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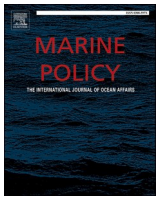

Estimating and comparing the direct economic contributions of reef fisheries and tourism in the Asia-Pacific

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ABSTRACT

Global estimates of the economic value of coral reefs have been made using benefit transfer and other valuation methods, but it is unclear whether these estimates match actualized values (e.g. market values of reef fish and reef tourism) or how they scale to specific regions. Here we empirically estimated the (actualized) direct economic contribution of fishing and tourism on coral reefs (i.e., direct use values) in the Asia-Pacific (APAC) region, which includes a majority (~80%) of the global reef area. We found that coral reefs in the APAC region directly contributed $25 billion annually on average over the years 2008–2012 to the region's economy from fishing and tourism alone. The majority of direct economic contributions (US$19.5 billion) was provided by reef tourism, while the remainder was divided between artisanal (US$2.4 billion) and industrial (US$3.2 billion) fisheries. The average economic productivity of coral reefs was estimated at US$112,000 per square kilometer of coral reef, although there were large deviations between countries in terms of economic utilization of their reefs. Our findings suggest that a highly-cited prior estimate of the global *potential* value of coral reefs (Cesar et al., 2003) is likely a significant underestimation of actual economic contributions. We discuss some of the implications for reef management. Most notably, our results indicate that the non-consumptive direct use of reef resources provide substantially more economic benefits than consumptive uses.

1. Introduction

Coral reefs are one of the most diverse ecosystems on Earth. They provide a wide range of ecosystem services, many of which are linked to human wellbeing and economic prosperity [12,39]. The most widely recognized socioeconomic benefits provided by coral reefs are from fishing, tourism, and coastal protection [10,47]. The Asia-Pacific (APAC) region is the most productive coral reef region, holding about 80% of the world's coral reef area [53] and containing the highest coral biodiversity [38]. The APAC region also has the highest socioeconomic dependence on coral reefs. Indeed, Teh et al. [56] estimated that half of the global number of coral reef fishers are located in Southeast Asia, and the region is highly dependent on coral reefs for fisheries and coastal protection [47].

Despite the critical importance of coral reefs to the APAC region, there has so far been no comprehensive empirical analysis of their economic value outside Australia [15,16], the Philippines [55], and the United States [3,9]. Although global [10,12,13] and regional [6] studies have estimated the economic value of coral reefs, these studies have two main limitations. First, existing studies tend to calculate a reef's potential (based on assumed net benefits of assumed reef use) rather than the realized economic value based on actual reef use [6,10]. Existing studies also tend to extrapolate per hectare values from local valuation studies to global coral reef areas [12,13]. In the absence of empirical evidence, it is unclear whether these potential and extrapolated values are attained in reality. Doney et al. [17] have previously highlighted ongoing confusion about the actual economic value of coral reefs: "*The worldwide value of coral reefs, however, is difficult to pin down; published estimates range from $29.8 billion/year* [10] *to $376 billion/year* [12], *although* Pendleton et al. [48] *find that data are insufficient to allow rigorous evaluation*".

Second, most previous studies do not provide country or regional analyses, which could provide valuable insights for the management of coral reefs. Pendleton et al. [47] evaluated human dependence on coral

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reefs from fisheries and coastal protection on a country basis, but did not include dependency on tourism, which according to Costanza et al. [13] is the major source of value from coral reefs. Understanding the actual economic contributions from reef fishing and tourism could help countries identify key social-ecological vulnerabilities as these two sectors might be affected by and adapting to environmental impacts in different ways. Furthermore, conservation policies could also have a differential effect on the ecosystem's consumptive versus non-consumptive uses.

Broadly speaking, the total economic value of reefs comprises their use and non-use values [41]. Use values include (1) direct use values (e.g., fishing and tourism), (2) indirect use values (e.g., coastal protection and biochemical recycling), and (3) option values (e.g., bequest). Non-use values are the existence value of the ecosystem. Our empirical analysis of direct use vales focused on coral reefs in the APAC region.

2. Methods

We analyzed and estimated the contribution of each country's direct use values associated with coral reefs to gross domestic product (GDP). We then compared out findings to global estimates of the value of tourism and fishing on reefs. We focused on direct use values for which regional open-access data exist: fishing [43,46] and tourism [52]. Other direct use values were excluded due to limitations imposed by data availability, most notably for using coral reefs as building materials, a source of aquarium fish, ornamentals from dead coral and seashells, and pharmaceuticals. Our final estimates are thus considered a conservative estimate of the direct economic contributions of fisheries and tourism on reefs.

3. Analytical approach and assumptions

We used a market-based approach to estimate the direct use value of APAC coral reefs. Because we aimed to estimate the contribution of reef fisheries and tourism to each country's GDP, we used the value added (VA) approach [9,15,16]. The VA contribution of coral reefs to the economy can be estimated by subtracting the cost of intermediate inputs from the (market) revenue produced by the coral reef (in our case, expenditures by tourists and landed values of reef fish). For the Great Barrier Reef in Australia, the VA fraction of revenue was estimated at 35% for reef tourism and 61% for reef fishing [16].

The intermediate inputs' value, however, could also be considered a contribution by coral reefs. Without coral reefs, intermediate inputs (such as materials and equipment) cannot be produced or utilized. However, not all indirect economic contributions are reaped in the country where the reef products or services are sold because intermediate inputs might be imported from other countries. The VA fraction for intermediate inputs can therefore be defined as the fraction of the total revenue from intermediate inputs that is captured within the country. For the Great Barrier Reef in Australia, the VA for intermediate inputs (as a fraction of revenue) was estimated at 38% for reef tourism and 24% for reef fishing [16].

In our analysis, we included both the direct VA and the VA for intermediate inputs. The residual revenue after subtracting these VA fractions comprises the value of intermediate inputs that are produced abroad. Our VA approach therefore aims to determine what fraction of the total market value was captured within a country versus what fraction leaked overseas. For example, reef tourism on the Great Barrier Reef captured 73% of the total revenue (35% direct VA plus 38% VA for intermediate input) within Australia. We analyzed the residual VA for intermediate inputs as a separate category representing the share of each country's economic coral reef value that leaks overseas. A large fraction of this residual value likely remains within the APAC region, with some leaking outside the region. We included this residual value because our aim was to estimate the global economic value of APAC coral reefs (even if part of that value leaks out to other parts of the world).

For Western Australia's Ningaloo Reef, VA fractions for reef tourism of 33% and 24% were found for direct and intermediate inputs respectively [15]. The significantly lower fraction of intermediate inputs VA for Western Australia (24% compared to 38% for the Great Barrier Reef) can likely be explained by the state's relative isolation from the rest of Australia and close trading ties with other APAC countries. Since Ningaloo Reef only accounts for 2% of Australia's total VA reef tourism, we applied the Great Barrier Reef's VA fractions for all of Australia. For other APAC countries, we adjusted their intermediate inputs VA fraction according to their import share of GDP. These adjustments reflect how, for example, small island states (or Large Ocean States) have a much higher fraction of imports within their economy [5,24], and thus reap less indirect economic benefits from tourism compared to countries like Australia. For all APAC countries, we assumed that the direct VA fraction of total reef tourism revenue was equal to Australia (the Great Barrier Reef) at 35%.

The intermediate inputs VA fraction was calculated using the following equation:

Intermediate inputs VA fraction by country = ((Import fraction of GDP Australia / import fraction of GDP country) * intermediate inputs VA fraction of Australia)

To understand what this equation means, consider Malaysia and Australia as examples. Malaysia had a high import fraction (as a share of GDP) over the years 2008–2012, while Australia had a much lower import fraction (70% for Malaysia compared to 20% for Australia; see [57,58]). This implies that Malaysia was not able to capture as much value from the intermediate inputs used by the reef tourism sector within the country as compared to Australia (Fig. 1). Import fractions for other APAC countries are given in the supporting information (Appendix B). We analyzed the intermediate inputs VA leaking overseas as a separate category. This category was not included in the economic contributions of each respective country.

We applied the same adjustment process for fisheries VA based on their relative import shares. However, here we accounted for the difference between more traditional artisanal and subsistence coral reef fisheries and more modern industrial and recreational coral reef fisheries. Specifically, artisanal and subsistence fishers often build their boats and make their fishing gear [21,33]. Thus, countries with such traditional fisheries are able to capture a larger share of the intermediate inputs' value within the country, even though they likely have a lower landed (market) value (or catch) in general. This is because traditional fisheries must spend more time on non-fishing activities [21,33]; they do not depend on imported raw materials, products, and/or services. We assumed that the share of landed values from fisheries that comes from artisanal and subsistence fisheries had a VA fraction of 100%. Thus, they are able to capture the full direct (and indirect) economic VA from the reef fish catch value. The economic share of traditional fisheries in the APAC is given in the supporting information (Appendix C).

To estimate the economic value of industrial and recreational coral reef fisheries, we used the same method as depicted in Fig. 1. For Great Barrier Reef fisheries, VA fractions of 61% and 24% (respectively) have previously been reported for direct and intermediate inputs [16]. For Western Australia's Ningaloo Reef, VA fractions of 50% and 18% were found for direct and intermediate inputs respectively [15]. For countries that had an artisanal and subsistence share of 100% (e.g., Fiji and French Polynesia), we assumed that all market value was captured within the country.

After calculating the economic contributions of coral reef fisheries and tourism, we estimated the economic productivity of coral reefs. This was achieved by comparing the economic VA from coral reefs (i.e., tourism and fishing) with each country's reef surface area. Finally, we estimated economic dependence on coral reefs by comparing the economic value of reefs to each country's GDP.

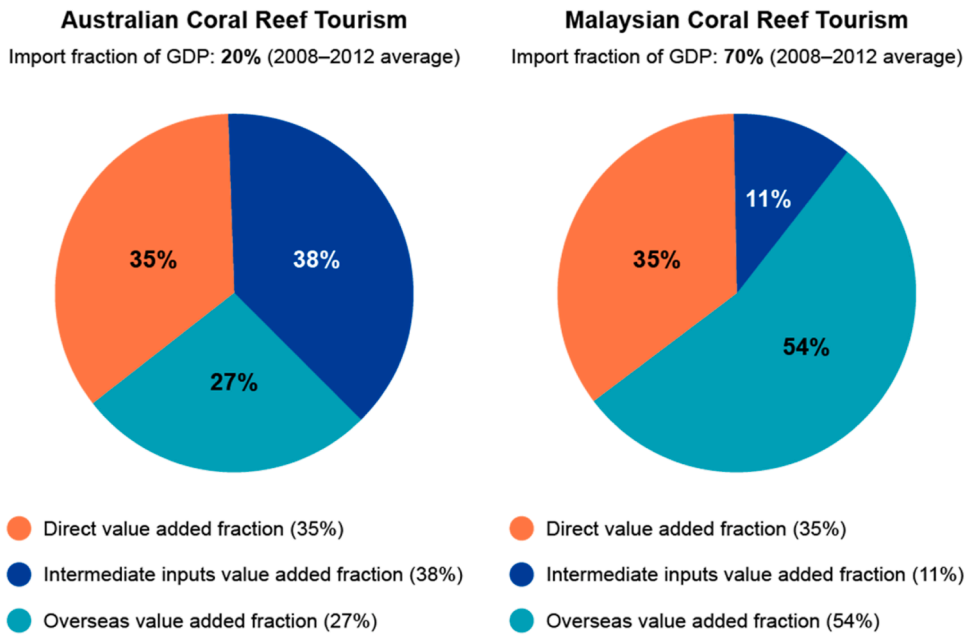

Fig. 1. An example showing the VA contributions methodology: Assignment of direct and intermediate inputs VA for coral reef tourism in Australia and Malaysia. The figure shows our assumption that the direct VA fraction is equal for all countries (35%), while the intermediate inputs VA fraction differs based on each country's import fraction of GDP [57]. That is, Malaysia has a much higher import fraction than Australia, and thus our methodology assumes that more economic value from coral reefs in Malaysia will leak overseas (54% in Malaysia versus 27% in Australia).

4. Data summary

We used the most recent and comprehensive data available on the economic contributions of fishing and tourism on coral reefs. For tourism expenditures, we used data provided by Spalding et al. [52]; for fisheries, we used data from the Sea Around Us project [46]. Because the tourism expenditure data in Spalding et al. [52] were based on an average over the years 2008–2012, we used fisheries and GDP data based on an average over that same time.

For reef tourism, we followed Spalding et al. [52]'s suggestion to include both the on-reef and reef-adjacent values of coral reefs. On-reef value was directly linked to coral reefs and included in-water activities such as diving and snorkeling. On-reef value was captured by assigning a fraction ranging from 0% to 70% of the total reef-coast tourism expenditures based on the reef use intensity. Reef use intensity was calculated using multiple sources including the ratio of dive shops to total hotels, social media data, and cross-verification with local experts. Reef-adjacent value captures the values provided by coral reefs through indirect benefits such as calm water, sandy beaches, fresh seafood, and attractive views. Spalding et al. [52] conservatively assigned 10% of the total reef-coast tourism expenditures to the presence of coral reefs. The reef contributions we used are based on work by Spalding et al. [52], but they are slightly modified to account for VA fractions and currency exchanges (to 2019 USD).

For reef fisheries, we used the landed values of fish from the Sea Around Us database [46]. Catch data in this database are reconstructed using a seven-step approach, starting with official statistical data from the Food and Agriculture Organization and other international reporting entities, and followed by making adjustments to account for missing sectors, taxa, and gear [45]. For our analysis, we included as a coral reef catch all fish stocks classified as 'reef-associated,' including both small, medium, and large species. 'Reef-associated' in this case follows the classification made in FishBase [22], which includes species that inhabit reefs as an established environment and species with a preference for reefs among other places. Our approach thus differs from previous studies [47,56] that did not include reef-associated pelagic fish species such as Jacks (*Caranx)* and Giant Trevally (*Caranx ignobilis*). The inclusion of both on-reef and reef-associated fish mimics the tourism logic that includes both on-reef and reef-adjacent values. We also differed from previous studies [47,56] by not including mollusks (*Mollusca)*, such as clams, cuttlefish, octopuses, and squid, in our analysis. Although these species can often be found on coral reefs, they also occur in other coastal habitats (and in the open ocean). The Sea Around Us database we followed, based on the FishBase classification, also did not classify mollusks as reef-associated. Finally, we excluded the inferred foreign catch to reduce the risk of double counting (i.e., data concerns arising when a foreign catch is likely reported as a domestic catch in the foreign country due to disagreements about maritime borders, such as those in the South China Sea).

We used World Bank [57,58] data for GDP and trade estimates for most countries. We took an equal-weighted average over the years 2008–2012. Other databases were used to analyze GDP data for: the Cook Islands, French Polynesia, New Caledonia, and Nauru [59]; Wallis and Futuna [11]; Taiwan [25]; and the Hawaiiian Islands [60]. Reef area estimates were based on Spalding et al. [53], except for China where we used a more recent estimate to account for larger coral reef areas (e.g., Spratly Islands) that are now economically used by the country [32].

5. Results

The estimated economic contributions from the direct use of coral reefs by fisheries and tourism in the APAC region amounted to an average annual value. This value was US$25.1 billion (2019 USD) over the period 2008–2012. Most economic contributions (i.e., US$19.5 billion or 78%) came from reef tourism. Economic contributions from reef fisheries had a relatively equal spread between artisanal (including subsistence) and industrial fisheries, at respectively US$2.4 billion (10%) and $3.2 billion (13%) annually.

In 16 countries, coral reefs contributed more than US$100 million annually, while in seven countries annual contributions were over US$1 billion (Fig. 2). Indonesia, China (including Hong Kong), and Australia had the largest economic contribution from coral reefs, at respectively US$3.3 billion, US$2.5 billion, and US$1.9 billion, annually. For most countries with coral reefs that contributed more than $100 million

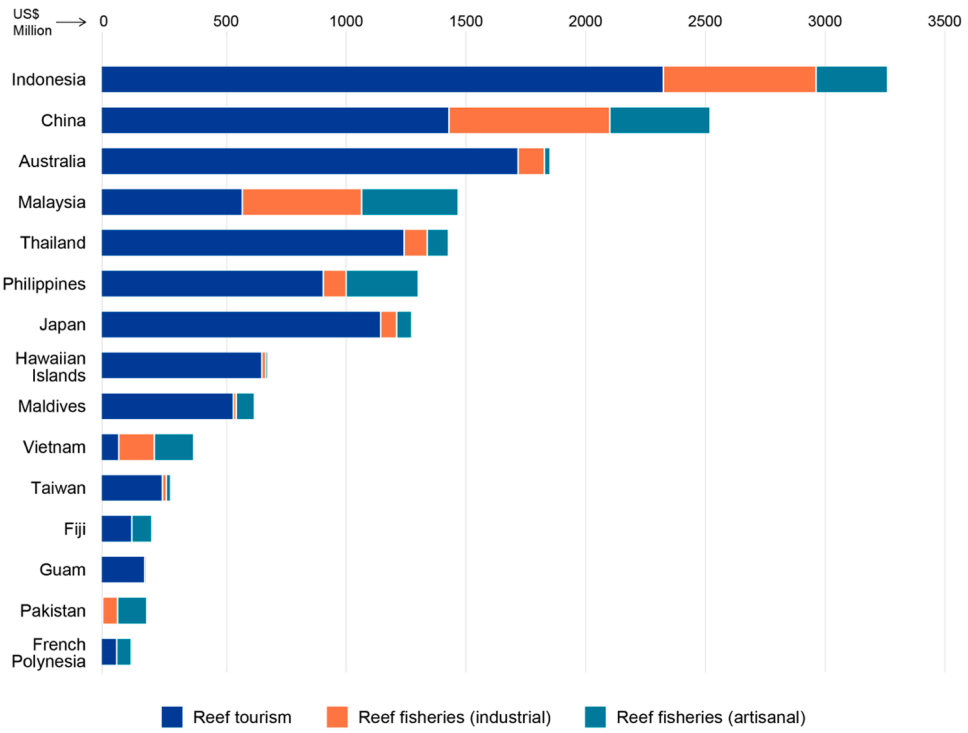

Fig. 2. Economic VA contributions of APAC coral reefs (2008–2012 annual average) for countries in which coral reefs contributed more than US$100 million annually. Coral reef tourism data are based on Spalding et al. [52] and fisheries are based on Sea Around Us [46]. Reef fisheries (artisanal) include both artisanal and subsistence fisheries values as classified by Sea Around Us. Reef fisheries (industrial) include both industrial and recreational fisheries values as classified by Sea Around Us.

annually, the largest economic contribution was provided by the reef tourism sector. The exception for these results were Malaysia, Vietnam, and Pakistan. A detailed summary for each APAC country is provided in the supporting information (Appendix A).

The highest economic dependence on coral reefs was found in Large Ocean States, i.e., countries with a relatively small landmass and population but a large ocean territory. Palau and the Maldives were most economically dependent on their coral reefs, with more than 20% of their national economic output (GDP) derived from coral reef tourism and fisheries (Fig. 3). The Federated States of Micronesia (8.9%), Fiji

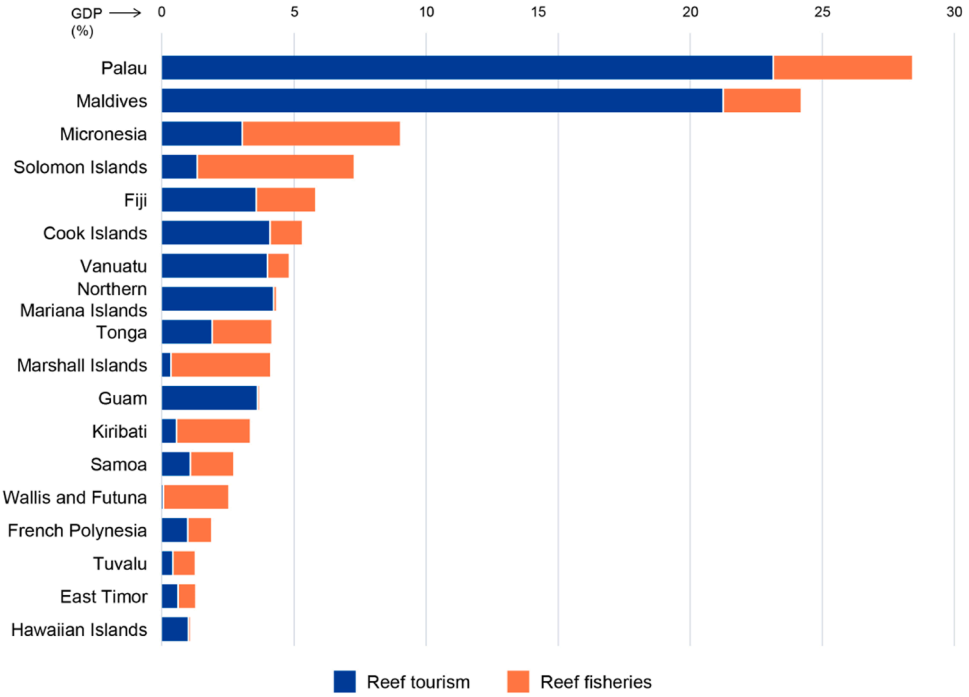

Fig. 3. Relative economic VA contributions of APAC coral reefs as a fraction of total national economic output (2008–2012 annual average), for countries with at least 1% of Gross Domestic Product (GDP) from reef contributions. Data for other countries are available in Appendix A.

(5.7%) and the Cook Islands (5.2%) also had direct use contributions from coral reefs valued at above 5% of GDP. Within the group of countries that had an economic dependence on coral reefs above 1% of GDP, there were an equal number of countries that were most dependent on reef fisheries (Micronesia, Solomon Islands, Tonga, Marshall Islands, Kiribati, Samoa, Wallis and Futuna, and Tuvalu) or on reef tourism (Palau, Maldives, Fiji, Cook Islands, Vanuatu, Northern Mariana Islands, Guam, and the Hawaiian Islands). In French Polynesia and East Timor, dependence was equally shared between reef fisheries and tourism.

APAC-wide, the economic productivity of coral reefs in terms of direct use from fishing and tourism was US$112,000 per square kilometer of coral reef. The economic productivity per area of coral reefs differed significantly between countries, ranging from US$550 per square kilometer in Tuvalu (lowest productivity) to US$795,000 per square kilometer in Guam (highest productivity). A detailed summary for each APAC country is provided in the Supporting Information (Appendix A). Three out of the four most economically productive coral reefs were overseas territories of the United States (Fig. 4). Major economies such as Thailand (US$670,000/km^2), Japan (US$440,000/km^2), Malaysia (US$410,000/km^2), Taiwan (US$290,000/km^2), and Vietnam (US$290,000/km^2) also had relatively high productivity. Other countries with significant economies that have large surface areas of coral reefs [53], such as Indonesia (51,000 km^2), Australia (49,000 km^2), the Philippines (25,000 km^2), and Papua New Guinea (14,000 km^2), had an economic coral reef productivity that was below US $65,000 per square kilometer. Except for the United States overseas territories, and Maldives and Palau to some extent, all the Large Ocean States had coral reefs with relatively low economic productivity around US$10,000 per square kilometer.

6. Discussion

We found that coral reefs directly contributed an average of US$25.1 billion (2019 USD) annually from fishing and tourism alone to economies in the APAC region over the years 2008–2012 (Appendix A). One out of each 1,000 US$ (0.1%) of the total economic activity in the APAC region economy was produced from coral reefs. The majority of economic contributions (US$19.5 billion) was provided by reef tourism, while the remainder was divided between artisanal (US$2.4 billion) and industrial (US$3.2 billion) fisheries. Our findings thus emphasize the important economic value of coral reefs, and particularly their contributions to small-scale local economies in the APAC region [56].

The direct economic contributions from reef tourism were higher than those from reef fisheries for most countries in our sample (Appendix A). Within the group of countries with the largest reef contributions, fisheries values exceeded those from tourism only in Malaysia, Vietnam, and Pakistan (Fig. 2). Several Large Ocean States were also more reliant on reef fisheries than reef tourism (New Caledonia, Micronesia, Samoa, and Tonga).

Our finding that direct use from reef tourism provides more economic value than direct use from fisheries in more countries suggests that reef tourism has a higher VA fraction per worker. People may have to choose a livelihood in either reef fisheries or reef tourism. Classical economic theory suggests that people choose the occupation that is expected to produce the highest economic benefit [50] and evidence for this theory in coral reef communities has been found, for example, in the Philippines [2]. Given that reef tourism is non-extractive, it has been argued that this sector is more sustainable than reef fisheries [52]. However, there are scenarios in which (often rapid) tourism development could actually worsen reef impacts compared to those exacted by local fishing communities [2]. Moroever, other studies have shown that fishing can provide intangible benefits, such as a sense of belonging, social cohesion, and identity [40,63]. Further empirical research is therefore needed to evaluate the relative ecological, economic, and social benefits and costs of reef fisheries and tourism. Based on such studies, and by further understanding the importance of local socio-economic and ecological context, sustainable social-ecological pathways could be developed.

Our findings have important implications for coral reef policy and management. Most notably, in the APAC region, the non-consumptive

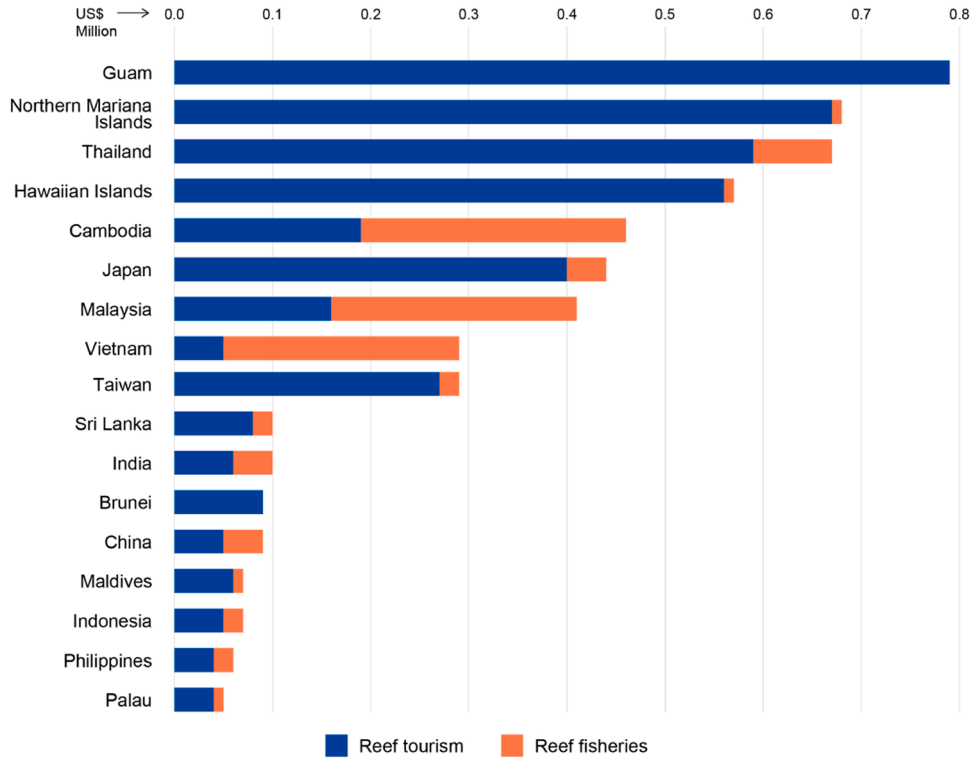

Fig. 4. Economic productivity of APAC coral reefs for countries with at least US$50,000 total VA per square kilometer of coral reef surface (2008–2012 annual average). Data for other countries are available in Appendix A.

use of reef resources (reef tourism) over our study period provided substantially more direct economic benefits than fisheries, which is a consumptive use. Conservation actions, such as the United Nations' target for marine protected areas (MPAs), may therefore have a significant impact on the economic and livelihood benefits that result from the direct use of reefs by tourism operators and fishers [36]. Although reducing extractive activities, such as fishing, is one key performance indicator for the success of MPAs [51], MPAs contribute to net increases in adjacent fish abundance [29,30,37], thus providing benefits for tourism and fisheries.

However, both the ecological and socioeconomic spillover effects of MPAs are poorly understood and tourism markets can be unreliable. Many MPAs are implemented without determining whether the benefits to local fishers will exceed the costs. The benefits of MPAs for fish stocks may also take several years to become apparent [29]. The reduction of extractive industries such as artisanal fisheries could also affect non-economic ecosystem benefits, such as sociocultural values tied to identities and culture [1,40] that affect people's wellbeing [26]. For these reasons, MPA placement needs to be carefully considered and deliberated with local communities, and successfully implementing MPAs may require significant short-term economic compensation to protect the livelihoods and wellbeing of those who depend on reefs, and to overcome resistance. For example, in Australia, rezoning the Great Barrier Reef Marine Park in 2004 was accompanied by a structural adjustment package totaling about US$210 million (2019 USD) to compensate for the initial negative impacts of regulatory changes on local fishing industries [34]. Including local communities in making decisions for coral reefs and reef fisheries is critical to ensure that rules and regulations do not negatively affect their livelihoods and wellbeing [20,31,62].

We found a large variation between countries in their economic dependence on reefs (% of GDP) and the economic productivity of their reefs (US$/km^2), at least in terms of direct use from tourism and fishing. Palau and the Maldives were by far the most economically dependent on their reefs (>20% of economic output; Fig. 3). Large Ocean States including Micronesia, the Solomon Islands, Fiji, and the Cook Islands also had a relatively high dependence on coral reefs (>5% of GDP). Australia had only limited economic dependence on coral reefs, at 0.2% of total economic output. However, it is important to note again that these values are dependent only on direct use values from fishing and tourism, and thus do not account for the total economic value of reefs to local economies. Still, the relatively low dependence of many Large Ocean States on coral reefs in terms of direct economic contributions from fishing and tourism was surprising, compared to accepted views [18]. For example, we estimated the economic dependence on reefs in terms of direct contributions from fishing and tourism of countries like French Polynesia, New Caledonia, Tuvalu, and Nauru to be below 2% of GDP. Total economic values however, including for example non-use and indirect use values, would be expected to be higher.

The economic productivity of coral reefs according to our analysis greatly varied between APAC countries, including those within the same subregion. The three overseas territories of the United States outperformed most other countries, with an economic productivity between US$570,000 and US$790,000 per square kilometer of reef, although Thailand also had a relatively high economic reef productivity at US $670,000 per square kilometer (Fig. 4). Better access to consumer markets in the United States and Europe might partly explain these findings. By contrast, the coral reefs in the Philippines (US$50,000 / km^2), Australia ($40,000 / km^2), and Papua New Guinea (US$10,000 / km^2) had considerably less direct economic use intensity. Australia's low productivity may be explained by the size of its total reef area (i.e., Australia holds 49,000 km^2 of reef area, which is only just behind Indonesia with 51,000 km^2 and followed by the Philippines with 25,000 km^2) and the scarcity of reef fisheries due to most of the country's reef area being protected [19]. The relatively low use of coral reefs in Papua New Guinea, a country with a significant human population and proximity to consumer markets in East Asia, is also noteworthy. We belief this finding is likely related to the country having outstanding conditions for land-based agriculture (contributing to local food production and livelihoods), lack of market access (e.g., for exporting fish), and volatile social conditions which make it a relatively unattractive destination for tourists.

Our findings cross-examine and scrutinize earlier (global) valuation studies of coral reefs. Cesar et al. [10]'s study has been cited more than 600 times to date and is often used as a reference to emphasize the important economic value that coral reefs have worldwide. Our results suggest that their estimate of a global *potential* value of US$41 billion (2019 USD) is likely a significant underestimation of actual economic contributions of coral reefs. Specifically, in the APAC region alone, we found the direct economic contributions of coral reefs amounted to US $25.1 billion (2019 USD) annually in the years 2008–2012. Importantly, our estimate only accounts for fishing and tourism; it excludes other ecosystem services, such as coastal protection, that were included by Cesar et al. [10] and were valued at US$11 billion annually worldwide [7]).

The latest estimated economic value of coral reefs by Costanza et al. [13], on the other hand, is at odds with our empirical results. Specifically, Costanza et al.[13] estimated the value of reef fisheries (food production) at US$23 billion (2019 USD). Our empirical analysis of actual direct contributions for the APAC region (which includes 80% of the world's coral reefs) found a value of US$5.6 billion for reef fisheries — significantly lower than the Costanza et al.[13] estimate. However, directly comparing our reef fisheries results to Costanza et al.[13]'s latest estimates is challenging because their values are based on several different studies, on data from different locations, and by using different methodologies [14].

For tourism, Costanza et al.[13] estimated that recreation on coral reefs globally was worth US$3.3 trillion. Yet empirical results show that the actual economic value from reef tourism in the APAC (where 80% of reefs are present) amounts to US$19 billion and globally to US$36 billion, both in 2019 United States dollars [52]. Taken together, our results suggest that the global estimate of $3.3 trillion [13] is likely too high. Some of this discrepancy may be explained by differences in study design and methodologies. For example, local tourism valuation studies are typically undertaken on coral reef locations that are intensively used for tourism purposes [14] and these cannot validly be extrapolated to less-intensively used locations. Recreation in other studies may also include broader recreational (non-tourism) values than those we used. However, a highly valued case study on recreation [9] examined the economic value of Hawaii's coral reefs that was used for Groot et al. [14]'s coral reefs valuation. This study estimated an annual recreational VA number that is lower than our estimate (US$440 million and US$666 million respectively, both in 2019 USD).

The deviation in our results relative to Costanza et al.[13] may not so much be caused by different valuation methodologies, but instead by the extrapolation of local valuation data to the global reef area. Extrapolation from local valuation studies to global ecosystems is more likely to produce miscalculations unless the sample of reefs from which the data were taken is truly representative [48,49]. Much of the global coral reef surface is remotely located near islands with low levels of population and economic activity. Even within highly populated and visited coral reef locations in Australia and Indonesia, tourism activity is highly clustered among only a small fraction of the total coral reef area. Results from a meta-analysis have indicated that value transfer might not even be appropriate between coral reef locations where reef recreation is taking place because of deviations in economic productivity between different reef destinations [4]. Power laws are ubiquitous in economics [23,42] and this applies to coral reef tourism as well.

Although the large discrepancy between reef tourism values by Costanza et al. [13] and Spalding et al. [52] can likely be explained as the result of applying a benefit transfer method, there are two additional, interrelated reasons why the reef tourism values we used in our

analysis [52] might be underestimated. First, the empirical analysis based on market values does not include a value for the potential consumer surplus. Consumer surplus is defined as the difference between what consumers are willing to pay for a product or service, compared to what they actually pay [35]. Second, Spalding et al. [52] assumed a conservative 10% of total reef-coast tourism expenditures, besides the value from on-reef activities, as being associated with coral reefs. Any potential consumer surplus might already be captured by nearby hotels and restaurants that charge consumers more money because the visitors believe the coral reef (for which they pay less than they would) is worth the visit [54].

Further research is required to evaluate whether a consumer surplus for reef tourism is compensated by a producer surplus for accommodation and restaurant providers. More generally, the concept of consumer surplus depends on unclear assumptions about substitutability and people's use of different products and services [28]. This concept also depends on regularly used, but limited methods to capture consumer surplus, such as the travel cost method [8] and willingness to pay [27]. We thus focused on estimating exchange values and direct contributions to GDP rather than estimating welfare values.

7. Limitations

Empirically estimating the economic contributions of reef fisheries and tourism is complex, particularly in data-limited environments where a variety of valuation approaches are used. We were dependent on the primary databases for reef fisheries and tourism values, as discussed in their respective reports [45,46] and published research [52]. Within these data sets, catch data from artisanal and subsistence fisheries are difficult to obtain [64], and the accuracy of catch data for some countries can be influenced by political reporting [44,61]. It is also unclear how much the catch for reconstructed artisanal and subsistence fisheries fell within the production boundary of the System of National Accounts for different countries, and whether their values are included within conventional GDP statistics. In line with other studies [65], we did not amend the official GDP statistics, and thus our VA fractions of GDP for some countries might be slightly overestimated, particularly for those countries with a high share of subsistence fisheries.

Our study also highlights the need to better understand the links between coral reefs and pelagic fish near reefs. There might be other (pelagic) fish species (e.g., scads and tuna) that are currently not classified as reef-associated but may be more or less dependent on coral reefs (e.g., for food or reproduction). If the presence of coral reefs increases the carrying capacity of other currently non-reef-associated fish species, there is a good argument for them to be included in the economic valuation of coral reefs.

Since the database we used for reef tourism values was based on contributions estimated from 2008–2012, we also estimated the reef fisheries values for the same time. Our empirical conclusions are therefore based on economic contributions from more than a decade ago. Further updating of datasets and analysis of time series is required to evaluate whether our results hold for more recent times. Cross-verifying our findings with each country's national statistical accounts is also difficult because disaggregated GDP data is limited.

Lastly, for accounting purposes, we used VA fractions for the direct and intermediate input contributions to determine what fraction of the total market value of direct reef use is captured within a particular country. Because we were not able to find the VA fractions of reef fisheries and tourism for all countries in our sample, we used the data from the Great Barrier Reef in Australia as a starting point for all other countries. Here, our data were based on studies by Deloitte Access Economics [15,16] which are widely cited in the academic literature, but themselves were not published in internationally peer-reviewed journals. We accounted for differences in the VA fraction of intermediate inputs based on the import share of each country. However, we used the estimates from the Great Barrier Reef (35% for reef tourism and 61% for reef fisheries) for the direct VA fraction of all other countries. Differences in VA fractions between countries would likely affect the direct use contributions assigned to different countries, but it would not have affected the total value we estimated. This is because the VA approach was only used for accounting purposes and did not decrease the total market value.

8. Conclusion

We found that direct economic contributions from reef tourism exceeded contributions from reef fisheries in the APAC region. Seventy-eight percent of the total economic contribution came from reef tourism. This finding validates previous studies that estimated reef recreation as the largest contribution to economic value. By calculating the actual economic value-added fraction of coral reefs, we cross-verified and refined estimates from ecosystem valuation studies that extrapolate findings from smaller studies to global estimates. Our results point to the importance of economic contributions from non-consumptive and consumptive uses of coral reefs, which are both influenced by marine conservation measures such as no-take zones in MPAs. Further research is required to evaluate how economic contributions from coral reefs can be sustained without jeopardizing the ecological integrity of the ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data accessible at Research Data Repository [66].

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105939.

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