Assessing the value of coral reefs in the face of climate change: the evidence from Nha Trang Bay, Vietnam

Quach Thi Khanh Ngoc
Faculty of Economics, Nha Trang University, Vietnam
ngocqtk@ntu.edu.vn

Abstract

Coral reef ecosystems provide many important services to society. Their importance is not only proved by their beauty but also because they provide food and livelihood for millions of people in communities around the world, especially in developing countries. This paper evaluates the economic value of coral ecosystems and potential impacts of climate change and socioeconomic activities on the loss of coral reefs in Nha Trang Bay, Vietnam. Economic valuation approaches and bioeconomic modeling are applied to combine socioeconomic data and projections of coral reef coverage based on the quantitative scenarios of sea surface temperature and fishing activity to articulate the potential economic consequences of future change in the coral reef. We find that coral coverage decreases by 2.49% when sea surface temperature increases by 1%. In addition, we also find that a 1% fishing effort increase induces a 0.259% reduction in coral coverage. The loss in economic value of coral under climate change and fishing effort scenarios is estimated which ranges from US$2.742 to US$30.638 million annually. This result is useful for policy makers draw conclusions for climate policy, biodiversity conservation, and sustainable development.

1. Introduction

Coral reef ecosystems provide many important services to society. Their importance is not only justified by their biodiversity and recreational value but also because they provide food and livelihood for millions of people in communities around the world, especially in developing countries. According to Wilkinson (2008), at least 500 million people in 109 countries depend directly on coral reefs for their economic well-being. Earlier studies estimate that coral reefs provide US$30 billion annually in goods and services that include fisheries, tourism, coastal protection, and intrinsic value (Moberg & Folke, 1999; Hoegh-Guldberg, 2004).

Despite the importance of corals, these habitats are being degraded due to a variety of factors including overfishing, coastal development, sedimentation, tourism overuse, climate change and acidification of the oceans (Edinger, et al., 1998; Hallock, 2005; Mumby & Steneck, 2008). Among these factors, rising sea surface temperature as a result of climate change is one of the most serious causes of stress to corals throughout the world. The reason for this is due to

the biological characteristics of corals as they survive only within a certain condition of temperature, light, and water chemistry conditions (Hoegh-Guldberg, 2004). These conditions are expected to change in the future due to the consequence of global warming and ocean acidification, which urged by anthropogenic carbon dioxide emissions (Turley & Gattuso, 2012). Climate change also imposes challenges since the causality and effects are not easily relieved by local action or management (Hughes, et al., 2003).

It is now widely recognized that climate change and coral reef economic value are linked (Chen, et al., 2015). The change in coral reefs due to climate change and other threats can affect the flow of ecosystem services providing the benefits people obtain from ecosystems. These benefits include the Millennium Ecosystem Assessment's provisioning services (fishing and fishing-related activities and marine farming), cultural services (tourism and related activities as well as education and research related to the marine environment), supporting services (primary production, nutrient, and water cycling), and regulating services (habitat provision for fisheries and other species, natural hazard protection - storm protection and beach erosion control, and many key environmental processes). Given the climate threats to coral reefs, an appropriate analytical framework for these threats requires the integration of natural science, economics, conservation, and public policies.

Research on ecosystem services has grown gradually and gained broader attention throughout the past decade (McDonough, et al., 2017). Monetary valuation and other type of ecosystem service information are often used as a measure of ecosystem service value to raise the awareness among users and provide information for managers and policy makers (Costanza, et al., 1997; Wright, et al., 2017). The methodology for qualification of ecosystem services is the main concern and the valuation challenge in conducting research since it is difficult to capture all benefits of ecosystem services in unique circumstances (Hanley & Barbier, 2009; Beaumont, et al., 2008).

A number of studies have quantified the economic value of coral reefs (Cesar, 2000; Brander, et al., 2007; Griffen & Drake, 2008; Laurans, et al., 2013) however, most of studies focus on a handful of coral reef ecosystems such as provisioning services (Christina, et al., 2014; Joelle, et al., 2015), regulating services (coastal protection) (Zanten, et al., 2014; Nalini, et al., 2015; Pascal, et al., 2016), cultural services (tourism and recreation) (Pietervan, et al., 2015; Diane, et al., 2017; Mark, et al., 2017; Subade & Francisco, 2014), and the management aspect (Johnson & Saunders, 2014; Kelly, 2015; Ngoc, 2017). Only a limited number evaluate the impacts of climate change on coral reefs. Some authors investigate effects of ocean acidification damages to coral reefs (Brander, et al., 2012; Speers, et al., 2016). Others highlight

the climate change impacts and adaptation options for reef fisheries (Cinner, et al., 2012; Iliana, et al., 2014).

Different valuation approaches have been developed and applied to address specific policy and management questions and to value coral reefs and marine ecosystem services. Three main perspectives on valuing coral reefs and marine ecosystems include economic, socio-cultural and ecological benefits (Fernandes, et al., 1999; Laurila-Pant, et al., 2015). The valuations can utilize the indicator systems (Yee, et al., 2014; Yee, et al., 2015; Kittinger, et al., 2012) or use quantitative tools for assessing the value of coral reefs to provide information for improving management (Groot, et al., 2012; Jarvis, et al., 2017; Subade & Francisco, 2014; Grafeld, et al., 2016; Fitzpatrick, et al., 2017; Elliff & Kikuchi, 2017). However, the main problem arising from the research is the interface between ecology and socio-economic. The lack of scientific information on the ecological aspect (reef structural complexity, species richness, and fish population) may affect the economic estimates.

This paper contributes to the literature eliciting values for coral reef ecosystem services by implementing economic valuation of coral reefs to present an estimate of total benefits and opportunities over time and a modified bioeconomic modeling to evaluate the climate change impacts on the coral reef cover through the dynamic of carrying capacity. The use of economic valuation and bioeconomic modeling aims to combine economic and ecological descriptions of the coral reef ecosystems. The links between climate change to coral reef cover and coral reef value are investigated to provide future scenarios of coral reefs under climate change predicted. Understanding this linkage is essential to draw conclusions for climate policy and biodiversity conservation.

In this research, we worked with communities living in Nha Trang Bay. Coral ecosystems in Nha Trang Bay play an important function in providing crucial goods and services to people living in this area. These goods and services provide an important source of income for local populations (through fishing, aquaculture, etc.), and sustenance to those living at subsistence levels. They are also a tourist attraction, contributing to local income and foreign exchange. Coral reefs in the area have been assessed as having a high potential for tourism development. However, the pressure from natural and socioeconomic activities including fishing, tourism development, and climate change imposes serious threats to coral reefs, raising the need to consider the socioeconomic aspect in the management of coral reefs. Good management of coral reefs is necessary to maintain sustainable use and benefits to the community over time.

This research will make a comprehensive valuation of coral reefs through five key goods and services: i) fisheries, ii) aquaculture, iii) tourism, iv) biodiversity and v) shoreline protection. The impact of climate change on coral reef value is measured by the changes in ecosystem services caused by climate related changes in coral reefs. This impact is assessed by applying a modified bioeconomic modeling and scenario building. Economic valuation and bioeconomic results will contribute in communicating the importance of coral reefs to people and policy makers and help them make appropriate management plans to mitigate and adapt to climate change in the future.

The paper is organized as follows: the next section describes the study site and state of the coral reef ecosystem. Section 3 describes the overall methodology and data sources used. Section 4 describes the economic value of each of ecosystem services. This section also provides the potential loss of coral reef cover and coral reef value under the impact of climate change and fisheries. The final section discusses the policy implications for coral reef conservation and sustainable development.

2. Background to the study site and the state of coral reef

2.1. Study site

Nha Trang is a coastal city and capital of Khanh Hoa Province, on the South Central Coast of Vietnam. The city has a metropolitan area of 251 km² and population of about 500,000. Nha Trang is well known for its beaches and scuba diving. It is considered among the world's most beautiful bays and a popular destination for Vietnamese and international tourists.

Nha Trang is a priority site listed in the Vietnam Biodiversity Action Plan and considered a biodiversity hotspot of the country. The area has a rich diversity of biological, ecological and landscape features. In 2002, Nha Trang Bay marine protected area was established, aimed at conserving biodiversity, focusing on coral reef ecosystems and enhancing local communities' livelihoods. The marine protected area encompassing nine islands is the first marine protected area in Vietnam. It acts as a marine biodiversity conservation center with 160 km2 that holds a special position in marine resource management and a pilot model for other protected areas in the country. A number of resource management projects focusing on alternative income generation has been initiated by government agencies and foreign donors such as DANIDA, WWF, and Ministry of Agriculture and Rural Development.

Recently the Vietnam government has approved a major development plan in which Nha Trang bay will become a special administrative economic zone by the end of this decade, with its role as a national and international ecotourism and entertainment center.

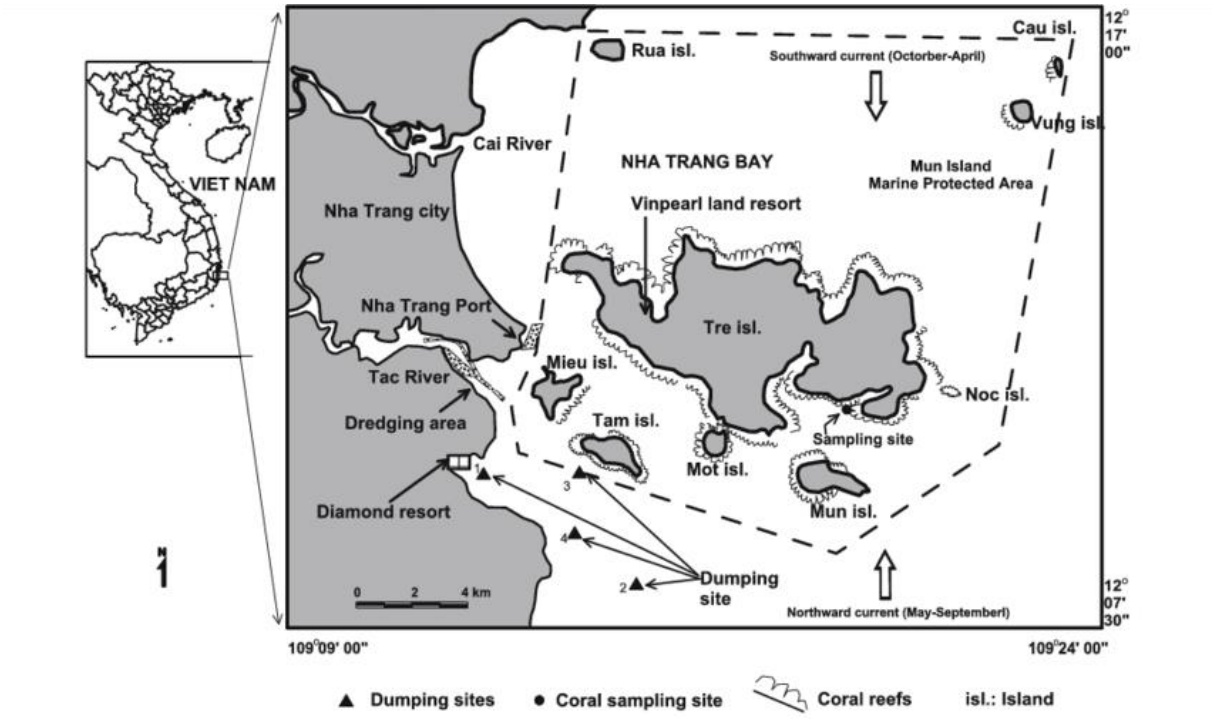

Figure 1: The map of Nha Trang Bay (adapted from Nguyen, et al., 2013)

2.2 The state of coral reefs

Previous studies revealed that Nha Trang Bay has high marine biodiversity with more than 812 ha of typical ecosystems; 6 kinds of mangroves; 7 kinds of sea grass; 115 taxa of seabed fauna in sea grass beds; 504 coral reef creatures (Tuan, et al., 2005). Coral reefs and seagrass in Nha Trang form a unique natural ecosystem, with important biodiversity. The total coral reef area in Nha Trang water is 730 ha. The list of coral species in the bay accounts for about 40% of the world's coral species (Tuan, et al., 2002).

The assessment of marine biodiversity of Nha Trang Bay was initially undertaken in 1993 by WWF for the period 1994 - 1998 and was then followed up every year from 2002 to 2012 by Institute of Oceanography as part of the implementation phase of the Hon Mun MPA pilot project. These assessments were resumed in 2015. There were 8 sites monitored from 2002 to 2012 and 13 sites monitored in 2015. The results show that coral cover fluctuates and varies between monitoring sites. The coral reef cover in the core zone of the MPA is significantly higher than in outside areas. However, coral reefs in Nha Trang have been experiencing degradation, especially for close to the mainland due to a mixture of factors including overfishing, increase in sediments, the outbreak of crown-of-thorns starfish (COTS), climate change and tourism (Long & Phan, 2008; Tuan, et al., 2004). The overall decline in hard coral

cover during the last 20 years was 13% with a higher decline in the period of 1994-2000 (16.3%) compared to that in the period of 2000-2006 (2.6%) and 2006-2015 (0.9%). Notably, coral reefs in the Nha Trang region are at risk from global climate driven threats like coral bleaching which was recorded in Nha Trang Bay in 1998 and 2010, as well as ocean acidification, which has led to coral mortality in these years (Ben, et al., 2015). A decrease in coral cover reduces habitat for fish and drives a shift in fish communities. Some reef fish species have declined in abundance, as has the catch (Long & Tuan, 2014).

3. Methods

To achieve our research objectives, we employ a mixed method design utilizing both quantitative and qualitative methods. The economic value of coral reefs is assessed first based on the total economic framework. The impacts of climate change and socioeconomic activities on coral reef coverage and the linkage between coral reef coverage will be also investigated through the dynamics of carrying capacity in the bioeconomic model and the benefit transfer approach.

3.1. The economic value of coral reef ecosystems

Goods and services resulting from coral reefs in Nha Trang waters are measured with monetary values by applying the concept of Total Economic Value (TEV). The TEV of coral reef ecosystems can be subdivided into use and non-use values. Use values are benefits that arise from the actual use of the ecosystem, both directly and indirectly, such as fisheries, tourism and beach front property values. Non-use values include an existence value, which reflects the value of an ecosystem to humans, irrespective of whether it is used or not.

There are three main families of valuation techniques to determine the economic value of ecosystem services including market-based, revealed preference and stated preference methods. The market-based methods use standard economic techniques for measuring economic benefits from market goods, based on the quantity people purchase at different prices and quantity supplied at different prices. The revealed preference methods involve a number of techniques such as travel cost method and hedonic pricing technique. Stated preference methods are based on asking people how much they would be willing to pay for services provided by a biological resource. The type of valuation technique chosen will depend on the type of non-market goods or services to be valued, as well as the quantity and quality of data available. Due to resource and budget constraints, in this study, five major goods and services defined from the state of coral reef resources in Nha Trang are evaluated. These goods and services include fisheries, marine aquaculture, tourism, biodiversity value and shoreline protection. Valuation

techniques will be used in this project, including market value, contingent valuation, and value transfer. The total economic value of coral reef ecosystems is shown in table 2.

The market value approach will be applied to fisheries and marine aquaculture to estimate the difference in the value of productive output as the basis for valuing coral reef services. Fishers were asked about the frequency of harvest (daily, weekly), and on the average quantity of product harvested each time they went fishing. The component of the catch, the price, and the operation cost are also investigated to compute the value-added of the fisheries. The aquaculture farmers were also asked about their production, selling price and relevant costs. From this information, the value-added of marine aquaculture is estimated.

For the tourism value related to reefs, both consumer surplus and producer surplus will be examined. The contingent valuation method by asking people what they are willing to pay for recreation benefits provided by coral reefs above what they actually spend is applied to define the consumer surplus. The effect on production, which looks at the difference in the production is applied to the producer side of tourism.

Biodiversity value relevant for coral reefs in Nha Trang is obtained from the study of (Xuan, et al., 2017). This study applies a discrete choice experiment to derive tourists' WTP for coral reef conservation and environmental quality in the Nha Trang. Based on average WTP per tourist, total consumer surplus can be calculated. For shoreline protection, the value is determined based on comparable areas and the benefit transfer method. The valuation estimates will also reflect the gains and losses of management responses of coastal and marine resources.

3.2. Evaluate impact of climate change on coral reefs and coral economic value

3.2.1. Bioeconomic modeling of coral reef cover

Changes in the coral cover are indicative of the health of coral communities and are calculated as the net difference between rates of growth (including both growths of individuals and recruitment of new corals) and the rate of mortality from all causes (Hughes, et al., 2003; Hoegh-Guldberg, 2004). Sea surface temperature (SST) has been found to be an important determinant of coral reef presence and health. Many studies have shown this evidence (Hughes, et al., 2003; Chen, et al., 2015).

To investigate the relationship between climate and socioeconomic conditions and the coral cover extent, we apply bioeconomic modeling. The climate factor is sea surface temperature and the socioeconomic conditions include fishing effort. The coral reefs provide the natural habitat for living creatures thus coral loss may also result in declines in habitat. This habitat is related to carrying capacity in marine areas. Some studies indicate that carrying

capacity is influenced by habitat size and quality. Larger habitats can support populations with higher carrying capacities; higher quality habitats support populations with higher carrying capacities (Griffen & Drake, 2008; Hakoyama & Iwasa, 2000). The fishing activity and climate change can deteriorate the coral reef ecosystem and thus are also expected to impact the carrying capacity. The dynamic of carrying capacity is modeled as follows:

$$K_{t+1} - K_t = G(K_t) - \delta E_t K_t + \gamma SST_t K_t \quad (1)$$

which specifies the change in carrying capacity (K) as a function of the growth rate G of carrying capacity due to coral reef habitat change and the fishing effort (E) and sea surface temperature (SST) impacts. The growth of carrying capacity is assumed to follow a logistic growth so $G(K_t) = \tau K_t(1 - K_t)$ as (Narine, et al., 2010), where τ is the growth rate of carrying capacity driven by coral reef habitat. Changes in coral reef cover may represent the carrying capacity changes over time. Based on the positive relationship between coral reef habitat and carrying capacity and following (Barbier, 2007), we assume K as a function of coral reef coverage, represented by coral coverage (S).

$$K(S_t) = \alpha lnS_t \quad (2)$$

Substituting (2) into (1), the change in carrying capacity in relation to fishing activity and climate change can be defined as follows

$$\frac{lnS_{t+1} - lnS_t}{lnS_t} = \tau - \tau\alpha lnS_t - \delta E_t + \gamma SST_t \quad (3)$$

Parameters of the dynamics of coral reef ecosystems can be estimated with the coral reef cover, fishing effort and SST using transformation Eq. (3). This model estimate is derived under the assumption of long run equilibrium of the coral reef systems.

3.2.2. Linking coral cover and economic value of coral reef

The relationship between coral cover and economic value of the coral reef will be investigated so that the impacts of climate change and fishery on the coral reef value can be evaluated. Due to the lack of data on the coral value of coral reef ecosystems in Nha Trang Bay. We will apply benefit transfer, using value estimated from other coral reefs. We will use the results from (Chen, et al., 2015) who apply a meta-analysis of 72 coral reef valuation studies to develop a transferable value of coral reefs. They assume a nonlinear relationship between coral coverage and coral reef recreational value and estimate a quadratic function with the dependent variable being coral reef recreational value. The meta-analysis shows that the coral reef value decreased by 3.8% when the coral cover was reduced by 1%. They also assume a crude proportion approach for other value factors of coral reefs. We will combine the coral reef

function with the meta-analysis results from (Chen, et al., 2015) to find the loss value of coral reefs under climate change and socio-economic scenarios.

3.3 Data collection

Data was collected from different sources, including peer reviewed, reports, focus group discussions and household and tourist surveys. The secondary data included information on coral reef and fish health, and a socioeconomic profile of local communities and resource users. The coral cover data were found in different sources, including (Tuan, et al., 2005) and (Ben, et al., 2015). The SST data was collected from NOAA (National Oceanic and Atmospheric Administration). Fishing effort was obtained from the Department of Agriculture and Rural Development. This dataset contains records of the above variables for the 1994 to 2012 period and the year 2015.

A focus group discussion was also conducted with the participation of different stakeholder groups, including government representatives, local communities, fishers, aquaculture farmers and tourists. The discussion produced the necessary information for household survey and identified the major threats to the coral reefs and marine resources. Fishing, aquaculture, and tourism activities were also discussed to determine the relevant information regarding the importance of coral reefs and their contribution to the revenue and value added of these activities.

A face-to-face household survey was conducted with a sample of 27 aquaculture farmers and 128 fishers. A questionnaire with the specific questions to tourists was elaborated and delivered to 145 domestic and foreign tourists. The contingent valuation method employed a hypothetical question to elicit respondents' maximum willingness to pay (WTP) for scuba diving, snorkeling and glass bottom boat experience in the Nha Trang Bay reef area. The mean willingness to pay was calculated directly from the surveyed local and foreign respondents. Aggregation is obtained by multiplying the mean willingness to pay by the annual number of visits. A summary of method and data can be seen in table 1.

Table 1: Coral reef ecosystem services, valuation methods, and data

Aspects	Methods	Data sources
1. TEV		
Fisheries	Market value	FGD, secondary data from IO and household survey.
Aquaculture	Market value	FGD, secondary data from DE and household survey

Tourism	Production and consumer surplus	FGD, secondary data from DSCT and tourism survey
Biodiversity	Benefit transfer	Xuan, et al., 2017
Shoreline protection	Benefit transfer	Samonte, et al., 2016
2. Valuing SST and fishing activity impact on the coral reef value		
Valuing SST and fishing effort on coral reef cover	Bioeconomic modeling	SST from NOAA, Fishing effort from DARD, the coral reef cover from IO.
Valuing coral reef coverage loss on the coral value	Benefit transfer	Chen, et al., 2015

IO: Institute of Oceanography

DE: Department of Economics

DSCT: Department of Sport, Culture, and Tourism

DARD: Department of Agriculture and Rural Development

4. Results

4.1. Total economic value

4.1.1. Fisheries

The fishing fleet in Nha Trang comprises a variety of vessels, utilizing 11 different types of gears and techniques. The most popular fishing method to catch fish in Nha Trang is longline and gillnet, used to catch a broad variety of fish, shrimps, and mollusk. Fishers are dependent on reefs for fishing and viable marine-based ventures. There are more than 2000 vessels operating in the Nha Trang Bay. In 2015, the fleet landed 10.3 thousand tons of different type of fish with a total value-added of US $15.03 million[1]. From our household survey with fishers, the ex-vessel prices of these fishes ranged from US$1.2/kg to US$7.16/kg.

Some qualitative and quantitative data and information related to reef fisheries have been mentioned in several publications and technical reports at national (Tuan, et al., 2005; Tuan, et al., 2007) and local scales (Tuan, et al., 2005; Long, et al., 2004). However, a recent analysis of fisheries related to coral reefs in some key areas in Vietnam indicates that coral reefs have provided high production of target resources. The Institute of Oceanography reported that the most abundant fish species recorded were members of the Labrids (wrasse), observed at 184.1 ± 57.8 individuals/500 m2. Caesionids (Fusiliers) were the most abundant family (178.9

[1] Source of number: Department of Economics, Nha Trang City

± 67.9 individuals/500 m2). Piscivores (ex. snapper, grouper), commercially important species, were recorded at very low levels (0.32 ± 0.28 individuals/500 m2).

Analysis by Institute of Oceanography of coral reefs in Nha Trang in 2015 shows that coral reefs in Nha Trang waters provided 324 tons of commercial species and 212,000 lobster seeds per year. Catch of ornamental fish such as butterflyfishes, angelfishes, wrasses, scorpionfishes etc., to supply the local and international aquarium trade have been recorded in many areas during the last decades. The number of ornamental fish collected from Nha Trang Bay for transportation to aquaria in Ho Chi Minh City was around 1,000 fish annually (Long & Tuan, 2014). The value added of fisheries associated with coral reefs from our fisher survey is 70% of revenue and is shown in Table 2. The annual value added from fisheries is estimated to be US$ 2.7 million.

Table 2: Annual fishery value associated with coral reefs in Nha Trang Bay, 2015

Species Group	Quantity	Total revenue (US$ million)	Value added (US$ million)
Reef-associated fishery (tons)	324	0.892	0.624
Lobster seeds (individual)	212.000	2.989	2.092
Ornamental fish (individual)	1000	0.037	0.031
Total		3.918	2.747

4.1.2. Marine aquaculture

Marine aquaculture with cage culture systems has grown rapidly in Nha Trang bay and is seen as contributing to food security, poverty alleviation, and export value. Unlike freshwater aquaria species, where most of these species are currently farmed, the great majority of marine aquaria species is stocked from the wild. Reef-dependent species often include various species of shrimp (e.g., Penaeus spp.), snapper (e.g., Lutjanus spp.), grouper (e.g., Epinephelus spp.), wrasses (e.g., Cheilnus spp.), conchs (e.g., Strombidae), mullets (e.g., Mugil spp.) parrot fish (e.g., Scarus spp.), porgies (e.g., Calamus spp.), and others (Long & Tuan, 2014). Lobster and grouper are the major marine aquaculture commodities in Nha Trang. The seed of lobsters and groupers still depends on the wild caught seed and brood stock. In this study, reef – related aquaculture is computed based on the value added of lobster and grouper production. In 2015, production from marine aquaculture systems in Nha Trang Bay was 37 tons of grouper and 220 tons of lobster[2]. The value added for lobsters and grouper from our household survey is 38%

[2] Source of number: Department of Economics, Nha Trang city

and 32% of total revenue. The average prices per kilo for the lobster and grouper is US$ 59.433 and US$ 11.087, respectively.

Table 3: Annual aquaculture value associated with coral reefs in Nha Trang Bay, 2015

Species Group	Quantity (tons)	Total revenue (US$ million)	Value added (US$ million)
Lobster	220	13.075	4.969
Grouper	37	0.410	0.132
Total		13.485	5.101

4.1.3. Tourism

A variety of tourist activities take place in Nha Trang Bay. These activities include SCUBA diving, snorkeling, swimming, sun bathing, some recreational fishing and visiting fishing villages. Since 2000, the tourism sector of Nha Trang has a colossal growth in an expanding market. The number of international visitors staying in Nha Trang is higher than the average level of the country. Our tourist survey revealed that about 90 percent of the tourists visiting Nha Trang participate in beach/marine recreation activities. Tourism in Nha Trang is reported by the Department of Tourism, Sport, and Culture with 710,000 foreign tourists and 3,397,000 domestic tourists in 2015, contributing a total revenue of USD321.1 million. 75% all of the tourists visit different islands around the bay. A conservative measure of about 600,000 people[3] (accounting for 14.3 percent of the total visitors to Nha Trang) visiting coral reef sites including people participate in scuba diving, snorkeling and glass bottom boat. The average tourist expenditure per day for foreign and local visitors was US$ 97.83 and US$ 52.81, respectively.

We compute the tourism value of reefs in Nha Trang based on tourism revenue and the welfare gain of the visitors or their consumer surplus reflecting the amount that visitors have been willing to pay in addition to the actual payment to enjoy the reef of Nha Trang Bay. The tourism revenues include direct revenues (e.g., diving fees and park entrance fees) and indirect revenues (e.g., lodging and resort accommodation, dive operations and restaurants). The consumer surplus will be estimated through the contingent valuation.

The expenditure tourism associated with reefs is estimated based on the percentage of tourists visiting coral sites. The discussion with people from Department of Tourism, Sport, and

[3] Source of number: Management board of Nha Trang Bay MPA

Culture and tourist agencies also revealed that 45 percent of revenue can be considered as value added. This gave the value added of tourism associated with reefs of about US$ 20.26 million.

We also asked the question in the tourist survey, If you were traveling to Nha Trang, what is the maximum amount that you would be willing to pay per person in addition to actual payment for your scuba diving, snorkeling or glass bottom boat experience? The amount ranges from US$ 1-20 for local tourists and US$ 2-35 for foreign tourists. From our survey, it revealed that the mean amount that the tourists would be willing to pay is US$3.52 and US$11.01 for local tourists and foreign tourists, respectively. This gives an estimate of the consumer surplus to be US$9.10 million. The value of coral reefs for tourism along Nha Trang Bay has a potential net annual return to the local economy of US$29.36 million.

4.1.4 Biodiversity

The biodiversity of coral reefs generates sustainable economic benefits if managed so management efforts are needed to secure availability for coming generations. As mentioned above, to determine the biodiversity value, we adopted the results by (Xuan, et al., 2017). This study investigated tourists' preferences in relation to specific coral reef state, environmental and socioeconomic targets in Nha Trang Bay. A higher WTP was found for greater coral reef coverage and environmental conditions. The results suggested that the WTP for improvement in coral reef status alone may be upwards of $US 0.988. From this study, the consumer surplus from coral reef conservation is estimated which is equal to US$ 0.593 million per year.

4.1.5 Shoreline protection

The coral reefs can buffer the coast from waves and storms. Previous studies suggest that a typical coral reef can absorb up to 90% of a wave's force and can thus protect the shore and infrastructure from erosion and damage (Lugo-Fernández, et al., 1998; Pascal, et al., 2016). As a result, without the wave buffering of coral reefs, rates of coastal erosion and beach loss would be significantly higher.

Nha Trang does not get many typhoons but does occasionally receive heavy rain as seen in the last 3 years. Over the past years, the beach of Nha Trang has indicated signs of erosion. Losing the natural reef in Nha Trang Bay may have significant physical and economic effects on the local communities who live in coastal areas near the coral reefs. The indirect benefit of coastal protection from coral reefs in Nha Trang was estimated to be worth USD 680.31/km2 (adjusted 2015 USD) or worth USD 0.005 million annually. This estimation is based on the

estimation of shoreline protection of coral reef in Philippines equal USD 557.01/km2 in 2011 (Samonte, et al., 2016).

4.1.6 Total economic value

The economic values of the individual coral reef associated goods and services will be aggregated to give the TEV for the Nha Trang bay coral reef ecosystem. The total economic value of the coral reef is US$ 37.806 mil/year. Tourism, aquaculture, and fisheries were the major economic sectors generating annual direct use values from the coral reefs of US$29.360 mil/year, US$5.101 mil/year and US$2.747 mil/year, respectively. For shoreline protection, indirect use value is estimated at US$0.005 mil/year. Nha Trang Bay coral reef, which covers an area of approximately 730 ha. Thus, the use values attributed to the direct utilization of ecosystem services provided by the reefs are significant.

4.2. Climate change and fisheries impacts on economic value of coral reefs

4.2.1. Empirical model estimate result

The coral reef cover function was investigated first to examine the SST and fishing activities that may have influenced the coral reef cover. The descriptive statistics of variables and a correlation matrix are shown in Table 4 and 5. The negative sign for SST and fishing effort in the correlation matrix denotes that for every variation in these variables, opposite variation in coral coverage is produced. The climate change and socioeconomic conditions will impact the future coral ecosystem.

Table 4: Description statistics on variables

	Coral (%)	SST ©	FishEffort (HP)
Mean	24.99	26.94	29,282.15
St. Dev	4.59	0.33	13,026.89
Min	18.5	26.26	9,566
Max	35.1	27.48	45,634

Table 5: The correlation between the variables for coral cover, SST and fishing effort

	Coral	*SST*	*FishEffort*
Coral	1		
SST	-0.609	1	

FishEffort	-0.894	0.463	1

A regression analysis is conducted and regression validation is assessed. The inclusion of the lagged dependent variable requires the Durbin-h statistic to test the presence of serial correlation. Regression results give the value of $nS^2 < 1$, so we can compute the Durbin – h test. The adjusted coefficient of determination, R^2 is also used for validation assessment of the model. The R^2 equals 0.49 and the Durbin – h test equals 0.882 showing that the model is valid.

Table 6: Estimates of model parameters

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.657346	0.515672	3.213955	0.005796
LagCoral	-0.19896	0.064799	-3.07035	0.007774
SST	-0.03603	0.015738	-2.28931	0.03698
FishEffort	-1.8E-06	9.49E-07	-1.88495	0.07896

The regression estimates displayed in table 6 indicate that the SST and fishing effort level significantly impact negatively on the coral coverage and on change of carrying capacity. The elasticities of coefficients for SST and fishing effort show the percentage change in coral cover given a change in SST and fishing effort. Our model also accounts for expected lagged coral coverage effects on the change in carrying capacity. Results show that a one period lag effect of coral coverage also impact the carrying capacity or coral reef habitat. The parameter estimates were used to generate the parameters of coral reef ecosystems and fisheries which are reported in table 7. These parameters can be used to compute the coral cover given observed values of SST and fishing effort which provides useful information for better management strategies and policies of this ecosystem.

Table 7: Parameters of the Nha Trang Bay coral reef ecosystem and fisheries

Parameter	Symbol	Value
Growth rate of carrying capacity	τ	1.657346
The coral reef effect on carrying capacity	α	0.120047
Catch ability coefficient	q	1.8E-06

4.2.2. Projecting climate change and fishing effort on coral cover and coral value

In order to allow quantitative valuations of potential impacts of climate change and fishing activity on coral reef value, we modeled SST and fishing effort in 50 year time (i.e. for 2065) informed by the qualitative scenarios. We evaluate the impact of climate change and fishing activity on coral reef cover and on the coral reef economic value.

We make some key assumptions. For SST, we assume two scenarios. In the first scenario, the SST is assumed to increase by 0.031^0C per year, the same as the trend during the past 20 years (BAU). In the second scenario, we assume the global warming intensifies, so the SST increases 10% more than the trend in the last 20 years (THU). For the fishing effort, we also make two assumptions. For the first scenario, the fishing effort is assumed to increase with the trend over the time period 1994 - 2015 equal to 1834 HP per year (HP1). For the second scenario, the fishing effort just increases by 635 HP per year, which is the trend for the period 2008 – 2015 (HP2). We choose this rate since from 2008 the Vietnamese government implemented a fuel subsidy for offshore fishing vessels. A credit program for offshore vessel construction with low interest was also developed. These two programs led to the decrease in the number of new onshore small scale vessels built since 2008. The growth rate of fishing effort decreases compared to that of the previous period. Substituting the SST and fishing effort from quantitative scenarios into (3) allows us to estimate the change in coral reef cover given the change in SST and fishing effort. The coral reef value change due to coral cover change is computed based on the result from meta-analysis of (Chen, et al., 2015)

The percentage change in coral reef value due to the change in SST and fisheries is shown in table 6 and 7. The projected loss of value ranges from US$2.756 mil to US$ 13.738 mil for the climate change impact and from US$2.742 million to US$30.638 million for fisheries impacts. Our estimation results indicate that the data support the theoretical assumptions and that in addition to socioeconomic activities (fisheries), climate change is also a key predictor of overall coral reef ecosystem health.

The combined loss of coral value due to both climate change and fisheries is shown in table 8. There are four possible scenarios including i) BAU and HP1, ii) BAU and HP2, iii) THU and HP1, and iv) THU and HP2. The total coral value loss ranges from US$5.496 to US$44.376 million annually.

Table 6: Damage to coral reef due to projected SST in millions of year the 2015 US dollar

Year	BAU (0.031/year)	THU (0.0341/year)	Percentage loss in coral coverage		Percentage loss in coral value		Reduction in coral reef value in US$mil	
			BAU (%)	THU (%)	BAU (%)	THU (%)	BAU	THU
2025	27.61 (1.12)	27.64 (1.25)	3.39	3.72	7.29	8.01	2.756	3.028
2025	27.92 (2.22)	27.98 (2.49)	6.63	7.20	14.25	15.62	5.338	5.905
2045	28.23 (3.29)	28.32 (3.75)	9.73	10.64	20.92	22.57	7.909	8.533
2055	28.54 (4.37)	28.66 (4.99)	12.69	13.85	27.28	29.77	10.313	11.255
2065	28.85 (5.37)	29.00 (6.25)	15.53	16.90	33.39	36.34	12.623	13.738

Table 7: Damage to coral reef due to projected fishing effort in millions of the year 2015 US dollar

Year	HP1 (%)	HP2 (%)	Percentage loss in coral coverage		Percentage loss in coral value		Reduction in coral reef value in US$mil	
			HP1 (%)	HP2 (%)	HP1 (%)	HP2 (%)	HP1	HP2
2025	63084 (41.34)	51549 (12.32)	9.60	3.44	20.65	7.40	7.807	2.742
2035	81534 (82.67)	57899 (21.93)	18.02	6.67	38.74	14.34	14.646	5.421
2045	99984 (124.01)	64249 (29.64)	25.41	9.77	54.53	21.01	20.616	7.943
2055	118434 (165.34)	70599 (35.97)	31.93	12.72	68.65	27.35	25.954	10.339
2065	136884 (206.68)	76949 (41.26)	37.69	15.55	81.04	33.43	30.638	12.639

Table 9: Loss in annual value coral reef value due to project SST and fishing effort in millions of the year 2015 US dollar

Coral reef value loss	BAU-HP1	BAU-HP2	THU-HP1	THU-HP2
2025	10.563	5.498	10.835	5.770
2035	19.984	10.759	20.551	11.326
2045	28.525	15.852	29.149	16.476
2055	36.267	20.652	37.209	21.594
2065	43.261	25.262	44.376	26.377

5. Discussion and Conclusions

The successful management and conservation of coral reefs are dependent on a comprehensive understanding of the goods and services that they provide. With a wide range of goods and services provided by coral reefs in Nha Trang Bay, significant social and economic benefits have been obtained. The findings from this study provide insight into coral reef value and the impact of climate change and fishing activities on coral reefs. The value of coral reefs in Nha Trang Bay is US $37.806 million per year not only indicate their benefits to society but also informs management regarding possible negative relationships between fisheries and coral reef health. Understanding this linkage could help to improve coral reef conservation and sustainable use of the coral reefs.

Among the use values of coral reef which measure direct use values and indirect use values, tourism contributes the largest source of revenue for Nha Trang city and is the fastest growing industry. Nha Trang attracts tourists year round, and the number of tourists arrivals increased by 18% annually from 2011 to 2015[4]. The development of tourism requires the development of tourist infrastructure through the construction of roads, railway tracks, ports and airports, and hotel and resorts. This, in turn, generates the adverse impact of tourism on the natural environment. The tourism development has also led to higher demand for seafood consumption, which also increased pressure on fishery resources.

Environmental impacts of fishing and aquaculture on coral reefs should be also discussed. With around 2000 fishing vessels operating surrounding Nha Trang Bay, there is a concern about their possible impacts on coral reef ecosystems, especially with open access fisheries where fishers can catch as much as they want. This has long been recognized as a problem in the fisheries sector but also impacts the coral reef ecosystem and other coastal resources. The fishers depend mostly on the sea for their survival, and often lack formal education and alternative livelihood opportunities. This, in turn, further increases pressures on coastal resources. The use of destructive methods of fishing still exists in Nha Trang and damages the sustainability of fisheries and their habitats. In recent years, poaching has occurred inside the Nha Trang Bay. The fishers invest in equipment to fish illegally and avoid being detected. The patrols hardly detect poaching since often the fishing vessels move outside the MPA, while in fact the net is located inside the protected area.

Regarding aquaculture, the use of trash fish as feed in aquaculture has effects outside the aquaculture industry. A growing demand for fish as animal feed for aquaculture leads to an increase in fishing effort on the wild fish stocks. Using fresh trash fish for aquaculture also

[4] Source of number: Department of Tourism, Sport, and Culture

leads to accumulation of anoxic sediments due to waste feed build-up. The environmental degradation and reduced water quality caused by aquaculture are becoming main threats to coral reefs and marine biodiversity in Nha Trang Bay (Tuan et al., 2014).

By incorporating coral reef habitat into a bioeconomic model through the carrying capacity dynamic, the results from this study have suggested that SST and fisheries have a significant negative impact on the coral reef coverage. The analysis is based on the dynamic bioeconomic fishery model that widely applied to study for fishery resources. In this study, however, the model is modified with carrying capacity dynamics which depend on the coral reef habitat dynamics. This approach provides a foundation of knowledge to address the issue of coral reef conservation and management. The empirical estimation results indicate that climate change and fishing activity will influence coral reef coverage and thus influence the carrying capacity. This clarifies the importance of coral reef conservation and management. The fisheries resource cannot be preserved without the coral reef protection.

The loss in coral coverage generates the loss in coral reef value. This study also projects the coral coverage loss and the economic value loss under future scenarios of SST and fishing effort. If the current trend in rising SST remains the same as the last 20 years, the coral reef coverage will decline as much as 15.53% and the coral value loss will reach US$12.623 million in 2065. If global warming generates an even higher increase in the SST (10% more than the present trend), the coral coverage will decline by 16.90% and the loss peaks at US$13.738 million in 2065, increasing 8.83% compared to that of the present trend.

The analysis of linkage between fishing effort and coral reefs shows that fishing imposes a higher pressure on coral reefs compared to climate change. If the fishing effort increases by the rate observed over the period 1994 – 2015, the loss of coral coverage reaches 37.69% and the economic loss reaches US$30.638 million in 2065. However if the fishing effort increases at the level of the period 2008-2015, the loss in coral coverage and coral value is much lower, being 15.55% for coral coverage and US$12.639 million for coral value in 2065.

The economic valuation results combined with the bioeconomic modeling and scenario building allow a demonstration of the economic consequences of climate change and fisheries on the coral reef ecosystem and the resulting economic outcomes. The message from our study is clear, to gain economic and environmental benefits from coral reefs, there is a need to have the more effective management of coral reef and marine biodiversity. This management must consider local threats such as overexploitation of marine resources and tourism and coastal development; and global threats, such as climate change. These issues are of concern since they may generate trade-offs in terms of development and conservation; and development and

climate change. For the decision-making and policy planning in the coming years, marine spatial planning, focusing on effective marine resource use and coral reef conservation should be developed. Climate change and climate change adaptation options should be incorporated into the development strategy of fisheries and other coastal industries and considered as the key factor for sustainable development. This requires widespread support and participation by stakeholders at all levels of the administrative rung. Efforts to increase perception, awareness, and knowledge are urgent and critical for conservation and management of coral reefs and the well-being of the fishers, industry, and urban population of Nha Trang.

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