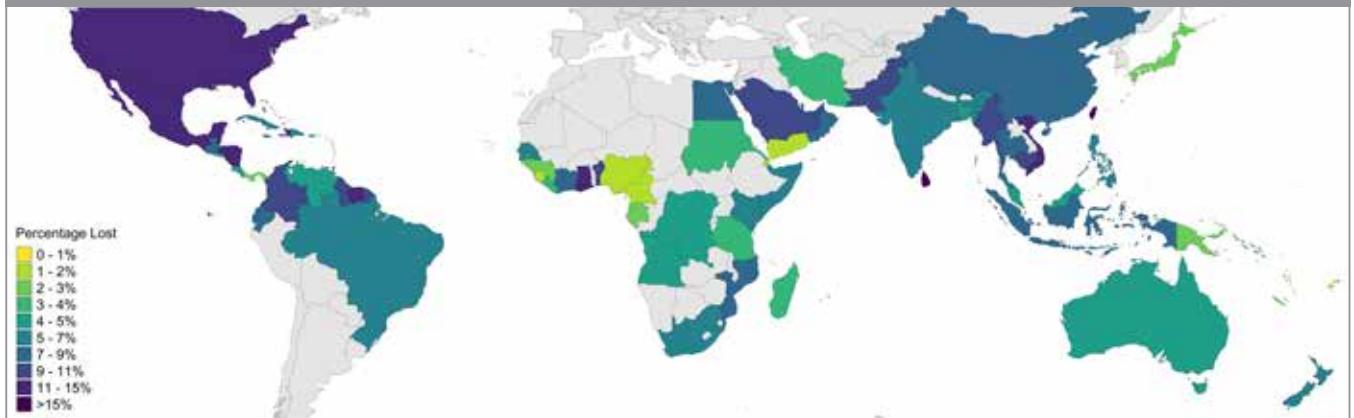
The largest areas of both loss and degradation are recorded from Southeast Asia, representing almost 40% of global losses and over 60% of degradation. It is important to note that this region also suffered considerable losses prior to the work described here, and many former mangrove areas were already lost prior to 1996, notably through conversion to aquaculture across much of western Indonesia, the Philippines and Thailand, as well as the heavy losses inflicted through warfare in southern Vietnam. The frontline for more recent losses in Southeast Asia includes eastern Indonesia where losses and conversion to aquaculture are still major threats.

Table 2.1: Net losses and gains between 1996 and 2016, including annualised percentage change, by region.

Region	1996 Area km ²	2016 Area km ²	Loss km ²	Gain km ²	% Change	Annual % Change
Australia & New Zealand	10,332	10,037	370	74	-2.86	-0.14
East & Southern Africa	7,630	7,329	424	122	-3.95	-0.20
East Asia	159	159	12	13	0.55	0.03
Middle East	334	319	19	4	-4.54	-0.23
North & Central America & the Caribbean	22,702	21,072	2,196	566	-7.18	-0.36
Pacific Islands	6,410	6,327	146	63	-1.29	-0.06
South America	19,632	19,063	1,106	537	-2.9	-0.14
South Asia	8,701	8,492	435	226	-2.4	-0.12
Southeast Asia	46,789	44,060	3,308	579	-5.83	-0.29
West & Central Africa	20,107	19,857	422	171	-1.24	-0.06
Total km²	142,795	136,714	8,437	2,356	-4.26	-0.21

⁷ A.-u. Rahman, Samiullah, R. Shaw, Fragile Mangroves and Increasing Susceptibility to Coastal Hazards in Pakistan, in: R. DasGupta, R. Shaw (Eds.), Participatory Mangrove Management in a Changing Climate: Perspectives from the Asia-Pacific, Springer Japan, Tokyo, 2017, pp. 17-30.

Map 2.1: The proportion of mangrove lost by country since 1996. It is important to note that for some countries, particularly in Asia, quite extensive areas were lost prior to this date and are not included in loss calculations, or indeed in the restoration models.



East Asia, by contrast, appears to have made small net gains in mangrove cover, although still having ongoing degradation. As with Southeast Asia, however, it is important to realise that widespread losses, notably in China, took place prior to this work with very large-scale conversion to aquaculture.

Changes in North and Central America are also dramatic and represent the most extensive proportional losses worldwide. Eastern and Southern Africa represents another region with relatively high loss and degradation. Degradation in many of these countries may well be linked to overharvest of timber and fuelwood.

At national levels, the MRP Map shows losses from 105 of the 108 countries and territories with mangroves, while degradation is recorded from 82 of these.



One of the frontlines of rapid mangrove conversion to aquaculture – a newly cleared mangrove area in Berau, Indonesia.

Table 2.2: Statistics on mangrove degradation worldwide.		
Region	Area of degraded mangrove (km²) in 2016	Proportion of 2016 mangrove degraded
Australia & New Zealand	54.6	0.5%
East Asia	2.6	1.6%
Eastern & Southern Africa	133	1.8%
Middle East	2.7	0.8%
North & Central America & the Caribbean	140.2	0.7%
Pacific Islands	5	0.1%
South America	92.6	0.5%
South Asia	32.4	0.4%
Southeast Asia	847	1.9%
West & Central Africa	78.5	0.4%
Grand Total	1,388.6	1.0%



Among the few remaining mangrove tracts in China, degradation remains a problem linked to interruption of freshwater input and tidal flows, but also to intensive use and trampling by fishers.

3. Restoration potential

Bottom Line:

Since 1996, there has been more than 8,120 km² of coastal land where mangroves have been lost but where restoration may be possible, with some 6,630 km² of these being highly restorable. The Mangrove Restoration Potential Map shows the distribution of these restorable areas across 105 countries and territories. In addition, it identifies some 1,389 km² of likely degraded mangroves where full recovery can be expected to bring further benefits with relatively little investment.

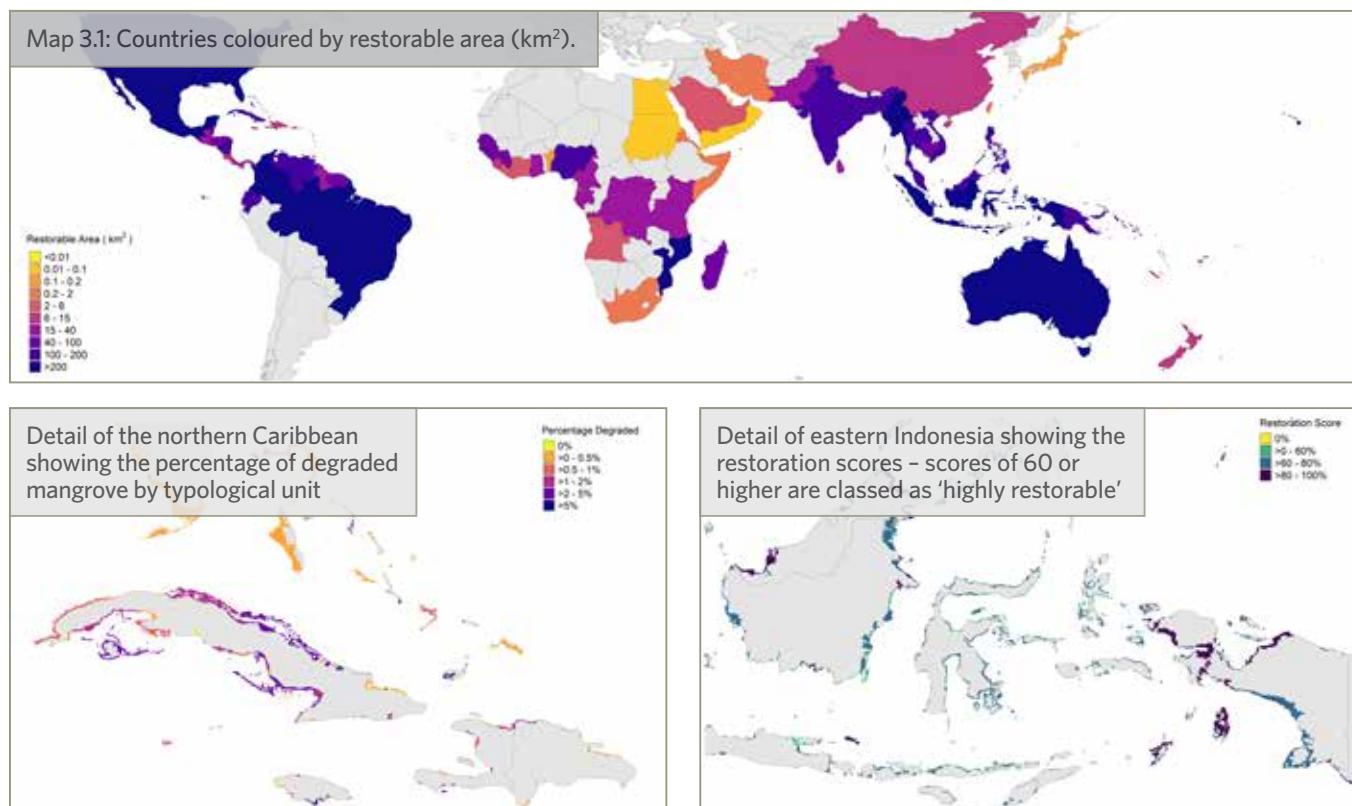
Mangrove restoration or rehabilitation is not something that can be easily undertaken on every coastline. Thus, while there is a strong and growing understanding of the importance of mangroves, and of the opportunity to restore them, there is a clear need for additional guidance to support policymakers and to steer planners towards the best opportunities.

As a starting point for mangrove restoration, it is prudent to consider putting them in places where they have been recently lost, provided the driver of loss can be prevented from recurring and the local conditions remain suitable. Such areas are most likely to have local conditions of soil, tides and elevation appropriate for restoration, while their proximity to remaining mangroves can greatly facilitate natural regeneration processes.



Mangrove restoration in Mauritius.

The work for the MRP Map focused on recent mangrove loss areas, using a map of all the areas that have been lost since 1996, taken from the Global Mangrove Watch maps. It also looked at areas that had been degraded in this same timeframe. Not all areas can be restored, of course. Areas that had been eroded to become permanent open water (subtidal) (16% of all loss) were excluded as no longer restorable. Similarly, urban areas were excluded (0.2% of all loss) as these are likely to have been subject



to high investment and intense modification. Within the remaining recently lost mangrove areas, we sought to understand those factors most likely to influence restoration success. These include: the tidal range; recent sea level rise; projected future sea level rise; recent change in sediments; time since loss; average size of loss patches; and the proximity of loss areas to remaining mangroves. An advisory team was convened to review these variables and, using Delphi methods, an averaged restoration potential score (from 1 to 100) was calculated for each of the more than 6000 mangrove units under assessment.

Our restoration potential score is only a starting point. Multiple other factors will govern the restorability of mangroves, ranging from localised ecological and geological factors, to political, social, legal and economic drivers. Many of these cannot be modelled, even at regional or national scales, and can only be understood in a local context. In other cases, the feasibility of restoration may depend on the proposed methods, scale and level of investment. Eroding coastlines are not always ideal for restoration, however, some highly successful methods are being developed in Southeast Asia which may enable such restoration, with sufficient investment⁸.

Mangrove restoration opportunities exist in every region and virtually every jurisdiction with mangroves, however a number of places are of particular interest (see Tables 3.1 and 3.2). Southeast Asia stands out as having the highest, overall, total extent that could potentially be restored. This figure would be further bolstered by the fact that large additional degraded areas would greatly enhance these numbers.

Mangrove restoration opportunities exist in every region and virtually every jurisdiction with mangroves



In parts of Southeast Asia such as here in the Philippines conversion to aquaculture predates our 1996 baseline and would provide additional areas for potential restoration

Table 3.1: Regional summary of restorable areas. Note that degraded mangrove areas were not included in the assessment of restorability and will provide additional benefits.

Region	Area restorable (km ²)	Proportion of original mangrove areas restorable	Average restorability score	Extent of highly restorable mangrove areas (km ²)	Area of degraded mangrove areas (km ²)
Australia & New Zealand	350.9	3.3%	0.73	328.6	54.6
East & Southern Africa	412.0	5.3%	0.72	407.0	133.0
East Asia	7.0	4.0%	0.69	6.5	2.6
Middle East	11.4	3.3%	0.63	7.9	2.7
North & Central America & the Caribbean	2,277.2	9.6%	0.65	1,636.3	140.2
Pacific Islands	166.6	2.6%	0.62	147.1	5.0
South America	1,068.2	5.2%	0.70	794.9	92.6
South Asia	352.7	3.9%	0.63	279.7	32.4
Southeast Asia	3,037.1	6.4%	0.64	2,591.2	847.0
West & Central Africa	437.1	2.1%	0.73	430.5	78.5
Grand Total	8,120.0	5.5%	0.67	6,629.9	1,388.6

⁸ Winterwerp, H., B. v. Wesenbeek, J. v. Dalfsen, F. Tonneijck, A. Astra, S. Verschure, and P. v. Eijk. 2014. A Sustainable Solution for Massive Coastal Erosion in Central Java: Towards Regional Scale Application of Hybrid Engineering. Deltares and Wetlands International, The Netherlands.

Country	Restorable area (km ²)	Proportion of original mangrove areas restorable	Average restorability score	Extent of highly restorable mangrove areas (km ²)	Area of degraded mangrove areas (km ²)
Australia	336	3.3%	0.74	314	54
Bangladesh	138	3.2%	0.60	129	1
Belize	65	12.9%	0.64	64	3
Brazil	491	4.2%	0.73	476	58
Colombia	216	8.6%	0.73	51	15
Cuba	160	4.5%	0.62	74	68
Ecuador	107	6.7%	0.69	26	1
Ghana	22	9.6%	0.67	22	2
Honduras	70	12.2%	0.65	69	3
India	152	4.1%	0.65	126	12
Indonesia	1,866	6.4%	0.64	1,616	419
Malaysia	168	3.4%	0.66	157	63
Mexico	1,455	12.8%	0.65	993	33
Mozambique	259	8.0%	0.70	258	40
Myanmar	436	7.9%	0.75	431	295
Nicaragua	104	10.6%	0.69	99	16
Nigeria	110	1.7%	0.69	105	0
Papua New Guinea	135	2.7%	0.61	126	4
Philippines	156	5.4%	0.62	129	14
Sri Lanka	29	12.1%	0.59	24	1
Thailand	175	6.9%	0.63	78	8
United States	227	10.5%	0.68	204	2
Venezuela	120	4.1%	0.61	109	12
Vietnam	174	9.6%	0.67	149	43

It is further important to note that the MRP Map only models restoration potential for areas where mangroves have been lost since 1996. There are likely to be many locations, where mangrove losses extend back prior to 1996. For example, vast areas of coastline across all of Asia were converted, most notably to aquaculture, often many decades ago. Thus in many places - for example in western Indonesia, Thailand, the Philippines and China - large areas of coastal aquaculture are not included in our restoration maps. Many of these are now unproductive and therefore also amenable to restoration.

It remains critically important that decisions of where and how to restore mangroves are also locally informed. This includes local ecological and physical conditions, of course, but equally local social, legal, and economic influences. Mangrove restoration can be greatly hampered if local land tenure is not understood and respected. Community engagement and support can ensure long-term security for restoration projects. Equitable benefit-sharing can prevent further degradation and provide an example which, in turn, leverages further restoration efforts.



Mangrove restoration at the smallest scale – here in an effort to reduce coastal erosion in Florida.

4. Carbon

Bottom line:

Mangrove losses since 1996 represent some 0.082 gigatonnes (GT) of carbon in aboveground biomass carbon and 0.354 GT of soil carbon. The Mangrove Restoration Potential Map shows that restoration could restore 0.069 GT of carbon in aboveground biomass, and help replace or avoid losses of some 0.296 GT of carbon in the top metre of the soil. These numbers are equivalent to the annual emissions from 25 million and 117 million US homes, respectively.

Mangrove forests are among the most effective ecosystems on Earth at carbon capture and storage. They sequester CO₂ from the atmosphere and store it in their biomass and in rich organic soils, where it remains stable, even for thousands of years.

Forest clearance has been a major influence of climate change to date, and while mangroves have never occupied a large extent, their rich carbon component makes their loss a significant contributor to greenhouse gas emissions. By contrast, restoring mangroves can reverse this, and enhance emissions reductions.

Alongside seagrasses and saltmarshes, mangroves are particularly important because of their soil. Unlike almost any other ecosystem, mangrove forests typically create thick, waterlogged, organic soils. As it falls to the ground, dead plant matter is often held in place by the mangroves'



The rich, permanently waterlogged soils of mangrove forests are a rich carbon store, which continues to accumulate over time.

complex roots system. There is little or no oxygen available to break it down and so it accumulates in a rich peat. Unlike freshwater peats, these soils give off relatively little methane (itself a potent greenhouse gas) and so they are critical carbon stores. Their organic carbon remains tight-packed, layer upon layer, out of circulation in the soil, sometimes for thousands of years.

Just the top metre of the world's mangroves holds over 6 GT of carbon and it has been estimated that, since 1990, mangroves have sequestered over 0.42 GT of carbon. This is neutralised carbon, packed away and posing no threat to our climate, our oceans, or our livelihoods. Given their high carbon content, high productivity and potential for sequestration, mangroves represent an optimal opportunity for climate mitigation.

The fate of carbon following mangrove clearance and loss varies. Living biomass is usually quickly converted to carbon dioxide through burning or aerobic decomposition, but soil carbon has a more varied fate. If the land is drained, decomposition will begin almost immediately. If it is flooded for fresh or brackish water agriculture or aquaculture then decomposition will be slower, but methane emissions may increase. In all cases, the process of restoration may help to halt these processes, stabilising the remaining soil carbon while restarting the process of carbon storage and sequestration.

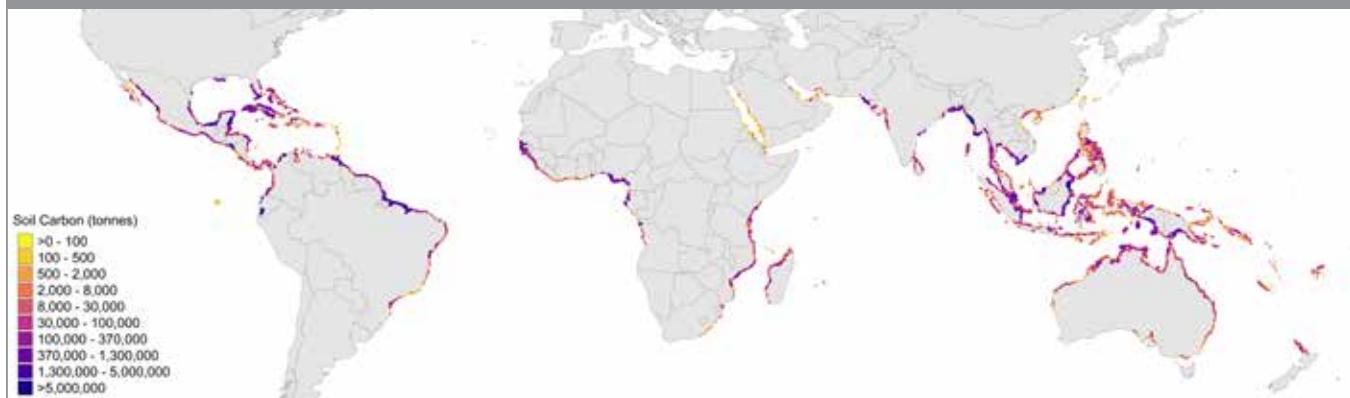
For the MRP Map, we took two recent studies that looked at the carbon content in aboveground biomass (the living plant material – trunks, branches and leaves – that makes up a constant carbon store while continuing to add dead matter to the soils below) and in soil⁹. The models from these papers were fitted to the maps of mangrove areas and to the potential restoration areas. The losses since 1996, documented in this study, represented a significant store of carbon, totalling 0.354 GT of soil carbon and 0.082 GT of carbon in aboveground biomass. These lost areas will still have some carbon values: while the living biomass will mostly be lost, the soil carbon may remain largely intact for a number of years.

The MRP Map shows the potential carbon stocks that might be expected when restored areas reach maturity. They cannot be seen as direct carbon gain, but rather a combination of biomass gains plus a mix of gains and avoided losses from the ongoing processes of soil carbon decomposition.

The most rapid carbon gains will of course come from the growth of new biomass, but such figures vary considerably.

⁹ Hutchison, J., A. Manica, R. Swetnam, A. Balmford, and M. Spalding. 2013. Predicting global patterns in the carbon storage of mangrove forests. Conservation Letters 7:233–240, UK.
Sanderman, J., T. Hengl, G. Fiske, K. Solvik, M. F. Adame, L. Benson, J. J. Bukoski, P. Carnell, M. Cifuentes-Jara, D. Donato, C. Duncan, E. M. Eid, P. z. Ermgassen, C. Ewers, L. Glass, S. Gress, S. L. Jardine, T. Jones, P. Macreadie, E. N. Nsombo, M. M. Rahman, C. Sanders, M. Spalding, and E. Landis. 2018. A global map of mangrove forest soil carbon at 30 m spatial resolution. Environmental Research Letters 13:12.

Map 4.1: Soil Carbon. The likely gains from restoration in terms of tonnes of carbon in the upper metre of soils in restorable areas. These gains will be a combination of novel carbon sequestration and avoided losses from remaining carbon still found in these places.



Map 4.2: Aboveground biomass. The likely gains in carbon on a unit area basis – wet tropical areas, notably in Southeast Asia, but also Colombia, show the highest potential carbon stocks from mature mangroves.



High latitude and desert margin countries will slowly mature into relatively low-biomass forests, with estimates of less than 50 tonnes of carbon per hectare of restoration for countries such as Pakistan, China, New Zealand and the United Arab Emirates. By contrast, mean aboveground carbon stores may be two to three times higher in the Philippines, Indonesia and Papua New Guinea.

Overall, restoration of the recently lost mangroves of the world in the MRP Map could lead to the storage of 0.069 GT of carbon in aboveground biomass. Such an effort would also help to avoid further emissions from an area including some 0.296 GT of soil carbon. Such numbers equate to the annual emissions from 25,000,000 US homes in sequestration and 117,000,000 homes in avoided emissions¹⁰.

As we see from the maps, some of the greatest gains can be projected from areas of most extensive losses in the wet tropics, with the deltas of East Kalimantan in Indonesia having some of the highest potential worldwide.

Given their high carbon content, high productivity and potential for sequestration, mangroves represent an optimal opportunity for climate mitigation

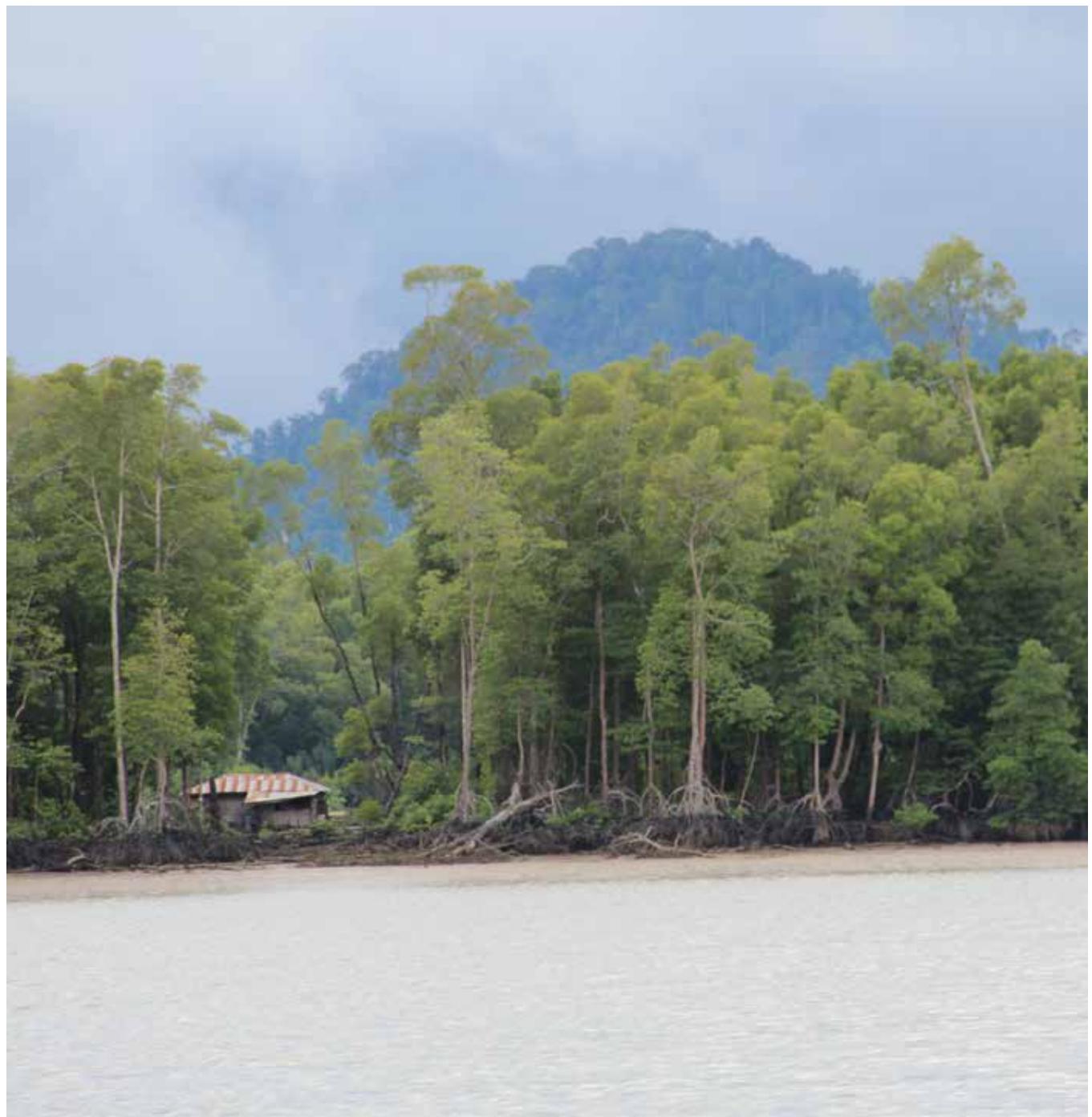


Mangrove forest soils are typically very rich in carbon, but this can be quickly broken down when the mangroves are cleared and the soils are drained.

¹⁰ Conversion based on the US Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator: www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 4.1: Summary statistics by region of the carbon content in soils and aboveground biomass by region.				
Region	Sum of soil Carbon restorable (Tonnes C)	Average soil carbon for restorable areas (Tonnes C/ha)	Sum of Restorable aboveground biomass (AGB) (Tonnes C)	Average AGB for restorable areas (Tonnes C/ha)
Australia & New Zealand	10,504,989	299	2,255,775	64
East & Southern Africa	9,820,102	238	2,606,629	63
East Asia	157,916	227	35,421	51
Middle East	341,216	300	60,759	53
North & Central America & the Caribbean	77,854,092	342	15,294,162	67
Pacific Islands	6,977,819	419	1,884,140	113
South America	35,484,949	332	8,812,221	82
South Asia	7,197,369	204	2,411,592	68
Southeast Asia	133,201,195	439	31,719,960	104
West & Central Africa	14,490,035	332	3,480,750	80
Grand Total	296,029,680	365	68,561,410	84

Table 4.2: Countries in the world with the highest total potential in terms of restorable aboveground biomass and soil carbon.				
Country	Sum of soil carbon restorable (Tonnes C)	Average soil carbon for restorable areas (Tonnes C/ha)	Sum of restorable aboveground biomass (AGB) (Tonnes C)	Average aboveground biomass for restorable areas (Tonnes C/ha)
Australia	10,004,523	297	2,202,314	65
Brazil	15,152,885	309	3,979,742	81
Colombia	8,979,489	416	1,875,519	87
Cuba	7,454,479	465	1,079,887	67
India	3,289,058	216	1,066,672	70
Indonesia	97,289,175	521	21,333,171	114
Malaysia	8,057,028	481	2,015,276	120
Mexico	42,347,923	291	9,517,522	65
Mozambique	5,523,955	213	1,537,505	59
Myanmar	10,395,258	239	3,428,517	79
Nigeria	4,369,782	398	1,004,834	91
Papua New Guinea	5,611,178	414	1,540,504	114
Philippines	6,286,157	402	1,584,510	101
Thailand	5,101,827	292	1,449,231	83
United States	11,503,103	507	1,336,668	59
Vietnam	4,235,332	243	1,311,131	75



Mangroves along the deltaic coasts of East Kalimantan, Indonesia can reach very high biomass.

5. Coastal protection

Bottom line:

Millions of people are protected from flooding annually by mangroves. The level of protection provided by restoration is highly dependent on the precise location and dimensions of restored areas and therefore not possible to map at global scales. However, the Mangrove Restoration Potential Map enables users to see locations where well-targeted restoration efforts might have the greatest impact.

Erosion, storm surges and rising seas are among the greatest threats facing low-lying coastal societies the world over. In many places mangroves help to mitigate these threats, building a living seawall that can slow or halt erosion, rapidly diminish wave-energy, and temper the flooding driven by storm surges. Mangroves protect millions of people from flooding every year, notably in densely populated areas of Vietnam, India, Bangladesh, China, and the Philippines. They also reduce the costs of flood damages worldwide by US\$82 billion each year, with major beneficiaries including China, the United States, India, and Mexico.

Mangroves are not unassailable, but nor are seawalls. A study in India showed that mangroves significantly reduced deaths related to storm surges in villages that had maintained their coastal mangroves, compared to those villages that had lost theirs; another study found that recovery from flooding and avoidance of soil salinization was better in villages behind mangroves than in those behind breached seawalls. Perhaps equally important is that mangroves are a low-cost option, they are self-repairing, and in many places they are even able to keep up with rising seas. All that, and they also yield fish and store carbon¹¹.

In eastern Bangladesh vast areas of mangroves have been converted to aquaculture ponds, greatly heightening impacts on people and infrastructure during the tropical storms that regularly pound this region. Recognising this, Bangladesh has invested in some of the longest-running and largest-scale restoration efforts.

For the MRP Map, we used an updated version of the annual protection benefits to people that was devised by The Nature Conservancy and partners at IH Cantabria¹². Their original study estimates that mangroves offer annual protection and flooding avoidance benefits to over 18 million people and savings of over US\$82 billion each year in terms of avoided damage to infrastructure. Their work was based on an older base-map, using mangrove extents from 2000, and could not be fitted perfectly to our map, however we were able to use their data to look at the geographical spread of protection for some 12.5 million people, giving a good indication of the distribution of benefits, even though our numbers (Table 5.1) are incomplete.

These input maps and models are highly dependent on the precise juxtaposition of people, mangroves and wave environments, and it is not possible to extrapolate directly from these datasets to the restorable areas. For this reason, we show the total numbers of people protected per mangrove unit, as well as dividing the total by mangrove extent to give a crude indicator of the relative value of mangroves per unit area (such numbers should be considered indicative only).

Restoration benefits will depend on the precise location and geometry of particular restoration projects and may

Table 5.1: Current protection provided by mangroves: modelled numbers of people benefiting from flood protection annually under normal (non-storm) conditions. Our model only accounted for 12.5 of the total 18 million people estimated by Losada et al, and so are under-estimates, although they are still likely showing correct regional variation. Likewise the average values presented here are only intended to give an indication of regional variation. True protection values are highly location-specific.

Region	Total population protected	Average value of people protected per km ² of mangrove	Sum of restorable area (km ²)
Australia & New Zealand	17,000	2	351
East & Southern Africa	652,000	84	412
East Asia	423,000	2449	7
Middle East	63,000	186	11
North & Central America & the Caribbean	870,000	37	2277
Pacific Islands	19,000	3	167
South America	409,000	20	1068
South Asia	5,018,000	558	353
Southeast Asia	4,085,000	86	3037
West & Central Africa	991,000	49	437
Grand Total	12,547,000	86	8120

¹¹ Spalding, M., A. McIvor, F. H. Tonneijck, S. Tol, and P. van Eijk. 2014. Mangroves for coastal defence. Guidelines for coastal managers and policy makers. www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf

¹² Losada, I. J., P. Menéndez, A. Espejo, S. Torres, P. Díaz-Simal, S. Abad, M. W. Beck, S. Narayan, D. Trespalacios, K. Pfieger, P. Mucke, and L. Kirch. 2018. The global value of mangroves for risk reduction. Technical Report. The Nature Conservancy, Berlin. www.nature.org/GlobalMangrovesRiskReductionSummaryReport

yield returns considerably lower or higher than these per unit area values.

Restoring mangroves for coastal protection purposes is now widespread: not only can they reduce flooding, but they can reduce erosion and even support the vertical



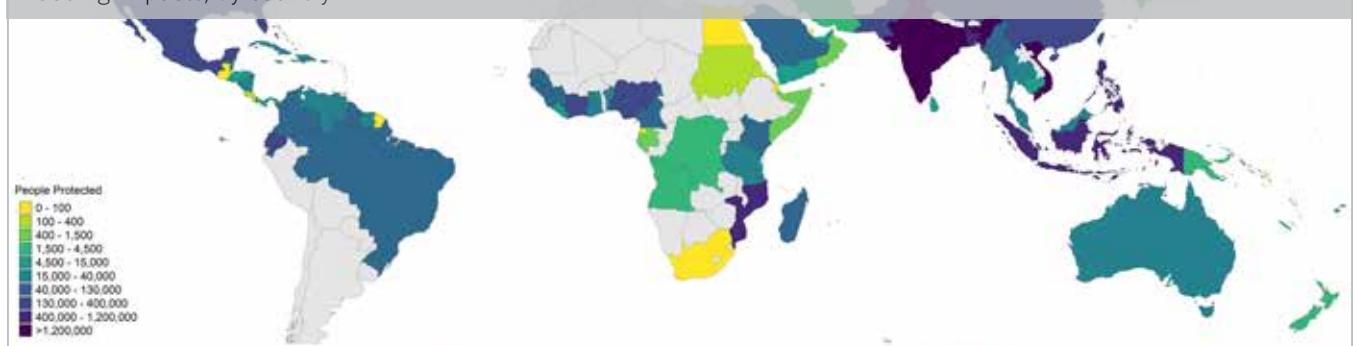
Erosion is common where coastal mangroves have been cleared. Here in Berau, Indonesia, grazing by cattle is preventing natural regeneration. Those costs to local communities are considerable.

accretion of sediments, bolstering their role in the face of sea level rise. At the same time, it remains important to realise that the benefits are not immediate. Initial benefits may be measurable within even just a couple of years, but it may take 10 years or more for the mangroves to start providing the dense protective barrier they once did.



Mangrove restoration in front of critical infrastructure in Fiji.

Map 5.1: Coastal protection provided by existing mangroves in 2016. Total numbers of people protected from annual flooding impacts, by country.



Total numbers of people protected per km² of mangrove each year. Numbers are for each mangrove unit in West Africa (left) and southern Philippines/northern Borneo (right).



6. Fisheries

Bottom line:

The critical role of mangroves in enhancing fish stocks is well known. For 39 commercially important fish and invertebrate species we have modelled detailed enhancement by mangroves. The Mangrove Restoration Potential Map shows that current mangrove cover adds over 1,000 trillion commercially valuable fish and invertebrates to coastal waters around the world every year. Restoration could add a further 60 trillion per year. Not all of these are at fishable sizes, but if even 1% were to grow to viable targets the benefits would be tremendous.

Mangrove forests are fish factories. Their complex networks of channels and shallow pools, fringed with tangled, interlocking roots provide a critical shelter, while their extraordinary productivity ensures reliable, rich food supplies for their residents. A host of fish and invertebrates breed in the mangroves or use them as nursery grounds. Others never leave. Fishers are well aware of this – the complex mangrove channels provide a sheltered fishing ground, yielding fish for themselves and for markets where species such as oysters, clams, shrimp and crabs claim a price premium. The narrow channels and shallow waters often prevent large-scale operators from entering the mangroves, but support huge numbers of small-scale local fishers. Meanwhile, beyond the mangroves, the constant supply of new fish and invertebrates to offshore ecosystems from the mangroves is often undervalued but provides a mainstay for industries such as shrimp trawling and a food supply for finfish right across the food chain¹³.

Current mangrove cover adds over 1,000 trillion commercially valuable fish and invertebrates to coastal waters around the world every year

The facts of fisheries enhancement have been well studied at local scales, but The Nature Conservancy has supported a unique new approach to understanding the geographic variation of such value at a global scale. Here we provide data from the ecological components of the model in which metrics were developed for individual species on exactly how mangroves enhance their abundance and biomass. The resulting numbers represent enhancement or the additional numbers that will be added to a system annually because of the presence of mangroves.

¹³ Hutchison, J., M. Spalding and P. zu Ermgassen. 2014. The Role of Mangroves in Fisheries Enhancement. The Nature Conservancy and Wetlands International, Cambridge, UK. www.wetlands.org/publications/the-role-of-mangroves-in-fisheries-enhancement/



Mangroves support millions of small-scale and artisanal fishers, such as here in the Caribbean.

These models are actually highly conservative. Reliable data on enhancement were only available for 39 species. In reality, many more are likely to be enhanced by the presence of mangroves. For the summary numbers here, we have separated out the finfish from the invertebrates.

The 32 finfish species cover a broad range¹⁴, including anchovies and silversides, parrotfish, snappers and carangids. For all, the numbers calculated represent young-of-the-year fish recruited to mangrove and directly adjacent areas as a result of the presence of mangroves. Although these figures do not include the larval stages, they include young individuals which for many species are not commercially viable and natural mortality would decrease these numbers, in some cases by one or two orders of magnitude prior to their reaching commercially harvested size-classes.

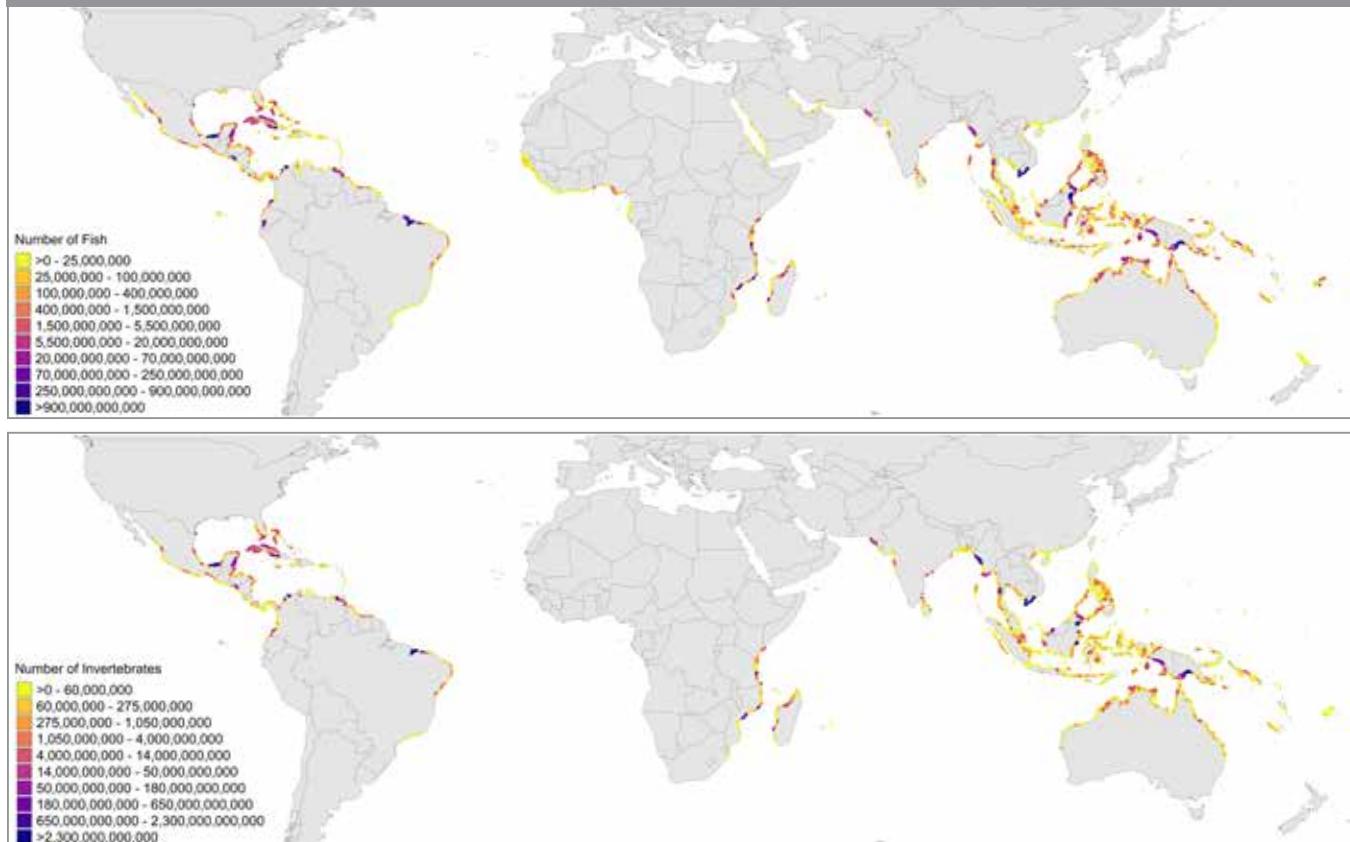
The seven invertebrate species¹⁵ include crabs, shrimps and one bivalve mollusc, and numbers for these represent all post-settlement-year classes, including commercially harvested size-classes.

¹⁴ The full list of finfish: *Atherinomorus lacunosus, Caranx latus, C. sexfasciatus, Centropomus undecimalis, Cetengraulis edentulus, Chaetodipterus faber, Chanos chanos, Diapterus auratus, Gerres cinereus, G. filamentosus, Haemulon flavolineatum, H. sciurus, L. analis, L. apodus, L. argentimaculatus, L. argentinus, L. cyanopterus, L. fulviflamma, L. griseus, L. jocu, L. russelli, L. synagris, Monodactylus argenteus, Mulloidichthys martinicus, Scarus guacamaia, S. iseri, Scatophagus argus, Siganus canaliculatus, Sillago sihama, Sparisoma rubripinne, Sphyraena barracuda, Terapon jarbua*.

¹⁵ Full list of invertebrates: *Anadara tuberculosa, Fenneropenaeus indicus, Fenneropenaeus merguiensis, Penaeus monodon, Scylla serrata, Ucides cordatus, U. occidentalis*.

Map 6.1: Benefits of restoration in terms of increasing finfish (upper) and invertebrates (lower) to mangrove units.

The former includes young fish, many not yet of commercial size, while the latter includes all post-settlement year-classes. Due to variance in the coverage, numbers are not directly comparable between the Americas and the Indo-Pacific regions, while West & Central Africa is likely to be significantly under-reported for fish and has no data on invertebrates.



Caution must be taken when comparing numbers between regions due to inconsistencies in available data. Thus, for the Americas there is considerable data on finfish, but no data for invertebrates beyond the Pacific coast. For West Africa there is no invertebrate data, and only a very small and potentially unrepresentative number of fish species. For these regions the numbers are clearly major underestimates.

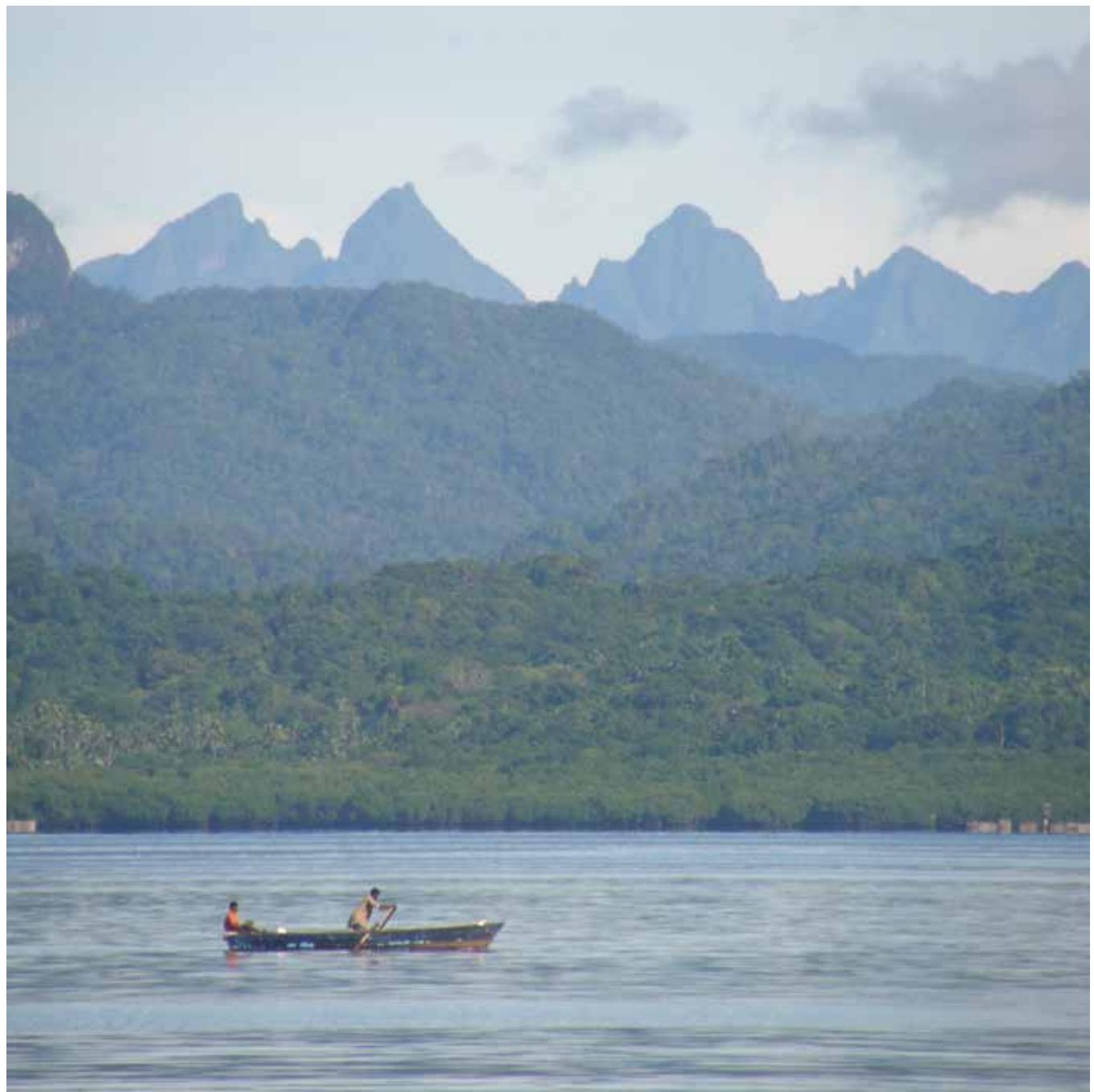
Recognising that there are limitations to the data coverage, and the fact that overall the findings are likely to be highly conservative, we can still develop approximate global estimates. Using these models, the enhancement of fish and invertebrates by the current mangrove cover is some 422 trillion (a trillion is a million million, so 422,000,000,000,000) individual finfish per year and some 594 trillion individual invertebrates per year of these species alone. Restoration could significantly enhance such numbers, with a further 23 trillion finfish and 40 trillion invertebrates each year.



Many commercially important fish such as these snapper in the Seychelles, come into the mangroves to breed, or settle here as juveniles before moving offshore.

Table 6.1: Regional statistics on the enhancement by mangroves of 40 commercial fishery species.				
Region	Annual finfish enhancement by 2016 mangroves (millions)	Potential annual finfish enhancement through restoration (millions)	Annual invertebrate enhancement by mangroves (millions)	Annual invertebrate enhancement through restoration (millions)
Australia & New Zealand	6,936,314	221,137	5,006,439	162,960
East & Southern Africa	45,130,882	2,170,344	34,522,003	1,363,861
East Asia	1,313	37	844	26
Middle East	74,193	1,668	22	0
North & Central America & the Caribbean	48,113,438	3,928,401	139,108,522	10,690,549
Pacific Islands	139,195,086	3,318,343	108,284,215	2,597,629
South America	59,893,074	3,937,903	179,037,081	11,409,449
South Asia	673,060	37,111	1,376,275	91,189
Southeast Asia	121,910,643	9,578,026	126,402,288	13,394,677
West & Central Africa	183,278	4,640	N/A	N/A
Grand Total	422,111,281	23,197,609	593,737,690	39,710,340

Table 6.2: Selected countries with the highest potential gains to fisheries from restoration.					
Country	Restorable area (km ²)	Finfish enhancement by 2016 mangroves (millions)	Potential finfish enhancement through restoration (millions)	Invert enhancement by 2016 mangroves (millions)	Potential invert enhancement through restoration (millions)
Australia	336	6,936,258	221,134	5,006,439	162,960
Brazil	491	51,840,719	2,247,590	159,189,229	6,923,510
Colombia	216	5,299,081	1,564,658	11,655,952	4,211,825
Cuba	160	5,698,092	603,114	14,486,955	1,553,945
Indonesia	1,866	66,825,525	5,871,640	81,612,014	10,712,828
Madagascar	80	3,134,540	123,077	3,004,646	129,479
Malaysia	168	22,802,177	509,228	21,132,330	520,151
Mexico	1,455	39,368,821	2,921,600	122,392,576	8,930,757
Mozambique	259	12,997,918	1,317,391	9,183,775	671,777
Myanmar	436	2,324,904	119,170	11,676,456	962,219
Nicaragua	104	1,502,982	313,306	416,398	70,358
Papua New Guinea	135	136,884,328	3,291,306	107,434,907	2,584,623
Tanzania	36	28,564,568	704,179	21,993,338	542,397
Venezuela	120	1,705,035	55,379	7,960,098	257,701
Vietnam	174	28,073,828	2,990,405	10,641,742	1,130,383



Fisheries in coastal waters such as here in Fiji benefit enormously from species that begin life in the mangroves before moving offshore.

7. Conservation and protection

Bottom line:

Worldwide there are some 2,500 protected areas that include mangrove forests within their boundaries. These include some 54,000km², or over 39%, of the world's remaining mangroves. Levels of degradation within protected areas are less than half those recorded from outside of protected areas.

Protected areas are one of the tools of choice for protecting biodiversity and for securing long-term delivery of ecosystem benefits. Using the World Database on Protected Areas¹⁶ we selected over 2,500 sites that include mangrove areas and looked at how these sites relate to mangrove loss and degradation.

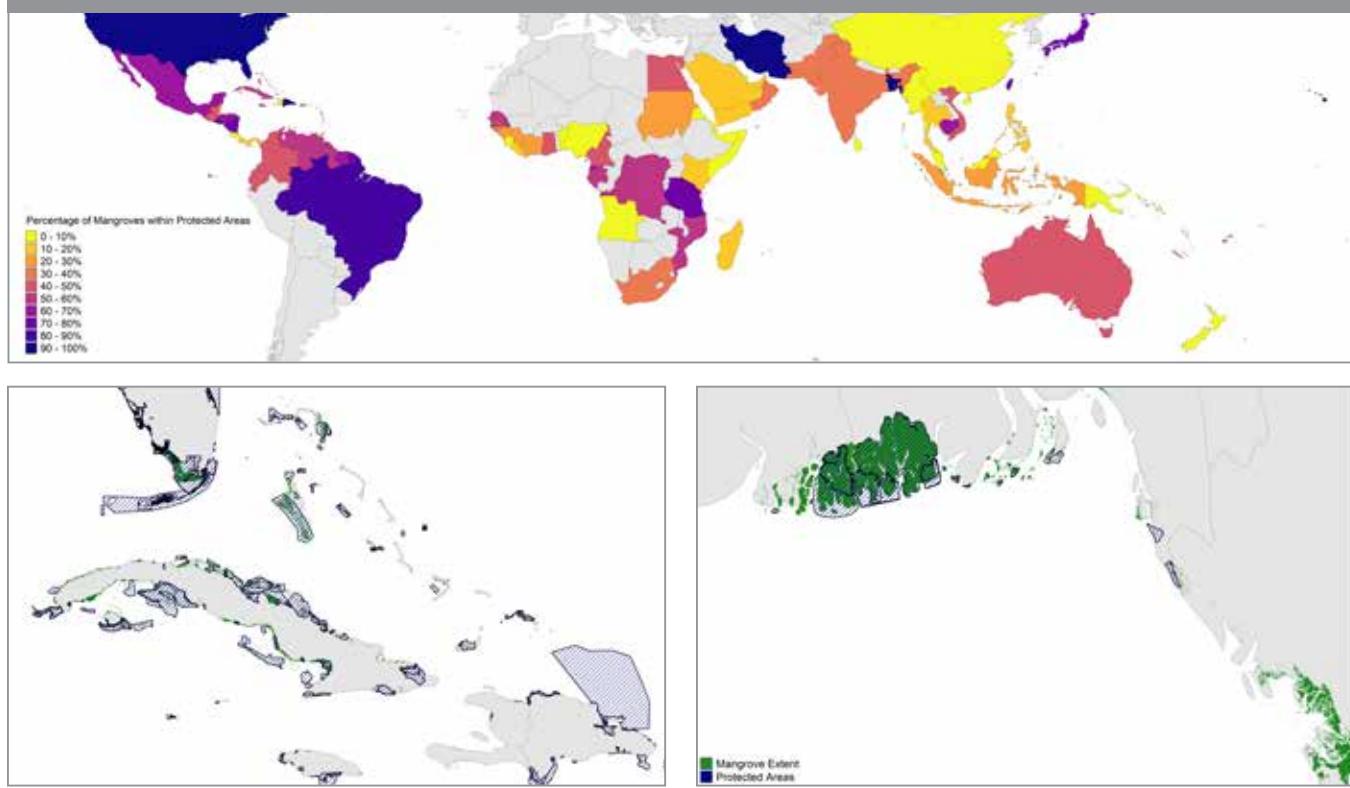
The extensive coverage of mangroves by protected areas represents a strong positive trend in coastal conservation. Worldwide over 39% of the world's remaining mangrove forests fall inside protected areas (Map 7.1), and 34 countries have placed more than half of their mangroves under such protection (Table 7.1).

Table 7.2 lists the countries with the greatest extent of mangroves in protected areas, plus some other important mangrove nations with smaller mangrove extents, which have protected more than 70% of their mangroves. Bangladesh, Brazil and the United States are among the many states with remarkably high proportional coverage by protected areas and very large mangrove extents in protected areas.

In contrast to these countries, several of the very largest mangrove nations have made very little progress in terms of protection: Indonesia, with the largest mangrove extent in the world, has only 24% of its mangroves within protected areas, while Nigeria, Myanmar, Malaysia and Papua New Guinea have between 2% and 5% of their mangroves incorporated into protected areas, ranking among the lowest coverages of any mangrove nations.

Our results show 6% of mangrove areas within protected areas have been lost since 1996, a lower rate than outside protected areas (7.1%), but not very different. This result is perhaps misleading, however, as many of these losses may have occurred prior to designation. Some of

Map 7.1: Proportion of mangroves within protected areas by country (upper map). Lower maps show mangroves and the location of some of the world's 2,500 protected areas that overlap mangroves. Left: southern Florida, the Bahamas and northern Cuba. Right: Bangladesh and the Indian Sundarbans.



¹⁶ IUCN and UNEP-WCMC 2018, The World Database on Protected Areas (WDPA) On-line, September, 2018. Cambridge, UK: UNEP-WCMC. Available at: www.protectedplanet.net.

Table 7.1: Regional breakdowns of mangrove protection.

Country	Area of 2016 mangrove protected (km ²)	Proportion protected	Proportion lost outside protected areas	Proportion lost inside protected areas	Proportion of unprotected mangrove degraded	Proportion of protected mangrove degraded
Australia & New Zealand	4,553	45.4%	4.6%	3.7%	0.51%	0.59%
East & Southern Africa	3,112	42.5%	6.7%	5.2%	2.05%	1.49%
East Asia	21	12.9%	8.5%	2.3%	1.73%	1.10%
Middle East	100	31.3%	6.8%	4.7%	1.10%	0.31%
North & Central America & the Caribbean	12,411	58.9%	11.8%	10.7%	0.66%	0.67%
Pacific Islands	563	8.9%	2.9%	1.5%	0.08%	0.05%
South America	13,649	71.6%	8.4%	5.7%	0.56%	0.46%
South Asia	5,428	63.9%	9.6%	3.2%	0.75%	0.17%
Southeast Asia	8,769	19.9%	8.4%	4.6%	2.21%	0.76%
West & Central Africa	5,317	26.8%	2.3%	3.0%	0.45%	0.25%
Grand Total	53,923	39.4%	7.1%	6.0%	1.3%	0.57%

Table 7.2: National breakdowns of mangrove protection.

Region	Area of 2016 mangrove protected (km ²)	Proportion protected	Proportion lost outside protected areas	Proportion lost inside protected areas	Proportion of unprotected mangrove degraded	Proportion of protected mangrove degraded
Australia	4,528	46.6%	4.6%	3.7%	0.5%	0.6%
Bangladesh	3,780	91.9%	19.3%	2.5%	0.2%	0.0%
Brazil	9,419	85.9%	6.4%	5.1%	0.7%	0.5%
Cameroon	1,077	47.3%	1.9%	1.4%	0.0%	0.0%
Colombia	1,054	46.5%	10.0%	10.1%	0.5%	0.9%
Cuba	1,764	52.3%	4.9%	6.9%	1.3%	2.7%
Dominican Republic	154	81.6%	4.7%	5.4%	0.8%	0.6%
El Salvador	283	86.3%	4.3%	5.0%	0.1%	0.2%
French Guiana	350	70.9%	13.2%	8.5%	0.0%	0.0%
Gabon	919	54.4%	2.6%	2.0%	0.0%	0.0%
India	1,381	39.8%	7.1%	3.6%	0.5%	0.1%
Indonesia	6,529	24.2%	8.7%	3.6%	1.8%	0.8%
Iran	77	98.3%	16.8%	3.1%	2.0%	0.3%
Mexico	6,072	62.3%	17.3%	12.3%	0.6%	0.2%
Mozambique	1,750	59.5%	12.0%	6.6%	1.2%	1.5%
Nicaragua	653	74.5%	11.4%	10.9%	1.3%	1.9%
Tanzania	935	80.0%	6.0%	3.0%	0.8%	0.9%
United States	1,707	90.4%	17.7%	11.9%	0.6%	0.1%
Venezuela	1,404	50.0%	6.0%	3.2%	0.6%	0.2%



Protected areas can be highly popular places for recreation and tourism , such as here in Java, Indonesia.

the losses recorded here date back to 1996, while many protected areas have been declared after this date. While dates of protected areas designation are not available for many sites, a good example of this problem can be seen in Cuba where many protected areas were declared quite recently and post-date the losses. Thus, we cannot use these losses as a direct metric for assessing the effectiveness of protection.

By contrast, rates of degradation of mangroves in protected areas (0.57%) are half those of mangroves outside protected areas. This statistic looks at the current status of mangroves in 2016 and so the date of designation will be less relevant. Protection should prevent some drivers of degradation, such as unsustainable timber extraction, and allow recovery. At the same time, other drivers of degradation, such as upstream water abstraction or changes to sediment supplies, cannot be influenced when they occur beyond the protected area boundaries and so we would expect some degradation to continue.

Restoration in Protected Areas

Clearly there is a considerable opportunity to enhance the role of protected areas as a key tool in mangrove conservation. In most cases protected areas already provide a legal and management framework in which mangroves can be secured, and within which future management and protection can be enhanced. Once established, they secure issues of land ownership and create a framework for legal censure to prevent

repeated losses. Importantly, we can also see the considerable opportunities for restoration within these areas. In some cases, these may be the best places to start investment.

The extensive coverage of mangroves by protected areas represents a strong positive trend in coastal conservation

Further challenges to mangroves may arise from beyond the boundaries of protected areas, such as the abstraction of water and sediment supplies, or coastal erosion and inundation driven by more remote coastal engineering or sea level rise. These challenges point to another critical fact, which is that mangroves cannot be conserved by the medium of protected areas alone.

While nearly two-fifths of the world's mangroves are now within protected areas, many more remain vulnerable. Given their value, the loss of any mangrove area is a loss both to local communities and to humanity as a whole. It will be valuable going forward to consider the legal and management status of the 60% of mangroves not currently in protected areas. Some may still be protected through generic regulations protecting forests or coastal vegetation. Others may be subject to broader coastal planning, or may be subject to offsetting regulations (requiring restoration for any losses through development). Other areas remain well-managed under forestry regimes. Between these, however, many of the world's mangroves remain in private or uncertain ownership with no mechanisms to ensure their long-term future.



Biodiversity protection is a key component of protected areas, such as here in Brisbane, Australia.



By safeguarding the natural infrastructure, protected areas can also support the maintenance of other benefits such as fisheries enhancement, carbon storage and coastal protection.

8. Review of restoration efforts

Bottom line:

We have reviewed more than 160 documented mangrove restoration efforts in 24 countries, including a total recorded extent of almost 2,000 km² planted over the last 40 years. In addition to these, a number of poorly-documented, large-scale efforts suggest further restoration efforts of more than double this extent, although many of these are thought to be unsuccessful. The better-documented efforts reported here already represent remarkable progress and solid evidence of the viability of scaling up to a systematic, global effort, maximising benefits for people and nature.

There have already been many efforts around the world to restore mangrove forests, ranging from large-scale programmes covering tens of square kilometres to small, often locally driven efforts to restore narrow coastal fringes or abandoned aquaculture ponds. To understand and quantify these existing efforts and build a more comprehensive review, we have begun to pull together a synthesis of mangrove restoration efforts, focusing attention on efforts that are well-documented and where there is some information about the approaches and costs, and some review of success. The current dataset focuses on restoration, but also includes a few cases where rehabilitation stops short of full restoration (for example, the planting of monocultures, or atypical species), and some cases of afforestation (placing mangroves in places where they did not formerly exist).

Mangroves are opportunistic: given the right settings, they thrive, and can often be restored with minimal planting. What is critical is to ensure that the location is restored in terms of elevation and water flows and that the social

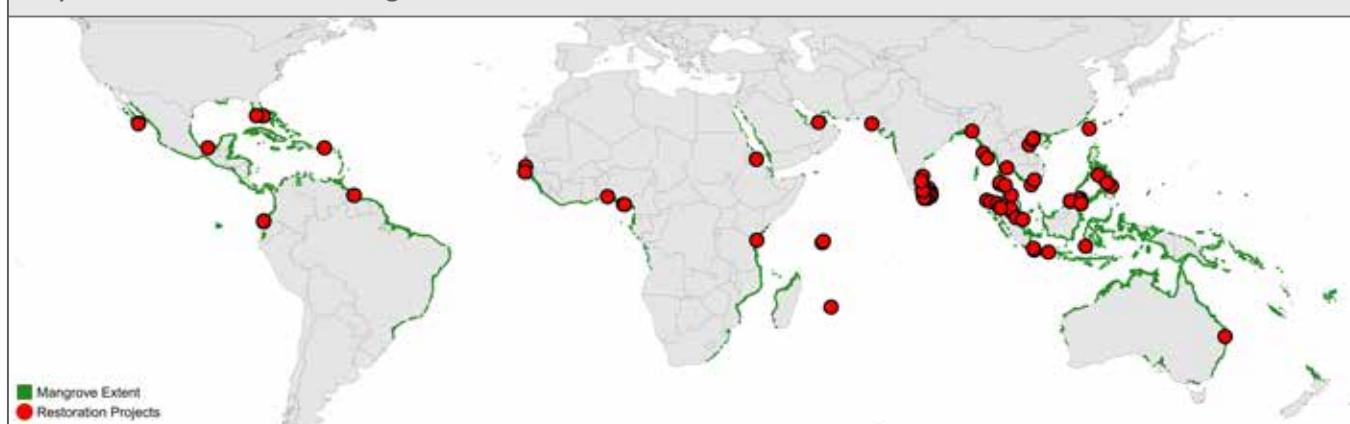
and political framework is secure against those impacts that caused their original loss, with clear ownership and regulations for the restoration locations.

The review work here has revealed an enormous range of restoration efforts, from the planting of scattered trees to large-scale restoration projects of thousands of hectares. These are located in 24 countries, covering every continent¹⁷.

Some of the most extensive restoration efforts worldwide are recorded in Bangladesh and Vietnam. In southern Vietnam vast areas of mangroves were lost through warfare and the deliberate spraying of herbicides from 1961 to 1971. In the north, large areas were cleared for the development of aquaculture. In both areas, mangrove losses led to notable increases in coastal erosion and hence efforts to restore mangroves have been ongoing for over 40 years. These range from simple cases where public participants, including schoolchildren, have planted trees, through to some of the latest, semi-engineering approaches, which aim to stabilise formerly eroding coasts and allow natural mangrove regeneration¹⁸.

The success or failure of mangrove restoration efforts are typically not well recorded. From the limited records available in our database, survival of mangroves is typically in the range of 60-90% after 10 years. Much lower survival is anecdotally reported from some of the larger programmes not included in our survey. Some efforts have failed completely: typically these have been where poor planning, a desire for a rapid fix, or a lack of ecological understanding have led to restoration in the wrong locations, or planting with the wrong species.

Map 8.1: Global distribution of mangrove restoration efforts from our assessment.



¹⁷ The findings from this work will be shared through the Global Mangrove Alliance and the Mapping Ocean Wealth website by the end of 2018. <http://oceanwealth.org>

¹⁸ López-Portillo, J., R. R. Lewis, P. Saenger, A. Rovai, N. Koedam, F. Dahdouh-Guebas, C. Agraz-Hernández, and V. H. Rivera-Monroy. 2017. Mangrove Forest Restoration and Rehabilitation. Pages 301-345 in V. H. Rivera-Monroy, S. Y. Lee, E. Kristensen, and R. R. Twilley, editors. Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function, and Services. Springer International Publishing, Cham.

Costs of mangrove restoration are very difficult to pin down. An earlier study suggested a median cost of around US\$3000 per hectare¹⁹, but it is perhaps the range of such values that are most important. We document locations where large-scale engineering to restore hydrology, combined with high staffing costs led to projects costing over US\$100,000 per hectare, while for many others it is difficult to determine any directly funded costs at all because local communities or volunteers have put in their time with no cost to any funder.

Beyond the projects documented in our database, we pulled together a listing of very large-scale projects that have been widely cited but poorly documented. For these we have only very limited information, but we located some 50 such projects with a claimed restoration area of nearly 5,000 km².

Many of these large-scale projects are government-backed, but have had very mixed results. Failures are almost always predictable and could be avoided with a minimum of guidance.

The potential for mangrove restoration is immense and the pay-backs in terms of ecosystem services generated will be considerable. It is, however, critical to undertake restoration with attention to both ecological and socioeconomic detail. By referring to successes, and learning from failures, it should be possible to ensure maximum benefits for minimum costs.

THE KEY ELEMENTS OF EFFECTIVE MANGROVE RESTORATION

It is clear from our review that most successful restoration projects commence with a good understanding of the conditions of the site being restored. This includes prior knowledge of both ecology and hydrology. In many cases restoration is largely achieved through the restoration of physical hydrological process. Restoring water flow and land elevation facilitates the natural transportation of mangrove propagules, and over time mangrove regeneration can occur with no planting. Planting, in contrast, can help both to accelerate recovery rates and in places where natural recruitment may be reduced. Ecological knowledge is critical – the correct species must be placed at the correct location within different parts of a system and at different elevations.

To increase the chances of successful restoration, long-term monitoring and management of the site should be incorporated into the project protocol. This should entail monitoring the growth and survival of mangrove species, as well as carrying out ongoing or additional hydrological modifications, supplementary planting or weed/pest removal. These approaches, applied together, should facilitate effective mangrove restoration.

Table 8.1: Summary data from the restoration projects recorded in our database. Not all projects record exact areas, or give sufficient data to assess success or failure.

Region	Number of restoration sites	Recorded area restored (ha)	Success	Failure
Australia & New Zealand	1	11	1	0
East and Southern Africa	16	113	11	3
East Asia	1	5	1	0
Middle East	3	n/a	3	0
North & Central America & the Caribbean	8	563	6	0
Pacific	0	N/A	N/A	N/A
South America	12	26	10	0
South Asia	48	127,832	24	22
Southeast Asia	72	47,597	34	16
West & Central Africa	5	14,000	3	1

¹⁹ Bayraktarov, E., M. I. Saunders, S. Abdullah, M. Mills, J. Beher, H. P. Possingham, P. J. Mumby, and C. E. Lovelock. 2016. The cost and feasibility of marine coastal restoration. *Ecological Applications* 26:1055-1074.

9. Scaling up mangrove restoration

Bottom line:

The Mangrove Restoration Potential Map (MRP Map) provides a starting point for a practical opportunity to scale up mangrove forest restoration globally. This will drive benefits at both local and global scales, while also helping countries to meet a variety of international obligations and commitments. The MRP Map draws attention to the potential for restoration at a resolution never previously seen. It gives the world, and individual countries, a broad indication of where to focus mangrove restoration efforts, and powerful statistics to explain why they should do this.

Our maps and statistics should support global, regional and in-country decisions on the need for and the opportunity to restore. Final restoration decisions about location and methods for restoration on-the-ground need to be made using detailed local knowledge of ecological, physical and social and economic factors, however, the MRP Map provides an initial pointer.

Many restoration efforts are already documented in mangrove areas, and incentives to increase these efforts are bolstered by several international commitments and targets. Funding streams that support implementation of these agreements may further incentivise leaders, policymakers and planners to implement mangrove restoration. Some of these international commitments are more fully explored here.

International Agreements, pledges and opportunities

The UN Framework Convention on Climate Change (UNFCCC) Paris Agreement

Mangrove forests are arguably the single most effective forest type, by area, in supporting climate mitigation, by both sequestering and storing carbon at prodigious rates. The UNFCCC Paris Agreement requires all Parties to set out their post-2020 mitigation actions and targets in the form of a Nationally Determined Contribution (NDC) – essentially an action plan that reflects the country's climate action ambition. Aggregated mitigation actions across NDCs globally will determine whether we are able to keep global average temperatures to well below 2°C above pre-industrial levels, or even at 1.5°C (Article 2.1 of the Paris Agreement).

Several countries already reflect mangrove restoration in their NDCs, yet they have difficulties putting quantitative numbers on this, both in terms of area and carbon content/sequestration potential. The MRP Map, and particularly its carbon data layers, can help inform these countries, while also encouraging further efforts by these and other countries to revise and strengthen the role of mangrove restoration in their next NDC submission to the UNFCCC (by 2020).



Dense mangroves such as these in East Kalimantan, Indonesia, are critically important to the world as carbon stores, and to local people for protecting coasts and generating fish.

In protecting coastlines from erosion and flooding, and in providing food security, through fisheries, to millions of coastal people, mangroves also present a highly effective tool to help with climate adaptation. Article 7.1 of the Paris Agreement calls for “enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change”. There is also encouragement for countries to engage in adaptation planning processes to build the resilience of socioeconomic and ecological systems. Adaptation actions will be recognised through the Global Stocktake of the Paris Agreement, which will review progress on the global goal on adaptation. Mangrove adaptation actions can be considered as part of Ecosystem-based Adaptation (EbA) – a nature-based solution that harnesses biodiversity and ecosystem services to reduce vulnerability and build resilience to climate change.

The Convention on Biological Diversity (CBD) Aichi Targets

Mangrove forests are rich in biodiversity and among the best documented ecosystems in terms of their delivery of benefits to people. The conservation of both biodiversity and ecosystem services lies at the core of the CBD. In 2010 the CBD member States agreed 20 ambitious biodiversity targets, collectively known as the CBD Aichi Targets. Mangrove restoration can be seen as helping to fulfil several of these targets. For example, by generating jobs and food security, restoration can enable national and local development and poverty reduction (Target 2). Two targets have a particular relevance – offering countries an incentive, even an obligation, to increase mangrove restoration efforts. These are:

Target 14: By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

Target 15: By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)

The mission of the Ramsar Convention is “the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world”. Among other things, the Convention requires and encourages Parties to identify key wetlands and to work towards their conservation and sustainable use. The Convention is highly cognisant of the place of people within wetlands and many Ramsar sites represent landscapes and seascapes where human activities such as fishing and other sustainable resource extraction continue.

Ramsar also plays an important role in highlighting the climate regulation function of the world’s marine and coastal wetlands (blue carbon ecosystems) and in stimulating their conservation and restoration for carbon mitigation. Of the 2330 Wetlands of International Importance (Ramsar Sites) worldwide, 952 are reported as marine and coastal wetlands, including some 290 that include mangrove areas. As noted earlier in this report, there are still considerable opportunities for restoration within protected areas generally, and Ramsar could be a highly effective agreement to encourage active restoration within its existing sites, and in new site declarations.

Sustainable Development Goals (SDGs)

The SDGs “are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity”, developed under the guidance of the UN Development Programme, and widely supported at local, national and international levels as a framework for action. Several have relevance for mangrove restoration, but perhaps particularly SDG 13 – Climate Action, and SDG 14 – Life Below Water.

Under the framework of SDG 14, in 2017 the international community convened a meeting entitled Our Ocean, Our Future, at which they prepared and agreed a formal Call for Action. This document makes specific references to mangroves, calling on the world to “Develop and implement effective adaptation and mitigation measures that contribute to increasing and supporting resilience to ocean and coastal acidification, sea-level rise, and increase in ocean temperatures, and to addressing the other harmful impacts of climate change on the ocean as well as coastal and blue carbon ecosystems such as mangroves, tidal marshes, seagrass, and coral reefs, and wider interconnected

ecosystems impacting on our ocean, and ensure the implementation of relevant obligations and commitments."

On the back of this statement, voluntary commitments (VCs) were submitted by various stakeholders, and the UN established nine Communities of Ocean Action (COA), including one specifically on mangroves. The goal of these COAs are to ensure updates on the implementation of the VCs, encourage new VCs and generate cross-learning and sharing of experiences amongst similar VCs. A mid-term report, due at the end of 2018, will show progress being made in terms of mangroves action, and identify gaps, which will, in turn, highlight areas of opportunity. The MRP Map will be of considerable use in furthering assessments of progress and fostering new commitments.

Bonn Challenge

The Bonn Challenge, led by the IUCN and Global Partnership of Forest Landscape Restoration, is a global effort to restore 150 million hectares of the world's degraded and deforested lands by 2020 and 350 million hectares by 2030. Although not a formal or binding agreement, as of October 2018, there have been 56 commitments resulting in 168.4 million hectares pledged



Recreation and tourism in mangrove forests now represents an important activity and source of revenue.



Snapper sheltering among mangrove roots in Cuba.

for restoration. Mangroves have never been singled out under this challenge, but as climate mitigation is a key focus, the MRP Map will be a valuable tool in supporting the expansion of Bonn Challenge actions into the future.

Global Mangrove Alliance

The Global Mangrove Alliance is a partnership of technical experts, civil society, governments, local communities, businesses, funding agencies and foundations that aims to accelerate a comprehensive, coordinated, global approach to mangrove conservation and restoration at a scale that matters. Mangrove restoration is a key priority for the Global Mangrove Alliance members, many of whom are already actively supporting restoration projects around the world. The Alliance is also creating an internet-based clearinghouse for information that is accessible to anyone, recognising that access to such information is critical as a means to collectively increasing the world's mangrove cover at a scale that matters for people and the planet.

International commitments have a critical role to play – these agreements already show recognition of the challenges, but they do need to be carried through. The MRP Map provides a tool to do this.



Young mangroves ready for restoration work, Guangxi Province, China

New approaches

At national levels the accelerating pressures on coastal spaces are driving a renewed push for integrated coastal zone management and /or marine spatial planning. The MRP Map can help inform spatial planners in their attempt to prioritise various conservation and restoration areas. Planning on a national or even regional scale can also enable an improvement and scaling up of previously scattered and disconnected attempts at mangrove restoration, and can generate a more holistic approach and overview of the potential.

The corporate sector also has a role to play. Increasingly, companies are being required to report on their corporate social responsibility, and this has implications for mangroves: industries that damage or destroy mangroves (from the building of hotels to clearance for housing or aquaculture) may increasingly be required to report on such impacts, and this may affect their bottom line. Conversely, restoration projects may be used by industry as a means of offsetting their impacts in terms of emissions or as a means of supporting local sustainability and development.

Investing in mangrove restoration clearly has a cost, but, as reported here, the benefits can be enormous. Increasing calls from the financial sector for sustainable investment opportunities are likely to lead to novel funding mechanisms for mangrove restoration. The Livelihoods Fund (<http://www.livelihoods.eu/>) provides an early example of how such investments might work – attracting support from impact investors for mangrove restoration projects worldwide. In future it seems highly likely that mangrove restoration could be built into novel investment products such as blue bonds. For these sorts of investment, both the scale of a project and the security and legal frameworks are of great importance. Having a better overview of opportunities, together with model-driven and globally-consistent assessments of value provides a new opportunity for the conservation sector and governments to engage with private finance to invest in mangrove restoration projects, for carbon purposes or other ecosystem services.

The insurance sector, likewise, has considerable interest in the role of mangroves in reducing coastal damages and there may be opportunities for developing funds to restore mangroves for coastal protection, or to create market mechanisms that might drive further restoration for the same coastal protection ends.



Clear waters are commonly found among fringing mangroves near coral reefs, such as these in Raja Ampat, Papua, Indonesia, Pacific Ocean. © Ethan Daniels

Using the Mangrove Restoration Potential Map

The maps and datasets shared in this report can be explored in their entirety through the Mangrove Restoration Potential Map application on maps.oceanwealth.org/mangrove-restoration/.

Through this tool users can view global, regional and national statistics, and can further interrogate individual mangrove units to see data summarised at these smaller scales. The MRP Mapping tool has two points for exploration:

- **The Geography view** commences with a global map and summary statistics, and provides the opportunity to focus in on each of the 10 main mangrove regions, or on any individual country. The statistics in the data-panel are revised depending on the selected geographic area, enabling viewers to see statistics on loss, degradation, restoration potential and key ecosystem services. Clicking on these layers re-draws the map to show the particular values selected.
- **The Typology view** enables users to point and select data for any particular typological unit and review similar statistics as well as some of the key elements of restorability, such as tidal conditions, sediments and sea level rise.

Most of the data being developed will also be released with our partners through peer-review publication in scientific literature, and as this happens every effort will be made to also share the input data and models in raw form.

Mangroves have moved from being ignored and overlooked to holding a position as one of the most valuable ecosystems on Earth. This is already reflected, to some degree, in the fact that almost 40% of mangroves have already been incorporated into protected areas, and that restoration efforts are already noted from around the world.

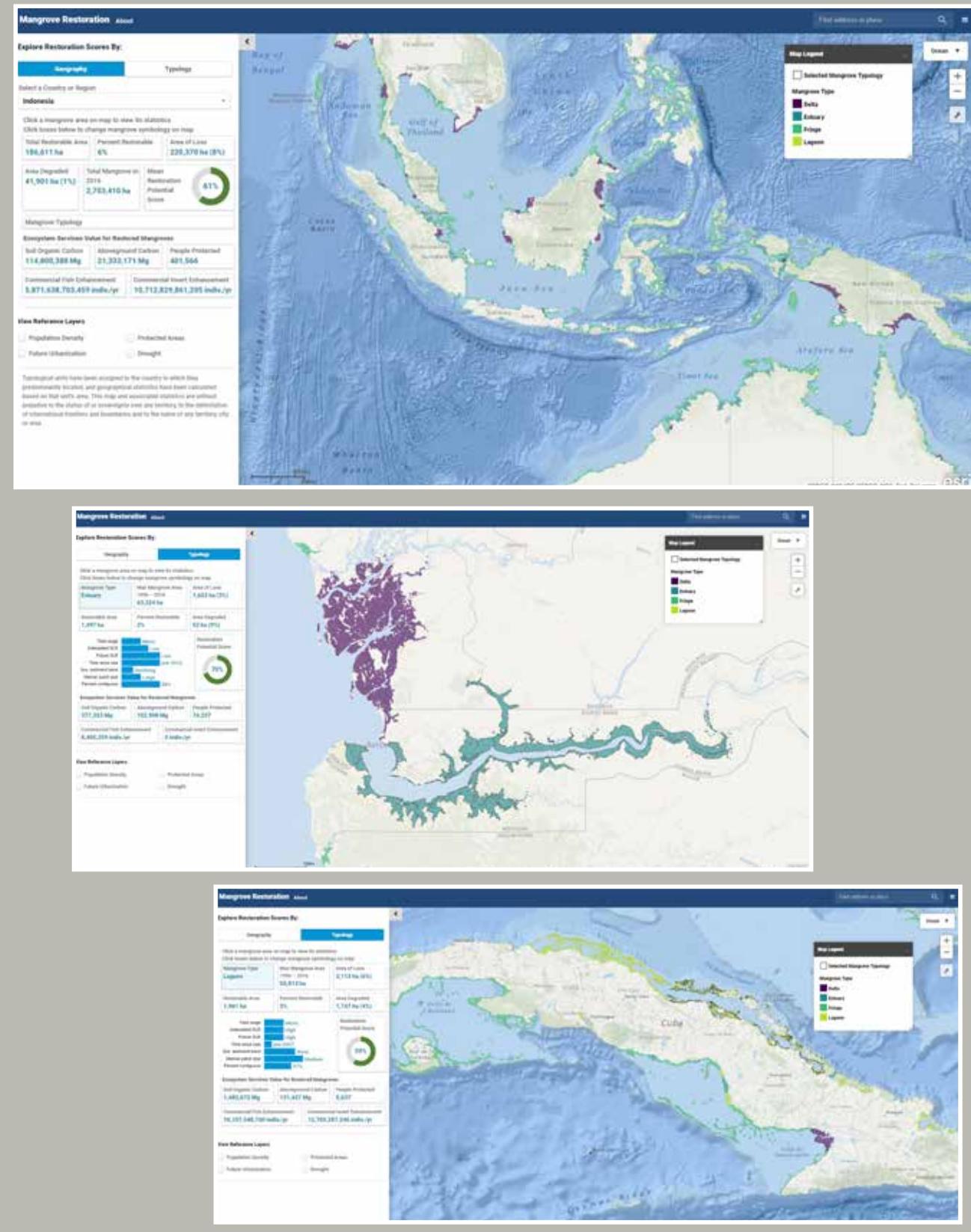
However, there is a need for more. The 60% of mangroves outside of protected areas still need to be safeguarded. Restoration efforts need to be encouraged and moved on from piecemeal efforts with highly variable success rates to a systematic, large-scale effort to return mangroves and strengthen local communities.



For many local communities, such as here in Micronesia, mangroves are a critical source of food security. © Ami Vitale/TNC

Map 9.1: The Mangrove Restoration Potential Map is available on maps.oceanwealth.org/mangrove-restoration.

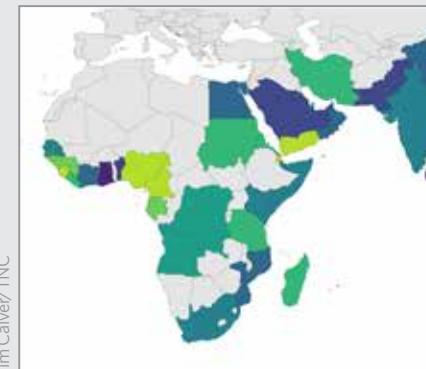
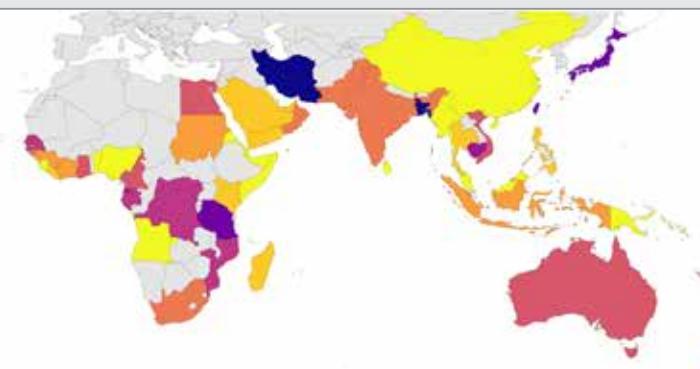
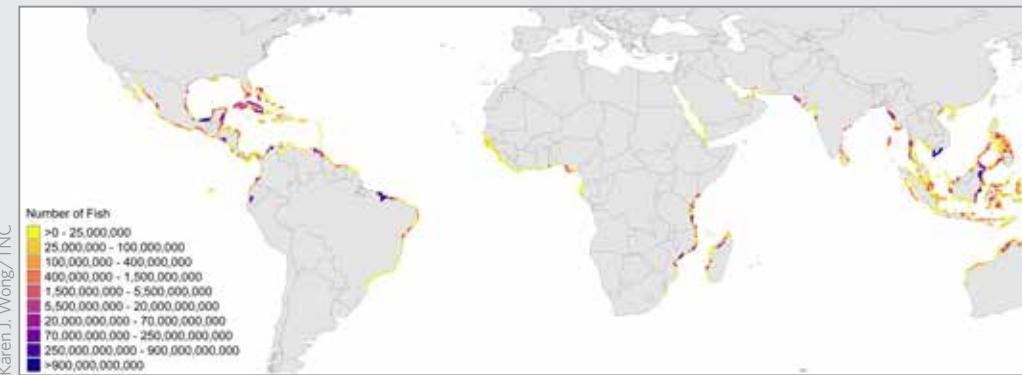
This mapping tool allows users to zoom from a global map and statistics to regions or individual countries (top panel, Indonesia), or to investigate the data by individual typological unit (lower panels, West Africa and central Cuba). In all cases, data are provided in the side panel, and clicking on key data elements re-draws the map to highlight these.



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Further information:

<http://oceanwealth.org/mangrove-restoration/>



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