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Chapter

Coral Reef Deterioration and Livelihoods of Coastal Communities: An Economics Perspective

Pasita Chaijaroen

Abstract

This chapter focuses on how coral reef deterioration impacts the well-being of the affected coastal communities. In a macro-level perspective, the chapter discusses 1) how coral reefs socioeconomically benefit humans and 2) how coral reef deterioration impacts humans. This part of the discussion sheds light on several adverse effects of coral reef degradation ranging from reductions in food availability and income to losses of jobs and built capital. In a micro-level perspective, the socioeconomic impact of coral reef degradation on vulnerable coastal communities is illustrated through a case study of the 1998 coral bleaching in Indonesia. The households affected by this bleaching event experienced a large income shock, which translated into reduced protein consumption and impeded child development. The chapter then concludes with two broad policy recommendations drawn from both the macro- and micro-level discussions. First, reef conservation and restoration are economically viable investments due to the immense socioeconomic values of coral reefs. Second, policy interventions are required to mitigate impacts of coral reef degradation on the vulnerable groups and to facilitate the adaptation process.

Keywords: human-coral interactions, coral reef degradation, coral bleaching, Indonesia, economic values of coral reefs

1. Introduction

The oceans cover more than 70% of our planet [1] and provide immense socioeconomic benefits to humans. For example, the oceans provide livelihoods to more than three million people worldwide [2]. In addition, 350 million jobs around the world are related to the oceans, and one billion people in developing countries rely on fish as their main source of protein [1]. These benefits on jobs and income are enjoyed more by developing countries rather than by the Organization for Economic Cooperation and Development (OECD) countries [2], suggesting the important role of marine resources in global socioeconomic development.
Coral reefs benefit the marine ecosystems in various ways—many of which translate into goods and services that sustain human livelihoods. Table 1 exhibits that humans derive various goods from the coral reefs, from food products to raw materials and live fishes [3, 4]. Coral reefs also provide crucial services to both the marine ecosystems and humans. For example, coral reefs serve as habitats for juvenile fishes and help protect shorelines against waves and storms.

Coral reefs are closely tied to the livelihoods of millions of people worldwide. Each year, almost $30 billion in net benefits are realized from three main functions of coral reefs: fisheries production, tourism, and shoreline protection [5]. When accumulated

<table>
<thead>
<tr>
<th>Goods</th>
<th>Renewable resources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Seafood products</td>
</tr>
<tr>
<td></td>
<td>• Raw materials/starts for medicines</td>
</tr>
<tr>
<td></td>
<td>• Raw materials (seaweed, materials for jewelry and decoration, etc.)</td>
</tr>
<tr>
<td></td>
<td>• Live fish and corals for aquarium</td>
</tr>
<tr>
<td></td>
<td>• Mining of reefs</td>
</tr>
<tr>
<td></td>
<td>• Coral blocks, rubble, and sand for building</td>
</tr>
<tr>
<td></td>
<td>• Raw materials for lime and cement</td>
</tr>
<tr>
<td></td>
<td>• Mineral oil and gas</td>
</tr>
<tr>
<td>Ecological services</td>
<td>• Shoreline protection</td>
</tr>
<tr>
<td>Physical structure services</td>
<td>• Buildup of land</td>
</tr>
<tr>
<td></td>
<td>• Promoting growth of mangroves and seagrass beds</td>
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<tr>
<td>Biotic services</td>
<td>• Maintenance of habitats</td>
</tr>
<tr>
<td></td>
<td>• Maintenance of biodiversity and a genetic library</td>
</tr>
<tr>
<td></td>
<td>• Regulation of ecosystem processes and functions</td>
</tr>
<tr>
<td></td>
<td>• Biological maintenance of resilience</td>
</tr>
<tr>
<td></td>
<td>• Biological support of other ecosystems via mobile links</td>
</tr>
<tr>
<td></td>
<td>• Export of organic production and plankton to pelagic food webs</td>
</tr>
<tr>
<td>Biogeochemical services</td>
<td>• Nitrogen fixation</td>
</tr>
<tr>
<td></td>
<td>• Carbon dioxide and calcium budget control</td>
</tr>
<tr>
<td></td>
<td>• Waste assimilation</td>
</tr>
<tr>
<td>Information services</td>
<td>• Monitoring and pollution record</td>
</tr>
<tr>
<td></td>
<td>• Climate record and control</td>
</tr>
<tr>
<td>Social and cultural services</td>
<td>• Recreation activities</td>
</tr>
<tr>
<td></td>
<td>• Esthetic values and artistic inspiration</td>
</tr>
<tr>
<td></td>
<td>• Sustaining the livelihood of communities</td>
</tr>
<tr>
<td></td>
<td>• Parts of cultural, religious, and spiritual values</td>
</tr>
</tbody>
</table>

*Source: Adapted from [3, 4].*

**Table 1.**
*Good and services provided by coral reefs.*
over a 50-year period, the net benefits will total to almost $800 billion in net present value terms [5].

Unfortunately, coral reefs around the world have been suffering from various stressors in recent years. As of 2003, 27% of coral reefs were permanently lost [5]. 90% of all coral reefs might be lost by 2050 even when all the objectives of the Paris Agreement are accomplished [6]. Human threats account for the majority of coral reef degradation and include activities such as coastal development, sand and coral mining, overfishing and destructive fishing, and water-shed pollution [7]. Natural threats to coral reefs include storms [8], ocean acidification, and coral bleaching events [7]; these natural threats are often exacerbated by human activities.

Human livelihoods are closely tied to the oceans; therefore, coral reef degradation could impose significant socioeconomic threats on economies and communities around the world. Section 2 will discuss economic benefits provided by coral reefs in the three main socioeconomic activities: fisheries, tourism, and shoreline protection. The section will also paint a picture of socioeconomic losses due to coral reef degradation in these sectors.

While the socioeconomic losses from coral reef degradation will be experienced worldwide, the most vulnerable group is small island nations and developing countries near the oceans. Some low-income countries and small island states derive more than 20% of their GDP from tourism and other ocean-related sectors compared to the less than 2% in high-income countries [2]. These vulnerable states usually have with few other economic and livelihood alternatives. Nine countries have been identified by [7] as most vulnerable to coral reef degradation: Haiti, Grenada, Philippines, Comoros, Vanuatu, Tanzania, Kiribati, Fiji, and Indonesia. These countries rely on reefs significantly with limited adaptation capability, but their reefs are facing high levels of threats. These aspects will be explored in Section 3 using a case study of the 1998 mass coral bleaching in Indonesia.

While some coral reefs were deemed permanently lost [5], some can still be replenished and restored. Coral reef conservation and restoration are usually economically viable because their benefits dwarf their costs by several times. Section 4 will discuss this policy aspect in detail. In addition to conservation and restoration, adverse effects of coral reef degradation call for policy interventions in terms of mitigation and adaptation. These policy implications will also be elaborated in Section 4.

2. Key socioeconomic benefits from coral reefs and consequences of reef degradation

Humans rely on coral reefs for various goods and services (see Table 1 for detail). Each year, almost $30 billion in net benefits are realized from coral reefs\(^1\) [5]. Of the many goods and services that human derive from coral reefs, three key ones have received significant attention in the economic literature: fisheries, tourism, and shoreline protection (see Table 2). Each of these functions will be discussed in detail as follows.

\(^{1}\) Net benefits are defined as total benefits minus total costs. When accumulated into a net present value term over a 50-year period, these net benefits total to almost $800 billion, assuming a discount rate of 3%.
2.1 Fisheries

Coral reefs are known for their significant contribution to the abundance of fish, from those that live on the reefs to those that rely on the reefs ecologically. For example, coral reefs serve as grounds for spawning, nursery, breeding, and feeding for many species [3]. Coral reefs also export organic matters and different types of plankton and, hence, support the pelagic food web [3]. Coral reefs, therefore, provide immense economic values to fisheries. For instance, in 2017, commercial fisheries in the Coral Triangle area and the Mesoamerican Reef provided up to $5.85 billions and $480 millions in total economic returns, respectively [9].

Income is not the only benefit that humans derive from fisheries; fish is a significant source of protein for humans. 3.3 billion people around the world derive 20% or more of their animal protein intake from fish [10]. Fish accounts for at least 50% of animal protein consumption in many developing nations, e.g., Bangladesh, Ghana, and many small island developing states [10]. In particular, many developing island nations depend heavily on coral reefs as a food source; island populations usually have limited options when it comes to protein sources [9].

In addition to providing food, the fisheries sector also provides around 39 million people around the world with jobs [10] and, consequently, supports their and their family’s livelihood. Similar to the reliance for consumption, developing and small island countries are more likely to depend on the oceans for jobs than other countries. Most of the people working in fisheries and aquaculture are in developing countries and in small-scale, artisanal fisheries [10].

Coral reef deterioration can translate into adverse effects in the fisheries sector. While coral reef degradation can improve reef fisheries productivity in the short term when benthic turf and invertebrates increase and reef structures are still intact [11], the long-term effects are likely to be negative [11, 12]. Abundance of many species targeted by reef fisheries will eventually decline because of changes in habitat structures as well as food sources [12].

Given the world’s significant reliance on fisheries, coral reef deterioration can have devastating effects on income, jobs, and consumption of millions of people around the world. Small-scale and artisanal fisheries have been identified as more vulnerable to

<table>
<thead>
<tr>
<th>Goods/services</th>
<th>Potential net benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tourism/recreation</td>
<td>9.6</td>
</tr>
<tr>
<td>Coastal protection</td>
<td>9.0</td>
</tr>
<tr>
<td>Fisheries</td>
<td>5.7</td>
</tr>
<tr>
<td>Biodiversity value</td>
<td>5.5</td>
</tr>
<tr>
<td>Total</td>
<td>29.8</td>
</tr>
</tbody>
</table>

Source: [5].

Table 2. Annual potential net benefits of coral reefs in USD billions.

2 The total economic returns consist of the direct economic impact from fisheries income and the indirect economic impact from the fisheries sector’s spending on other sectors’ goods and services. This report focuses only on commercial fisheries; therefore, the reported returns are underestimated.
changes in fish stocks and fishing conditions than commercial fisheries because they are more constrained, for instance, by limited mobility, capital, and access to credits [13, 14]. Cultural values, limited access to international markets, and a lack of alternative livelihoods also reduces artisanal fisheries’ capacity to adapt to these changes [14–16].

2.2 Recreation and tourism

Coastal tourism constitutes a large part of the travel and tourism industry, one of the largest industries in the world. Coral reefs are the backbone of coastal tourism, from serving as dive sites to providing by-product attractions such as white-sand beaches, serene seas, and beautiful waters. Each year, over 350 million people visit coral reef coasts in 102 out of the 117 countries and territories with coral reefs around the world [6].

The tourism value of coral reefs is estimated to be $37.8 billion per year. This value, however, is derived from only about 30% of the world’s coral reefs because the rest of them are too remote [6]. For many countries, coral reefs are vital to their income, economy, and livelihoods. For example, 26 countries/territories earn more than a quarter of their GDP from tourism. In addition, many major coral-reef destinations are in developing small island nations which have few other alternative livelihoods [6].

Coral reef degradation, therefore, could have tremendous effects on many economies around the world. Coral reef degradation could lead to declines in the number of tourists [17] and the number of dives Ceasar et al. [18], as well as destination changes [19, 20] and reduced willingness to pay for coral reefs [17, 19]. While parts of the economic losses are lost income to businesses and workers in the tourism sector, a significant portion of these losses are tourists’ loss of welfare. Many tourists are aware of coral reef degradation, though the degree varies by destinations [17, 20, 21]. This awareness is usually associated with reduced tourist satisfaction [17, 19, 22] resulting in a lower willingness to pay for coral reefs and decreased tourist welfare [17, 19].

Past research has shown that total economic losses in tourism from coral bleaching range from several thousands to millions of US dollars per site event [17, 18, 23]. For example, the 1998 coral bleaching event resulted in approximately $350,000 loss in total welfare per year in Palau [17]. The coral bleaching event in 2010 was associated with an economic value loss of $50–80 millions in Thailand, Indonesia, and Malaysia [23].

2.3 Shoreline protection

More and more of the world’s population are living near coastlines. Almost 2.4 billion people live within 100 km of the coast; people living in coastal communities represent 37 of the world’s population as of 2017 [24]. In addition to housing a significant proportion of the world’s population, the coastlines around the world are also filled with built infrastructure and properties. Damages to coastal areas, therefore, extend to not only humans but also the land and built capital.

Risks across the shoreline, including potential damages from flood and storm, have been increasing. In the first decade of the 2000s, 4.3% of the world’s GDP are susceptible to tropical cyclones, a significant increase from the 3.6% in the 1970s [25]. Risks of economic losses from cyclones increased in all regions, with the average annual GDP exposed to cyclones tripled from $25.7 billion in the 1970’s to 1576.5 billion in the
first decade of the 2000s. While the average global GDP exposed to floods is smaller at 100 billion in the first decade of the 2000s, this exposure also tripled from that in the 1970s [25].

Coral reefs have been found to play a significant role in protecting shorelines from land erosion and damages from floods and storms. This protection extends over 150,000 km of coastlines in more than 100 countries around the world [7]. According to a meta-analysis of over 200 studies, coral reefs, on average, reduce wave energy by 97% and, therefore, protect shorelines against winds and storms. Most of this protection (86%) is derived from reef crests [8]. Over 100 million people are expected to benefit from coral reefs’ shoreline protection and, hence, the reduced risks of flooding and storm damages. Specifically, up to 100 million people are living below 10-m elevation and within 10 km of a reef. Extending this range a little bit further to within 50 km of reefs, there are about 197 million people who live below 10-m elevation. Table 3 exhibits the 15 countries with the highest number of people living in this latter range.

When quantified into dollar amounts, shoreline protection benefits could dwarf economic benefits from fisheries, aquaculture, and tourism [27]. A recent global study [26] finds that coral reefs reduce expected damages from storms by more than $4 billion per year. With a 1-m change in reef profile (i.e., the without reef scenario), the storm damages could have more than doubled (118%). In addition, flooding of land would have increased by 69% and affected 81% more people each year in the without...

<table>
<thead>
<tr>
<th>No.</th>
<th>Number of people</th>
<th>Annual averted damages</th>
<th>Annual averted damages/GDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indonesia</td>
<td>41</td>
<td>Indonesia 639</td>
</tr>
<tr>
<td>2</td>
<td>India</td>
<td>36</td>
<td>Philippines 590</td>
</tr>
<tr>
<td>3</td>
<td>Philippines</td>
<td>23</td>
<td>Malaysia 452</td>
</tr>
<tr>
<td>4</td>
<td>China</td>
<td>16</td>
<td>Mexico 452</td>
</tr>
<tr>
<td>5</td>
<td>Vietnam</td>
<td>9</td>
<td>Cuba 401</td>
</tr>
<tr>
<td>6</td>
<td>Brazil</td>
<td>8</td>
<td>Saudi Arabia 138</td>
</tr>
<tr>
<td>7</td>
<td>United States</td>
<td>7</td>
<td>Dominican Rep. 96</td>
</tr>
<tr>
<td>8</td>
<td>Malaysia</td>
<td>5</td>
<td>United States 94</td>
</tr>
<tr>
<td>9</td>
<td>Sri Lanka</td>
<td>4</td>
<td>Taiwan 61</td>
</tr>
<tr>
<td>10</td>
<td>Taiwan</td>
<td>3</td>
<td>Jamaica 46</td>
</tr>
<tr>
<td>11</td>
<td>Singapore</td>
<td>3</td>
<td>Vietnam 42</td>
</tr>
<tr>
<td>12</td>
<td>Cuba</td>
<td>3</td>
<td>Myanmar 33</td>
</tr>
<tr>
<td>13</td>
<td>Hong Kong</td>
<td>2</td>
<td>Thailand 32</td>
</tr>
<tr>
<td>14</td>
<td>Tanzania</td>
<td>2</td>
<td>Bahamas 14</td>
</tr>
<tr>
<td>15</td>
<td>Saudi Arabia</td>
<td>2</td>
<td>Belize 9</td>
</tr>
</tbody>
</table>

Sources: Adapted from [8, 26].
Notes: This table illustrates top 15 countries that benefit most from coral reef shoreline protection in terms of the number of people living below 10-m elevation and within 50 km of the coast (in million) [8]. The annual averted damages cover damages to built capital in USD millions per year. The annual averted damages relative to GDP show each country’s damage size relative to its economy size [26].
reef scenario. Table 3 provides a list of countries that enjoy the highest annual flood protection benefits in this hypothetical situation. Most of these countries are developing; some are small island nations. In a more extreme case, flood damages from a 100-year storm event would have been $272 billion, a 91% increase from the scenario with the reefs. At a country level, this extreme-case benefit of reefs surpasses $1 billion for more than 10 countries around the world, most of which are developing countries. Regardless of whether the protection benefits are for annual floods or a 100-year storm event, small island nations in the Caribbean and the South Pacific see the highest benefits relative to their GDPs.

To sum up, this section provides a macro-level overview on how coral reef degradation can result in tremendous socioeconomic losses, ranging from reductions in food availability, income, and welfare to losses of jobs and built capital. Developing countries, including small island nations, have been identified as more vulnerable to coral reef degradation because their economies and livelihoods depend significantly on the oceans.

To illustrate how coral reef deterioration affects a vulnerable group, the next section will discuss micro-level socioeconomic impact through a case study in one of most vulnerable developing island nations. Oftentimes, an economic shock creates rippled effects far beyond its first-order effects. Coral reef deterioration is no exception. The case study below will also exhibit how coral reef deterioration affects not only income but also other socioeconomic aspects of the affected coastal communities.

3. Case study: the 1998 coral bleaching and the Indonesian fisheries sectors

The mass coral bleaching in 1998 was the most severe bleaching event up until its occurrence [28, 29]. High sea surface temperatures and bleaching spots were reported throughout the tropical zone worldwide [29, 30]. 16% of the world’s corals were lost in this bleaching event [29]. In Indonesia, coral bleaching spots were reported in West Sumatra, Central Java, Bali and Lombok area, Southern Sulawesi, and Papua; with mortality rates up to 50% [30]. This bleaching event could potentially pose significant threats on the Indonesian fisheries sector, most of which were considered small scale [31] and, hence, particularly susceptible to the changes in ocean conditions and fish stocks.

This section presents how the severe episode of coral bleaching in 1998 affected the lives of Indonesian fisheries households—from their economic well-being to their health and other socioeconomic outcomes. The discussion in this section is based on findings from two studies. The first study [32] highlights how the bleaching affected income, labor outcomes, and consumption. The second study [33] demonstrates how the bleaching event impacted reproductive decisions as well as how the economic hardship from coral bleaching might have adverse effects on child development.


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3 More than half of the marine fishing boats in Indonesia were nonpowered in 2000 [31].
4 Both studies merged the household survey data from the Indonesian Family Life Surveys [34–37] with reported coral bleaching spots from [30] and sea surface temperature anomalies published by the National Oceanic and Atmospheric Administration (NOAA).
fisheries households in the areas with reported coral bleaching, were compared against other households using regression analyses that controlled for a number of potential confounding factors. The first study shows that the 1998 bleaching event socioeconomically affected the households in three ways [32]. First, the affected households experienced a significant decline in income—the average of 27%—in 2000 but not in 2007. Lower fishery yields were one plausible reason for this income shock. The lack of alternative livelihoods, at least in the short term, could have also contributed to this income shock. In 2000, the affected households could not increase their working hours or find new or secondary jobs potentially because fisheries skills might not be valuable in other jobs. Moreover, fishery workers usually have lower education than other workers. Evidence from 2007, however, shows more adaptation capacity. The affected households were then more likely to switch to a new industry and to increase their labor supply relative to other households.

Finally, the affected fisheries households consumed less protein in both 2000 and 2007, but other consumption was generally unaffected. Some consumption also increased in 2007 as income improved. The reduction in protein consumption came as no surprise because the affected households rely on the ocean for both their income and food sources. Nonetheless, this protein consumption shock raises concerns over nutrition intakes and other consequential outcomes, especially those related to child development.

In fact, economic shocks usually affect fertility decisions as well as various child development and later-in-life outcomes. Economic shocks may increase or decrease fertility [38–40]. In the case of the 1998 coral bleaching in Indonesia, the affected households were more likely to have children relative to other households in 2000 [33]. This rise in fertility was only a temporary shift of fertility timing rather than a permanent increase in the total number of children. One plausible reason is the temporary lowered opportunity costs of children due to limited job prospects in 2000.

Unfortunately, some evidence in 2000 points toward an increase in the likelihood of severe malnutrition among the children born to the affected households. By 2007, the affected households already enjoyed a significant improvement in income, but their children were still more likely to fail a grade in school despite their higher enrollment rate than the other children’s. These findings are consistent with a large literature in economics in which shocks in the first 5 years of life usually affect children’s health and schooling outcomes as well as have long-term consequences into adulthood [41–43].

What is striking about the results in [33] is that the affected households decided to temporarily increase their fertility, but their children’s health and schooling outcomes were inferior to their peers’. This finding along with the other adverse effects of coral bleaching on income, labor market outcomes, and consumption sheds light on how coral reef degradation can affect many socioeconomic dimensions, even when the analyses were restricted to just one economic sector. These findings, together, call for comprehensive policy interventions in mitigation and adaptation.

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5 The control factors include household socioeconomic status prior to coral bleaching, time-invariant factors within each household and province, and time-varying factors that were experienced nationwide, e.g., the Asian economic crisis in 1998.

6 The average 27% reduction in income is an estimate from the most preferred specification. Estimates from other specifications ranged between 27% and 46%.
While the findings discussed in this chapter may be applicable to similar coral reef degradation events in similar parts of the world, these findings will not extrapolate to all cases. Different countries usually have different economic activities, market structures, cultures, and norms. Coral reef degradation also differs in terms of spatial and temporal scales as well as severity. More work in this area is definitely needed to better understand micro-level linkages between coral reefs and humans.

4. Policy implications

The immense economic values of coral reefs discussed in Section 2 imply that coral reef conservation and restoration are economically sound investment. In addition, the case study in Indonesia in the previous section highlights the needs for policy makers to step in and help facilitate mitigation and adaption as coral reefs deteriorate. This section will broadly discuss these two types of policies in further detail.

4.1 Coral reef conservation and restoration

One concept related to the oceans that has been gaining traction in recent years is blue economy, a concept that integrates economic prosperity from marine resources with sustainability [6]. The world economy depends heavily on marine resources; yet, these resources are facing with many risks and challenges. Small island nations and many coastal countries then have to balance between growing the ocean economy and maintaining healthy ocean ecosystems [6]. This subsection will discuss the blue economy policy agenda related to coral reefs. It will first highlight the economic viability of coral reef conservation and restoration and then will elaborate on some major policy tools.

Maintaining healthy coral reefs has been proven to be an economically sound policy agenda. An analysis of economic returns [6] to different coral reef statuses suggests that bringing the reefs to a healthy status is worth the investment with returns up to 44 times. For instance, an additional $37 billion in economic value can be unlocked if the reefs in Indonesia are replenished back to the healthy status by 2030. This type of analyses implies that the private sector as well as governments and nongovernmental organizations (NGOs) should take parts in reef conservation and restoration, and that economic prosperity can conform with sustainability.

In addition, coral reef restoration makes economic sense because restoration is oftentimes the most cost effective policy available. For example, reef restoration is cost effective in protecting coastlines when compared to artificial defenses [8].

In addition to the estimated economic value above, coral reef conservation and restoration could provide significant societal benefits such as health benefits from water pollution abatement and carbon capture from coastal afforestation. The expansion of no-take zones, as another example, helps preserve fish stocks and biodiversity. Owing to the large potential benefits, the restoration of coral reefs has gained salience in recent years. By 2013, nurseries across the Caribbean, Southeast Asia, and the Pacific and Indian Oceans raised more than 86 coral species and over 100,000 colonies [6].

For marine resource conservation, marine-protected areas (MPAs) is a commonly used policy tool. For coral reefs, studies have shown that a partial closure (20–40% of all reef areas in a location) could lead to net increases in fishery catches in remaining areas [6]. However, the current MPAs only cover about 4% of the world’s ocean surface [6], while a 30–40% of coverage is needed for an effective protection [44].
terms of matching, the current MPAs coverage matches well with coral reefs most important in tourism, but the coverage of reefs that are important for shoreline protection is not as comprehensive [6].

Other policies options have also been proven to be economically sound. For example, four policy interventions have been evaluated for the Mesoamerican Reef and the Coral Triangle Area: 1) expansion of no-take MPAs, 2) implementation of vegetative filter strip to reduce erosion, 3) afforestation to reduce erosion, and 4) construction of wetlands to treat wastewater [6]. Results show positive and high returns on investments in all but one case (see Table 4).

4.2 Policies to support mitigation and adaptation

While restoration and conservation could mitigate coral reef deterioration, some degradation is still expected, for example, due to climate change. As discussed in Section 3, coral reef degradation can adversely affect people whose livelihood depends on the ocean in many ways, ranging from income losses to lowered consumption and impeded child development. These negative socioeconomic impacts imply the needs for comprehensive policy interventions to 1) mitigate these impacts and 2) facilitate adaptation. This subsection outlines the policy implications drawn from the case study in Section 3 and briefly discusses how they might extrapolate to other cases.

The first step in policy intervention is to mitigate the adverse effects of coral reef degradation on income and consumption. Protein and nutrition supplements could provide a direct consumption support. Conditional cash transfers can also be

<table>
<thead>
<tr>
<th>Mesoamerica reef</th>
<th>Coral triangle</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-take zone</td>
<td>30</td>
</tr>
<tr>
<td>Vegetative filter strip</td>
<td>5</td>
</tr>
<tr>
<td>Afforestation</td>
<td>7</td>
</tr>
<tr>
<td>Constructed wetlands</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: Compiled from [5].

Notes: This table illustrates the projected present values of costs and benefits along with returns on investments (ROI, in multiples) in four conservation initiatives in the Mesoamerica Reef and the Coral Triangle.
effective in alleviating the immediate income and consumption shocks while lessening further negative impacts, e.g., on child development. One reason is that consumption increased with income; therefore, a cash transfer could have boosted consumption. By conditioning the transfers on child-related outcomes, such as prenatal care and school enrollment, these transfers would also support child development. In fact, conditional cash transfers have been shown to improve preventive healthcare utilization, increase protein consumption, and decrease wasting and stunting in children both in Indonesia and elsewhere in the world [45–49].

Policies to mitigate labor and fertility outcomes and facilitate adaptation in a longer term should target both capacity building and labor market friction reduction. Specifically, capacity building is required in a number of areas. For example, in the case study in Section 3, the temporary increase in fertility followed by inferior children outcomes suggests that the affected households might have underestimated the effects of coral bleaching. Educating these households about the plausible long-term effects could have helped them make informed fertility decisions [33]. Capacity building in terms of skill acquisition could also facilitate labor adjustments such as adoption of new fishing gears and techniques, finding a part-time job, or switching to a new industry. Labor market frictions might have also contributed to the delay in labor adjustments after the 1998 coral bleaching in Indonesia. Policies that reduce search costs and facilitate information flows, e.g., job matching services, could also help expediting labor market adjustments [32].

While these policy recommendations are drawn from one specific coral bleaching event in Indonesia, they can be applicable to other bleaching events as well as coral reef degradation in general with some caveats. Many countries that are suffering or will suffer from coral reef degradation are developing countries and island states with many characteristics similar to Indonesia. The problems that these countries face are generally similar, ranging from low/moderate income to inadequate accesses to good education and healthcare. In this sense, the general policy recommendations outlined in this subsection will also apply to these countries. Nonetheless, developing countries usually differ in finer details. For example, one country might have a basic universal healthcare coverage, while others do not. Compulsory schooling is six years in some countries and nine years in others. For this reason, specific policy recommendations should be tailor-made to suit each country’s coral reef prospects and socioeconomic environment.

5. Conclusion

Coral reef deterioration can impact humans in many ways. From a macro-level perspective, coral reef deterioration can pose significant threats on global food availability, income, job security, and built capital along the coastlines, among others. From a micro-level perspective, coral reef deterioration can affect several dimensions of human life. For example, a case study on the 1998 coral bleaching in Indonesia in Section 3 reveals the adverse effects of coral bleaching on household income, protein consumption, labor market outcomes, fertility decisions, and child development.

The adverse effects of coral reef deterioration call for policy intervention in two key dimensions. First, coral reef conservation and restoration are usually economically sound due to immense socioeconomic threats from coral reef deterioration. A number of conservation and restoration policy tools are discussed in Section 4.1. Second, policy interventions are required to mitigate the effects of coral reef degradation and
to facilitate adaptation, as shown through the 1998 coral bleaching case study in Indonesia. These interventions were discussed at length in Section 4.2.

While this chapter covers many elements of the impact of coral reef deterioration on humans, further studies in various areas are still needed. Most of the current literature on human-coral interactions only covers certain functions of some coral reefs. Given the vast differences across different coral reefs and the coastal communities around them, further work is required to better understand these human-coral interactions in greater detail. For example, other functions of coral reefs apart from the main ones mentioned in this chapter should be studied, and future works should be done in many more countries and geographical areas. One of the main reasons for the scarce literature in this field is the lack of data sets that contain information on both coral reef status and the socioeconomic status of the local communities. Advancement in data technologies such as remote sensing and geographic information system (GIS) could bring out more detailed studies in the future. These studies will be crucial for designing tailor-made policies that match well with each local environment.

Finally, despite the clear evidence on the importance of reef conservation and restoration, policy implementation in the real world is still lagged behind. Many coral reefs around the world are currently under significant threats. Capacity building, financial resources, and international collaboration should be ramped up, especially in developing countries and small islands where the socioeconomic threats are the largest.

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