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

3
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14
15 **Abstract**

16 Coral reef ecosystems possess tangible and intangible economic benefits to human
17 society that are still underestimated and not fully understood. This study aimed: 1) to
18 calculate the total economic value (TEV) of coral reef ecosystems, and 2) to calculate the

19 losses due to coral reef destruction over a 20-year period, from 1994 to 2014, in the
20 vicinity of selected small islands in the Pangkajene and Kepulauan (PANGKEP) Regency,
21 Indonesia. To estimate the TEV of the coral reef ecosystem, data obtained from a social
22 survey were analyzed to determine the economic value of use and non-use. Based on the
23 calculation, the TEV of coral reef ecosystems was estimated to be USD 11.96 billion or
24 2.82 million USD/ha. The economic losses due to coral reef destruction over the 20-year
25 period from 1994 to 2014 were USD 1 billion or 50.18 million USD/yr. We anticipate
26 that the economic loss of coral reefs will continue to rise due to the intensification of
27 destructive fishing practices. Therefore, an effective management policy should be
28 established to prevent further destruction of coral reefs in this area in the future.

29

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

32

33

34 **1. Introduction**

35 Coral reefs are among the most productive ecosystems in the marine environment,
36 and have functional roles in supplying goods and services for human benefits, including
37 fisheries, tourism, scientific research, shoreline protection, and medicines (e.g., Moberg
38 and Folke 1999; Souter and Linden 2000; UNEP 2006; Brander et al. 2007; Tseng et al.
39 2015). Regrettably, coral reef ecosystems are severely threatened and many are in a
40 devastated condition, either due to negative impacts associated with human activities (e.g.,
41 destructive fishing practices, reclamation, pollution, waste dumping, and uncontrolled
42 tourism activities) or the effects of climate change (e.g., ocean acidification, bleaching
43 phenomena, and sea-level rise) (Morton 1994; McManus 1997; Pet-Soede 2000; Harley
44 et al. 2006; Brander et al. 2007; Burke et al. 2011; Yusuf and Jompa 2012; Nashr 2015;
45 Pendleton et al. 2016). In addition, nutrient runoff from soil erosion and fertilizers are
46 potentially serious threats to the long-term sustainability of coral reef ecosystems, causing
47 outbreaks of crown-of-thorns starfish (Wooldridge and Brodie 2015; Lamy et al. 2016)
48 and coral reef diseases due to certain pathogenic viruses that infect coral reefs (Weil et al.
49 2006; Haapkyla et al. 2011). The destruction and loss of coral reefs result in a significant
50 ecological imbalance of the marine environment in the form of dynamic, structural, and
51 functional changes to ecosystems, especially the abundance and biodiversity of coral fish

52 and loss of fish species that rely on coral reef ecosystems (Hughes 1995; Weil et al. 2006;
53 Komyakova et al. 2013). This leads to a reduction in the economic value of coral reefs in
54 terms of supplying goods and services for the benefit of human society.

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

67 Using multi-temporal LANDSAT images, Yasir Haya and Fujii (2017) estimated
68 that live coral cover had been reduced from 7,716 ha in 1994 to 6,885 ha in 2002, and to
69 4,236 ha in 2014, or by 174 ha/yr during the period from 1994 to 2014. The study was

70 based on the calculation of the percentage cover of both live coral and coral rubble using
71 the point intercept transect (PIT) method in the vicinity of 10 islands in the PANGKEP
72 Regency, Spermonde Archipelago. They concluded that live coral cover was present in
73 only 24% of the study area, while 95.8% of the area contained some dead coral in the
74 form of rubble spread across various sites, suggesting that the majority of coral damage
75 was caused by destructive fishing practices, namely blast fishing, cyanide fishing, and the
76 use of mini trawl nets (DFW-Indonesia 2003; Chozin 2008; Nurdin and Grydehoj 2014).

77 Destructive fishing activities have large-scale destructive impacts, not only in
78 terms of damage to coral reefs but also due to loss of biological productivity and economic
79 benefits, i.e., reef fisheries, marine tourism, coastal protection (White et al. 2000; Wells
80 2009), and the livelihood of fishermen. This has even triggered social conflicts among
81 coastal communities (DFW-Indonesia 2003; Nurdin and Grydehoj 2014). The high
82 intensity of destructive fishing activities can result in the functional disturbance of coral
83 reefs as a supply of goods and services for the benefit of human society. Such disturbances
84 can reduce the income of local people, which leads to a reduction in the utilization of
85 coral reefs (Grigalunas and Congar 1995; Moberg and Folke 1999).

86 From an economic perspective, coral reef destruction leads to a loss of economic
87 value of coral reefs and has long-term economic impacts. Healthy reefs contribute

88 approximately 20 tons/km²/yr of fish and edible products, but the destruction of coral
89 reefs due to dynamite and cyanide fishing reduces the production of fish by approximately
90 4 tons/km²/yr (White et al. 2000). The damage caused to coral reefs results in an estimated
91 average economic loss of between 33,900 and 306,800 USD/km² (Pet-Soede et al. 1999).
92 In Indonesia, the use values (UVs) of coral reefs, i.e., its contribution to the economic
93 benefits of the fisheries sector, tourism sector, and coastal protection are 2.2 billion, 258
94 million, and 782 million USD/km²/yr, respectively (Burke et al. 2011). Those economic
95 values do not include the value of biodiversity, the value of bequeathing coral reefs, and
96 the value of their continued existence.

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

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

113

114

115 **2. Materials and Methods**

116 **2.1 Study site**

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

123

124

125 **2.2 Data Source and Materials**

126 *2.2.1 Data Source*

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

135 A purposive random sampling method was used, in which the local fishermen
136 were classified into two categories according to the fishing gear and fisheries production
137 (Sekaran 2003), with a minimum sample size of 30 for each group (Sekaran 2003; Howell
138 2016). The respondents interviewed to obtain the UVs of reef-related tourism and
139 scientific research were dive operators, university lecturers/students, officials from the
140 marine and fisheries agency of PANGKEP Regency, and residents from the local
141 communities.

142

143 2.2.2 *Questionnaire Survey*

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

150

151 **2.3 Framework Valuation of the Total Economic Value**

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

155

$$156 \quad \text{TEV} = \text{UV} + \text{NUV} = (\text{DUV} + \text{NUV}) + (\text{BV} + \text{EV}), \quad (1)$$

157

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

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

163

164 2.3.1 *DUVs of Coral Reefs*

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

168

$$DUV = \sum_{i=1}^N Q_i, \quad (2)$$

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

171 Here, Q_1 is the DUV of reef-related fisheries (USD/yr), Q_2 is the DUV of reef-
172 related tourism (USD/yr), and Q_3 is the DUV of reef-related scientific research (USD/yr).

173

174 a. *DUVs of Reef-related Fisheries*

175 DUVs of coral reefs from the fisheries sector were derived from catching fish and
176 seaweed farming. Coral fishes, crabs, squids and octopuses, and seaweeds all contribute
177 to the value of reef-related fisheries, which was estimated using the effect on production
178 (EOP) method, based on a production approach (Grigalunas and Congar 1995; Chee
179 2004; Adrianto 2006). The calculation of DUVs for reef-related fisheries involves several
180 steps (Adrianto 2006; Wahyuddin 2007; Wawo et al. 2014) as follows:

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

184

$$185 \quad Q = \beta V_1^a V_2^b V_3^c V_4^d, \quad (3)$$

186

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

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

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

204

205 *b. DUVs of Reef-related Tourism and Scientific Research*

206 The DUVs of coral reefs related to tourism and scientific research were estimated
207 using the travel cost (TC) method (Sinden 1994; Chee 2004). In this approach, the average
208 cost spent by each person to take trips and receive benefits from coral reef ecosystem at
209 certain tourism and research locations were calculated. The tourism related cost was

210 estimated and converted to an economic value, which consisted of a transportation fee,
211 lodging tariff, food and beverage charges, equipment rental, and an entrance ticket. The
212 annual DUVs of reef-related tourism were obtained by multiplying the average cost per
213 trip with the total number of visitors (tourists) per year. The method used in this study to
214 estimate the DUVs of reef-related tourism was the TC method, which was also applied to
215 determine the DUVs for reef-related research activities.

216

217 *2.3.2 IUVs of Coral Reefs*

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

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

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

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

229

$$230 \quad V = L_S \times W_B \times H_B, \quad (4)$$

231

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

234 Second, the coastal protection value of coral reefs (SPV (USD)) was calculated

235 by multiplying the volume of breakwaters (V) with the construction cost per unit (C ,

236 USD/ m^3) as follows:

237

$$238 \quad SPV = V \times C, \quad (5)$$

239

240 2.3.3 *NUVs of Coral Reefs*

241 NUVs are the values of coral reefs that people assign to economic goods

242 (including public goods) even if they never have and never will use them. They can be

243 distinguished from the UVs, which are derived from the direct use of the goods. The

244 NUVs estimated in this study were the value of bequeathing coral reefs and the value of

245 their continued existence.

246

247 *a. Bequest Values (BVs)*

248 BVs are benefit values given by individuals based on their WTP to save coral reef
249 resources to make them available for future generations. In this case, this study was used
250 the benefit transfer (BT) method to estimate the BV. This was based on Hargreaves-Allan
251 (2004) who estimated the bequest values of coral reefs off Wakatobi Island, Indonesia,
252 which is close to the study area. The BV of coral reefs is 412,000 USD/ha/yr (2004). In
253 this case, the Hargreaves-Allen's value in 2004 was adjusted for inflation to obtain the
254 correct value for 2014 using the following equation (Unsworth and Peterson 1995):

255

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

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

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

261

262 *b. Existence Values (EVs)*

263 When consumers's preferences are not revealed by markets, economists usually
264 use direct questions regarding their WTP for services or goods to calculate their
265 preferences. One of the approaches most often used is the contingent valuation method
266 (CVM), which is favored by researchers due to its applicability to a variety of
267 environmental goods and its capacity to assess the EV (Aoun 2015). The EV is the value
268 obtained solely due to the presence of natural resources and the environment. The EVs of
269 coral reefs were estimated based on individuals' WTP for coral reef resources (FAO
270 2000). The WTP data among the respondents in this study were obtained by questionnaire
271 and direct interviews. The EVs were calculated based on Wahyudin (2007) using the
272 follows steps:

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

275

$$276 \quad WTP = \beta_0 X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} \dots X_n^{\beta_n}, \quad (7)$$

277

278 where $X_1, X_2, X_3 \dots X_n$ are the variables of economic and social status among individuals
279 or users of reef-related resources. β_0 is the intercept, whereas $\beta_1, \beta_2, \beta_3 \dots \beta_n$ are the
280 coefficients of socio-economic status of respondents or users of reef related resources.

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

284

$$\begin{aligned} 285 \quad \ln WTP &= \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \dots \beta_n \ln X_n, \\ 286 \quad &= \{\beta_0 + \beta_1 \ln \bar{X}_1 + \beta_2 \ln \bar{X}_2 + \beta_3 \ln \bar{X}_3 + \dots \beta_n \ln \bar{X}_n\}, \\ 287 \quad &= \beta', \end{aligned} \tag{8}$$

288

289 where $\bar{X}_1, \bar{X}_2, \bar{X}_3 \dots \bar{X}_n$ are the average natural logarithm of the education level,
290 income, age, family member and other social factors, and β' is the sum of the
291 coefficient intercept added to the average of the natural logarithm of each variable
292 multiplied by the coefficient of each variable.

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

295

296
$$WTP = \exp(\beta'), \quad (9)$$

297

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

301

302
$$EV = WTP \times N, \quad (10)$$

303

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

307

308
$$EVHA = \frac{EV}{L}. \quad (11)$$

309

310 **2.4 Economic Losses of Coral Reef Destruction**

311 The overexploitation of natural resources has a negative impact on ecology and
312 biodiversity. Economic activities may damage ecosystem functions and, subsequently,
313 ecosystem services that lead to human wellbeing and balanced ecosystems (Grigalunas

314 and Congar 1995; Moberg and Folke 1999; Chapin et al. 2000). The economic losses due
315 to coral reef destruction were estimated with the following assumptions: (1) the only
316 changeable variable was coral reef area (3,480 ha degraded during the period of 1994 –
317 2014 or a destruction rate of 174 ha/yr (Yasir-Haya and Fujii 2017); (2) the component
318 of coral reef values used to estimate the economic losses was the UV; (3) the local
319 currency (Indonesian Rupiah; IDR) was converted into USD (1 USD = IDR 13,000).

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

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

331 where $PVEL(Y_i)$ is the present value of the economic loss in year i (value in USD) and

332 $EL(Y_i)$ is the economic loss in year i (value in USD).

333 Furthermore, to obtain the total economic loss (TEL) from 1994 to 2014, real

334 discount rates were calculated using the following formula:

$$TEL_{1994-2014} = \sum_{Y_i=1994}^{2014} PVEL(Y_i) \times (1 + r)^{(2014-Y_i)}. \quad (13)$$

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

336 In this case, this study was set the discount rate to 10% (White et al. 2000; Cesar

337 2000) to obtain the current value of coral reef damage or economic loss.

338

339

340 **3. Results**

341 **3.1 Use Values (UVs) of Coral Reefs**

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

344

345 3.1.1 Direct Use Values (DUVs)

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

350

351 a. *DUV of reef-related fisheries*

352 Based on the questionnaire results, average prices (P) varied between 1.63 and
353 3.05 USD/kg, whereas the education level (E) was mostly elementary school (60%) and
354 junior high school (40%). The age of the fishermen conducting fishing activities in the
355 coral reef areas varied between 41 and 48 years old, with the number of family members
356 ranging from 5 to 7 people. These data were processed using regression analysis to obtain
357 the demand function, and then processed using Maple software to determine the demand
358 curve (Figure 2), the values of the WTP, and consumer surplus (Appendix A2).

359 Based on the calculation, the total DUV of coral reef-related fisheries was 2.9
360 million USD/yr (Table 1). Seaweed farming accounted for most of this figure (1.3 million
361 USD/yr), while the rest consisted of coral reef fish, crabs, squids, and octopus (803,000,
362 513,000, and 251,000 USD/yr, respectively). These values indicate the production value
363 of the coral reef fisheries in 2014. The values obtained from demand function were
364 reflected in the form of a demand curve (Figure 2). This figure shows that the production
365 rate was relatively low for coral reef fish, and squid and octopuses, both of which are sold
366 for high prices in the market. On the other hand, crabs and seaweeds were produced in
367 large quantities and were sold at cheaper prices.

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

375

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

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

390 Hence, the total UV of reef-related tourism and recreation in the two largest
391 destinations in 2014 was estimated to be USD 116,162 or 27 USD/ha (Table 3). This
392 value is lower than the value reported for several similar tourist destinations, including
393 the Danajon's reefs in the Philippines (227 USD /ha). According to Samonte et al. (2016),
394 the net benefits of coral reefs from tourism and recreation have high annual BVs if the

395 coral reefs are well managed and intact. For example, the BVs of coral reefs are estimated
396 to be 663 million USD/yr in the Caribbean, 269 million USD/yr in Pacific, 779 million
397 USD/yr in Japan, 483 million USD/yr in the USA and 1,147 million USD/yr in Australia
398 (Cesar et al. 2003).

399

400 c. *DUVs of Reef-related Scientific Research*

401 The economic value of reef-related scientific research was also calculated using
402 the TC method. The total number of researchers who visited the study area in 2014 was
403 71 (Statistics Indonesia, Regency of the PANGKEP 2014), which included researchers,
404 professors, and students. The average duration of stay to conduct research in the study
405 area was four days, with an average cost of 231 USD/person/trip. Hence, the DUV of
406 reef-related scientific research was estimated to be USD 16,401 or 3.87 USD/ha in 2014.

407

408 3.1.2 Indirect use value (IUV)

409 Based on the calculated length of the coast line of the 31 inhabited islands (37,995
410 m), barrier width (1 m), and barrier height (1.5 m), then a volume of the coastal protection
411 barrier of 56,992.50 m³ was obtained. If the construction cost of the barrier was assumed
412 to be 297 USD/m³, then the total UV of reef-related shoreline protection was USD

413 16,931,157 or 3,997 USD/ha. This amount represents the economic value of coral reefs
414 functioning as a barrier to prevent coastal erosion.

415

416 **3.2 Non Use Values (NUVs) of Coral Reefs**

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

421

422 **3.2.1 Bequest Value (BV)**

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

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

430

431 3.2.2 Existence Value (EV)

432 The estimation of coral reef EV in this study was conducted using the CVM. The
433 results of the questionnaire surveys show that the average age and number of family
434 members of the respondents were 48 and 6-7, respectively. A statistical analysis of the
435 WTP, which indicates the incomes and characteristics of local fishermen, resulted in a
436 value of 66.62 USD/person (Appendix A3). Using the total population in the study area
437 (31,983 persons), the estimated EV of coral reefs was USD 2,130,707 or 503 USD/ha
438 (4,236 ha of coral reef cover). The results clearly show that WTP is driven by age,
439 household size, monthly income, and education level. These findings were not surprising
440 because income and education level are associated with WTP, while age and household
441 size influence income.

442

443 **3.3 Total Economic Value (TEV) of Coral Reefs**

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

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

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

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

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

474

475 **3.4 Total Economic Loss (TEL) of Coral Reefs**

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

481 factor, the TEL of coral reefs due to coral reef damage from 1994 to 2014 was estimated
482 to be USD 819,500 (Table 4).

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

488 Based on the calculation, the economic loss was found to have fluctuated over the
489 period from 1994-1995 to 2013-2014. In the period 1994-1995, the economic loss due to
490 coral reef damage was USD 54,147,209, and it then increased rapidly to USD 90,442,098
491 in the period of 1995-1996. In the period of 1996-1997, the financial loss rose
492 significantly to a peak of USD 109,557,342. It then gradually decreased to USD
493 16,390,800 from the period of 1996-1997 to 2013-2014. The total value of the economic
494 loss due to coral reef damage from 1994 to 2014 was USD 1 billion or 50 million USD/yr.

495 Our results indicated a loss equivalent to 288 USD/ha, which was low compared
496 to the value of the economic losses estimated by Cesar (1996). According to Cesar (1996)
497 the financial loss due to damage to Indonesia's coral reefs over a 25-year period ranged
498 from 981 to 7,612 USD/ha (by blast fishing) and from 428 to 4,756 USD/ha (by cyanide

499 fishing). There may be several reasons for the differences with the results of this study,
500 including: 1) the difference in the size of coral reef area considered by the two studies; 2)
501 the difference in the UV of coral reefs included as input data in the two studies; 3) the
502 difference in the period of calculation, i.e., 20 years in this study and 25 years in Cesar
503 (1996); 4) the difference in the number of fishermen active over the period of the two
504 studies; and 5) differences in the kinds and amounts of fishing gears and vessels used.
505 Although there were differences between the estimated results of the two studies, our
506 results indicate that there has been a decrease in the economic value of coral reefs in the
507 study area due to a decline in the coral reefs' function as a source of fishery products in
508 the last 20 years (1994-2014), which has been caused by destructive fishing practices.
509 According to Yasir Haya and Fujii (2017), destructive fishing practices have resulted in
510 3,480 ha of damaged coral reef during 1994-2014, i.e., 174 ha/year.

511 Based on these results, there have been large economic losses due to the
512 substantial decline in coral cover over the 20 years from 1994 to 2014. Although reef
513 fisheries production data during the period are unavailable, this study referred to the
514 results of Yasir Haya and Fujii (2017), which estimated a loss of 3,480 ha of coral reef
515 area over the period of 1994-2014, i.e., a destruction rate of 174 ha/yr. These conditions
516 would have a negative impact on the productivity of coral reef-related fisheries. It is likely

517 that economic losses will continue to accrue if destructive fishing persists and better
518 management of coral reef resources do not materialize.

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

523

524

525 **4. Discussion**

526 **4.1 Values of Coral Reefs**

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

533 In spite of the degradation, the coral reefs in the PANGKEP Regency still benefit
534 to the local community and the environment. Direct benefits could be calculated using

535 monetarily, while the indirect benefits could not be quantified monetarily. However, as
536 the whole, it is concluded that the coral reefs in this area possess high tangible and
537 intangible value. Tangible values generally consist of consumable or non-consumable use
538 values, e.g. fishery and tourism, while intangible values are non-use benefits or costs
539 needed for long-term ecosystem maintenance.

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

552 However, the value is considered to be relatively low compared to Costanza et al.
553 (1997), which is 2.2 million USD/ha. There are several reasons for this discrepancy,
554 including an annual increase in the number of local fishermen, which causes a significant
555 loss of production value in the coral reef fisheries. The high price of fish as a commodity
556 in the domestic market encourages fishermen to intensify their fishing activities, which
557 in turn leads to overexploitation and a loss of coral reef value. The low economic benefit
558 regarding the direct value of this overexploitation has resulted in massive coral reef
559 degradation in the region.

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

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

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

576

577 **4.2 Socio-economic factors**

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

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

592

593 **4.3 Sustainability of Coral Reefs**

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

600 Specifically, the benefit expected by the presence of MPAs is the restoration of
601 fish stock and ecosystem function. The sustainable benefit includes the spillover effect of
602 fish larvae from MPAs to the surrounding non-MPAs. The spillover effect enables to
603 provide additional fish stocks outside of the MPAs while maintaining the fish stocks
604 inside the MPAs (Bohnsack 1994). Even though the expectation had been review in

605 several references (Lauenroth and Burke 2008; Carpenter and Springer 2005; Roberts et
606 al. 2002; Spalding et al. 2001; Weeks et al. 2010; White et al. 2000), several empirical
607 studies had been conducted to elucidate the real function of MPAs. Therefore, integrated
608 approaches are needed to design future MPAs by involving local communities. Local
609 involvement in the planning, designing, establishing and managing MPAs is considered
610 to be crucial to make MPAs effective in long term period.

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

621

622

623 **5. Conclusion**

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

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

641

642

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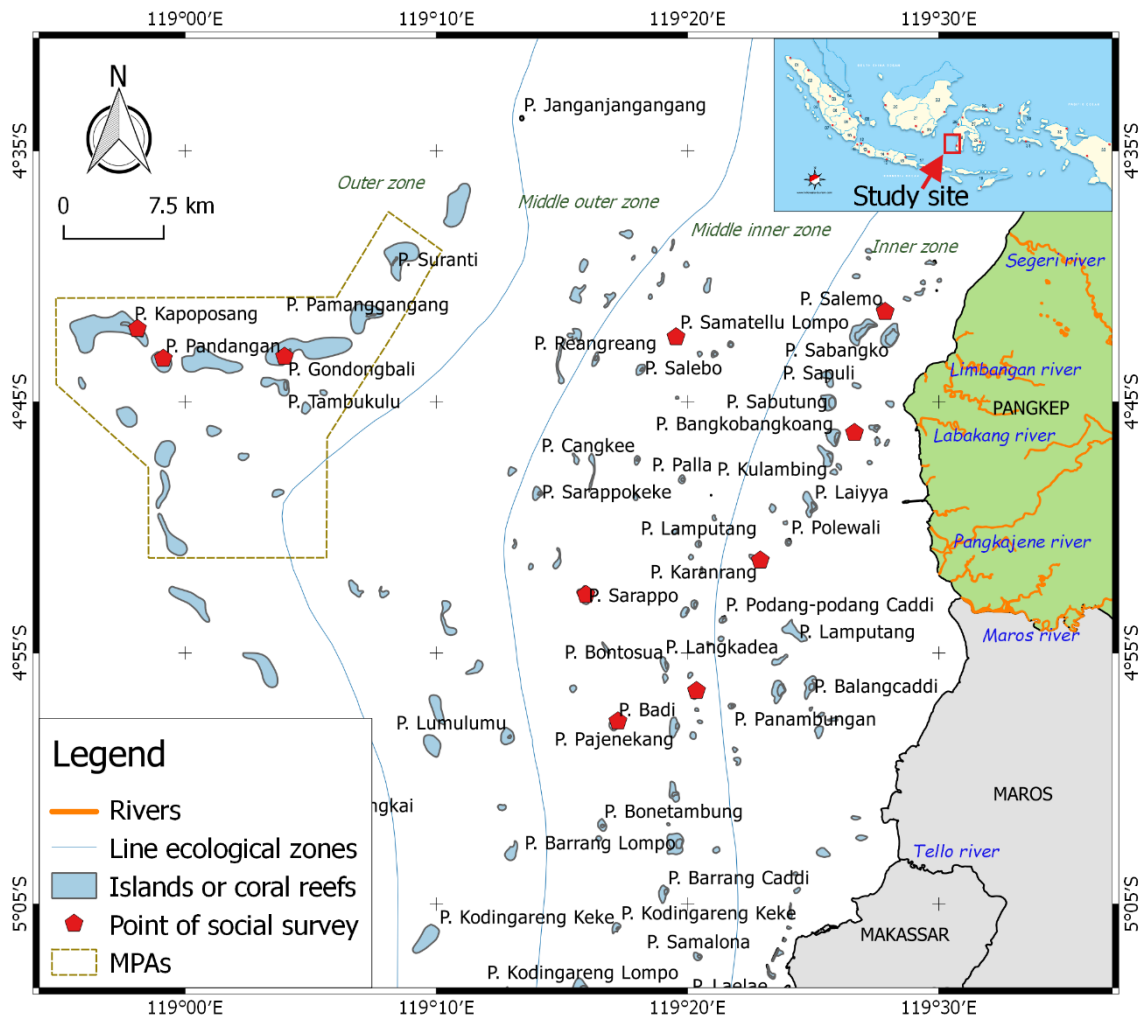
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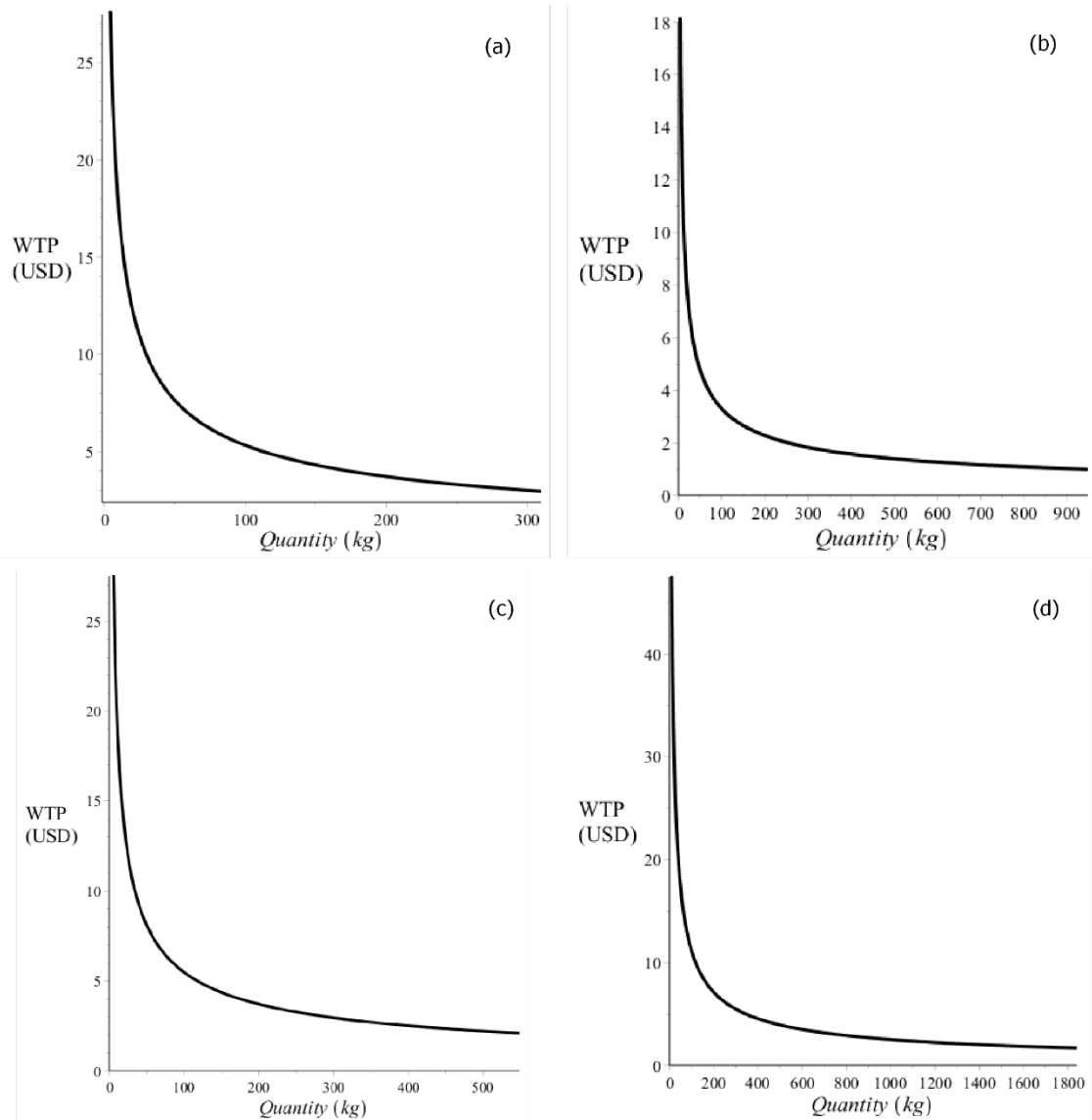
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835
836



838 Figure 1. Map of the study area in the PANGKEP Regency, Spermonde Archipelago,

839 South Sulawesi, Indonesia

840



841 Figure 2. Demand function of the coral reef benefits related to the fisheries using the
 842 effect on production (EOP) method for: (a) the coral reef fish catch, (b) the crab catch,
 843 (c) the squids and octopuses catch and (d) seaweed farming
 844

845 Table 1. Direct use benefits of coral reef-related fisheries calculated using the effect on production (EOP) method. The calculation is presented in
 846 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

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

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

849

850 Table 2. Components of tourist expenditure for visitors to the Kapoposang Marine Park and
 851 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

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

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

854 Table 3. Estimated economic value of coral reefs in the study area based on the categorization
 855 of the economic value of coral reefs in the PANGKEP Regency, Spermonde Archipelago,
 856 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	
	<i>Subtotal:</i>	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	
	<i>Subtotal:</i>	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

857

858 Table 4. Estimated current values of economic loss (USD) due to the destruction of coral reefs
859 from 1994 to 2014 in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The GDP
860 Implicit Price Deflator (Organization for Economic Co-operation and Development (OECD),
861 2016) was used, and a discount rate of 10% was applied for the estimation. The destruction rate
862 and economic loss of coral reefs was assumed to be 174 ha/yr and 819,500 USD, respectively,
863 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

864

865 **Appendix A1. Effect on Production (EOP) method**

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

870

871
$$Q = \beta V_1^a V_2^b V_3^c V_4^d, \quad (A1)$$

872

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

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

882

$$883 \quad \ln Q = \beta + a \ln V_1 + b \ln V_2 + c \ln V_3 + d \ln V_4, \quad (\text{A2})$$

$$884 \quad = (\beta + b \ln \bar{V}_2 + c \ln \bar{V}_3 + d \ln \bar{V}_4) + a \ln V_1,$$

$$885 \quad = \beta' + a \ln V_1, \quad (\text{A3})$$

886

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

889

$$890 \quad \beta' = (\beta + b \ln \bar{V}_2 + c \ln \bar{V}_3 + d \ln \bar{V}_4). \quad (\text{A4})$$

891

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

895

$$896 \quad Q = \text{EXP}(\beta') V_1^a, \quad (\text{A5})$$

897

898 as written in the following equation:

899

900
$$Q = \text{EXP}(\beta^*) V_I^a, \text{ if } Q = \text{EXP}(\beta^*), \tag{A6}$$

901

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

903

904
$$Q = \alpha X_I^\sigma. \tag{A7}$$

905

906 When the demand function (Q) is known, then the utility value (U) of coral reefs

907 which is also expressed as the total value of the WTP, can be determined using the

908 following equation:

909

910
$$U = \int_0^a f(Q)dQ, \tag{A8}$$

911

912 where U is the utility value or the total value of WTP for coral reef ecosystems, $f(Q)$ is

913 the price of the average WTP.

914 Furthermore, the payable value for coral reefs (PQ) could be calculated by

915 multiplying $f(Q)$ by the total average BV of coral reefs (\bar{Q}) as follows:

916

$$917 \quad PQ = f(Q) \times \bar{Q}. \quad (A9)$$

918

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

921

$$922 \quad CS = U - PQ, \quad (A10)$$

923

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

928

$$929 \quad EV = CS \times N. \quad (A11)$$

930

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

934

935
$$\frac{EV}{ha} = \frac{CS \times N}{L}. \tag{A12}$$

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

938

939 *A2.1 Regression analysis and coefficient determination*

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

943 Table A2.1 Result of correlation and determination analysis which were resulting from multiple
 944 regression analysis in terms of direct use value of reef-related fisheries. In this case, there are
 945 5 independent variables (i.e., price, age, education, family member, and income) and one
 946 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

947

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

952 The value of R Square (R²) shows the contribution percentage of the X-variables (i.e.,
 953 price, age, education, family member, and income) to the Y-variable (demand-Q). In this case,
 954 Crabs and Squids / Octopuses have a percentage of 85%, seaweeds (79%) and reef fish (76%).

955 Adjusted R² illustrates the value of R² that adjusted. This value is always smaller than
 956 R² values and can be a negative value. According to Harbord and Higgins (2008) that Adjusted

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

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

962

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

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

966

967
$$\ln Q = \beta + a (\ln P) + b (\ln Ag) + c (\ln F) + d (\ln E) + e (\ln I), \quad (A13)$$

968

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

972

973 Table A2.2 Coefficient of the fishermen characteristics in terms of fisheries production in coral
 974 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

975

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

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

978 a. Fish coral:

$$979 \quad \ln Q = 25.96 - 1.91 (\ln P), \quad (A14)$$

980 b. Crabs:

$$981 \quad \ln Q = 25.40 - 1.86 (\ln P), \quad (A15)$$

982 c. Squids and Octopuses:

$$983 \quad \ln Q = 26.69 - 1.77 (\ln P), \quad (A16)$$

984 d. Seaweeds:

$$985 \quad \ln Q = 14.64 - 1.54 (\ln P). \quad (A17)$$

986

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

988 a. Coral Fish:

$$989 \quad Q = 188601317946.42 P^{-1.91}, \quad (A18)$$

990 b. Crabs:

$$991 \quad Q = 11433584409.38 P^{-1.86}, \quad (A19)$$

992 c. Squids and Octopuses:

$$993 \quad Q = 41616852299.79 P^{-1.77}, \quad (A20)$$

994 d. Seaweeds:

$$995 \quad Q = 9492363691.66 P^{-1.54}. \quad (A21)$$

996 To facilitate the estimation of some component values in effect on production (EOP)

997 methods in terms of utilities, average WTP, debt values, and consumer surplus, then this study

998 was used Maple software. Maple is math software that combines the world's most powerful

999 math engine with an interface that makes it extremely easy to analyze, explore, visualize, and

1000 solve mathematical problems (Maple 2015). By using Maple Software, the function A18

1001 through A21 can be formulated using the following equation:

1002

1003 a. Reef fish:

1004 $f(Q) = \frac{58.70}{Q^{0.52}},$ (A22)

1005 b. Crabs:

1006 $f(Q) = \frac{63.40}{Q^{0.53}},$ (A23)

1007 c. Squids and Octopuses:

1008 $f(Q) = \frac{73.31}{Q^{0.56}},$ (A24)

1009 d. Seaweeds:

1010 $f(Q) = \frac{219.44}{Q^{0.64}}.$ (A25)

1011 Furthermore, from the function A22 through A25, several values as shown in Table
1012 A2.3 were obtained.

1013

1014 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

1015

1016

1017 **Appendix A3. Calculation of Existence Value of Coral Reefs using Contingency Valuation**
 1018 **Method (CVM)**

1019
 1020 In order to estimate the value of willingness to pay (WTP), questionnaire data were
 1021 tabulated and analyzed statistically for further analysis. Based on regression analysis,
 1022 relationship between the WTP and characteristics of the community are given in Table A3.1.

1023
 1024 Table A3.1 The result of correlation and determination analysis which were resulting from
 1025 multiple regression analysis in terms of existence value of coral reefs. In this case, there are 4
 1026 independent variables (i.e., income, age, education, and family member) and one dependent
 1027 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

1028
 1029 Based on the results of the statistical analysis, the function of WTP could be formulated
 1030 into the following equation:

1031
$$\ln WTP = \beta + a (\ln I) + b (\ln Ag) + c (\ln E) + d (\ln F), \quad (A26)$$

1032 where I is income, Ag is the age, E is the education level, and F is the number of family
 1033 members. While β , a , b , c , and d , are the coefficients of which values are given as in Table
 1034 A3.2.

1035
 1036 Table A3.2 Coefficient of fisherman characteristics in terms of the willingness to pay for the
 1037 sustainability of coral reefs

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

1039 By inputting the average value of income (I), age (Ag), education (E), the number of
1040 family members (F), and their coefficient in Table A3.2, then the WTP values could be
1041 estimated as follows:

1042

$$1043 \quad \ln WTP = 13.67 \quad (A27)$$

$$1044 \quad = 866,059.138 \text{ (1 USD = 13,000 IDR)}$$

$$1045 \quad = 66.62 \text{ USD /person.}$$

1046