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The pressures and opportunities for coral reef preservation and restoration in the Maldives

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Abstract

The ocean plays a fundamental role in the human well-being and development. Therefore, it is vital to preserve and restore the marine ecosystem services that are being damaged through climate change and anthropic activities, even more in countries such as the Maldives that has been classified under a high degree of exposure and vulnerability.

The purpose of this article is to provide an overview of the problems facing coral reefs in the Maldives through relevant scientific insights; outline the importance of reef conservation in this area, given their ecosystem services; and briefly discuss policies and mitigation plans for reef conservation in the Maldives against anthropic activities and climate change, including potential funding sources and how best to engage with local communities and other stakeholders in this effort. This will help to achieve several SDGs.

List of acronyms

CFA	Conservation Finance Alliance
EEZ	Exclusive Economic Zone
GDP	Gross Domestic Product
GEF	Global Environmental Fund
GFCR	The Global Fund Coral Reef
GHGs	Green House Gases
GPI	Genuine Progress Indicator
IMF	International Monetary Fund
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
MEA	Millennium Ecosystem Assessment
MEE	Ministry of Environment and Energy
NAPA	National Adaptation Plan of Action
PES	Payment for Ecosystem Services
PIM	Public Investment Management
PIMA TA	Public Investment Management Assessment - Technical Assistance
SAP	Strategic Action Plan.
SDGs	Sustainable Development Goals
SIDS	Small Islands Developing States
SLR	Sea Level Rise
SST	Sea Surface Temperature
TEEB	The Economics of Ecosystems and Biodiversity Foundations
UN	United Nations
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WTO	World Trade Organization
WWF	World Wide Fund for Nature

1 Introduction

In recent years, climate change and anthropic activities have been shown to affect many biological marine ecosystems and their services detrimentally (Claudet et al., 2020). The mitigation of climate and anthropic impacts has never been more imperative, especially for countries like the Maldives whose vulnerability to climate change impacts paired with a long-standing dependency to marine ecosystem services threaten their economies, well-being and livelihoods. Mitigation has been defined as an anthropic intervention to decrease the sources of greenhouse gases (GHGs) or improve their sinks (IPCC, 2014). Given the high biomass and biodiversity of corals that can be observed in the EEZ of the Maldives, this country is defined as a coral reef province (Naseer & Hatcher, 2004), which therefore requires reliable plans and policies to assist in safeguarding its marine resources with an understanding of the needs of

future generations. Coral reefs in the Maldives have a particularly important role in the livelihood and welfare of its people as a key resource in the economy through tourism and activities. And yet, the Maldivian corals remain poorly known as underdeveloped systems of data collection and analyses fail to fully highlight the underlying value of existing resources and the challenges associated with safeguarding them (Mukherjee & Chakraborty, 2013; Schoenaker et al., 2015; Radovanović & Lior, 2017). This article therefore aims to showcase points of view from different experts and fields on the importance of preserving and restoring the coral reefs in The Maldives.

2 What is the current state of coral reefs in the Maldives?

2.1. Geographical Overview Of The Republic Of Maldives

The Republic of Maldives is an archipelagic state composed of 1192 coralline islands located in the Indian Ocean, south-west of India and Sri Lanka. The small island nation, with its capital in Malé, extends for 860 km in longitude, from the Ihavandippolu Atoll in the northern hemisphere (7°06'54"N), to the southernmost atolls, Fuvahmulah and Addu, lying just under the equator (0°42'24"S). The islands, grouped into 20 atoll-systems for administrative purposes (Zubair et al., 2011), sit on top of two parallel submerged ridges with an average altitude of 1.5 m and no point higher than 2.3 m above mean sea level (Di Fiore et al., 2020). The islands are geographically fragmented over a total area of 115,300 km² (Maldives National Bureau of Statistics, 2020), but the land area only accounts for roughly 298 km² (Kothari & Arnall, 2017). The majority of the islands have a land area between 0.5 to 1 km² (Domroes, 2001), with no island larger than 10 km² (Stojanov et al., 2017).

Around 62% of the total resident population of the Maldives, estimated at around 530,953 individuals (World Bank, 2020a), is scattered throughout the country from central to peripheral islands. Numbers vary across atolls with a small population (between 1,000 and 4,500 inhabitants) to much fewer inhabited islands and atolls with over 15,000 inhabitants (Malatesta & di Friedberg, 2017). In contrast, the remaining 38% of the population lives in the capital island of Malé, in a surface area of less than 2 km² (Maldives National Bureau of Statistics, 2020). The urban centre of the island, one of the most densely populated in the world, has a population density over 39,000 inhabitants/km² and is expected to continue growing with increased urbanization (Bisaro et al., 2020). Indeed, the Greater Malé Region attracts communities from remote islands, owing to its wider access to both infrastructure and economic opportunities (MEE, 2016). To date, 187 islands are inhabited, 145 are resorts islands, structured following the so-called 'One island, one resort' model, and the remaining islands are dedicated to airports, plantations, industrial and agricultural activities, garbage storage and prisons, or remain uninhabited (dell'Agnese, 2019).

2.2. A Coral Reef Province

The Maldivian atoll ecosystems include a great variety of habitats, such as extensive shallow and deep lagoons, deep slopes, sandy beaches, and limited mangrove and seagrass areas. However, the Maldives are known across the globe to be an historical archetype of a coral reef province (Naseer & Hatcher, 2004). Coral reefs in the Indian Ocean, where the Maldives are situated, make up about 11% of the global reef area (Burke et al., 2011). The Maldivian reefs

cover an area of approximately 4,500 km², comprised of 2,041 distinct coral reefs (Naseer and Hatcher, 2004), corresponding to nearly 5% of the world's reefs and representing the 7th largest coral reef system in the world in terms of area covered (Spalding et al., 2001).

Maldivian reefs are known for the diversity of life forms that they host, despite vast knowledge gaps on the biodiversity they sustain. The major actors in coral reef ecosystems are usually stony corals, which are colonial animals able to build a skeletal structure made of calcium carbonate. The Maldives hosts some 300 species of reef building corals (Pichon & Benzoni, 2007) that support the incredible biodiversity of organisms living in Maldivian waters. The Maldives accounts for a total of 1,100 species of demersal and epipelagic fish, including sharks, 5 species of marine turtles and 20 species of whales and dolphins (Frazier et al. 1984; Anderson, 2005; Ali and Shimal 2016). The majority of species are invertebrates, including 400 species of mollusks, 120 species of copepods, 15 species of amphipods, over 145 species of crabs and 48 species of shrimps (Convention on Biological Diversity). This census of species is subject to change as these species are often cryptic, morphologically very simple and difficult to study from a taxonomical point of view (Maggioni et al. 2016, 2017a,b, 2021; Montano et al. 2015a,b; Seveso et al. 2020).

3 Why should coral reefs in the Maldives be protected?

3.1. A Unique Ecosystem Under Threat

The last decades have witnessed a continuous decline of coral reefs around the world. Only twenty-five states have jurisdiction in most of the world's warm-water coral reef ecosystems, however threats to these ecosystems trespass geographic barriers in several of these states and continue to increase. Exploitative uses of the ocean such as intense fisheries, coral and sand mining, and non-exploitative but damaging reef uses such as anchoring on reefs (Shareef, 2010) have resulted in a loss of topographic complexity and species diversity, leaving behind an unconsolidated substrate, which is only subject to further erosion. Coastal zones have undergone changes through the addition of hard structures such as seawalls, breakwaters and jetties, which have become the standard in many inhabited islands, as a direct consequence of the advance of human settlements towards beaches. This expansion has led to increased land reclamation, the creation of artificial islands and of new touristic resorts, which in turn introduce new risks linked to plastic pollution and emerging contaminants (Fallati et al. 2017; Saliu et al., 2018, 2022; Duvat, 2020; Pancrazi et al., 2020; Rizzi et al., 2020; Montano et al. 2020; Galli et al. 2021). Research indicates that coral reefs can effectively protect coastlines from tropical cyclones and other large wave impacts.¹ “Restored reefs could reduce wave energy immediately, becoming more valuable through the years as they grow, keeping pace with rising sea levels. While reducing risk, coral reefs also support biodiversity, improve water quality, and support fisheries and tourism.”² This is of relevance to the Maldives, as about over 80 per cent of the land area is less than one meter above mean sea level, so it is particularly at risk from future sea level rise.

In the Maldives specifically, multiple stressors are affecting coral reef communities, resulting in a rapid decrease in diversity, area coverage and ecological interactions in reef ecosystems.

¹Arc Center of Excellence Coral Reef Studies. 2018. Coral reefs protect coasts from severe storms.” April.

²Stanford Report. 2014. [Coral Reefs Provide Protection from Storms and Rising Sea Levels, Stanford Research Finds](#). The research was conducted by scientists from the University of Bologna, the Nature Conservancy, the U.S. Geological Survey, Stanford and the University of California, Santa Cruz.

The Maldivian reefs have been among the most affected areas in the world by climate change, thermal stressors, and related coral bleaching episodes with 60 percent to 100 percent coral mortality reported after the event of 1998 (Zahir, 2010), followed by another bleaching event in 2010 (Tkachenko 2012, 2015). The more recent event in 2015-2016 is to date considered the longest and most widespread global coral bleaching event (Hughes et al. 2018; Sully et al., 2019). The Maldivian reefs were severely affected: sea surface temperatures peaked from late April to mid-May 2016 with recorded temperatures over 32°C. The overall percentage of bleached corals was recorded at around 75%, including corals sitting as far as 15m depth (Ibrahim et al., 2017; Perry & Morgan 2017). Other stressors also include an increased recurrence of different epizootic disease caused by fungi, protozoa and bacteria (Montano et al. 2012, 2013, 2014, 2015c; Seveso et al. 2012, 2015), as well as by the anomalous outbreaks of corallivorous organisms that feed on corals, such as the crown-of-thorns seastar *Acanthaster* species and the cushion star *Culcita* species (Saponari et al., 2014, 2018; Montalbetti et al., 2019, 2022).

3.2. An Endangered Pillar Of The Maldivian Economy

The marine environment has always been fundamental to societal welfare and development in the Maldives (Collins, 2013). Coral reefs began to be used for building purposes in the 1970s to offer natural coastal protection and fisheries opportunities (Lam et al., 2019). This period saw the advent of tourism, which quickly became the economic sector with the highest growth rate, due in part to significant developments in island infrastructure that made tourism the country's main industry (World Trade Organization [WTO] 2019; Collins, 2013). Since 2015, the service sector has accounted for about 75% of the country's GDP (Maldives National Bureau of Statistics, 2020). Indeed, the Maldives' economy has grown fast since the 1970s, with a GDP which were among the lowest in the world and yet reached the level of upper-middle-income countries in the 2010s (Encyclopædia Britannica, 2020). However, tourism has been seriously affected by COVID-19, with the hotel occupancy rate falling from 73% in January 2020 (pre pandemic) to 69percent in February, 36% in March, 4% in April, 5.2% in May and 2.5% in June (Republic of Maldives. Tourism Yearbook, 2021). Consequently, in the first quarter of 2020, tourism revenues fell by 23.4%, and GDP contracted by 5.9% (World Bank, 2020b). While real GDP growth rebounded to 37% in 2021, it will likely remain below 2019 levels until 2023. It is projected that even if long and medium-term tourism stays strong, visitor arrivals will not return to pre-pandemic levels until 2023. Extra financial aid will be difficult to get due to the pandemic's global impact (World Bank, 2020b).

While coral reefs are a major factor in the Maldives' appeal as a tourist destination, coral mining has resulted in massive degradation of shallow reef-flat areas, with important negative impacts on coastal protection . This has called for the launch of monitoring programs (Risk & Scott, 1991), carried out by the Ministry of Fisheries and Agriculture which is mandated with an aspect of environmental management expressly associated with marine resources and fisheries. The majority of the work related to marine resources, fisheries, monitoring, and research on reef health is carried out by the Marine Research Centre, which in turn is regulated by the Ministry of Fisheries (Jaleel, 2013). To promote sustainable tourism the Maldives is (1) diversifying the products from tourism offered by the Maldives; (2) increasing the benefits of tourism accruing to local communities; (3) increasing the number of Maldivians employed in the tourism sector, (4) strengthening regulatory frameworks governing the tourism industry

and the monitoring capacity of relevant institutions; and (5) achieving sustainable growth in the guesthouse tourism sector (SAP, 2019).

4 Which funding is needed to preserve and restore coral reefs in the Maldives?

4.1 Funding From A Government Invested In Coral Reef Conservation

In 1978, the Maldives became a member of the World Bank, which has brought support for the implementation of 32 sustainable projects, requiring US\$295 million. The partnership aimed to help the country achieve more sustainable and inclusive growth, and improve the use of natural, human, and financial capital (World Bank, 2020a). Moreover, since 1983, the IFC has invested over US\$157 million in the Maldives (World Bank, 2020a). The International Monetary Fund (IMF) is providing financing solutions, publishing research on economic implications of climate change and providing policy advice to help member countries capture the opportunities of low-carbon, resilient growth. The Fund is also offering data analytics including through a Climate Change Indicators Dashboard, capacity development to help member countries address climate change challenges. Maldivian government continues to look for different ways to increase its private and public resources available for climate action. To this end, partnerships with the private sector, civil society, philanthropists, and local governments must secure climate finance—through annual budget increases and new budgetary contributions, local contributions, and Public Sector Investment Program allocations. Additionally, the Maldivian government through the establishment of a National Climate Change Trust Fund continues its efforts to attract climate finance through investments in projects, providing loans and innovating their financing mechanisms to increase low-emission and resilience development programs. The National Strategic Framework will be updated every five years to attract international climate finance, by prioritizing areas for donor support and establishing a system to track private and public climate finance flows. In order to finance investments in climate actions, the Maldivian government will also continue allocations from the Maldives Green Fund, among others, creating incentives for different stakeholders to invest in green development (MEE, 2020).

The cost of coral reefs restoration is high; it can range anywhere from US\$11,717/ha to US\$2,879,773/ha (Bayraktarov et al. 2016; Hein et al. 2018). Coral reefs protection can be financed in several ways: governments that provide financial support through direct government expenditures, market regulation, pollution credits and taxes, subsidies and fiscal policies (Iyer et al., 2018), can be paired with fees and taxation systems directed at users to generate resources for protected areas. Fees and taxation systems are methods to charge users of natural resources for the management costs of those resources (Iyer et al., 2018). The Maldives use a green tax, levied on tourists staying at resorts, hotels, or on vessels. The green tax is used in diverse projects like the Maldives Clean Environmental Project as well as for island sanitation, the establishment of sewage systems and the construction of regional laboratories for water research. This total green tax revenue between January and November 2020 amounted to around US\$21 million (Figure 1). Alternatively, debt-for-nature swaps can create very targeted funding for conservation (Iyer et al., 2018), defined by Quintela et al. (2003) as “a multiple-party transaction in which the sovereign debt of a country is forgiven or partially forgiven by its debtors, in exchange for certain commitments to biodiversity conservation by the indebted country.” The debt is usually owed in hard currency and the

creditors tend to be mature economies. For biodiversity offsets and insurance schemes, technical capacity and expertise are needed, thus requiring more time and resources.

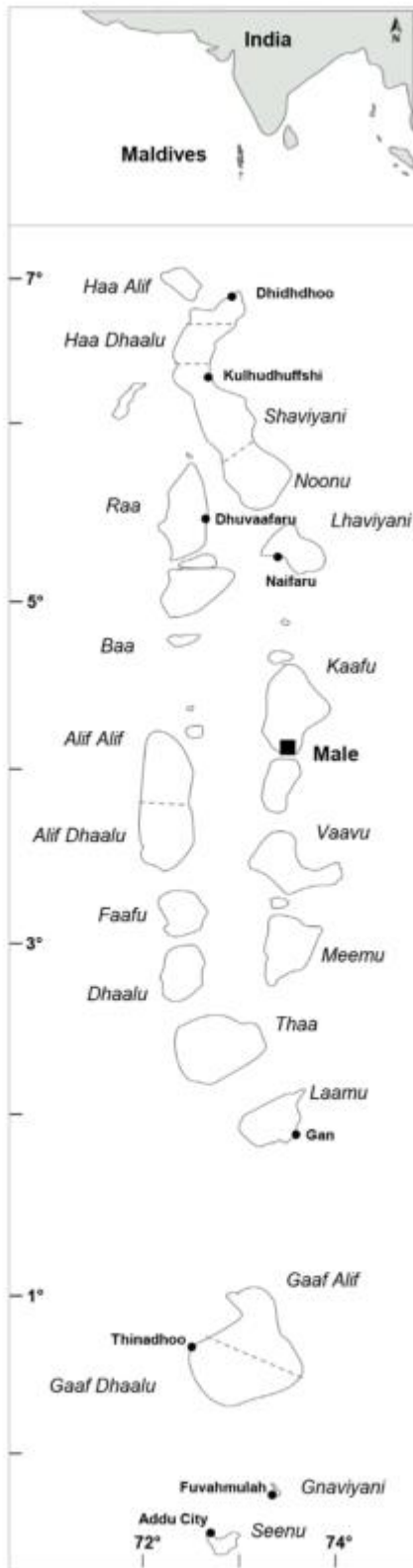


FIGURE 1
 Map of the Republic of Maldives showing its geographical position (upper panel) and a focus on its atolls (bottom panel). The 26 geographic atolls of the Maldives are here grouped and represented into 20 atoll-systems for administrative purposes. The names of the atolls are written in italics, while the names of the main cities are written in bold.

4.2. The Acknowledgement Of Socioeconomic Co-Benefits

One possible mechanism to support coral reef conservation that is popular among decision makers is based on payments for ecosystem services (PES). PES is defined as the payment that an ecosystem services owner (a landowner or community, for example) will receive to protect a specific ecosystem service, thereby supporting human well-being from both a socio-economic and ecological perspective (Costanza et al., 2017). This means that the coastal protection and maintenance of natural habitats and biodiversity (including fish stock) that are naturally provided by coral reefs potentially hold financial benefits for local communities. However, this approach has to be implemented with great care because, as Braat & de Groot (2012) explains, some advocates argue that “it is analytically more appropriate to conceptualize payments for ecosystem services as incentives for collective action rather than as quasi-perfect market transactions to solve market failures.” Alternative sources of funding for such ecosystem services include conservation trust funds that can provide targeted financial support for specific ecosystems (UN Environment, 2019). The Global Fund Coral Reef (GFCR) is a 10-year financial instrument specifically created to restore and protect coral reefs ecosystems. It is supported by the Conservation Finance Alliance (CFA), which is an investment and development plan. The GFCR acts as an investment link to bring funds for improved resilience of coral reefs and livelihoods of local communities, by providing grants for projects that can have both positive environmental and socioeconomical impacts. The investments provided by the GFCR are managed by BNP Paribas and supported by blue economy expertise from Althelia Funds (Mirova/Natixis). There are currently around \$125 million provided by donors, near \$375 million in partner assets and between \$2-3 billion unlocked from global private and public financial instruments (GFCR, 2021).

The relationship between education – social perception – valuation of ES must be carefully considered to develop a better approach for realistic valuation of nature. This approach is still a long way from being achieved coherently and productively but can be considered a valuable tool to mitigate climate change impacts and contribute to conservation. The participation of institutions will be vital to ensure biodiversity conservation and the sustainable use of ES in the long-term (TEEB Foundations, 2010). Furthermore, decision-makers must understand the complex interrelations between social, cultural, and economic factors and values. Policymakers and stakeholders can promote integrated coastal zone management with shared benefits and increased knowledge and research. New financial tools and mechanisms can help states gain access to additional resources to fill the capacity gap. The need to diversify and increase funding for coral reefs could fuel the implementation of a mechanism specifically for coral reef ecosystems conservation for the benefit of society alongside biodiversity.

5 Can adaptive governance of coral reefs be used in the Maldives?

5.1. Tools For A National Approach To Coral Reef Management And Conservation

The Maldivian Constitution states specifically in its Article 22 that “the State has a fundamental duty to protect and preserve the natural environment, biodiversity, resources and beauty of the

country for the benefit of present and future generations”. In addition, Article 67(h) states that “the Executive has the duty to prevent and protect the natural environment, biodiversity, resources and beauty of the country and to abstain from all forms of pollution and ecological degradation,” (Constitution of the Republic of Maldives, 2008; Dhunya et al., 2017). The Maldives has considerable scope for adaptive capacity, being part of The Commonwealth Blue Charter, which defends coral reef restoration and protection as well as approaches to sustainable blue economies and coastal fisheries (The Commonwealth Blue Charter 2018). Since the launch of a sea wall project around the capital Malé in September 1988, the government has implemented several projects aimed at adapting to environmental threats. Frontier analysis based on the positive relationship between the adaptation index and income levels suggests that distance to the frontier is large for the Maldives, among several countries (IMF, 2021). The green and adaptive infrastructure gap in the country is threatening both climate mitigation (renewables and nature preservation) and adaptation (coastal protection, water and waste management and resilient infrastructure).

Marine protected areas are among the most useful tools to reduce human pressures on coral reefs and restore their natural functions (Dryden et al., 2020). The Maldives have proposed to transform a vast part of the country as a UNESCO Biosphere Reserve to protect diverse key ecosystems and the related ecosystem services which can support the sustainable development of the Maldivian economy (Dryden et al., 2020)³. Yet, the marine area with currently implemented protection in 2022 covers less than 1% (614 km²) of the country’s 920,739 km² exclusive economic zone (EEZ) (Table 1).

Table 1. Marine Protection Status in Maldives

	Zones	Area (km ²)	% of EEZ
Implemented, of which	65	614	<1%
- Fully or highly protected	39	472	<1%
- Less protected /Unknown	26	142	<1%
Total designated	65	614	<1%

Source: Marine Protection Atlas (mpatlas.org/countries/MDV).

Note: EEZ = Exclusive Economic Zone.

5.2. Adapting To Climate Change

The Maldives is active in international climate fora and have shown early commitment to adaptation and mitigation plans for climate change. The number of scientific and technical assessments undertaken in the country since 1987 has reiterated the need for long-term adaptation to climate change (NAPA, 2006)⁴. The country was a prominent player in the negotiations that led to the United Nations Framework Convention on Climate Change (UNFCCC) and was the first to sign the Kyoto Protocol to the UNFCCC. The Maldives submitted the First National Communication (FNC) to the UNFCCC in 2001 following the implementation of the Maldives Greenhouse Gas (GHG) Inventory and Vulnerability

³ There is three biosphere reserve in the Maldives: Baa Atoll Biosphere Reserve designated in 2011, Addu Atoll Biosphere Reserve designated in 2020, Fuvahmulah Biosphere Reserve designated in 2020.

⁴ The Government of Maldives. National Adaptation Programme of Action (NAPA).

Assessment: A Climate Change Enabling Activity. The Maldives' strategy to reduce CO₂, CH₄ and N₂O emissions was created under the influence of the 2006 IPCC Guidelines.

In 2006, the Maldives adopted the National Adaptation Program of Action (NAPA), which lays out a framework for action built around the complex relationship between sustainability and adaptation to climate change.⁵ The first NAPA was then used in that same year to communicate the most urgent and immediate adaptation needs of the Maldives, as stipulated under UNFCCC Decision 28/CP and supporting the sustainable development goals (SDGs). Various national mitigation and adaptation strategic plans and policies have been enacted since then.⁶

Since the adoption of NAPA, the Maldives have implemented various non-structural interventions and institutional reforms in support of climate adaptation⁷, which involved developing guidelines, operating frameworks and action plans to help guide current and/or future planning. These plans are quite granular in nature, invariably outlining sectoral action plans for each vulnerable sector. And yet, implementation is lacking as the Maldives have not enacted any regulations to directly address climate change nor do they have concrete financing plans. This implementation gap is particularly problematic for coral reef protection and restoration, despite a bleaching response program created and developed to guide different stakeholders in the assessment, detection and response to coral bleaching events in the Maldives. The plan would be implemented through an early warning system, an incident response plan and communications strategies, with the help of task forces, coast guards, the Environmental Protection Agency and the Marine Research Centre (Marshall et al., 2017).

5.3. A Financial Challenge And Opportunity

Although investing in adaptation infrastructure can yield high returns, it is fiscally costly. Financing large adaptation investment will challenge fiscal space in many countries, which have deteriorated due to the COVID-19 pandemic (IMF, 2021). The Maldives featured among countries with high adaptation costs and limited fiscal space even before the COVID-19 (IMF, 2021). With worsening of the growth-debt trade-off post pandemic, financing adaptation costs would require further strengthening of policies – domestic revenue mobilization, expenditure rationalization, a prioritization of adaptation investment—, and/or mobilization of grant and concessional financing (IMF 2022).

The increased likelihood of adverse climate-change-related shocks calls for building climate-change resilient infrastructure in the Maldives. Building resilient infrastructure will yield dividends and cost-savings under worsened climate conditions. Fulfilling these infrastructure

⁵ NAPA was prepared with support from the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP). Preparations for this programme began in October 2004 and while the process was halted because of the South Asian tsunami of December 2004, a follow-up started again in February 2006. On mitigation, the [Update of Nationally Determined Contribution \(NDC\) of Maldives \(2020\)](#) by the Ministry of Environment lays out plans to reduce 26 percent of emissions by 2030 and to strive to achieve net zero by 2030, if there is adequate international support and assistance. To achieve the emission reduction targets, the NDC sets forth ambitious plans to increase the share of renewable energy in the energy mix through various initiatives.

⁶ i) Climate Change Emergency (2021), ii) Nationally determined Contribution (NDC) 2020, iii) Strategic Action Plan (2019-2023 (2019), iv) Maldives Climate Change Policy Framework (MCCPF) (2015), v) Disaster Management Act (2007), and (vi) National Adaptation Program of Action (2006).

⁷ On mitigation, the Maldives recently adopted the Climate Emergency Act, adopted (29th April 2021). It provides a complete framework for Maldives' ambitious plan to achieve net-zero carbon emissions by 2030. The Act mandates to submit the subsequent year's national carbon budget to the Parliament for approval 3 months before the end of each year.

needs requires a comprehensive analysis of investment plans with respect to their degree of climate resilience, their impact on future economic prospects, and their funding costs and sources. Melina & Santoro (2021), calibrating a theoretical model for the Maldives, show that there is a significant dividend associated with building resilient infrastructure⁸. Under worsened climate conditions, the cumulative output gain from investing in more resilient technologies increases up to a factor of two. Firstly, building resilient infrastructure in the Maldives can halve the losses in terms in GDP (Table 2) at the trough triggered by a natural disaster. Investing in resilient infrastructure yields a dividend even before a disaster occurs, as its greater gross rate of return and durability imply that its net return is higher (the greater durability is captured by a smaller depreciation rate of resilient infrastructure relative to that of standard infrastructure). The additional tax pressure required for reconstruction in the case of standard infrastructure would be (politically) infeasible. The supplementary increase in tax revenues should be of the tune of 6-7 percentage points of GDP, in the aftermath of a shock. Secondly, financing public investment (in standard or adaptation infrastructure) with higher taxation would lead to a sacrifice in terms of GDP, and private consumption and investment in the ramp up of the investment effort⁹. Grant financing can reduce this cost or eliminate it if it covers the investment plan in full. Melina & Santoro (2021) also highlight that it is more financially convenient for donors to help build resilience prior to the occurrence of a natural disaster rather than helping to finance the reconstruction afterwards.

TABLE 2 Maldives GDP composition.

Area	GDP composition
Agriculture and fishing	8%
Industry	11.83%
Manufacturing	2.49%
Services (includes tourism)	70.76%
Others	6.92

The World Bank noted that many strategies are “needed to explore potential financing for scaling nature action, including policy, debt, and non-debt instruments. There isn’t a single financial instrument that can provide all the financing needed to plug the gap in nature or climate financing. Rather, a broad range of financial structures and investment types should be considered, of course paying close attention to debt-limits, implications on concessional resources, macro- and fiscal realities,” (World Bank, 2022).

Access to concessional climate finance remains a challenge, however. Authorities stated that there are very few projects that are under global climate funds because it is difficult to access these funds owing to the bureaucratic process and the need for scientific evidence to qualify as climate ready (F&D, 2021). Some of the main obstacles to timely access to global climate funds seem to be the lack of capacity to satisfy preconditions for climate finance, including provision of scientific evidence and involved paperwork. In this context, given that the Maldives has limited fiscal space, particularly post COVID-19, the authorities reiterated their request to the international community to step up cooperation efforts through financial

⁸ Melina and Santoro. (2021). “Enhancing Resilience to Climate Change in the Maldives, IMF Working Paper No. 2021/096

⁹ The Maldives Monetary Authority (MMA) has recently joined IFC’s Sustainable Banking Network (SBN, January 2021). The primary objective was to formulate a National Sustainable Financing Framework with a clear roadmap to support broad based adoption of sustainable finance policies, including both improved environment and social risk management by financial institutions.

assistance, capacity development, and facilitation of access to global climate finance and at concessional rates. (F&D 2021)

5.4. A Strategy Within A Global Vision

Nations around the world can share common objectives for the sustainable management of marine ecosystems. They include (i) engaging in mitigation solutions to increased GHG concentrations in the atmosphere, while supporting adaptation in developing states and particularly SIDS; (ii) regulating and monitoring fish stock to maintain stocks under the targeted levels (science-based limits) while measuring, protecting and controlling adjacent ecosystems; (iii) leading integrated planning processes to avoid and decrease land-based sources of ocean pollution, emphasizing on waste treatment effectiveness; (iv) monitoring and controlling pollution from non-living resources, including shipping; and (v) integrating marine spatial planning and coastal zone management in physical reconstruction of the coastline (UN Environment, 2019). Policymakers must use both local knowledge systems in the field and ocean task forces driven by scientific knowledge to construct policy. International leadership is needed to ratify and implement international treaties, agreements and conventions (Stuchtey et al., 2020).

Coral reefs are classified as a priority and transboundary concern. However, the majority of coral reefs are under national jurisdiction and therefore challenging to characterize as global public goods even if they have the characteristics of common pool resources, despite being under threat from cumulative impacts of a range of human activities. It has been defined that shared concern, despite coral reefs not being a shared resource, can be the foundation for collective action, as outlined in the rationale of the Convention on Biological Diversity. In 2016, the United Nations Environment Assembly emphasized the need for protection of oceanic ecosystems through international cooperation, calling for an increase in governmental efforts to encourage financial and technical support from donors (UNEA, 2016; UN Environment, 2019). The idea of generating a supranational ocean agency was presented on the UNESCO program “Man and the Biosphere” (Bridgewater, 2016). This ocean agency can be generated by UN resolution or can be generated by founding groups that can stimulate other stakeholders to get involved (Stuchtey et al., 2020),

There has never been a more urgent need for national strategies coherently put together within a global vision for a resilient ocean, from coral reef ecosystems to the global climate system. Initiatives like the UN decade of Ocean Science for Sustainable Development (2021-2030) and the UN Decade of Ecosystem Restoration (2021-2030) present an opportunity for such structured action, including by aggregating funding related to coral reef management on local, national and international scales. Addressing financial and anthropogenic capacity challenges is now critical. Limited capacity is a central barrier to international reef-related commitments in different countries, particularly in SIDS (Small Island Developing States), less developed countries, and some developing countries (UN Environment, 2019).

6 Conclusion

Climate change and anthropic activities have been shown to affect many biological marine ecosystems and their services adversely, including coral reefs. While the exact biological and chemical impacts of climate change and ocean acidification on coral reefs remain unclear in

the Maldives, multiple stressors, including epizootic disease, are affecting coral reef communities, resulting in a rapid decrease in diversity, area coverage and ecological interactions in reef ecosystems. The Maldivian reefs have been among the most affected areas in the world by climate change, thermal stressors, and related coral bleaching episodes with 60% to 100% coral mortality reported. Investing in coral reef restoration, would help to rebuild resilience through preservation of biodiversity and secure ecosystem services supporting coastal protection, fisheries, food security, tourism, among others (Lam et al. 2019). Coordinated efforts from the government, organizations and all affected stakeholders are needed to improve conservation strategies towards facilitate the livelihoods and well-being of the Maldivian population. Therefore, a sustainable plan with shared benefits for all stakeholders paired with an updated set of regulations is needed in the different sectors impacted by coral reefs degradation. Long-term monitoring mechanisms for coral reef protection must rely on the active participation of local communities. The Maldivian government is currently implementing the SAP 2019–23, which provides a central policy framework aiming to monitor progress in different sectoral areas in order to enhance the livelihoods and well-being in the country. This framework includes metrics of well-being across diverse sectors, such as blue economy, caring state, family dignity, good governance, and decentralization, involving topics like clean energy, fisheries and marine resources, tourism, health, education, sports, gender equality, public service reforms, among others. However, the pace of its implementation remains slow due to a lack of facilitating regulations and limited access to concessional climate finance; this framework and its underlying programs in the SAP should therefore adapt and morph into early warning systems, incident response plans and communications strategies. Some of the main obstacles to timely access to global climate funds appears to be the lack of capacity to satisfy preconditions for climate finance, including provision of scientific evidence and involved paperwork. Many strategies are needed to explore financing tools to scale-up nature action, including policy, debt, and non-debt instruments (World Bank 2022) and debt-nature swaps could also be considered in the overall scheme. Alternative sources of funding for specific ecosystem services include conservation trust funds that can provide targeted financial support for specific ecosystems (UN Environment, 2019), such as the Global Fund Coral Reef (GFCR), which is a 10-year financial instrument specifically created to restore and protect coral reefs ecosystems.

The ocean is the cornerstone of the human development of small island developing states (SIDS), making coral reefs the ‘rainforests of the sea’, able to provide benefits to millions of people worldwide (Mulhall, 2008; ORG, 2007; Mongbay, 2011). The Maldives’ economic development relies heavily on the islands’ ecosystems and particularly the coral reefs, which are under continuous exposure from climate change threats. It is imperative that these challenges are met urgently and managed sustainably which local communities, whose inclusion can change the perception of protected areas as unproductive to a productive national asset. Coral reefs are classified as a priority and transboundary concern, therefore this sustainable management priority is one of global concern and not restricted to Maldivian waters only. There is an urgent need to put together national strategies coherently within a global vision for a resilient ocean, from coral reef ecosystems to the global climate system. Initiatives like the UN decade of Ocean Science for Sustainable Development (2021-2030) and the UN Decade of Ecosystem Restoration (2021-2030) present an opportunity for such structured action, particularly as they aggregate funding related to coral reef management on local, national and international scales as financial and anthropogenic capacity challenges remain a major hurdle to effective conservation. Indeed, limited capacity is a central barrier to international reef-related commitments in different countries, particularly in SIDS (Small Island Developing States), less developed countries, and some developing countries (UN

Environment, 2019). Multilateral organizations like the International Monetary Fund together with other Multilateral Development Banks are well placed to provide financial solutions and capacity development and scale up nature action by leveraging private sector participation. A globally relevant sustainable management of marine ecosystems should rely on (i) engaging in mitigation solutions to increased GHG concentrations in the atmosphere, while supporting adaptation in developing states and particularly SIDS; (ii) regulating and monitoring fish stock to maintain stocks under the targeted levels (science-based limits) while measuring, protecting and controlling adjacent ecosystems; (iii) leading integrated planning processes to avoid and decrease land-based sources of ocean pollution, emphasizing on waste treatment effectiveness; (iv) monitoring and controlling pollution from non-living resources, including shipping; and (v) integrating marine spatial planning and coastal zone management in physical reconstruction of the coastlines.

SUPPLEMENTARY MATERIAL: ES VALUATION METHODOLOGY THAT CAN BE APPLIED TO CORAL REEFS IN THE MALDIVES

An ecosystem is a complex, dynamic, and adaptive open system of animals, plants, microorganisms, and the natural environment coexisting interdependently (European commission, 2013). The association between physical elements and natural species is known as natural landscapes, which provide valuable ecosystem services to humanity (MEA, 2005; Díaz et al., 2006). The more common definition of ecosystem services found in the literature focuses on the ecological characteristics, functions, or processes of an ecosystem that directly or indirectly contribute to human well-being (Costanza et al., 1997; MEA, 2005).

Coral reefs are among the most economically and ecologically valuable ecosystems on our planet, providing a vast number of ecosystem services such as food sources, raw materials, genetic diversity, substrate, erosion prevention, coastal protection, bioprospecting, tourism, and fisheries production, among others (De Groot et al., 2012; Bindoff et al., 2019). Coral reefs have been defined as the ‘rain forests of the sea’ providing benefits to millions of people worldwide (Mulhall, 2008; ORG, 2007; Mongbay, 2011). Worldwide coral reefs cover less than 0.1% of the ocean, and yet they support over 25% of marine biodiversity, as well as near 250 million people directly through tourism, fish production, and coastal protection.

Dryden et al. (2020) separate the value of corals as “direct” and “indirect”. Extractive activities like fisheries, mariculture, aquarium trade, pharmaceutical, and non-extractive activities like tourism, research, education, aesthetics, and culture are part of the direct values set. Biological services such as the support of seabirds, turtles, and marine mammals, the creation of connected ecosystems, and physical services like wave break and erosion of reef structures producing sand for beach maintenance and island formation are part of the indirect values set.

Coral reefs have intrinsic value, which if considered through the prism of human benefits, is defined as “aesthetic” or “cognitive”. Aesthetics, an unconscious and immediate result of cognitive mechanisms, can control and regulate emotions, thereby having a direct impact on human cognitive development and cultural enrichment (Blood & Zatorre, 2001; Kawabata & Zeki, 2004; Reber et al., 2004; MEA, 2005). And yet, the majority of studies on ES have focused on economic benefits such as regulating and provisional services and their effect on biodiversity (Hooper et al., 2005; Cardinale et al., 2012), while the relationship between biodiversity and aesthetic value has scarcely been explored (Tribot et al., 2016). The few

assessments of aesthetic values of marine ecosystems have highlighted that recreational areas are highly threatened by anthropic activities (UNEP, 2006), and should therefore be considered in conservation planning strategies (Kalivoda et al., 2014). Aesthetic experiences can generate ecosystem conservation action through social motivation. Hence, the landscape can be a good medium to educate the general public on environmental issues (Gobster et al., 2007; Jorgensen, 2011), and promote beauty and ecology through the relationship of “functional beauty” (Parsons & Carlson, 2008), building both on aesthetic experiences and ecological understanding (Tribot et al., 2016).

Erosion protection, flooding protection and protection from monsoons are direct ES from coral reefs, evaluated close to \$22 billion per year in the Maldivian (REF). The South Asian Monsoon (SAM) generates changes in the atmospheric and ocean circulation of the tropical Indian Ocean, impacting rainfall on land and oceanic primary productivity (García et al., 2019). The replacement cost of coral reefs for shoreline protection is evaluated around \$2.75 million per km² (Hedges, 2018) contributing to the oceanic expansion and damage (Firth et al., 2016; Bishop et al., 2017).

Complex valuation methodologies

The valuation of coral reefs can play a vital role in their management, reflecting the benefits perceived (Ahmed et al., 2004). They are crucial, not only as a source of livelihood to dependent coastal communities but also to national and international population, due to their contribution to food security, tourism, coastal protection, and indicators of climate change (Fabres, 2004). Valuing those services must therefore include marketable values (functions, products, and services) and non-marketable values (cultural importance, opportunities, and simple existence) (Ahmed et al., 2004).

The environmental and socioeconomic context will influence the choice of the most appropriate valuation method for a given service. Provisioning services are often valued through direct market pricing methods while regulating services are mainly valued using replacement cost and avoided cost. Habitat is also valued through direct market pricing, contingent value, and factor income while cultural services are mainly valued using travel cost and direct market pricing.

In addition, it should be emphasized that “values derived from different valuation methods may not be measuring the same economic construct, hence, values from different methods may not be directly comparable” (De Groot et al., 2012). Coral reef tourism provides approximately 43.17% of GDP and has a value of US\$ 205,505/km² /year (Spalding et al., 2017), for the whole country this equates to a total of approximately US\$ 1 billion/year.

Different methodologies are needed to define and value the services derived from an environment’s functions however there are several limitations and complementarities in each method, from qualitative methods such as semi-structured interviews to quantitative methods like questionnaires (Rasmussen et al., 2016). Other examples include site-scale and landscape-scale modelling, biophysical observations and economic studies (Bagstad et al., 2013). In addition, some services are not always known by those who benefit from them, therefore the collective preferences are not the sum of individual preferences, and there is no “single model fits all” scenario. Many systems are nonlinear, the different scenario approach is not predictive

and must be paired with informed and up-to-date policies and decision-making (Hilmi et al., 2017).

Some authors argue that the most appropriate methods rely on the value of the market trade and the net factor income (Ngazy et al., 2004; Ahmed et al., 2004; Cesar and Chong, 2004), which estimate the relationship between economic activity and coral reefs. It is important to include the replacement cost as well (Ahmed et al., 2004) due to the vital role of reefs in protection against natural hazards. Non-market values are encompassed through methods such as Hedonic pricing, contingent valuation price, and travel costs (Costanza et al., 2017; Hilmi et al., 2017). This type of valuation has gained in relevance due to the integration of objectives of social justice, sustainability, and economic efficiency into public and private decision-making processes (Farley, 2012; Jacobs et al., 2016), thereby generating metrics such as GPI (Genuine Progress Indicator), which considers both social and environmental costs of ES management (Kubiszewski et al., 2013; Reyes et al., 2013; Long & Ji, 2019). Interestingly, most current valuation methods assign a higher value to a scarce resource with a higher acquisition capacity than a vital resource which is more abundant (WWF Perú, 2014). Note, however, that “values from different valuation methods may not be measuring the same economic construct, hence, values from different methods may not be directly comparable” (De Groot et al., 2012).

Ecosystem Services at risk

Despite the key impact of coral reefs on coastal human development, around 24% of the world’s corals are under imminent risk of collapse, and another 26% are under a longer-term threat of collapse (The Commonwealth Blue Chart, 2018; Hein et al., 2020). The recent report of the Intergovernmental Panel on Climate Change (IPCC) highlights that around 90% of corals could be damaged and lost by 2050, even in a scenario with an increase limited to 1.5°C (Bindoff et al., 2019). There are many environmental stressors like overfishing, destructive fishing practices, pollution, and habitat destruction that are harming coral reefs in the Indian Ocean and Asia (Burke et al., 2011; Lam et al., 2019).

The degradation of ecosystems and their associated services is harming many of the world’s poorest people and communities, becoming a key driving factor of poverty in vulnerable countries (TEEB Foundations, 2010). The interlinkages between ES will multiply adverse effects of the degradation of ecosystems: for example, coral bleaching will disperse species and decrease available biomass, while also reducing tourist arrival rate and driving the collapse of fisheries, thereby decreasing the food resources and protein intake of a whole community (Hilmi et al., 2021). The recovery of the stock can take a long time, which will significantly decreasing the well-being of a population or community dependent on this marine resources (TEEB Foundations, 2010).

For example, the loss of coastal protection provided by coral reefs from sea level rise (SLR) will have projected impacts on coastal ecosystems from loss of functionality and biodiversity, to lateral and inland migration, and habitat contraction. This adds to compound risks associated with climate change as warmer regions will have a vaster impact on SLR heat uptake than cold regions (Oppenheimer et al., 2019), which may drive fishers to increase their effort to get resources in already overexploited areas. Consequently, an extensive number of destructive and illegal practices like dynamite fishing are perpetuated across Southeast Asian countries (McClanahan and Arthur, 2001; Allen and Werner, 2002; Cinner, 2009; Kimura et al., 2014), in turn directly harming destroying coral reef habitats and their associated species and thus,

income sources (Souter & Linden, 2005; Lam et al., 2019). In addition, the increase in temperature due to climate change is generating massive bleaching events, affecting the growth, development, and survival of corals and fish communities through habitat degradation (Paddock et al., 2009; Anlauf et al., 2011; Pandolfi et al., 2011; Lam et al., 2019).

Ocean heat absorption has increased, and consequently sea surface temperature (SST), coral reefs bleaching, and ocean acidification. The SST in the Maldives can change between islands, but has generally increased across the islands over the last two decades beyond the resilience levels of local coral reefs (Pearce, 2020). This has caused two massive bleaching events in the area, first in 1997/1998 and then in 2016. During the first event in shallow areas around 80% of corals either completely or partially bleached (Rajasuriya et al., 2002; Dryden et al., 2020). Ibrahim et al. (2017) explain that recent studies about the 2016 bleaching events show that 73% of corals on shallow (<13 m) reefs were negatively impacted.

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