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Assessing economic values of coral reefs in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia

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Abstract

Coral reef ecosystems possess tangible and intangible economic benefits to human society that are still underestimated and not fully understood. This study aimed: 1) to calculate the total economic value (TEV) of coral reef ecosystems, and 2) to calculate the losses due to coral reef destruction over a 20-year period, from 1994 to 2014, in the vicinity of selected small islands in the Pangkajene and Kepulauan (PANGKEP) Regency, Indonesia. To estimate the TEV of the coral reef ecosystem, data obtained from a social survey were analyzed to determine the economic value of use and non-use. Based on the calculation, the TEV of coral reef ecosystems was estimated to be USD 11.96 billion or 2.82 million USD/ha. The economic losses due to coral reef destruction over the 20-year period from 1994 to 2014 were USD 1 billion or 50.18 million USD/yr. We anticipate that the economic loss of coral reefs will continue to rise due to the intensification of destructive fishing practices. Therefore, an effective management policy should be established to prevent further destruction of coral reefs in this area in the future.

Keywords: coral reefs, economic benefit, economic loss, policy making, Spermonde Archipelago

1. Introduction

Coral reefs are among the most productive ecosystems in the marine environment, and have functional roles in supplying goods and services for human benefits, including fisheries, tourism, scientific research, shoreline protection, and medicines (e.g., Moberg and Folke 1999; Souter and Linden 2000; UNEP 2006; Brander et al. 2007; Tseng et al. 2015). Regrettably, coral reef ecosystems are severely threatened and many are in a devastated condition, either due to negative impacts associated with human activities (e.g., destructive fishing practices, reclamation, pollution, waste dumping, and uncontrolled tourism activities) or the effects of climate change (e.g., ocean acidification, bleaching phenomena, and sea-level rise) (Morton 1994; McManus 1997; Pet-Soede 2000; Harley et al. 2006; Brander et al. 2007; Burke et al. 2011; Yusuf and Jompa 2012; Nashr 2015; Pendleton et al. 2016). In addition, nutrient runoff from soil erosion and fertilizers are potentially serious threats to the long-term sustainability of coral reef ecosystems, causing outbreaks of crown-of-thorns starfish (Wooldridge and Brodie 2015; Lamy et al. 2016) and coral reef diseases due to certain pathogenic viruses that infect coral reefs (Weil et al. 2006; Haapkyla et al. 2011). The destruction and loss of coral reefs result in a significant ecological imbalance of the marine environment in the form of dynamic, structural, and functional changes to ecosystems, especially the abundance and biodiversity of coral fish and loss of fish species that rely on coral reef ecosystems (Hughes 1995; Weil et al. 2006; Komyakova et al. 2013). This leads to a reduction in the economic value of coral reefs in terms of supplying goods and services for the benefit of human society.

The factors influencing the destruction of coral reefs mentioned above have affected the condition of coral reefs in the Pangkajene and Kepulauan (PANGKEP) Regency, Spermonde Archipelago, Indonesia, which was the study location selected for this study (Figure 1). Several previous studies have indicated that coral reefs in this area are in a seriously bad condition. The Coral Reef Rehabilitation and Management Program (COREMAP) in 2005 founded that 74.26% of the coral reefs in the PANGKEP Regency were in a bad condition, and only 25.74% of them were in good condition (http://kkji.kp3k.kkp.go.id/index.php/en/marine-protected-area-data/details/7/92). The dominant causal factors of the destruction of coral reefs in the study area are destructive fishing practices, collecting coral for use as a building material, and coral bleaching that has occurred from the end of 2009 until mid-2010, accounting for approximately 12% of the total coral reef damage (Yusuf and Jompa 2012).

Using multi-temporal LANDSAT images, Yasir Haya and Fujii (2017) estimated that live coral cover had been reduced from 7,716 ha in 1994 to 6,885 ha in 2002, and to 4,236 ha in 2014, or by 174 ha/yr during the period from 1994 to 2014. The study was based on the calculation of the percentage cover of both live coral and coral rubble using the point intercept transect (PIT) method in the vicinity of 10 islands in the PANGKEP Regency, Spermonde Archipelago. They concluded that live coral cover was present in only 24% of the study area, while 95.8% of the area contained some dead coral in the form of rubble spread across various sites, suggesting that the majority of coral damage was caused by destructive fishing practices, namely blast fishing, cyanide fishing, and the use of mini trawl nets (DFW-Indonesia 2003; Chozin 2008; Nurdin and Grydehoj 2014).

Destructive fishing activities have large-scale destructive impacts, not only in terms of damage to coral reefs but also due to loss of biological productivity and economic benefits, i.e., reef fisheries, marine tourism, coastal protection (White et al. 2000; Wells 2009), and the livelihood of fishermen. This has even triggered social conflicts among coastal communities (DFW-Indonesia 2003; Nurdin and Grydehoj 2014). The high intensity of destructive fishing activities can result in the functional disturbance of coral reefs as a supply of goods and services for the benefit of human society. Such disturbances can reduce the income of local people, which leads to a reduction in the utilization of coral reefs (Grigalunas and Congar 1995; Moberg and Folke 1999).

From an economic perspective, coral reef destruction leads to a loss of economic value of coral reefs and has long-term economic impacts. Healthy reefs contribute approximately 20 tons/km^2/yr of fish and edible products, but the destruction of coral reefs due to dynamite and cyanide fishing reduces the production of fish by approximately 4 tons/km^2/yr (White et al. 2000). The damage caused to coral reefs results in an estimated average economic loss of between 33,900 and 306,800 USD/km^2 (Pet-Soede et al. 1999). In Indonesia, the use values (UVs) of coral reefs, i.e., its contribution to the economic benefits of the fisheries sector, tourism sector, and coastal protection are 2.2 billion, 258 million, and 782 million USD/km^2/yr, respectively (Burke et al. 2011). Those economic values do not include the value of biodiversity, the value of bequeathing coral reefs, and the value of their continued existence.

The aim of this study was to determine the economic benefits of coral reef ecosystems and to calculate the economic losses due to coral reef damage. The economic benefits of coral reefs estimated in this study refer to the economic value typology in the framework of the total economic value (TEV) formulated by Pagiola et al. (2004), Pierce and Morgan (2009), and Freeman III et al. (2014). The TEV is measured by the UVs of ecosystem goods and services: the direct use value (DUV), indirect use value (IUV), and non-use value (NUV) (i.e., the value of bequeathing coral reefs and the value of their continued existence). In addition, economic losses due to the degradation of coral reefs were estimated.

It is expected that the estimation of both the benefits and losses associated with coral reefs in this study could be used as a recommendation for policy makers when allocating the UVs of coral reefs, and as a reference for sustainable coral reef management. The valuation (i.e., the monetary price) of the coral reef economy could also be used as input data by public administrators and stakeholders to determine the compensation required due to coral reef destruction, which can occur at any time due to certain destructive ecological activities (Grigalunas and Congar 1995; Boyd 2010).

2. Materials and Methods

2.1 Study site

The study considered 10 sites (islands) in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The selection of the sites used in this study was based on the Hutcinson's ecological zones (Hoeksema 2012). This consisted of an inner zone (Salemo, Saugi, and Karanrang Islands), middle inner zone (Badi and Sanane Islands), middle outer zone (Sarappo Lompo and Samatellu Lompo Islands), and outer zone (Gondongbali, Pandangan and Kapoposang Islands), as shown in Figure 1.

2.2 Data Source and Materials

2.2.1 Data Source

The study used both primary and secondary data. The primary data were collected from questionnaires and direct interviews, whereas the secondary data were gathered from statistical data, existing documentation, and previous research reports published by several formal institutions, i.e., fisheries statistical data, visitation data (tourists and researchers), and data relating to the cost of coastal protection (Saunders et al. 2007). The respondents interviewed to obtain the UVs of reef-related fisheries were traditional fishermen, commercial fishermen, and seaweed farmers, and were all inhabitants of the selected islands.

A purposive random sampling method was used, in which the local fishermen were classified into two categories according to the fishing gear and fisheries production (Sekaran 2003), with a minimum sample size of 30 for each group (Sekaran 2003; Howell 2016). The respondents interviewed to obtain the UVs of reef-related tourism and scientific research were dive operators, university lecturers/students, officials from the marine and fisheries agency of PANGKEP Regency, and residents from the local communities.

2.2.2 Questionnaire Survey

A questionnaire was designed to obtain data and information related to fisheries, tourism, research, and the respondents' perspective regarding the value of reef ecosystems (Yasir Haya 2017). The questionnaire collected selected personal details of those surveyed (i.e., name, age, education level, selling price of fish, income level, and the number of family members), the type of fishing gear used, fishing locations, operational costs, and the willingness to pay (WTP) for the continued existence of coral reefs.

2.3 Framework Valuation of the Total Economic Value

One approach to evaluate the economic benefits of coral reef ecosystems is the total economic value (TEV) (Pagiola et al. 2004; Pearce and Moran 2009; Freeman III et al. 2014):

$$TEV = UV + NUV = (DUV + NUV) + (BV + EV), \qquad (1)$$

where UV is the use value (USD/yr), NUV is the non-use value (USD/yr), DUV is the direct use value (USD/yr), NUV is the non-direct use value (USD/yr), BV is the bequest value (USD/yr), and EV is the existence value (USD/yr).

The derivative equations of the total economic value (TEV) of coral reef ecosystems are presented in the following subsections.

2.3.1 DUVs of Coral Reefs

DUVs of coral reef ecosystems in this study were a consequence of use by the fisheries, tourism, and scientific research sectors. The equation used to calculate the value is written as follows (Fauzi 2006):

$$DUV = \sum_{i=1}^{N} Q_{i,} \tag{2}$$

where DUV is the total direct use value (USD/yr) and Q_i is the DUV of the individual sectors.

Here, Q_1 is the DUV of reef-related fisheries (USD/yr), Q2 is the DUV of reef-related tourism (USD/yr), and Q3 is the DUV of reef-related scientific research (USD/yr).

a. DUVs of Reef-related Fisheries

DUVs of coral reefs from the fisheries sector were derived from catching fish and seaweed farming. Coral fishes, crabs, squids and octopuses, and seaweeds all contribute to the value of reef-related fisheries, which was estimated using the effect on production (EOP) method, based on a production approach (Grigalunas and Congar 1995; Chee 2004; Adrianto 2006). The calculation of DUVs for reef-related fisheries involves several steps (Adrianto 2006; Wahyuddin 2007; Wawo et al. 2014) as follows:

1) Determine the demand function for a given resource, which includes coral fishes, crabs, squids, octopuses, and seaweed farming, using the following demand equation (3) (Appendix A1):

$$Q = \beta\, V_1^{\,a}\, V_2^{\,b}\, V_3^{\,c} V_4^{\,d}, \tag{3}$$

where Q is the total resource gained, V_1 is the market price per unit of resource calculated in all sites of the study, whereas V_2, V_3, and V_4 are variables regarding the socio-economic status of respondents or users of reef-related resources, β is the intercept, a is the coefficient of the price, whereas b, c, and d are coefficients of the socio-economic status of respondents or users of reef related resources.

2) Linear transformation of the demand function *Q* to obtain the coefficient value of each selected parameter using a linear regression, as shown in Appendix A1.
3) Approach the tabulated result with a linear regression.
4) Obtain the total WTP and consumer surplus (CS) using Maple software. Maple is a math software that combines the world's most powerful math engine with an interface that makes it extremely easy to analyze, explore, visualize, and solve mathematical problems (Maple 2015).
5) Calculate the area's economic value in terms of utilization activities by multiplying the CS with the number of fishermen/farmers.
6) Obtain the utilization economic value per ha by dividing the area's economic value by the total area of live coral cover.

The calculations used in procedures 2) to 5) are given in detail in Appendix A1.

b. DUVs of Reef-related Tourism and Scientific Research

The DUVs of coral reefs related to tourism and scientific research were estimated using the travel cost (TC) method (Sinden 1994; Chee 2004). In this approach, the average cost spent by each person to take trips and receive benefits from coral reef ecosystem at certain tourism and research locations were calculated. The tourism related cost was estimated and converted to an economic value, which consisted of a transportation fee, lodging tariff, food and beverage charges, equipment rental, and an entrance ticket. The annual DUVs of reef-related tourism were obtained by multiplying the average cost per trip with the total number of visitors (tourists) per year. The method used in this study to estimate the DUVs of reef-related tourism was the TC method, which was also applied to determine the DUVs for reef-related research activities.

2.3.2 IUVs of Coral Reefs

IUVs are indirect benefits gained from coral reef ecosystems, i.e., coastal protection, and biological support to fisheries, turtles, and other marine life. In this study, the benefit of coral reefs as a natural form of coastal protection was examined.

An estimation of the benefits of coral reefs as a natural form of coastal protection was made using the replacement cost (RC) method, by calculating the construction costs of breakwaters along the shorelines of 31 inhabited islands. Unit costs and volumes for the breakwater construction were obtained from the Regional Department of Public Works of the PANGKEP Regency.

The calculation of IUVs of reef-related coastal protection consists of two steps as follows.

First, the volume of the breakwater (V (m^3)) was calculated as follows:

$$V = L_S \times W_B \times H_B, \tag{4}$$

where L_S is the coastline length (m), W_B is the barrier width (m), and H_B is the barrier height (m).

Second, the coastal protection value of coral reefs (SPV (USD)) was calculated by multiplying the volume of breakwaters (V) with the construction cost per unit (C, USD/m^3) as follows:

$$SPV = V \times C, \tag{5}$$

2.3.3 NUVs of Coral Reefs

NUVs are the values of coral reefs that people assign to economic goods (including public goods) even if they never have and never will use them. They can be distinguished from the UVs, which are derived from the direct use of the goods. The NUVs estimated in this study were the value of bequeathing coral reefs and the value of their continued existence.

a. Bequest Values (BVs)

BVs are benefit values given by individuals based on their WTP to save coral reef resources to make them available for future generations. In this case, this study was used the benefit transfer (BT) method to estimate the BV. This was based on Hargreaves-Allan (2004) who estimated the bequest values of coral reefs off Wakatobi Island, Indonesia, which is close to the study area. The BV of coral reefs is 412,000 USD/ha/yr (2004). In this case, the Hargreaves-Allen's value in 2004 was adjusted for inflation to obtain the correct value for 2014 using the following equation (Unsworth and Peterson 1995):

$$BV(Y_i) = \sum_{Y_i=2005}^{2014} BV_{HA} \times \frac{GDP(Y_i)}{GDP(Y_{i-1})}, \qquad (6)$$

where $BV(Y_i)$ and $GDP(Y_i)$ are the BV and gross domestic product (GDP) in Indonesia (Organization for Economic Co-operation and Development (OECD), 2016), and BV_{HA} is the Hargreaves-Allen's BV from 2004 (i.e., 412,000 USD/ha/yr).

In addition, the value of $BV(Y_i)$ was used to estimate the BV in the study area using the BT method.

b. Existence Values (EVs)

When consmers's preferences are not revealed by markets, economists usually use direct questions regarding their WTP for services or goods to calculate their preferences. One of the approaches most often used is the contingent valuation method (CVM), which is favored by researchers due to its applicability to a variety of environmental goods and its capacity to assess the EV (Aoun 2015). The EV is the value obtained solely due to the presence of natural resources and the environment. The EVs of coral reefs were estimated based on individuals' WTP for coral reef resources (FAO 2000). The WTP data among the respondents in this study were obtained by questionnaire and direct interviews. The EVs were calculated based on Wahyudin (2007) using the follows steps:

1) Determination of the WTP function for the NUVs of coral reefs using the following equation:

$$WTP = \beta_0 X_1^{\beta 1} X_2^{\beta 2} X_3^{\beta 3} \ldots X_n^{\beta n}, \qquad (7)$$

where $X_1, X_2, X_3 \ldots X_n$ are the variables of economic and social status among individuals or users of reef-related resources. β_0 is the intercept, whereas $\beta 1, \beta 2, \beta 3 \ldots \beta n$ are the coefficients of socio-economic status of respondents or users of reef related resources.

2) Transformation of the WTP function into a linear function to estimate each of the parameters analyzed using linear regression. Equation (7) is then transformed into the following equation:

$$
\begin{aligned}
ln\ WTP &= \beta_0 + \beta_1\ lnX_1 + \beta_2\ ln\ X_2 + \beta_3\ lnX_3 + \ldots\ \beta_n\ ln\ X_n, \\
&= \{\beta_0 + \beta_1\ ln\bar{X}_1 + \beta_2\ ln\bar{X}_2 + \beta_3\ ln\bar{X}_3 + \ldots\ \beta_n\ ln\bar{X}_n\}, \\
&= \beta', \qquad (8)
\end{aligned}
$$

where $\bar{X}_1, \bar{X}_1, \bar{X}_3 \ldots \bar{X}n$ are the average natural logarithm of the education level, income, age, family member and other social factors, and β' is the sum of the coefficient intercept added to the average of the natural logarithm of each variable multiplied by the coefficient of each variable.

3) Equation (8) was then back transformed to its original function to calculate the value of the WTP per capita, using the following equation:

$$\text{WTP} = \exp(\beta'), \tag{9}$$

4) Calculation of the EVs of coral reef ecosystems in a certain location (i.e., PANGKEP Regency) by multiplying the WTP values with total users (N) of the reef-related resource using the following equation:

$$\text{EV} = \text{WTP} \times \text{N}, \tag{10}$$

5) Calculation of coral reef EV per ha (EVHA) (USD/ha) by dividing the EV by the coral reef area (*L; ha*) for a certain location (i.e., PANGKEP Regency), using the following equation:

$$\text{EVHA} = \frac{\text{EV}}{\text{L}}. \tag{11}$$

2.4 Economic Losses of Coral Reef Destruction

The overexploitation of natural resources has a negative impact on ecology and biodiversity. Economic activities may damage ecosystem functions and, subsequently, ecosystem services that lead to human wellbeing and balanced ecosystems (Grigalunas and Congar 1995; Moberg and Folke 1999; Chapin et al. 2000). The economic losses due to coral reef destruction were estimated with the following assumptions: (1) the only changeable variable was coral reef area (3,480 ha degraded during the period of 1994 – 2014 or a destruction rate of 174 ha/yr (Yasir-Haya and Fujii 2017); (2) the component of coral reef values used to estimate the economic losses was the UV; (3) the local currency (Indonesian Rupiah; IDR) was converted into USD (1 USD = IDR 13,000).

To discount the economic losses from past coral reef degradation, it was determined whether the discounted values were expressed in real or nominal terms. Real values have been adjusted for inflation, while nominal values are expressed in uninflated terms. This approach was proposed by the Division of Economics, U.S. Fish, and Wildlife Service, to assess the resulting damage due to the release of oil or other hazardous materials to the environment (Unsworth and Peterson 1995). This approach can be used to estimate the current value of the economic loss due to coral reef damage in the study area. To obtain these values in real terms, the inflation rate from 1994 to 2014 was adjusted. Using the GDP Implicit Price Deflator (Brander et al. 2007), the value of economic loss due to past coral reef damage was determined using the following formula (Unsworth and Peterson 1995):

$$PVEL(Y_{\mathrm{i}}) = \sum_{Y_i=1994}^{2014} EL(Y_i) \times \left(\frac{GDP_{2014}}{GDP(Y_i\,)}\right), \tag{12}$$

where $PVEL(Y_{\mathrm{i}})$ is the present value of the economic loss in year *i* (value in USD) and $EL(Y_i)$ is the economic loss in year *i* (value in USD).

Furthermore, to obtain the total economic loss (TEL) from 1994 to 2014, real discount rates were calculated using the following formula:

$$TEL_{1994-2014} \; = \sum_{Yi=1994}^{2014} PVEL(Y_{\mathrm{i}}) \; \times \; (1 + r)^{(2014-Yi)}. \tag{13}$$

where $TEL_{1994\text{-}2014}$ is the TEL from 1994 to 2014 and *r* is the discount factor.

In this case, this study was set the discount rate to 10% (White et al. 2000; Cesar 2000) to obtain the current value of coral reef damage or economic loss.

3. Results

3.1 Use Values (UVs) of Coral Reefs

Based on the TEV framework of this study, the UVs of coral reefs consisted of DUVs and IUVs.

3.1.1 Direct Use Values (DUVs)

Based on the field survey and the data analysis, the categories of economic benefits included in the DUVs were set as reef related fish, crab, squid, and octopus catches, seaweed farming, tourism, and scientific research. The results of this calculation are presented in the following section.

a. *DUV of reef-related fisheries*

Based on the questionnaire results, average prices (P) varied between 1.63 and 3.05 USD/kg, whereas the education level (E) was mostly elementary school (60%) and junior high school (40%). The age of the fishermen conducting fishing activities in the coral reef areas varied between 41 and 48 years old, with the number of family members ranging from 5 to 7 people. These data were processed using regression analysis to obtain the demand function, and then processed using Maple software to determine the demand curve (Figure 2), the values of the WTP, and consumer surplus (Appendix A2).

Based on the calculation, the total DUV of coral reef-related fisheries was 2.9 million USD/yr (Table 1). Seaweed farming accounted for most of this figure (1.3 million USD/yr), while the rest consisted of coral reef fish, crabs, squids, and octopus (803,000, 513,000, and 251,000 USD/yr, respectively). These values indicate the production value of the coral reef fisheries in 2014. The values obtained from demand function were reflected in the form of a demand curve (Figure 2). This figure shows that the production rate was relatively low for coral reef fish, and squid and octopuses, both of which are sold for high prices in the market. On the other hand, crabs and seaweeds were produced in large quantities and were sold at cheaper prices.

The DUVs of reef-related fisheries was estimated to be as low as USD 2.9 million or 675 USD/ha, with total coral reef cover of 4,236 ha in 2014 (Table 1). This value is much higher than that of the Taka Bonerate Marine Protected Area (MPA), South Sulawesi, Indonesia (7.8 USD/ha) (Sawyer 1992) and the Great Barrier Reef MPA (4.2 USD/ha) (Driml 1999). However, the DUVs of reef-related fisheries in this area is much lower than the global average BV of reef-related fisheries (Costanza et al. 1997), which is 2.2 million USD/ha.

b. *DUVs of Reef-related Tourism and Recreation*

The DUVs of coral reef-related tourism and recreation were determined by calculating the total expenses incurred by tourists or visitors. The questionnaire results showed that there were two main tourism destinations in the PANGKEP Regency, the Kapoposang Marine Park and Panambungan Island. In 2014, the Kapoposang Marine Park and Panambungan Island received 150 and 50 visitors, respectively (Statistics Indonesia, Regency of Pangkajene and Kepulauan 2014). The average TC obtained from the interview respondents was 723 USD/person/trip (Kapoposang Marine Park) and 154 USD/person/trip (Panambungan Island), which included fees for round-trip transportation, accommodation, scuba diving equipment, local guides, boat rental, food and beverage charges, and other costs (Table 2). Assuming an average duration of four days per trip (Kapoposang Marine Park) and one day per trip (Panambungan Island), the DUV of reef-related tourism and recreation in the Kapoposang Marine Park and Panambungan Island was estimated to be USD 108,462 and USD 7,700, respectively (Table 3).

Hence, the total UV of reef-related tourism and recreation in the two largest destinations in 2014 was estimated to be USD 116,162 or 27 USD/ha (Table 3). This value is lower than the value reported for several similar tourist destinations, including the Danajon’s reefs in the Philippines (227 USD /ha). According to Samonte et al. (2016), the net benefits of coral reefs from tourism and recreation have high annual BVs if the coral reefs are well managed and intact. For example, the BVs of coral reefs are estimated to be 663 million USD/yr in the Caribbean, 269 million USD/yr in Pacific, 779 million USD/yr in Japan, 483 million USD/yr in the USA and 1,147 million USD/yr in Australia (Cesar et al. 2003).

c. *DUVs of Reef-related Scientific Research*

The economic value of reef-related scientific research was also calculated using the TC method. The total number of researchers who visited the study area in 2014 was 71 (Statistics Indonesia, Regency of the PANGKEP 2014), which included researchers, professors, and students. The average duration of stay to conduct research in the study area was four days, with an average cost of 231 USD/person/trip. Hence, the DUV of reef-related scientific research was estimated to be USD 16,401 or 3.87 USD/ha in 2014.

3.1.2 Indirect use value (IUV)

Based on the calculated length of the coast line of the 31 inhabited islands (37,995 m), barrier width (1 m), and barrier height (1.5 m), then a volume of the coastal protection barrier of 56,992.50 m^3 was obtained. If the construction cost of the barrier was assumed to be 297 USD/m^3, then the total UV of reef-related shoreline protection was USD

16,931,157 or 3,997 USD/ha. This amount represents the economic value of coral reefs functioning as a barrier to prevent coastal erosion.

3.2 Non Use Values (NUVs) of Coral Reefs

The NUVs investigated in the PANGKEP Regency, Spermonde Archipelago, consisted of both bequest values (BVs) and existence values (EVs), respectively. The annual total NUV of coral reefs estimated in the study area was USD 11,949,932,130. The estimated NUVs of coral reefs are described below.

3.2.1 Bequest Value (BV)

Using the BT method, and by adjusting to the 2004-2014 inflation rate and the GDP Implicit Price Deflator, the BV of coral reefs in the study area was estimated to be USD 11,947,701,429 (Table 3). The results clearly show that the high value in the study area was due to the vast area of live coral cover (4,236 ha).

The high value in the study area reflects the significant public concern regarding the current status of the coral reef ecosystem, as well as the desire to preserve the coral reef ecosystem for future generations.

3.2.2 Existence Value (EV)

The estimation of coral reef EV in this study was conducted using the CVM. The results of the questionnaire surveys show that the average age and number of family members of the respondents were 48 and 6-7, respectively. A statistical analysis of the WTP, which indicates the incomes and characteristics of local fishermen, resulted in a value of 66.62 USD/person (Appendix A3). Using the total population in the study area (31,983 persons), the estimated EV of coral reefs was USD 2,130,707 or 503 USD/ha (4,236 ha of coral reef cover). The results clearly show that WTP is driven by age, household size, monthly income, and education level. These findings were not surprising because income and education level are associated with WTP, while age and household size influence income.

3.3 Total Economic Value (TEV) of Coral Reefs

It has been reported that approximately 3,480 ha of coral reefs in the study area are in bad condition (Yasir Haya and Fujii 2017), but these coral reefs could still provide as much as USD 11,969,783,716 EV, which consists of the UV (USD 19,951,580; 0.2%) and NUV (USD 11,949,832,136; 99.8%).

For the UV, coral reefs as a source of goods (i.e., direct benefits as fisheries) provided economic benefits of USD 2,887,860 or 682 USD/ha. The benefits of the coral reefs as a source of services (i.e., tourism, recreation, and research) also contributed to their economic value in 2014 (USD 132,563 or 31 USD/ha). The DUVs of reef-related fisheries, tourism, recreation, and research, and the IUV of coral reef-related coastal protection had the highest UV, with a combined value of USD 16,931,157 or 3,996.96 USD/ha. This indicates that coral reefs in the study area provide a significant DUV to the community when they are properly managed.

The "non-use" benefits related to the coral reef conservation for future generations (i.e. bequest value) consisted of 98% of the total economic value of coral reefs in the PANGKEP Regency. The high portion was estimated because of the relatively wide area of coral reefs of 4,236 ha and high bequest value. According to a previous study (Boutwell and Westra 2013), there were no references for the bequest value of coral reefs in the PANGKEP Regency, and therefore, the bequest value in the Wakatobi MPAs with similar characteristics and geography was referred to Hargreaves-Allen’s value in 2004 (Hargreaves-Allen 2004).

The high bequest value indicates that coral reefs in the PANGKEP Regency could be the source of livelihood for future generations when the local community within the area shows great awareness and activities of saving coral reef ecosystems.

In general, the TEV of coral reefs in the study area (2.8 million USD/ha) was within the range of typical values for Southeast Asian coral reefs (2.3-27 million USD/ha (Burke et al. 2011). This indicates that the coral reef ecosystem in the PANGKEP Regency could still provide economic value in the form of goods and services, even though the coral reefs have been continuously degraded by destructive fishing. The TEV does not consider all economic activities in the study area, such as small-scale businesses, i.e., stalls for primary needs, boat rental, and carpentry (Driml, 1999).

3.4 Total Economic Loss (TEL) of Coral Reefs

To estimate the economic loss of coral reefs due to coral reef damage in the PANGKEP Regency, the total area of reef destroyed from 1994 to 2014 (3,480 ha) can be used as input data (Yasir Haya and Fujii 2017). The destruction resulted in a direct loss of benefit of coral reefs, which also meant a loss of income for fishermen, tourism services, and coastal protection. Using the GDP Implicit Price Deflator and a discounting factor, the TEL of coral reefs due to coral reef damage from 1994 to 2014 was estimated to be USD 819,500 (Table 4).

The TEL of coral reefs due to reef destruction shown in Table 3.4 was obtained by multiplying the destruction rate (174 ha/yr) with the benefit of the UV in 2014 (4,710 USD/ha) (Yasir Haya and Fujii 2017). After adjustment for inflation using the GDP Implicit Price Deflator and a discounting factor in each year, the current value of annual damages was obtained.

Based on the calculation, the economic loss was found to have fluctuated over the period from 1994-1995 to 2013-2014. In the period 1994-1995, the economic loss due to coral reef damage was USD 54,147,209, and it then increased rapidly to USD 90,442,098 in the period of 1995-1996. In the period of 1996-1997, the financial loss rose significantly to a peak of USD 109,557,342. It then gradually decreased to USD 16,390,800 from the period of 1996-1997 to 2013-2014. The total value of the economic loss due to coral reef damage from 1994 to 2014 was USD 1 billion or 50 million USD/yr.

Our results indicated a loss equivalent to 288 USD/ha, which was low compared to the value of the economic losses estimated by Cesar (1996). According to Cesar (1996) the financial loss due to damage to Indonesia's coral reefs over a 25-year period ranged from 981 to 7,612 USD/ha (by blast fishing) and from 428 to 4,756 USD/ha (by cyanide fishing). There may be several reasons for the differences with the results of this study, including: 1) the difference in the size of coral reef area considered by the two studies; 2) the difference in the UV of coral reefs included as input data in the two studies; 3) the difference in the period of calculation, i.e., 20 years in this study and 25 years in Cesar (1996); 4) the difference in the number of fishermen active over the period of the two studies; and 5) differences in the kinds and amounts of fishing gears and vessels used. Although there were differences between the estimated results of the two studies, our results indicate that there has been a decrease in the economic value of coral reefs in the study area due to a decline in the coral reefs' function as a source of fishery products in the last 20 years (1994-2014), which has been caused by destructive fishing practices. According to Yasir Haya and Fujii (2017), destructive fishing practices have resulted in 3,480 ha of damaged coral reef during 1994-2014, i.e., 174 ha/year.

Based on these results, there have been large economic losses due to the substantial decline in coral cover over the 20 years from 1994 to 2014. Although reef fisheries production data during the period are unavailable, this study referred to the results of Yasir Haya and Fujii (2017), which estimated a loss of 3,480 ha of coral reef area over the period of 1994-2014, i.e., a destruction rate of 174 ha/yr. These conditions would have a negative impact on the productivity of coral reef-related fisheries. It is likely that economic losses will continue to accrue if destructive fishing persists and better management of coral reef resources do not materialize.

These results could also be used as the basis for calculating rehabilitation costs, compensable losses, and compensation costs, and for establishing an educational campaign for fishermen. To provide compensatory welfare for the 31,983 fishermen in the study area, the compensation cost would be 31,382 USD/person.

4. Discussion

4.1 Values of Coral Reefs

Coral reef destruction in this area is considered to be a result of low appreciation of the value of the ecosystems by the local stakeholders. In other word, the local stakeholders still undervalue the real worth of benefits produced by coral reef ecosystems, which leads to the degradation. Economic valuation is an approach used to measure the degree of local appreciation to the coral reefs by comparing the prices of service or good given by the local stakeholders with the real whole values of the coral reefs.

In spite of the degradation, the coral reefs in the PANGKEP Regency still benefit to the local community and the environment. Direct benefits could be calculated using monetarily, while the indirect benefits could not be quantified monetarily. However, as the whole, it is concluded that the coral reefs in this area possess high tangible and intangible value. Tangible values generally consist of consumable or non-consumable use values, e.g. fishery and tourism, while intangible values are non-use benefits or costs needed for long-term ecosystem maintenance.

The value of coral reefs related to fisheries in the study sites is much higher than the coral reefs inside of the MPAs. This discrepancy is possibly caused by differences in the management systems. In MPAs, the use of coral reefs has been regulated according to a zoning system (i.e., core zone, buffer zone, use zone, etc.), with fishing activities only permitted in the use zone. In contrast, there is no zoning system for the use of coral reefs implemented in the area investigated in this study. Coral reef management without a zoning system tends to encourage excessive exploitation of coral reefs by fishermen throughout the year. Therefore, effective management of coral reefs will initially reduce the income of fishermen, but will provide a more sustainable option in the long term. These results are consistent with the income model proposed by Pet-Soede et al. (1999) in terms of a comparison of fishermen's net income when practicing either destructive or non-destructive fishing.

However, the value is considered to be relatively low compared to Costanza et al. (1997), which is 2.2 million USD/ha. There are several reasons for this discrepancy, including an annual increase in the number of local fishermen, which causes a significant loss of production value in the coral reef fisheries. The high price of fish as a commodity in the domestic market encourages fishermen to intensify their fishing activities, which in turn leads to overexploitation and a loss of coral reef value. The low economic benefit regarding the direct value of this overexploitation has resulted in massive coral reef degradation in the region.

In the marine ecotourism sector, the number of domestic and international visitors to the PANGKEP Regency which was 200 in 2014 is considered to be low compared to that to the Wakatobi Regency which amounted to 14,270 in 2014 (Statistics Indonesia, Regency of Wakatobi 2016). There were several factors responsible for the small number of tourists who visited the PANGKEP Regency: (1) the Kapoposang Island as a destination for marine ecotourism is located in the outer zone of PANGKEP Regency and is far from the mainland of Sulawesi, from either Makassar City or PANGKEP Regency. It requires a 6-8 hour boat journey to reach the location. (2) There is no public transport available for tourists and, therefore, extra fees are required to rent boats. (3) Destructive fishing (e.g., blast and cyanide fishing) is practiced intensively at Kapoposang Island.

This has resulted in many issues with visitors who are concerned about safety. Tourists have therefore been encouraged to visit other locations where destructive fishing is less widely practiced.

Therefore, anew policy for improving marine transportation infrastructure is needed to be implemented. Also, efforts to prevent destructive fishing practices are required to be made by the policy makers and relevant stakeholders in this area.

4.2 Socio-economic factors

Socio-economic factors related to fishermen living within coral reef area in the PANGKEP Regency affect the coral reef ecosystems as natural resource. Low education level and lack of awareness about the importance of coral reefs trigger the destructive fishing practice that cause long-term economic losses. Other triggers include low income level and no alternative livelihoods. In the study area, these were the boosting factors for individuals (fishermen) to conduct destructive fishing to fulfil daily needs of their family without any significant consideration of its long-term ecological impact. A social survey to key stakeholders revealed that perpetrators of the DFP was primary resulting from low education level, lack of awareness and no alternative livelihood and low income.

To solve this issue, planning of new comprehensive policies is considered to be necessary. The policy must be responding several crucial points: 1) lack of educational facilities and teaching staffs, 2) lack of access to business capitals, 3) high operational costs of fishing, 4) further fishing locations from the settlements of traditional fishermen, 5) high prices of commodities which leads to capital loss of fisheries people.

4.3 Sustainability of Coral Reefs

To anticipate the continuing loss of economic value of coral reefs and to ensure the sustainability of ecosystem function in study area, establishment of MPAs is considered to be necessary. The MPAs have been established in various coral reefs to manage fisheries, biodiversity conservation, habitat restoration, tourism and the other human activities in effective and sustainable ways (e.g. Ward and Hegerl 2003; Sumaila and Charles 2002; Christie and White 2007).

Specifically, the benefit expected by the presence of MPAs is the restoration of fish stock and ecosystem function. The sustainable benefit includes the spillover effect of fish larvae from MPAs to the surrounding non-MPAs. The spillover effect enables to provide additional fish stocks outside of the MPAs while maintaining the fish stocks inside the MPAs (Bohnsack 1994). Even though the expectation had been review in several references (Lauenroth and Burke 2008; Carpenter and Springer 2005; Roberts et al. 2002; Spalding et al. 2001; Weeks et al. 2010; White et al. 2000), several empirical studies had been conducted to elucidate the real function of MPAs. Therefore, integrated approaches are needed to design future MPAs by involving local communities. Local involvement in the planning, designing, establishing and managing MPAs is considered to be crucial to make MPAs effective in long term period.

Coral reef exploitation inside the MPAs are not only related to fisheries but also to tourism since the environment-friendly nature of this sector, and it is considered that tourism could improve the economic condition of local people which may lead to coral reef protection. In this study, economic value of coral reefs related to the tourism both inside and outside MPAs was calculated for 2014. The result shows that the economic value was estimated to be USD 108,462 inside the MPAs (i.e. in the Kapoposang Island), while the value was around USD 7,700 outside the MPAs (i.e. in the Panambungan Island). Therefore, coral reefs within MPAs could provide relatively high economic value compared to those outside MPAs, showing the effectiveness of MPAs for saving coral reefs.

5. Conclusion

The PANGKEP's coral reefs are valuable resources, providing many functions and benefits as economic goods and services, e.g., fisheries, tourism, recreation, research, and protection of the coastal environment and marine biodiversity for many generations of fishermen and the local community.

In 2014, the total economic benefit of coral reefs was USD 12 billion or 3 million USD/ha. In contrast, during the period between 1994 and 2014, the coral reefs experienced a loss in economic value of USD 1 billion or 50 million USD/yr. The loss was due to extensive coral reef use, especially related to fisheries (i.e., coral reef fish, crabs, squids and octopuses, and seaweed farming), tourism and recreation, research, and coastal protection. The economic value of coral reefs has continued to decline and economic losses will continue to rise in the future due to the intensive use of destructive fishing practices. The following practices could be adopted to reduce the loss of economic value of coral reefs: 1) selection of appropriate fishing gears, 2) development of an alternative livelihood for small and traditional fishermen, 3) environmental education to improve public awareness, 4) price standardization of fishery products to stabilize fishermen's income, 5) strict law enforcement and severe penalties to prevent destructive fishing practices, and 6) designing effective marine protected areas.

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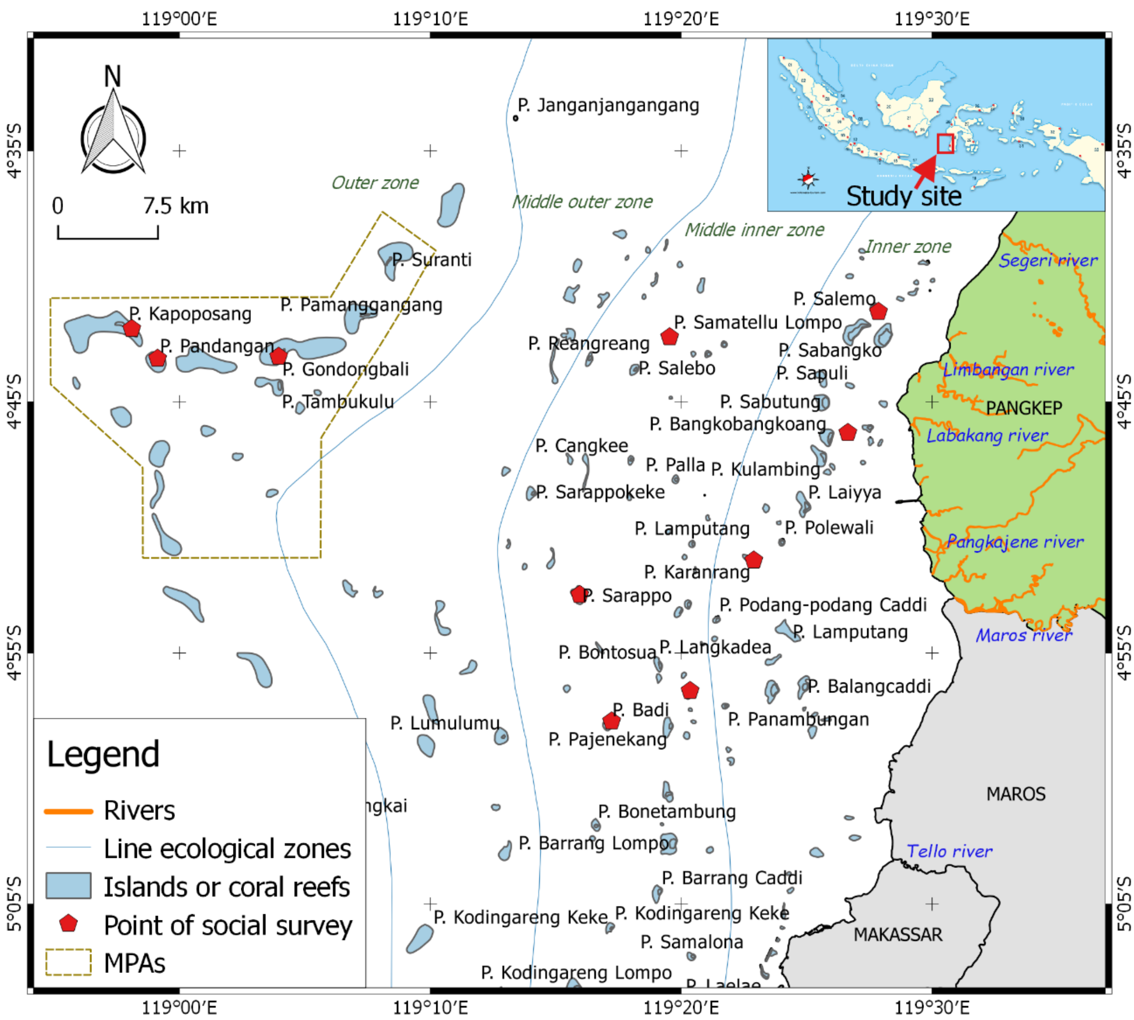

Figure 1. Map of the study area in the PANGKEP Regency, Spermonde Archipelago, South Sulawesi, Indonesia

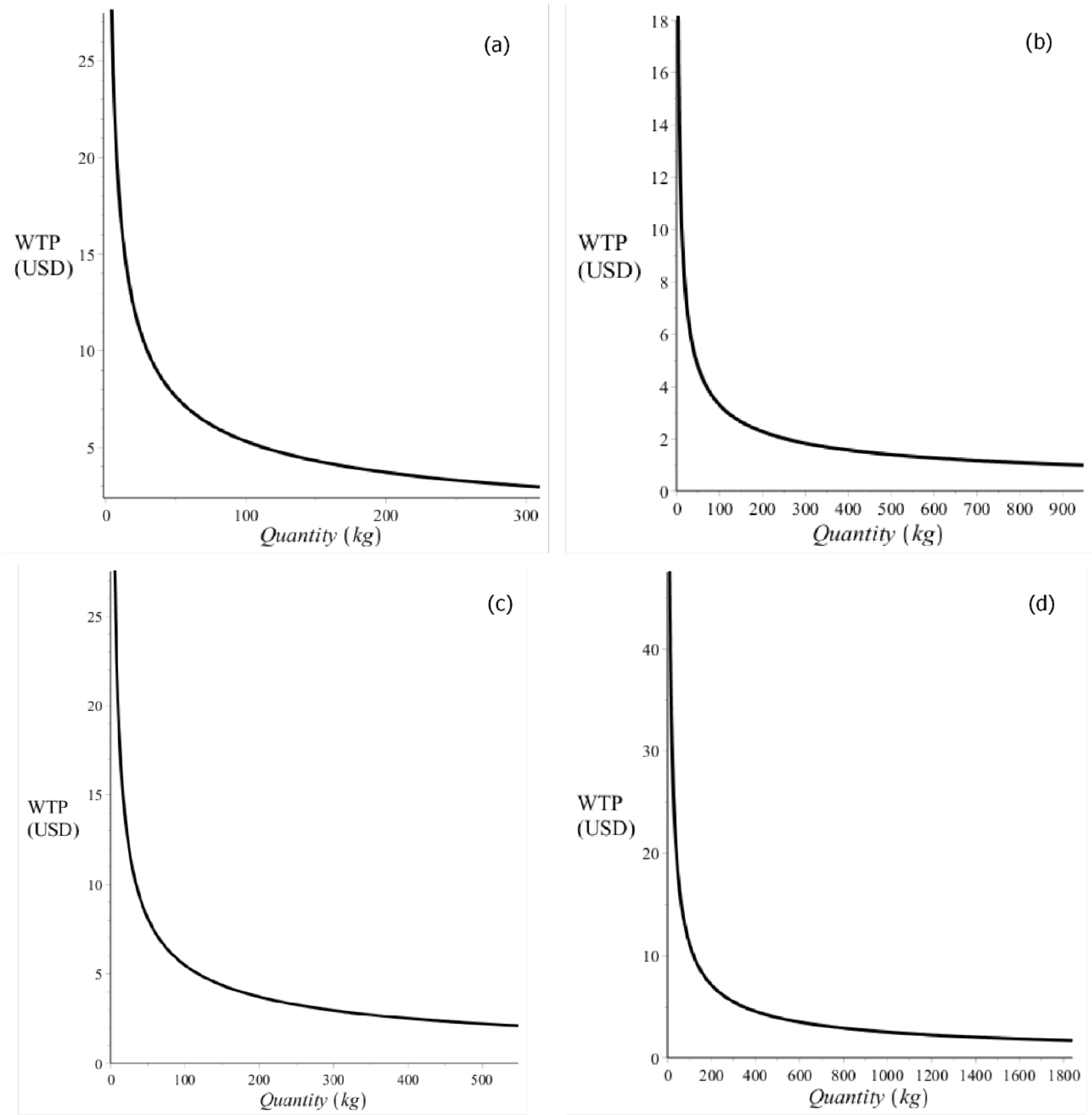

Figure 2. Demand function of the coral reef benefits related to the fisheries using the effect on production (EOP) method for: (a) the coral reef fish catch, (b) the crab catch, (c) the squids and octopuses catch and (d) seaweed farming

Table 1. Direct use benefits of coral reef-related fisheries calculated using the effect on production (EOP) method. The calculation is presented in detail in Appendix A2

Type of direct use value from fisheries	The number of respondents (N)	Average price (USD /kg)	Ratio of education level	Average age (years old)	The number of families	Total number of fishers/ farmers (N)	Demand function	Total area of coral cover (ha) (in 2014)	Values of reef-related fisheries (in 2014)	
									USD	USD /ha
Coral reef fish	31	3.05	Ratio 2[**]	41	5-6	807	$f(Q) = 58.70\ Q^{-0.52}$		803,035	190
Crabs	31	1.63	Ratio 1[*]	45	5-6	290	$f(Q) = 63.40\ Q^{-0.53}$		512,720	121
Squids and octopuses	31	2.22	Ratio 2[**]	48	6-7	169	$f(Q) = 73.31\ Q^{-0.56}$	4,236	251,166	59
Seaweeds	30	1.75	Ratio 1[*]	46	6-7	231	$f(Q) = 219.44\ Q^{-0.64}$		1,319,939	312
Total									2,886,860	675

[*] Ratio 1 is the ratio of education level in the fishermen group that dominated (>65%) by elementary school.

[**] Ratio 2 is the ratio of education level in the fishermen group that dominated (>65%) by junior high school.

Table 2. Components of tourist expenditure for visitors to the Kapoposang Marine Park and Panambungan Island in 2014

Component	Expenses (USD)
Kapoposang Marine Park*	
Transportation between Makassar and Kapoposang (round trip)	153.84
Accommodations	107.69
Food and beverages	92.30
Scuba diving equipment rent (one set)	46.15
Air tank charge (one unit)	15.38
Local guides	76.92
Local boat rent	230.76
Total	723.08
Panambungan Island**	
Transportation between Makassar and Panambungan (round trip)	76.92
Accommodations	0.00
Food and beverages	26.92
Scuba diving equipment rent	11.54
Air tank charges	3.85
Local guides	19.23
Local boat rent	15.38
Total	153.85

* The average length of stay was four days per person per trip

** The average length of stay was one day per person per trip

Table 3. Estimated economic value of coral reefs in the study area based on the categorization of the economic value of coral reefs in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The area of coral reefs was fixed to 4,236 ha in 2014

Category of value	Component of value	USD	USD/ ha	Ratio (%)
Sub-Use Value (UV)	Direct use values:			
	– Coral fisheries	803,035	190.00	0.2
	– Crabs	512,720	121.00	
	– Squids and octopuses	252,166	59.29	
	– Seaweeds	1,319,939	312.00	
	Subtotal:	2,887,860	682	
	– Tourism and recreation in the Kapoposang Marine Park	108,462	25.60	
	– Tourism and recreation in the Panambungan Island	7,700	1.82	
	Subtotal:	116,162	27.42	
	– Researches	16,401	3.87	
	Indirect use values:	16,931,157	3,996.96	
	– Coastal protection			
Non-Use Value (NUV)	Bequest value	11,947,701,429	2,820,515.00	99.8
	Existence value	2,130,707	502.99	
Total Economic Value (TEV)		11,969,782,716	2,825,728.53	100.0

Table 4. Estimated current values of economic loss (USD) due to the destruction of coral reefs from 1994 to 2014 in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The GDP Implicit Price Deflator (Organization for Economic Co-operation and Development (OECD), 2016) was used, and a discount rate of 10% was applied for the estimation. The destruction rate and economic loss of coral reefs was assumed to be 174 ha/yr and 819,500 USD, respectively, during the study period

Period	GDP Implicit Price Deflator	Adjustment for inflation (GDP Deflator in current year / GDP Deflator in previous year)	Economic loss (in 2014; USD)	Calculation of discount damages	Present value of economic loss (in 2014; USD)
1994-1995	11.42	10.80	8,853,501	6.12	54,147,209
1995-1996	12.43	9.92	16,266,806	5.56	90,442,098
1996-1997	13.99	8.82	21,675,336	5.05	109,557,342
1997-1998	24.52	5.03	16,488,981	4.59	75,766,420
1998-1999	27.99	4.41	18,054,494	4.18	75,418,102
1999-2000	33.72	3.66	17,987,422	3.80	68,307,205
2000-2001	38.54	3.20	18,360,553	3.45	63,385,610
2001-2002	40.81	3.02	19,815,176	3.14	62,188,512
2002-2003	43.05	2.87	21,132,446	2.85	60,293,334
2003-2004	46.73	2.64	21,630,895	2.59	56,104,972
2004-2005	53.43	2.31	20,811,348	2.36	49,072,069
2005-2006	60.96	2.02	19,899,904	2.14	42,657,212
2006-2007	67.82	1.82	19,376,690	1.95	37,759,687
2007-2008	80.13	1.54	17,661,658	1.77	31,288,704
2008-2009	86.76	1.42	17,477,024	1.61	28,146,922
2009-2010	100.00	1.23	16,173,403	1.46	23,679,480
2010-2011	107.47	1.15	15,990,406	1.33	21,283,231
2011-2012	111.50	1.11	16,318,444	1.21	19,745,317
2012-2013	117.04	1.05	16,410,100	1.10	18,051,110
2013-2014	123.34	1.00	16,390,800	1.00	16,390,800
Total economic losses for the past 20 years (1994-2014)					1,003,685,337

Appendix A1. Effect on Production (EOP) method

A given resource demand function was determined as follows. The subordinate units of resources were related to the DUVs of coral reefs estimated in this study, which consisted of coral fish, crab, squids and octopuses, and seaweed farming. The subordinate resource units were calculated using the following demand function (Q):

$$Q = \beta V_1^{\,a} V_2^{\,b} V_3^{\,c} V_4^{\,d}, \tag{A1}$$

where Q is the total resource gained, V_1 is the variable of market prices per unit of resources calculated in all the study sites, V_2 is the variable of age, V_3 is the variable of education level, V_4 is the variable of number of family members, β is the intercept, a is the coefficient of price, b is the coefficient of the age, c is the coefficient of the education level, d is the coefficient of the family member (Adrianto 2006; Wahyuddin 2007; Wawo et al. 2014).

Equation (A1) was then transformed in the form of a linear function to calculate the coefficient value of each of the selected parameters (the subordinate units of resources) using a linear regression technique as in the following equation:

$$ln\ Q = \beta + a\ lnV_1 + b\ ln\ V_2 + c\ lnV_3 + d\ ln\ V_4, \quad \text{(A2)}$$

$$= (\beta + b\ ln\bar{V}_2 + c\ ln\bar{V}_3 + d\ ln\bar{V}_4) + a\ lnV_1,$$

$$= \beta' + a\ lnV_1, \quad \text{(A3)}$$

where $\bar{V}_2$ is the average age, $\bar{V}_3$ is the average education level, $\bar{V}_4$ is the average number of family members.

$$\beta' = (\beta + b\ ln\bar{V}_2 + c\ ln\bar{V}_3 + d\ ln\bar{V}_4). \quad \text{(A4)}$$

Equation (A3) was reverse transformed to its original function based on the results from the integration of socio-economic coefficients and variables to obtain the demand function of the DUV of coral reefs, expressed in the form of:

$$Q = \text{EXP}\ (\beta')\ V_1{}^{a}, \quad \text{(A5)}$$

as written in the following equation:

$$Q = \mathrm{EXP}\ (\beta')\ V_1{}^{a}, \text{ if } Q = \mathrm{EXP}\ (\beta'), \qquad \text{(A6)}$$

where a is concurrently denoted as σ, hence, Equation (A6) is written as:

$$Q = \alpha\ X_1{}^{\sigma}. \qquad \text{(A7)}$$

When the demand function (Q) is known, then the utility value (U) of coral reefs which is also expressed as the total value of the WTP, can be determined using the following equation:

$$U = \int_0^a f(Q)dQ, \qquad \text{(A8)}$$

where U is the utility value or the total value of WTP for coral reef ecosystems, *f(Q)* is the price of the average WTP.

Furthermore, the payable value for coral reefs (PQ) could be calculated by multiplying f(Q) by the total average BV of coral reefs ($\bar{Q}$) as follows:

$$PQ = f(Q) \times \bar{Q}. \quad \text{(A9)}$$

The consumer surplus value (CS) is calculated as the direct value of coral reef ecosystems per individual:

$$CS = U - PQ, \quad \text{(A10)}$$

where U is utility value of coral reefs in 2014. From Equation (A10), the economic value (EV) of the direct use of coral reef ecosystems in a certain location (i.e., PANGKEP Regency in this study) is obtained from the CS multiplied by the total population of direct users of reef-related resource units (N):

$$EV = CS \times N. \quad \text{(A11)}$$

In addition, the economic value per ha of coral reefs is obtained from the EV divided by the area of coral cover (L) in a certain location (i.e., PANGKEP Regency in this study), and expressed by the following equation:

$$\frac{EV}{ha} = \frac{CS \times N}{L}. \tag{A12}$$

Appendix A2. Calculation of direct use values (DUVs) using the effect on production (EOP) method

A2.1 Regression analysis and coefficient determination

Based on multiple regression analysis, there is relationship between demand of fisheries production and the community characteristics (i.e., price, age, education level, family member, and income) which are expressed in Table A2.1.

Table A2.1 Result of correlation and determination analysis which were resulting from multiple regression analysis in terms of direct use value of reef-related fisheries. In this case, there are 5 independent variables (i.e., price, age, education, family member, and income) and one dependent variable (i.e., demand-Q)

Regression statistics	Reef fish	Crabs	Squids and Octopuses	Seaweeds
Multiple R	0.87	0.92	0.92	0.89
R Square (R^2)	0.76	0.85	0.85	0.79
Adjusted R^2	0.73	0.83	0.80	0.74
Standard Error of the estimate	0.16	0.053	0.18	0.17

Based on the Table, Multiple R describes the strong relationship between X-variables (i.e., price, age, education, family member, and income) with the Y-variable (demand-Q). Based on the results, the highest correlation (R) was obtained from Crabs and Squids and Octopuses of 0.92, then it followed by seaweeds (0.89) and Reef fish (0.87).

The value of R Square (R^2) shows the contribution percentage of the X-variables (i.e., price, age, education, family member, and income) to the Y-variable (demand-Q). In this case, Crabs and Squids / Octopuses have a percentage of 85%, seaweeds (79%) and reef fish (76%).

Adjusted R^2 illustrates the value of R^2 that adjusted. This value is always smaller than R^2 values and can be a negative value. According to Harbord and Higgins (2008) that Adjusted

R2 can be used as the coefficient of determination if the variables analyzed are more than two independent variables (X-variables).

Standard error of the estimate describes a measure of the number of regression model errors in predicting Y-values. From the regression results, it obtained values of USD 0.18 (Squids and Octopuses), USD 0.17 (Seaweeds), USD 0.16 (reef fish), and USD 0.053 (Crabs).

A2.2 Calculation of the DUV of coral reef-related fisheries

The linear regression equation of the reef-related fisheries in the PANGKEP Regency is expressed as follows**:**

$$\ln Q = \beta + a (\ln P) + b (\ln Ag) + c (\ln F) + d (\ln E) + e (\ln I), \qquad \text{(A13)}$$

where Q is demand of market, P is price, Ag is the average age, F is the number of family members, E is the education level, and I is income. While β, a, b, c, d, and e, are the coefficients of which values are given as in Table A2.2.

Table A2.2 Coefficient of the fishermen characteristics in terms of fisheries production in coral reefs. In this case, there are four types of fisheries production in the coral reef ecosystems.

Types of production	Coefficient values					
	Intercept (β)	Price (a)	Age (b)	Family member (c)	Education (d)	Income (e)
Reef fish	26.18	-1.91	-0.13	0.19	-0.15	0.00
Crabs	25.38	-1.86	0.01	0.01	-0.003	0.00
Squids and Octopuses	27.21	-1.77	-0.75	-0.04	0.28	0.00
Seaweeds	14.47	-1.54	-0.67	0.10	0.0002	0.72

If the coefficients obtained by the regression analysis (Table A2.2) are substituted into

Equation (A13), it is modified in the following:

a. Fish coral:

$$\ln Q = 25.96 - 1.91 (\ln P), \quad \text{(A14)}$$

b. Crabs:

$$\ln Q = 25.40 - 1.86 (\ln P), \quad \text{(A15)}$$

c. Squids and Octopuses:

$$\ln Q = 26.69 - 1.77 (\ln P), \quad \text{(A16)}$$

d. Seaweeds:

$$\ln Q = 14.64 - 1.54 (\ln P). \quad \text{(A17)}$$

Then function A14 through A17 were transformed into a non-linear equation as follows:

a. Coral Fish:

$$Q = 188601317946.42\, P^{-1.91}, \quad \text{(A18)}$$

b. Crabs:

$$Q = 11433584409.38\, P^{-1.86}, \quad \text{(A19)}$$

c. Squids and Octopuses:

$$Q = 41616852299.79\, P^{-1.77}, \quad \text{(A20)}$$

d. Seaweeds:

$$Q = 9492363691.66\, P^{-1.54}. \quad \text{(A21)}$$

To facilitate the estimation of some component values in effect on production (EOP) methods in terms of utilities, average WTP, debt values, and consumer surplus, then this study was used Maple software. Maple is math software that combines the world's most powerful math engine with an interface that makes it extremely easy to analyze, explore, visualize, and solve mathematical problems (Maple 2015). By using Maple Software, the function A18 through A21 can be formulated using the following equation:

a. Reef fish:

$$f(Q) = \frac{58.70}{Q^{0.52}}, \quad \text{(A22)}$$

b. Crabs:

$$f(Q) = \frac{63.40}{Q^{0.53}}, \quad \text{(A23)}$$

c. Squids and Octopuses:

$$f(Q) = \frac{73.31}{Q^{0.56}}, \quad \text{(A24)}$$

d. Seaweeds:

$$f(Q) = \frac{219.44}{Q^{0.64}}. \quad \text{(A25)}$$

Furthermore, from the function A22 through A25, several values as shown in Table A2.3 were obtained.

Table A2.3 The result of calculation of some component of value in the EOP method

Types of fisheries production	Utility value (U) in USD	Average WTP in USD	Payable value (PQ) in USD	Consumer Surplus (CS) in USD
Reef fish	1,907	3	912	995
Crabs	3,305	2	1,537	1,768
Squids and Octopuses	2,640	2	1,153	1,486
Seaweeds	8,832	2	3,118	5,714

Appendix A3. Calculation of Existence Value of Coral Reefs using Contingency Valuation Method (CVM)

In order to estimate the value of willingness to pay (WTP), questionnaire data were tabulated and analyzed statistically for further analysis. Based on regression analysis, relationship between the WTP and characteristics of the community are given in Table A3.1.

Table A3.1 The result of correlation and determination analysis which were resulting from multiple regression analysis in terms of existence value of coral reefs. In this case, there are 4 independent variables (i.e., income, age, education, and family member) and one dependent variable (i.e., the WTP)

Model	Multiple R	R Square	Adjusted R Square	Standard error of the estimate
The WTP	0.78	0.61	0.45	0.39

Based on the results of the statistical analysis, the function of WTP could be formulated into the following equation:

$$\ln \text{WTP} = \beta + a (\ln I) + b (\ln Ag) + c (\ln E) + d (\ln F), \quad \text{(A26)}$$

where I is income, Ag is the age, E is the education level, and F is the number of family members. While β, a, b, c, and d, are the coefficients of which values are given as in Table A3.2.

Table A3.2 Coefficient of fisherman characteristics in terms of the willingness to pay for the sustainability of coral reefs

The WTP	Intercept (β)	Income (a)	Age (b)	Education (c)	Family member (d)
Coefficient	6.40	0.30	0.81	0.42	-0.71

By inputting the average value of income (*I*), age (*Ag*), education (*E*), the number of family members (*F*), and their coefficient in Table A3.2, then the WTP values could be estimated as follows:

$$\ln WTP = 13.67 \qquad (A27)$$

$$= 866{,}059.138 \text{ (1 USD = 13,000 IDR)}$$

$$= 66.62 \text{ USD /person.}$$