



HOKKAIDO UNIVERSITY

Title	Assessment of coral reef degradation and the economic loss in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia
Author(s)	Yasir Haya, La Ode Muhammad
Degree Grantor	北海道大学
Degree Name	博士(環境科学)
Dissertation Number	甲第12861号
Issue Date	2017-09-25
DOI	https://doi.org/10.14943/doctoral.k12861
Doc URL	https://hdl.handle.net/2115/67653
Type	doctoral thesis
File Information	LaOde_Muhamma.pdf



**Assessment of coral reef degradation and the economic loss
in the Pangkajene and Kepulauan Regency,
Spermonde Archipelago, Indonesia**

(インドネシア・スペルモンデ諸島パンカジェネ・ケプラウワン県における
サンゴ礁の劣化及びその経済損失の評価)

LA ODE MUHAMMAD YASIR HAYA

DOCTORAL DISSERTATION

**Division of Environmental Science Development
Graduate School of Environmental Science
Hokkaido University, Japan
2017**

Abstract

Destruction of coral reefs at global scale stays at an alarming rate for decades due to multiple stressors. There is no exception for coral reefs in the Pangkajene and Kepulauan (PANGKEP) Regency in the Spermonde Archipelago, Indonesia which is located in the Indo-Pacific Coral Triangle. They have been under the stresses caused by various harmful impacts. Since human activities, as well as natural disturbances, posed major threats to the coral reefs, these livelihoods may also be at risk. Currently, no comprehensive information on the status and condition of coral reefs in this area is available for this resource management.

This research was conducted to identify the extent of coral damage by using remote sensing and in-situ measurement data to analyze the changes in coral reefs. This study was determined the changes in coral habitats over a period of 20 years from 1994 to 2014 using multi-temporal Land Satellite (Landsat) image data substantiated with in-situ measurement data collected in 2014. The results show that there has been a decline in live coral cover for 20 years, from 7,716 ha in 1994 to 4,236 ha in 2014, with a destruction rate of 174 ha/yr. The ratio of the coral cover in the coral reef transects varied from averagely 24% for live corals to 96% for coral rubbles. The decline in live coral habitats is considered to be caused mainly by destructive fishing practice, followed by excessive total suspended solids in surface waters.

The total economic values of coral reefs in the study area were also estimated by the sum of the direct use, non-use, and existence values. The total economic value in 2014 was estimated to be USD 12 billion or 3 million USD/ha, which were related to fisheries, tourism, recreation, research, coastal protection, existence value and bequest value. While the total economic value is considered to be still high, this study indicates that the value has been lost by USD 1 billion or 50 million USD/yr for the 20 years since 1994. The economic loss was resulting from loss values of coral reefs, including economic losses of fisheries (i.e., coral fishes, crabs, squids, octopuses and seaweeds), tourism, recreation, and coastal protection. The economic loss of coral reefs is anticipated to continue in future. Therefore, in order to save coral reef ecosystems, the local governments of the PANGKEP Regency need to develop and implement the comprehensive strategic policies, to take protective measures of coral reefs such as by designing new marine protected areas (MPAs).

List of Contents

Abstract.....	i
List of Contents.....	ii
List of Tables	iv
List of Figures.....	vi
Chapter I. Introduction.....	1
1.1 Background: Coral reefs in Indonesia.....	1
1.2 Study area.....	4
1.3 Objectives and Overview of Dissertation	4
Chapter II. Mapping the change of coral reefs using remote sensing and <i>in situ</i> measurements in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia	7
2.1 Introduction.....	7
2.2 Materials and Methods.....	9
2.2.1 Data sources.....	9
2.2.2 Image processing	11
2.3 Results.....	16
2.3.1 Status of coral reefs	16
2.3.2 Image processing	18
2.3.3 TSM detection	18
2.3.4 Water column correction	20
2.3.5 Unsupervised classification, reclassification and ground truthing	20
2.3.6 Accuracy assessment	22
2.3.7 Change in coral reef habitat.....	23
2.4 Discussion	24
2.5 Conclusions.....	25
Chapter III. Economic assessment of the benefits and losses of goods and services derived from coral reefs: a case study in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia.....	55
3.1 Introduction.....	55
3.2 Materials and Methods.....	57
3.2.1 Data source and materials.....	57
3.2.2 Framework valuation of the total economic value	58
3.2.3 Economic losses of coral reef destruction	62
3.3 Results and Discussion	63
3.3.1 Use values (UVs) of coral reefs.....	64
3.3.2 Non-use values (NUVs) of coral reefs.....	66

3.3.3 Total economic value (TEV) of coral reefs	67
3.3.4 Total economic loss (TEL) of coral reefs	68
3.4 Conclusion	69
Chapter IV. General Discussion	76
4.1 Threats on coral reefs in the PANGKEP Regency	76
4.2 Value of coral reefs in the PANGKEP Regency	78
4.3 Designing effective marine protected areas (MPAs)	79
4.4 Future perspective of the study	80
Chapter V. General Conclusion	83
Acknowledgments.....	85
References.....	87
Appendices.....	102
Appendix A1. Questionnaire sheet and list interview of the coral reefs in the Pangkajene and Kepulauan (PANGKEP) Regency, Spermonde Archipelago, Indonesia.....	102
Appendix A2. Effect on production (EOP) method.....	113
Appendix A3. Calculation of direct use values (DUVs) using the effect on production (EOP) method.....	116
Appendix A4. Calculation of existence value of coral reefs using contingency valuation method (CVM).....	119

List of Tables

Table 2.1 Types and characteristics of Landsat images used in this study. Multi-temporal Landsat imagery data were obtained from the United States Geological Survey (2014)	27
Table 2.2 Classification of benthos in the PIT method.....	28
Table 2.3 Coral cover (%) as a guidance of categorization defined by Gomez and Yap (1988)	29
Table 2.4 Description of classifications. Visually, the coral reef could be sorted into 2 categories (live and dead coral) according to their color. The live coral is generally found far from land, close to the deep water zone, while dead coral is commonly distributed close to the shoreline (COREMAP 2001, cited in Suwargana 2014)	30
Table 2.5 Example of the confusion matrix calculation (from Congalton and Green 2008). In this matrix, N_{ij} is the number of samples classified, where i, j, k and + are the row in the remotely sensed classification and the column in the reference data set (field data), k is the next sample number, + is the total of samples in column or row, respectively. In this case, each column (field data) of the matrix represents the instances in a predicted class while each row (image classification) represents the instances in an actual class and vice versa.....	31
Table 2.6 Status of coral reefs in study site based on the result of PIT method at 23 transects in 10 islands.....	32
Table 2.7 Distance of fishing locations from the mainland (before and in 2014) in the study site. The number in columns of "Before 2014" and "In 2014" were the number of fisherman who chose favorite locations for fishing in the period of before 2014 and in 2014, respectively.....	34
Table 2.8 The maximum TSM concentration estimated from the multi-temporal Landsat imagery data in dry (April-Sept.) and rainy (Oct.-March) seasons in the inner zone of the PANGKEP Regency, Spermonde Archipelago.....	36
Table 2.9 Results of the classification of coral reefs and seabed habitats estimated by the multi-temporal Landsat imagery data in the PANGKEP Regency, Spermonde Archipelago, Indonesia	37
Table 2.10 Confusion matrix value on the classification of four classes of the seabed habitats in the PANGKEP Regency, Spermonde Archipelago, Indonesia	38
Table 2.11 Ratio of producer's accuracy (PA) and the user's accuracy (UA). The calculation was conducted for four marine habitat classifications in the PANGKEP Regency, Spermonde Archipelago, Indonesia. Reference data mean the classes which are classified correctl.....	39

Table 2.12 Change in the area of coral reefs from 1994 to 2014 in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The change of area in each class was established based on the overlay of coral reef distribution and condition map derived from Landsat 5 TM (1994), Landsat 7 ETM (2002), and Landsat 8 OLI (2014) images	40
Table 3.1 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	71
Table 3.2 Components of tourist expenditure for visitors to the Kapoposang Marine Park and Panambungan Island in 2014	72
Table 3.3 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	73
Table 3.4 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	74

List of Figures

Figure 1.1 Map of study area in the PANGKEP Regency, Spermonde Archipelago, South Sulawesi Province, Indonesia	6
Figure 2.1 Categories used in PIT method. AC: Acropora; NA: Non-Acropora; SP: Sponge; R: Rubble; SC: Soft coral; SA: Sand; DCA: Dead coral algae; A: Abiotic. In this case, the rubble was classified as dead corals.....	41
Figure 2.2 Flowchart research on mapping and analysis of changes in coral reefs.....	42
Figure 2.3 Ratio of live corals and dead corals at all sites in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The graph summarizes the calculation for each category obtained by PIT method in each village (2-3 observation transects per village)	43
Figure 2.4 Averaged ratio of coral rubbles to total dead corals in the villages in the PANGKEP Regency, Spermonde Archipelago, Indonesia	44
Figure 2.5 Ratio of preferred destructive fishing areas (%) obtained by analyzing the results of questionnaires distributed to 296 respondents, which were strongly linked to the fishing gears used and target fish species frequently caught	45
Figure 2.6 Spectral profile of object classes (sand, seagrasses, dead corals, live corals and sea water) on three series Landsat Imagery data: (a) Landsat TM 1994, (b) Landsat 7 ETM 2002, and (c) Landsat 8 OLI 2014.....	46
Figure 2.7 Distribution and concentration of total suspended matter (TSM) of the two seasons in the inner zone: a) dry season in the Landsat 5 TM, 1994; b) dry season in the Landsat 7 ETM, 2002; c) dry season in the Landsat 8 OLI, 2014; d) rainy season in the Landsat 5 TM, 1994; e) rainy season in the Landsat 7 ETM, 2002; f) rainy season in the Landsat 8 OLI, 2014.....	47
Figure 2.8 Average monthly rainfall in 1994, 2002 and 2014 in the study area (Source: The modern-era retrospective analysis for research and applications, Version 2; MERRA-2)	48
Figure 2.9 Plots of spectral values of the coral reef status obtained by three series of multi-temporal Landsat imagery ((a)-(c) for Landsat 5 TM, 1994; (d)-(f) for Landsat 7 ETM, 2002; (g)-(i) for Landsat 8 OLI, 2014) in the PANGKEP Regency, Spermonde Archipelago, Indonesia. (a) and (d): Band 2 vs. Band 3; (b) and (e): Band 1 vs. Band 3, (c), (f) and (g): Band 2 vs. Band 3; (h): Band 2 vs. Band 4; (i) Band 3 vs. Band 4	49
Figure 2.10 Depth invariant index derived from three series of multi-temporal Landsat imagery data ((a)-(c) for Landsat 5 TM, 1994; (d)-(f) for Landsat 7 ETM, 2002; (g)-(i) for Landsat 8 OLI, 2014) in the PANGKEP Regency, Spermonde Archipelago, Indonesia, using gradient of the linier line. (a) and (d): Band 2 vs. Band 3; (b) and (e): Band 1 vs.	

Band 3, (c), (f) and (g): Band 2 vs. Band 3; (h): Band 2 vs. Band 4; (i) Band 3 vs. Band 4.....	50
Figure 2.11 Distribution and condition of coral reefs in the PANGKEP, Spermonde Archipelago, Indonesia, obtained from three series multi-temporal Landsat imagery data. (a) Landsat 5 TM, 1994; (b) Landsat 7 ETM, 2002; (c) Landsat 8 OLI, 2014...	51
Figure 2.12 Map of change in bottom substrate in the PANGKEP Regency, Spermonde Archipelago, Indonesia: (a) from 1994 to 2002 and (b) from 2002 to 2014. The Kapoposang MPAs is located in the outer zone of the PANGKEP islands which also experienced a drastic decline in coral reef habitats in this period	52
Figure 2.13 Change in composition of coral reefs from 1994 to 2014. During the period, 45.1% of the coral reef area has been transformed (left pie chart): 91.6% from live to dead corals, 7.2% from live corals to sand, and 1.2% from dead corals to sand (right pie chart)	53
Figure 2.14 Tidal prediction in the PANGKEP Regency, Spermonde Archipelago, Indonesia with a coordinate point of observation: 1190 15'36" S and 40 48'36" E. The data is processed by using the prediction model from http://www.miz.nao.ac.jp/staffs/nao99/index_En.html . Accessed 10 October 2016 ..	54
Figure 3.1 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.....	75
Figure 4.1 Spillover mechanism in the marine protected area (MPAs) (source: Bohnsack 1990).....	82

Chapter I

Introduction

1.1 Background: Coral reefs in Indonesia

Coral reefs are one of the foremost productive ecosystems in the marine environment and represent high benefit values for human as a source of income, fisheries resources, construction materials, tourism and recreation and many others for thousands of years (Hodgson 1999; McManus 1997; Mumby and Steneck 2008). They also play an important role in preserving the balance of marine resources, and function as the marine environmental health indicators (Hourigan et al. 1988; Hein et al. 2015). Coral reef ecosystems are also utilized as valuable resources for supplying goods and services, such as fisheries, tourism, scientific research, shoreline protection, and so forth (Moberg and Folke 1999; Souter and Linden 2000; UNEP 2006; Brander et al. 2007; Tseng et al. 2015).

Detrimental effects in changes of coral reefs at global scale have been for last two decades, mainly in the Caribbean and the Western Atlantic region (Aronson and Precht 2001; Gardner et al. 2003), the Great Barrier Reef (De'ath et al. 2012), as well as the Indo-Pacific (Bruno and Selig 2007). Currently, anthropogenic threats are the main causal factors of coral reef destruction that exceed natural threats at the global scale. This inevitable reality is certainly called for serious protection and preservation of coral reef resources to minimize the main causal factors by formulating and implementing science-based policy programs (Salvat 1987; Wilkinson 1992; Roberts 1997). There has not been any significant consensus on how to formulate a holistic approach to protect and preserve coral reef ecosystems in a more meaningful way.

Indonesia is a tropical country that is located in the center of the Coral Triangle of the greatest marine biodiversity on earth together with the Philippines, Malaysia, Timor-Leste, Papua New Guinea and the Solomon Islands. The Coral Triangle region have the area of approximately 75,000 km² of coral reefs and contain nearly 600 different species of reef-building corals alone. More than 120 million people live so dependently on coral reefs in the region (<http://www.worldwildlife.org/publications/stewarding-biodiversity-and-food-security-in-the-coral-triangle-achievements-challenges-and-lessons-learned>). Indonesia's coral reefs are approximately 50,875 km² in the area and cover 18% of the world's coral reefs (World Resource Institute (WRI) 2002). In addition, Indonesia's coral reefs are the most biologically productive in the world, which consists of an incredibly diverse array of flora and fauna. Today, more than 480 species of hard corals have been recorded in the eastern Indonesia which accounts for about 60% of the world's species of hard corals described (Suharsono and Purnomohadi 2010). The highest

diversity of coral reef fish is found in Indonesia, with more than 1,650 species in the eastern Indonesia only. In fact, Indonesia's coral reefs are a supporter of one of the world's largest marine fisheries, producing 3.6 million tonnes of the total marine fish production in 1997. Because of many reefs in the eastern Indonesia have yet to be surveyed, so the actual extent of Indonesia's biodiversity is still unknown for certain. (Hopley and Suharsono 2000). However, Indonesia's rich supplies of corals and reef fish are endangered by unsustainable fishing practices (Radjawali 2012).

Coral reef destruction at global and regional scales as depicted above is compatible with the local condition in the Pangkajene and Kepulauan (PANGKEP) Regency, Spermonde Archipelago, as a part of eastern Indonesia's coral reef zone. Coral reefs in this archipelago experienced serious threats due to anthropogenic causes as shown in both direct and indirect activities of the local communities (DFW-Indonesia 2003; Pet-Soede 2000) and natural causes that include the impact of climate changes (Yusuf and Jompa 2012). The main causal factors of coral reef destruction in this archipelago are unsustainable fishing activities such as the use of bombs and cyanide. These devices have causes a double impact, not only the damage to coral reefs but also the death of marine species that rely on the coral reefs (Pet-Soede 2000; DFW-Indonesia 2003).

Human activities, including agricultural and pond farming activities, produce pollutant, such as sewage, pesticides, and organic and anorganic fertilizers. These pollutants are usually discharged into the sea waters that lead to harmful impacts on coral reef ecosystems and other living organisms (Fabricius 2005; D'Angelo and Wiedenmann 2014). Several activities carried out by the local communities in the PANGKEP and Maros Regencies such as uncontrolled deforestation and lime mining are considered to contribute to the erosion of soil surface layers and occurrence of harmful materials at a high rate through sedimentation that runs into the sea waters and local estuaries (Augustinus 2001). Total suspended matters (TSM) in the sedimentation that cover polyps of coral reefs trigger stresses to coral reefs which leads to death of corals (Davies-Colley and Smith 2000; Jones et al. 2015).

On the other hand, global increase of seawater temperature threatens coral reefs through bleaching process. In the mid-February to March 2016, this phenomenon was identified in several observation sites in Badi, Bontosua and Sanane Islands. The water temperature was 3°C higher than the climatology of 29°C (Syafyuddin Yusuf of Hasanuddin University, per. comm.). In this case, bleaching rapidly proceeded in most of the coral reefs in 7 through 15 m depth, while the bleaching was not detected in coral reefs in shallow water of 1-5 m depth. This is probably caused by higher ability of shallow coral reefs to adapt to the higher temperature condition. In general, it is estimated that

about 20% of coral reefs in the study site have been bleached, which mostly consist of *Foliaceous Encrusting, Porites and Fungia Sp.*

Biologically, the presence of *Acanthaster planci* in coral reefs has a negative impact on live corals. This species are capable of damaging coral reefs in a wide scale. Moran (1990) notified that each individual *A. planci* can prey on corals of which habitat area is 5-6 m² in a year. Although this study did not directly measure the abundance of *A. planci* in the study area, Yusuf (2008) reported that in the Kapoposang Island, *A. planci* has increased by approximately 120 individuals per 100 m² or 1-2 individuals/m² in 2006. For six months, hard coral conditions have decreased by approximately 35% in terms of live coral coverage. The increased abundance of *A. planci* was considered to be caused by decrease of predatory species such as triton's trumpet, starry puffer fish, white-spotted puffer fish, triggerfish, harlequin shrimps and the lined fireworms that control abundance of *A. planci* in nature (Moran 1988). In other words, the food chains in the study sites have been disrupted due to excessive exploitation of the species.

Destruction of coral reef ecosystems generates various negative impacts for local communities that include losses in long-term productivity of coral reefs and tourism sector (Wells, 2009). This condition would eventually damage ecological functions of coral reefs for supplying goods and services which in turn lead to economic losses to local people as direct benefit users of coral reef ecosystems (White et al. 2000; Wells 2009).

Previous studies on coral reef ecosystem in the PANGKEP Regency, Spermonde Archipelago have delivered various topics and scopes of researches using different methods. They covered wide range of topics including socioeconomic impacts of destructive fishing (Pet-Soede 2000), profiling destructive fishing (DFW-Indonesia 2003), coral reef condition after bleaching phenomenon (Yusuf and Jompa 2012), economic valuation of coral reefs (Haslindah et al. 2012), patron-client traditional relationship and destructive fishing activities (Nurdin and Grydehøj 2014), numerical modeling of distribution of coral reefs in Kapoposang Island using the "Satellite Pour l'Observation de la Terre (SPOT) 5" imagery (Faizal and Jompa 2010), and physical changes of coral reefs in Suranti Island using remote sensing technology (Nurdin et al. 2014).

However, the previous studies have conveyed overlapping information and knowledge gaps that fail to provide comprehensive insights to be used as wide-ranging references by the local government and involved institutions in formulating comprehensive strategic policies in respect of conservation of coral reef ecosystem. Nevertheless, these studies bear some limitations, namely that: 1) they focused on specific islands, 2) the research were conducted sporadically and not comprehensively, 3) the data and information were not shared one another, so it was difficult to be referred for policy

planning, 4) the information related to multidimensional threats to the coral reefs were limited.

Considering the problems as stated above, this study aims to analyze three essential aspects related to direct roles of coral reefs and their environment that includes physical changes of coral reef habitats, socioeconomic aspects of coral reefs in the local community, and formulation of alternative strategic policies in managing coral reefs to look for more significant efforts in improving the status of coral reefs in the study area.

1.2 Study area

The study was carried out in the PANGKEP Islands, Spermonde Archipelago, South Sulawesi Province, Indonesia (Figure 1.1). Geographically, the sites were situated within 118°54'36"E - 119°35'24"E and 4°30'36"S - 5°03'48"S. Administratively, there are 41 islands (including 31 islands inhabited) that consist of two districts of Liukang Tuppabiring and Tuppabiring Utara (Statistics Indonesia of Pangkajene and Kepulauan Regency 2014). Along the coastal area from Makassar City to the PANGKEP Regency, there are six rivers and five of them are active rivers all the year around. Ecologically, corals in the Spermonde Archipelago including those in the PANGKEP Regency are classified into four ecological zones (Hoeksema 2012), namely inner zone that contains muddy sand as a bottom substrate, followed by middle inner zone which contains many coral islands, middle outer zone of which coral reef areas are still submerged, and outer zone as a barrier reef zone which contains coral islands (Figure 1.1).

Since 1994, 50,000 ha of the outer islands in the PANGKEP Regency have been designated as marine protected areas (MPAs) by the decrees of the Minister of Forestry No. 588/Kpts-VI/1996 and the Minister of Marine and Fisheries No. 66/MEN/2009 (Figure 1.1). In addition, this site is within the coral reef rehabilitation and management program (COREMAP) location which was implemented from 2004 to 2010. Since then, the exploitation and use of coral reefs have been restricted to ensure the sustainable management.

1.3 Objectives and Overview of Dissertation

Considering the problems mentioned above, this study aims to cover several issues: 1) assessing coral degradation by using in-situ and satellite data, 2) elucidating causes of the coral degradation by social survey to local stakeholders, 3) estimating values and losses of the coral reefs by economic evaluation methods, and 4) providing suggestions and recommendations for saving the coral reefs scientifically based on the results obtained by this study. Therefore, the general objective of this study is to assess

the changes in coral cover for 20 years from 1994 to 2014 and the socioeconomic value of coral reefs (i.e., economic benefits and economic loss) in the PANGKEP Regency, Spermonde Archipelago, Indonesia.

This dissertation consists of five chapters. The following chapter illustrates the analysis of coral cover changes in the last 20 years from 1994 to 2014 in the PANGKEP Regency, Spermonde Archipelago, using several sets of data that consist of data of multi-temporal Land Satellite (LANDSAT) imagery, ground truth, coral reef transect and social survey. Based on the results obtained in Chapter II, economic benefit values and economic loss values of the coral reefs in the study site were estimated, as described in Chapter III. Chapter IV contains a general discussion to bridge the results of this study and recommendations for future policy making. The last chapter sets forth summary and conclusion of the overall results of Chapters I through IV.

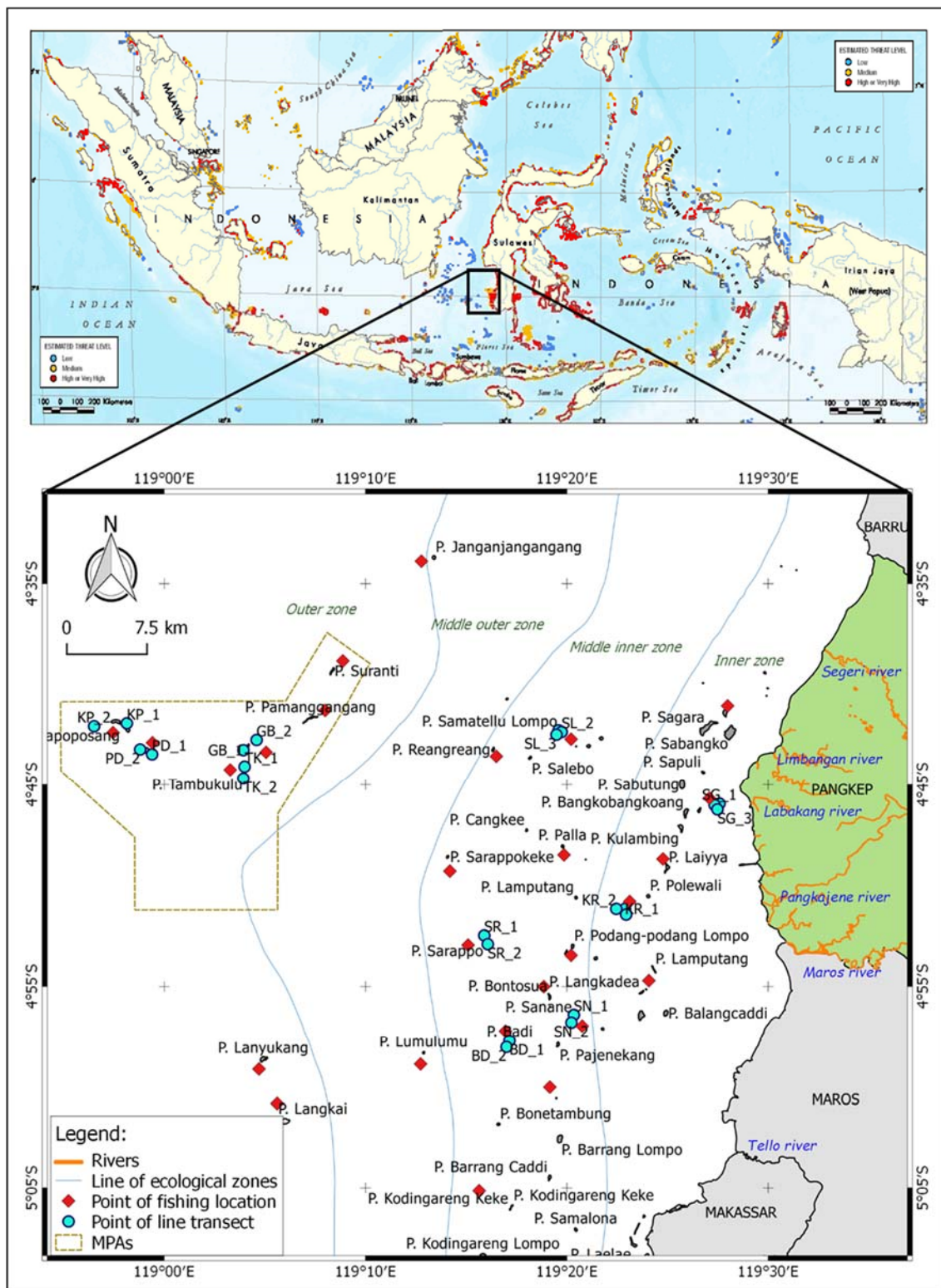


Figure 1.1 Map of study area in the PANGKEP Regency, Spermonde Archipelago, South Sulawesi Province, Indonesia

Chapter II

Mapping the change of coral reefs using remote sensing and *in situ* measurements in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia

2.1 Introduction

Coral reefs have been exploited as resources for income, fisheries, construction materials, tourism and recreational and other purposes for thousands of years (Hodgson 1999; McManus 1997; Mumby and Steneck 2008). Ecologically, coral reefs fulfill an important role in maintaining the balance of marine resource productivity and serve as indicators of the health of the marine environment (Hourigan et al. 1988; Hein et al. 2015).

In recent decades, changes in coral reef ecosystems have occurred on both regional and global scales due to natural effects and anthropogenic factors (Burke et al. 2011; Wilkinson 2008). Burke et al. (2011) reported that more than 60% of the world's coral reefs were threatened directly by one or multiple factors, including overfishing, destructive fishing, coastal development, and environmental pollution. Among these, overfishing and destructive fishing were the most widely practiced, affecting more than 55% of the world's coral reefs (Bruno and Selig 2007; Burke et al. 2011). Furthermore, on a regional scale, the threat of coral reefs occur in the Coral Triangles. Coral Triangles, lying in Indonesia, the Philippines, Malaysia, Timor-Leste, Papua New Guinea and the Solomon Islands, are the world's center of marine biodiversity, particularly coral reefs (World Wild Fund (WWF) 2016).

Since 1998, the Indonesian Government has paid significant attention to manage coral reef ecosystem through the Coral Reef Rehabilitation and Management Program (COREMAP). The purpose of this program is protection, rehabilitation and management focused on the sustainable use of coral reefs and related marine ecosystems in Indonesia, which in turn will support the welfare of coastal communities (World Bank 2015). Unfortunately, in some locations, COREMAP has been insignificantly reducing coral reef exploitation activities, especially in areas outside COREMAP sites. Fishing activities that threaten coral reef ecosystems continued to be practiced inside some COREMAP locations, such as Pangkajene and Kepulauan (PANGKEP) Regency in Spermonde Archipelago, South Sulawesi. The large size of the area and limited resources (equipment and coral reef data) were considered as major obstacles in monitoring and protecting the coral reefs. Up-to-date information is essential for designing an effective policy and management systems to protect coral reefs. One of the methods that could be used to fill this gap is the use of remote sensing technology.

Remote sensing technology has several advantages over other technologies in terms of providing multi-year databases so that only periodic coral reef field monitoring is necessary (Goodman et al. 2013; Mumby and Harborne 1999). Remote sensing can be effectively used to determine the status of coral reefs and has been used by researchers for scientific investigation, management, and mapping. Roelfsema et al. (2002) used Landsat Thematic Mapper (TM) imagery to study the spatial distribution of microalgae in coral reefs. Lubin et al. (2001) measured coral reef and non-coral reef reflectance using a coupled ocean–atmosphere radiative transfer model and showed that various spectral features could be used to distinguish coral reefs from the surroundings. The data used as input are generally obtained from surface or aircraft data, although aircraft data are generally obscured in terms of spectral measurements. Lubin et al. (2001) support the conclusion of recent research that the use of satellite remote sensing is effective for coral reef mapping. Although detailed reef mapping (e.g., species identification) is difficult, Mumby (2001) developed an explicit method to chart coral species distribution.

The combination of remote sensing and *in situ* data can be used to verify the evolution of coral reef degradation, including its recovery over timescales of years to decades. Scopéltis et al. (2009) identified the typology of coral reef communities using remote sensing data combined with integrated *in situ* data between 1973 and 2003 in Saint-Leu Reef in the Indian Ocean. Five aerial photographs and two QuickBird images combined with field observations were used to detect the changes in coral reefs during three impact periods, two caused by storms in 1989 and 2002, and one by coral reef bleaching in 2002. Scopéltis et al. (2009) concluded that there was no significant change in the patchy reefs between 1973 and 2006 due to the rapid recovery rate of corals (*Acropora* Sp.) from bleaching. Palandro et al. (2008) quantified coral reef degradation in Florida Keys Natural Marine Sanctuary, USA, from 1984 to 2002, using Landsat imagery and determined the coral reef destruction to be 61%, or 3.4% /yr. Using different generations of Landsat imagery, i.e. Landsat 5 TM (1987), Landsat 7 ETM (2000), and Landsat 8 OLI (2013), with field observation data from 2004, El-Askary et al. (2014) detected changes in coral reefs in Hurgadha, Egypt. Using supervised classification, changes in coral reef habitats can be identified qualitatively and quantitatively for specific periods.

Similar studies have been conducted in Indonesia. Nurdin et al. (2015) have studied changes in the coral reefs of the coastal area of a small island (Suranti Island) in the PANGKEP Regency by using multi-temporal Landsat imagery as their primary data source. However, there are no previous studies that have focused on changes in the coral reefs of all the islands over the PANGKEP Regency.

Additionally, this study was not only used the data from the multi-temporal Landsat imagery (from the year of 1994 to 2014), but also the in-situ data of the coral reef habitats monitoring. Purkis and Pasterkamp (2004) reported that the integration of these data will provide advantages in terms of accuracy, time, cost-effectiveness and coverage area (Jupiter et al. 2013; Hedley et al. 2016; Mumby et al. 1999; Mumby et al. 2004).

Considering these conditions, to elucidate changes in coral conditions and the causes in the PANGKEP Regency, it is considered important to analyze large-scale data as well as limitation of data availability in this area. Therefore, this study aimed to provide a map of the coral reefs distribution around the area, identify and calculate the changes in the ratio of coral cover in two decades from 1994 to 2014.

2.2 Materials and Methods

2.2.1 Data sources

2.2.2.1 Satellite Landsat imagery data

This study used Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM), and Landsat 8 Operational Land Imager (OLI) multi-temporal imagery, acquired in 1994, 2002, and 2014, respectively. The analysis of changes in the coral reefs was performed for a 20-year period, considering the ability of coral reefs to recover from stress conditions occurring within this period (Wilkinson 2008).

As well as coral cover analysis, this study detected changes in the total suspended matter (TSM) concentrations in the sea waters using multi-temporal Landsat imagery data in the same period. The Landsat imagery data used were the Landsat multi-temporal images that were recorded in different seasons (rainy and dry seasons). The types and characteristics of the Landsat image are summarized in Table 2.1.

The study area was covered in the same scene in Landsat 5 TM and 7 ETM (path/row: 114/63), whereas Landsat 8 OLI covered the area in two scenes (path/row: 114/63 and 115/63). The Landsat data had a spatial resolution of 30 m. The Landsat image acquired in 2002 was chosen to minimize the loss of information due to incomplete data caused by technical problems during data acquisition. Moreover, the data obtained before Scan Line Corrector (SLC) turned-off selection were recommended by NASA's Millennium Coral Reef Mapping Project (NASA 2009).

2.2.2.2 Data of rainfall

The rainfall data (mm / day) were used to determine the effect of rainfall on the dynamics of the maximum change of TSM concentration in the waters at two different seasons (dry and rain) in 1994, 2002, and 2014. In this study, the rainfall data for the 20

years from 1994 to 2014 were obtained from the satellite (the Modern-Era Retrospective analysis for Research and Applications, Version 2; MERRA-2) (<https://cds-cv.nccs.nasa.gov/CREATE-V/>). Furthermore, the daily rainfall data were averaged and compiled as monthly rainfall data.

2.2.2.3 Data of coral reef condition

In-situ data of coral reef condition were collected using the point intercept transect (PIT) method (Hill and Wilkinson 2004). The locations for PIT survey were chosen to represent Hutchinson's ecological zone of the Spermonde Archipelago (Hoeksema 2012), i.e., inner zone (Saugi and Karanrang Islands), middle-inner zone (Badi and Sanane Islands), middle-outer zone (Samatellu and Sarappo Islands), and outer zone (Tambakulu, Gondongbali, Pandangan, and Kapoposang Islands), as can be seen in Figure 1.1. Transect points were chosen based on the coral distribution area around the coastline. A 50-m transect line was set above the coral reefs at 3-10 m depth, parallel to the coastline. The position of each transect line (coordinate point) was taken using a global positioning system (GPS), type of Garmin/eTrex Vista HCx. Technically, the point coordinates were taken exactly at the centerline of the transect. The objects along the line were observed and documented. In the PIT method, objects over the transect line were recorded at a 0.5 m spacing.

In order to evaluate the condition of the coral reefs, all categories in the PIT method (Figure 2.1) were further classified as shown in Table 2.2. Live coral cover (%) was calculated to evaluate the condition of coral reefs as proposed by Gomez and Yap (1988):

$$\text{Live coral cover (\%)} = \frac{\text{Each component}}{\text{Total component}} \times 100. \quad (2.1)$$

Based on the percentage of live coral cover, the condition was classified from “bad” to “excellent” (Table 2.3) according to Gomez and Yap (1988). The percentage of coral rubble can be regarded as an indicator of coral reef damage caused by destructive fishing (Jameson et al. 1999). In addition to live coral cover, the coral mortality index (MI) was also used to evaluate the coral reef condition (Gomez et al. 1994):

$$\text{MI} = \frac{\text{Ratio of dead coral (\%)}}{\text{Ratio of live coral (\%)} + \text{Ratio of dead coral (\%)}}. \quad (2.2)$$

2.2.2.4 In-situ ground control point and ground truth data

In addition to the in-situ data obtained by the PIT method, the ground control point (GCP) and ground truth (GT) coordinate points were determined using a global positioning system (GPS), type of Garmin/eTrex Vista HCx. Generally, the GCP points were road intersections, docks, or other landmarks identifiable in the satellite images. Ground truth data were obtained using GPS for each type of seabed cover, including live corals, dead corals, seagrasses, and sand. In addition, the GT data were applied to check the accuracy of the image classification results.

2.2.2.5 Social survey data

In order to ensure the results of primary data analysis, social survey was conducted to obtain complementary information about fishing activities in the coral reef area, i.e. fishing location, fishing gear used, destructive fishing activities and so on. In the case of social survey, questionnaires were distributed to the fishermen and their households following Krejcie and Morgan (1970)'s method. Based on the population size on ten inhabited islands, 296 fishermen were chosen as respondents through purposive random sampling.

2.2.2.6 Secondary data

This study was used a PANGKEP regional administration map (1:250,000) and Indonesia coastal environmental map (1:250,000) obtained from the Government of PANGKEP Regency to identify the islands and bathymetry in the study area.

2.2.2 Image processing

In this study, the image processing was carried out in the areas not affected by turbidity and sedimentation because the sensor is only able to penetrate the turbidity of the water at a depth of less than 1 m. Based on Hutchinson's ecological zone, reef areas analyzed include middle inner zone, outer middle zone, and the outer zone (Hoeksema 2012). Image processing consisted of several phases as described the following subsections.

2.2.2.1 Atmospheric correction

Scattering and absorption of molecules by the atmosphere decreases the quality of information in the satellite image by up to 10%, depending on the spectral channel (Che and Price 1992; Ishizaka et al. 1992). Therefore, an atmospheric correction is

essential in order to minimize the effect of the atmosphere in multi-temporal images before comparing and analyzing the data (Hadjimitsis et al. 2010). In this study, an atmospheric correction was applied to the three series of Landsat imagery data using Dark Object Subtraction 1 (DOS1) Method (Chavez 1996). For easier atmospheric correction, this study was applied semi-automatic classification plugin (SCP) in QGIS version 2.10 (Congedo and Macchi 2013).

2.2.2.2 Geometric correction

Geometric correction for Landsat 5 TM and Landsat 7 ETM imagery data was conducted using the same GCPs on Landsat 8 OLI corrected as a reference. This aims to improve the accuracy and minimize the geometric error in Landsat imagery data. Eight GCPs were chosen for the geometric correction using order polynomial transformation and the nearest neighbor interpolation algorithm (Baboo and Devi 2011). The corrected image is acceptable if the root mean square error (RMSE) is a one-half pixel wide (RMSE = 0.5). Overall, the RMSE less than 0.5 pixel were achieved for each transformation.

2.2.2.3 Mosaic image

Mosaicking is a process to merge two or more scenes into a single scene or image. The process was applied to Landsat 8 OLI imagery data since in this Landsat image, the study area (PANGKEP in the Spermonde Archipelago) was captured in two scenes (path/row: 114/63 and 115/63). This is in contrast to previous Landsat imagery data that require only one scene (path/row: 114/63). Since 2010, Landsat 8 OLI has replaced previous Landsat versions such as Landsat 7 ETM and Landsat 5 TM. In the mosaicking process, the digital value of both images needs to be balanced and normalized by using smooth intensity filter modulation (SFIM) pan sharpen wizard of ER Mapper in order to increase the spectral qualities of merged images (ERDAS 2008).

2.2.2.4 Subset image (cropping)

Creating a subset image, or “cropping,” aims to delimit the area of interest, reinforce geospatial phenomenon, and focus on the study area. In addition, the subset image produces objects that are larger in size, allowing existing information such as color to be seen more clearly.

2.2.2.5 Image composite (true color)

True color on Landsat 5 TM and Landsat 7 ETM was displayed by using combination bands of Red: Green: Blue (R: G: B) 3: 2: 1, whereas the color was displayed

as R: G: B = 4: 3: 2 on the Landsat 8 Operational Land Imager (OLI). This band combination is often used to detect feature types covering shallow bottom waters in the preliminary stage. Chlorophyll in vegetation were detected using green canal (band 2 in Landsat 5 TM and Landsat 7 ETM, and band 3 in Landsat 8 OLI).

High chlorophyll concentration on the mainland provided a high digital reflection value and was shown as dark green. Water bodies were detected using band 1 (Landsat 5 TM and 7 ETM) and band 2 (Landsat 8 OLI) in the blue composite so that water bodies could be depicted in blue.

2.2.2.6 Total Suspended Matter (TSM)

One of the controlling factors for the growth of coral reefs is the total suspended matter (TSM) concentration in the coastal water. The threshold of the TSM concentration for normal coral reef growth is 10 mg/L (Erftemeijer et al. 2012). The growth of coral reefs is considered lower if the concentration is higher than the threshold. In this study, the TSM concentrations were detected in both of dry and rainy seasons to compare a difference of the maximum TSM concentrations between the seasons in the three different years (1994, 2002 and 2014). Further, too-high TSM concentrations prevent from detection by the Landsat satellite. Light intensity exponentially decreases with the water depth, due to light absorption and scattering by water molecules, suspended particles and soluble materials (e.g., Weinberg 1976; Falkowski et al. 1990). In such a condition, the detection capacity of the Landsat satellite could be less than 1 m depth.

On the other hand, the TSM concentrations in coastal waters can be estimated from the Landsat image using near infra-red (NIR) band, by using an algorithm of Zheng et al. (2015), as described in the following functions:

$$TSM_{OLI} = 6110.3 \times R_{rs}(NIR) - 1.8242, \quad (2.3)$$

$$TSM_{TM/ETM} = 4616.4 \times R_{rs}(NIR) - 4.362, \quad (2.4)$$

where TSM_{OLI} is the total suspended matter for Landsat 8 OLI (mg/L), $TSM_{TM/ETM}$ is the total suspended matter for Landsat 5 TM or 7 ETM (mg/L), $R_{rs}(NIR)$ is the NIR band reflectance (λ), which is Band 5 for the Landsat 8 OLI sensor and Band 4 for the Landsat 5 TM or 7ETM sensors. The areas in which the concentration of TSM is higher than 10 (mg/L) were excluded for further analysis in this study because of the poor detection

capacity of the Landsat satellite with high TSM concentration and light attenuation. In this case, coral reefs in the bottom waters were not able to be detected by the Landsat sensor.

2.2.2.6 Water column correction

Correction of the water column was done to improve image quality by reducing the interference in the water column. The technique commonly used for the correction of the water column is based on an algorithm developed by Lyzenga (1978; 1981). The radiance measurements were performed on the same type bottom substrate with different depth so that the radiance values of band i and band j are correlated linearly. By using statistical analysis, a gradient value of the linear line equation was an approximation of the attenuation coefficient between band i and band j which is formed by two pair bands between red, green and blue bands (Research Center for Oceanography-Indonesian Institute of Sciences 2014). The equation is written as follows (Green et al. 2000):

$$\text{Depth invariant index} = \ln(L_i) - \left[\left(\frac{k_i}{k_j} \right) \times \ln(L_j) \right], \quad (2.5)$$

where L_i and L_j are the radiance after atmospheric correction for band i and band j respectively, and $\frac{k_i}{k_j}$ is the ratio of the diffuse attenuation coefficients of band i and j .

2.2.2.7 Unsupervised classification, reclassification and ground truthing

An unsupervised classification was performed using image-processing software (ER Mapper 7.2) and the three depth-invariant bands derived from the Lyzenga model. Unsupervised classification algorithms identify natural groups within multi-spectral data (Call et al. 2003). Iterative Self-organizing Class Analysis (ISOCCLASS) was used for the classification. Image-processing software were automatically classifies spectral value into spectral classes (Lillesand et al. 2004). Then analyst simply match objects on the field with the help of global positioning system (GPS). In this case, 30 unlabeled classes with 150 iterations were produced from images, which included water column correction. After that, reclassification was applied to the results of the unsupervised classification image based on visual interpretation (spectral class color) and digital image value. Interpretation of the digital image value was carried out using the cell value profile tools

of the ER Mapper 7.2 (ERDAS 2008) and the visual interpretation (Table 2.4) referred to the COREMAP image interpretation guide (COREMAP 2001, cited in Suwargana 2014).

Based on the results, shallow features could be classified into five categories: sea, live corals, dead corals, seagrasses, and sand. The results of the classification were then verified using field data (243 points) to obtain the level of accuracy of mapping.

2.2.2.8 Accuracy assessment

Accuracy assessment is closely related to the position and thematic accuracy (Congalton and Green 2008), which is done by using a confusion matrix. This method compares the image obtained from classification results as the basis for the actual class with field data, which are assumed to represent the seabed cover (Campbell 1987; Call et al. 2003). Data row are obtained by remote sensing data classification, which signify the accuracy calculation by the producer, while the data column is a calculation result of field observations by researchers and used in user's accuracy calculation (Table 2.5). More consistencies between classification and observation results would generate higher overall accuracy, which is calculated using the following equation (Congalton and Green 2008):

$$\text{Overall accuracy} = \frac{\sum_{i=1}^k N_{ii}}{N} \times 100\%, \quad (2.6)$$

$$\text{Producer accuracy } j = \frac{N_{jj}}{N_{+j}} \times 100\%, \quad (2.7)$$

$$\text{User accuracy } i = \frac{N_{ii}}{N_{i+}} \times 100\%. \quad (2.8)$$

Not all agreement can be attributed to the success of the classification. Therefore, the Kappa analysis were also performed to assess the extent of classification accuracy as that accounts for not only diagonal elements but all the elements in the confusion matrix (Campbell 1987; Call et al. 2003). The Kappa analysis is a multivariate technique analysis used to calculate the discrete value of classification accuracy of the confusion matrix, and is done by evaluating the Kappa coefficient (K), calculated by the following equation (Green et al. 2000):

$$K = \frac{N \sum_{i=1}^k N_{ii} - \sum_{i=1}^k N_{i+} N_{+i}}{N^2 - \sum_{i=1}^k N_{i+} N_{+i}}, \quad (2.9)$$

where N_{ij} is the number of observation at column j and row i , N_{ii} and N_{jj} are the numbers of observation categorized as the thematic class of i and j , respectively, N_{i+} and N_{j+} are

the numbers of observation classified as the thematic class of i from satellite data and that of j from in-situ data, and N is the total number of observations.

The K would be lower than the value of overall accuracy and it has a range between 0 and 1. Based on several previous studies, the Kappa analysis is one of the methods to validate the result of image classification (Campbell 1987; Call et al. 2003; Green et al 2000; Lillesand et al. 2014). In order to interpret the K value, this study was referred to the Fleiss interpretation (1969) that categorized as follows: > 0.75 as “very good”, $0.40-0.75$ as “fair” to “good”, and <0.4 as “bad”.

2.2.2.9 Vectorization

The image classification results were converted into vector data formats. This approach had three objectives: to manipulate the data in the image, to remove disturbance (e.g., ocean surface wave movement and turbidity of the water), and to map the distribution and condition of the coral reefs and conduct an analysis of changes in the reefs.

2.2.2.10 Post-classification

In this stage, this study was produced maps of the coral reef distribution and condition based on the extracted Landsat multi-temporal imagery data. There were produced three maps, one each for 1994, 2002, and 2014 when the images were acquired. This study also was generated maps of the changes in coral reef condition over a 20-year period obtained by overlaying the map of coral reef change between 1994 and 2002 with the map of coral reef change from 2002 to 2014. All stages of the data processing and analysis in this study are shown in Figure 2.3.

2.3 Results

2.3.1 Status of coral reefs

The physical status of coral reefs was expressed in the classification system by calculating the ratio of the certain coral coverage area. The common method used to determine the physical status of coral reefs is the Point Intercept Transect (PIT) (Hill and Wilkinson 2004). Our observations of coral reef condition in 2014 using the PIT method in ten locations (nine inhabited islands and one uninhabited island) are shown in Figure 2.3 and Table 2.6.

Table 2.6 indicated that among the total stations consisted of 23 stations observed in this study, five stations of coral reefs exhibited good physical condition, two stations

were in moderate physical condition, and sixteen stations showed bad physical condition, respectively.

The mean live coral cover percentage was 24%, and the mean percentage of the dead coral cover was 62%, although the percentage differed significantly among transects. These values reveal that the condition of the coral reefs in the study area was relatively bad. Furthermore, the coral mortality index (MI) was 0.75, which is classified as severely damaged. Coral reefs classified as bad or severely damaged are considered to negatively affect the coral reef ecosystem, including species abundance and diversity (Jones et al. 2004; Komyakova et al. 2013).

Components of rubbles on the coral reefs (coral rubbles) can be indicators to identify the activity of destructive fishing because of the physical damage to coral reefs in the form of wreckages or rubbles commonly caused by the use of bombs on fishing (Jameson et al. 1999). Based on the result, coral rubble in the study area had the highest percentage of coverage relative to the other components, as can be seen in Figure 2.4.

The percentage of coral rubble varied among transects, with a mean of 95.8%. The lowest percentage was found at Saugi Island (87.8%), and the highest occurred at Badi Island and Kapoposang Island (both 100%). The high ratio of coral rubbles in the study area indicates that most of the coral reef damages are derived from destructive fishing practices, i.e. blast fishing and cyanide fishing.

Location of destructive fishing practices in the study area were related to the distance from settlements and post-supervision. Remote areas are often difficult to be monitored by supervisory officers and local communities. Based on a calculation using “Plugin Distance between Points of Quantum Geographic Information System (QGIS)”, there was a relationship between the distance from the mainland and the number of fishermen that like to choose remote locations to catch reef fishes in a year (before and in 2014) (Table 2.7).

The islands located close to the mainland generally had a lower frequency of coral fish catching compared to the islands located farther from the mainland. Based on the result, it is found that especially, the coral reefs located farther from the mainland or remote areas, i.e. Kapoposang MPAs, Langkai, Lanyukang, Suranti, Jangang-Jangang Islands, are used as favorite locations of destructive fishing practices using bombs and cyanide.

In this study, correlation test were examined by using statistical analysis to know how relationship between the distance of fishing location and the amount of respondent to choose a favorite fishing location. The result of the correlation analysis, it shows that there is a positive correlation between the distance of fishing location and the amount of

respondent to choose a favorite fishing location with a coefficient correlation (r) was 0.68 (in 2014) and 0.75 (before 2014).

The characteristics of the fishing locations obtained from the questionnaire survey showed four types of locations preferred by fishermen (Figure 2.5). The respondents' preferences were deep sea/offshore (44%), reef flat (22%), reef edge (19%), and coastal water (15%). The high ratio of preferences for deep sea/offshore is considered to be resulting from that the area is the main target for fishermen using large vessels. Some of the fishermen set artificial fishing grounds (locally known as “*rumpon*”) and use small bombs to herd fish into the nets. In contrast, based on the result, flat and edge reefs (totally 41%) are considered to be preferred for blast and cyanide fishing which were strongly linked to the fishing gears used and target fish species frequently caught.

2.3.2 Image processing

A geometric correction process was performed using eight GCPs, which resulted in average RMSE of 0.5 for Landsat images. Atmospheric correction were conducted to the three series Landsat imagery data. Based on the result, profile spectral shows the spectral reflectance at sea surface after atmospheric correction on Landsat image, within visible bands with central wavelength range of 0.485 through 0.660 μm (blue, green and red bands). The pattern in shorter wavelength of Landsat 8 OLI is different from Landsat 5 TM and Landsat 7 ETM, as shown in Figure 2.6.

Visually, the objects in terms of reflectance in descending order are sand, seagrasses, dead corals and live corals. This result agrees with a previous result by Luczkovich et al. (1993) which reported higher reflectance of sand than seagrasses and coral reefs. It is clearly demonstrated that the atmosphere correction improves the visible band, hence it is possible to differentiate each object. This shows that the Landsat image with spatial resolution 30 m can be used as an input in the analysis to detect the change of coral reef covering a wide area. Landsat image offers advantages not only in detecting and mapping coral reef geomorphology and underwater habitat but also in being freely available and updated periodically. Therefore, it was extensively used previously by several previous studies (e.g., El-Askary et al. 2014; Hedley et al. 2016; Kordi and O'Leary 2016; Palandro et al. 2008; Roelfsema et al. 2002; Wahiddin et al. 2015).

2.3.3 TSM detection

Sensor Landsat has the capability to identify total suspended matter (TSM) in the water by using band near infra-red (NIR). TSM is the optical properties of a suspension that causes light to be scattered and absorbed rather than transmitted through the water

column (Davies-Colley and Smith 2001) and it became a limiting factor for the growth of coral reefs (Parwati et al. 2013; Zheng et al. 2015). Distribution of the TSM concentration in around inner zone areas can be evidence directly in the field where there are six rivers estuary, i.e. Tello, Maros, Pangkajene, Labakkang, Limbangan, and Segeri, along with the coastal areas from Makassar to the PANGKEP Regency (Figure 2.7). They are as a supplier of sediment materials to the sea water.

Based on the image processing, the maximum TSM concentration in the dry season was 120 (mg/L), 186 (mg/L), and 203 (mg/L) for Landsat 5 TM (in 1994), Landsat 7 ETM (in 2002) and Landsat 8 OLI (in 2014), respectively. The maximum TSM concentration in the rainy season, on the other hand, was 190 (mg/L), 221 (mg/L) and 223 (mg/L) for Landsat 5 TM (in 1994), Landsat 7 ETM (in 2002) and Landsat 8 OLI (in 2014), respectively (Table 2.8). Obviously higher TSM concentrations were found nearby river mouths in the rainy season, while lower TSM concentrations were found in the dry season particularly in the areas further from the mainland (Figure 2.7). In general, the TSM concentration and distribution area have increased from 1994-2002 to 2002-2014 periods. This trend is possibly caused by several factors, e.g. land use activities (Tonasa Cement Factory in the PANGKEP Regency and Bosowa Cement Factory in the Maros Regency), rainfall and oceanographic factors in the coastal area.

The average rainfall level has prominent seasonal change from 0 to 15 mm/day (Figure 2.8). In the rainy season, the rainfall increases from October and reaches the maximum in January, then drops dramatically in February, followed by slight increase in March. In dry season, the rainfall decreases from April and reaches the minimum in September. The seasonal change of rainfall is considered to affect the change in the TSM discharged into the sea.

High TSM concentration affects coral reef growth by decreasing the sunlight penetration and further hinders the photosynthesis. The threshold of TSM concentration for normal coral reef growth is 10 mg/L (Erftemeijer et al. 2012). Coral reef growth is considered to be lower with higher TSM concentration than the threshold. In the inner zone, therefore, the TSM concentration generally exceeds the threshold, which implies that the coral reef growth is disturbed and coral reef ecosystem and its sustainability are threatened.

To avoid possible biases in change in coral cover, the area of the inner zone (coastal water nearby the mainland) was excluded in the analysis. Therefore, for further analysis, this study was focused on middle inner through outer zones.

2.3.4 Water column correction

The percentage of live coral cover in the PIT method used to estimate the spectral live coral cover per pixel. Technically, the coordinates of the transect observation of coral plotted into the image and then carried out extraction pixel value by point on the bands visible (i.e., blue, green and red) to obtain the pixel value of the coral reefs at each transect observation. After that, these spectral values of the tree series Landsat images were calculated by using statistical analysis to obtain the gradient coefficient of the ratio of two pair bands as the ratio of the diffuse attenuation coefficient (k_i/k_j) (Figure 2.9).

The spectral values of live coral reefs are distributed around the linear line in particular on the band ratio of blue and green bands (Figure 2.9 (a, (d), (g)). Distribution of spectral value with the ratio of two pair bands of blue and green look fairly consistent on three series of Landsat imagery data according to determination coefficient of Landsat 5 TM, 1994 (0.90), Landsat 7 ETM, 2002 (0.98) and Landsat 8 OLI, 2014 (0.92). Because the ratio of the diffuse attenuation coefficient is stable for combination of radiance (L) at blue and green wavelengths in live coral reefs, they are detectable by using L at two wavelengths.

The values of the gradient of the linear line (k_i/k_j) at each Landsat imagery were applied to the three series of Landsat imagery data to obtain new images. Results of the water column correction are shown in the Figure 2.10.

Based on the result shows that the object of the live corals, dead corals, seagrass and sand can be distinguished visually by color and spectral values. Grouping the spectral value is done by the image processing program. A cluster of spectral with the cyan color is interpreted as corals and seems to dominate in the three series of Landsat imagery, while in the class of dead coral, shown as cluster of green color is also widespread especially on Landsat 8 OLI, 2014.

2.3.5 Unsupervised classification, reclassification and ground truthing

In this stage, data of multi-temporal Landsat images resulted from water column correction especially in ratio of the blue and green band were used as input in the unsupervised classification process. Utilization of blue and green band for this classification due to the energy from spectrum of band blue and band green can penetrate deeper to the water column compare to the other band.

The results of unsupervised classification were obtained several categories with each category represents underwater objects. Furthermore, the process of identification and classification of the coral reefs and seabed habitats was done based on the guidelines COREMAP (See Table 2.3 for the classification).

In addition, the field survey data were set as references in reclassification phase, which after adjustment it was produced 4 classes of dominant covers underwater: live corals, dead corals, seagrasses and sand. The grouping from 30 to 4 classes was backed by field survey data. In this case, different unlabelled classes with the same object were combined into one class. After that, these classes were done reclassification to be 4 classes (Table 2.9 and Figure 2.11).

The result of the images classification on multi-temporal Landsat imagery of data (i.e., Landsat 8 OLI, 2014, Landsat 7 ETM, 2002, and Landsat 5 TM, 1994) (Table 2.9), shows that the class of live corals is a class with the highest percentage of 58% (209,301 pixels), followed by dead corals amounted to 24% (85,049 pixels), sand 11% (37,712 pixels) and the lowest is seagrasses at 7% (26,754 pixels).

In 1994, the areas were 7,716 ha, 1,128 ha, 838 ha, and 1,082 ha for live coral, dead coral, seagrass, and sand, respectively, which implies a low percentage of damaged coral reefs (11%) compared to live corals (72%). A high percentage of live coral offers advantages in terms of ecology and economic security for local people in this area. The coral reef distribution, including its condition based on analysis of the 1994 Landsat image, is shown in Figure 2.11 (a). The pattern of live coral distribution (in cyan) can be clearly seen in all zones, although some red spots indicating dead corals are also observed. Red spots can be clearly observed in the outer zone, which includes the Kapoposang Marine Conservation Area. This area comprises Kapoposang, Pandangan, Tambakulu, Gondongbali, and Suranti Islands.

In 2002, Live corals were still visible and distributed in all of the study sites, although red spots had begun to appear in some coral reefs, especially in the northern part of the outer-middle to outer zone, such as Suranti Island and Jangang-Jangang coral clusters, and also in the southern part of the outer zone, such as Lanjukang Island and coral clusters. In the middle inner zone, dead corals had also begun to appear, but the area was still dominated by live coral. In this period, coral reef damage was more severe in the outer zone compared to the middle inner and middle outer zones (Figure 2.11 (b)). Overall, the coral life was reduced by 8 % and dead coral increased by 10%.

In 2014, the percentage of dead corals increased by 20%, or about 4.316 ha. Contrasting with dead coral, the percentage of live corals in this period decreased by 25% or about 4,326 ha. As can be seen in the Figure 2.11 (c), distribution of dead coral clearly visible red and spread, not only in the area of coral reefs within the outer zone but also in the middle inner zone.

2.3.6 Accuracy assessment

After designed the map of coral reef physical condition through the interpretation of satellite images, the next step was accuracy test. An accuracy test was performed on the classification result of the Landsat 8 OLI image based on the field data obtained in 2014 for four habitat classes (live corals, dead corals, sand, and seagrasses) which aims to validate the correctness and proper of measurement and it could be used for further analysis. Points for accuracy test taken as many as 243 points which are scattered throughout the study area, and is considered to represent any characteristics of the object in the field. The field data were then used to construct the error matrix (Tables 2.10 and 2.11). Based on the data analyses of the error matrix, the individual and overall accuracy was expressed in percentage value (%).

The precision of classification is calculated using overall accuracy of the confusion matrix, which in this case field survey data is set as a reference in validation. Confusion matrix also produces value producer accuracy (PA) and user accuracy (UA). The results in Table 2.6 shows that 198 of 243 points are correctly classified and OA accuracy value obtained is 81%. According to Lillesand et al. (2014), interpretation result was considered good if it has accuracy higher than 80%. Therefore, the level of accuracy in this study is considered good.

Furthermore, the Kappa coefficient (K) was calculated based on confusion matrix to validate the result of classification. The level of K was determined by the image resolution and image processing techniques. Similarly, the distribution of random points based on the density of each category in the ground truth data (i.e. proportionate stratified samples) would lower the value of errors. In this case, the K of 0.77 indicates that the pixels were more correctly classified by 77% than would be expected by chance alone.

PA value is the value of each pixel on a proper class, which had been classified. The biggest value of PA cover seabed habitats found on dead corals (88%), which is correctly classified and omission error of 12%. Omission error value is to remove areas that should be included in the class (Boschetti et al. 2004). The smallest PA value is found in sand (77%) with omission error 23% (Table 2.11).

UA value is the average probability of actual pixels representing each class in the field. In Table 2.10, dead corals (84%), which is correctly classified and error commission value of 16 % represents the largest UA values. Commission error is an error in mapping according to the class, which includes areas that should be removed from the class (Boschetti et al. 2004). The smallest UA value is both seagrasses and sand with the percentages of 80% respectively, which is also correctly classified and the value of each commission error of 20%.

Based on the accuracy test, there was a bias between image interpretation results and the actual data in the field, which was contributed by several factors such as water condition and error in field data collection. During image acquisition, different objects at the bottom of the waters with almost identical spectral reflectance would cause similar appearance in the image. Another factor is a human error caused by the observer during data acquisition in the field. During the survey, agitated and wavy water condition made the sampling at planned coordinate difficult to execute.

2.3.7 Change in coral reef habitat

In this study, it was demonstrated that depth invariant index algorithm could be applied to multi-temporal Landsat imagery data in order to extract information of objects existing in shallow water. Validation by in-situ data in classification stage was a key factor in determining mapping accuracy of 81%. Based on the result, the Landsat multi-temporal images of 1994, 2002, and 2014 showed that the coral reefs have changed over the 20-year period from 1994 to 2014 with different trends, i.e., a decline in live corals and increase in dead corals. The statistics for the changes in coral reef habitats from 1994 to 2014 are shown in Table 2.12. The results of the 2002 Landsat 7 ETM image classification show a drastic change in the live and dead coral categories. Live corals area decreased significantly, by 11%, from 7,716 ha in 1994 to 6,885 ha in 2002 (Figure 2.12 (a)). In contrast, the dead corals area doubled, from 1,128 ha to 2,210 ha, during the same period. The area of seagrasses experienced a slight increase by 8 ha, whereas the sandy area decreased significantly from 1,082 ha in 1994 to 1,023 ha in 2002.

Most of the damage to the coral reefs has occurred recently, between 2002 and 2014. The coral reef condition and its distribution based on the Landsat 8 imagery data from 2014 is depicted visually in Figure 2.12 (b). It can be clearly observed that dead corals (in red) is dominant compared to the other categories. There is a marked change in live coral cover, which decreased by 39% from 6,885 ha in 2002 to 4,236 ha in 2014, in contrast to the dead coral cover, which doubled from 2,210 ha in 2002 to 4,316 ha in 2014 (Figure 2.12 (b)). There was an increase in the area of seagrasses, from 846 ha in 2002 to 906 ha in 2014, and the sandy area increased significantly, from 1,023 ha in 2002 to 1,306 ha in 2014.

In addition, the results of the Landsat image multi-temporal classification and spatial analysis show that the area of live corals decreased by 45% from 7,716 ha in 1994 to 6,885 ha in 2002, and then declined dramatically to 4,236 ha in 2014; thus, over the last 20 years, the area of live corals has decreased by 3,480, or 174 ha/yr.

The changes in the coral reefs during the last 20 years are summarized in Figure 2.13. From 1994 to 2014, 45% of the coral cover changed. The total change comprised changes from live to dead corals (92%), dead corals to sand (7%), and live corals to sand (1%). The large change from live to dead corals implies the influence of anthropogenic activities, which cause damage and high mortality of coral reefs.

2.4 Discussion

Base on the results, the application of the water column correction using gradient of the ratio of two pair bands and unsupervised classification to the three series of Landsat imagery data (from 1994, 2002, and 2014) were effective in extracting information on four habitat classes (live corals, dead corals, sand, and seagrasses) in shallow water. It was relatively straightforward to differentiate the four classes based on color and spectral values. All classes generated by image classification and field survey indicated that the approach could be applied effectively in mapping. This was supported by the high overall accuracy of 81% and the K of 0.77, which means that the mapping precision is considered good. While the accuracy of 81% is good enough, the rest (19%) is considered to be strongly influenced by precision in taking ground truth points using GPS. In this case, ocean waves and currents are also considered to affect the precision of objects on the sea bottom.

The analysis to detect changes in coral reefs habitat based on multi-temporal imagery data revealed a significant change during the two decades from 1994 to 2014. A dramatic change occurred in live and dead coral cover, whereas there were no significant changes in the sand and seagrasses cover. Although changes were detected at all sites, marked changes occurred in the middle-outer zone and outer zone, which are located farthest from the mainland (Figure 2.12).

On average, live corals and dead corals covered 24% and 62% of the total area, respectively; these values were classified as bad and severely damaged, respectively (Gomez and Yap 1988; Gomez et al. 1994). This finding suggests that the two methods of coral reef classification (Landsat image classification and PIT method) can be used effectively to determine the state of degradation of coral reefs.

Rainfall and oceanographic factors, i.e. current, wave and the wind affect the distribution of the TSM in the study area (Jones et al., 2016). The analysis of Landsat satellite images show that the TSM can be transported to the coral reefs of the islands, which are adjacent to the inner middle zone. Compared to the dry season, the rainfall factors in the rainy season greatly affect the maximum TSM concentration in the inner zone (Figure 2.7).

By contrast in the inner zone, change in coral reefs from the middle to the outer zone for the last 20 years (from 1994 to 2014) are affected by fishing activity. Based on the result, the coral reefs in the study area dominated by coral rubble. This is indicating that the cause of coral reef decline was predominantly destructive fishing practices such as blast fishing and cyanide fishing. This is evidenced by the results obtained from the PIT method, which showed a mean coral rubble cover of 96%, as shown in Figure 2.4. The other evidence is that more than 40% of the fishing locations in the study area are in the area of coral reefs (reef flat and reef edge), as shown in Figure 2.5. Our findings are in accordance with the results of previous studies (DFW-Indonesia 2003; Edinger et al. 1998; Pet-Soede 2000).

Besides the influences of TSM concentration, the ability of satellite sensors to record marine object is influenced by oceanographic factors, e.g., tides which varied daily due to the moon and the sun gravitational forces. The tidal graph of the Spermonde Archipelago waters obtained from the NAO 99b Tidal Prediction System, as shown in Figure 2.14. The graph shows the curve of tidal taken in accordance with the recording time of images. The images were recorded in 1994, 2002, 2014 (path/row: 114/63) and 2014 (path/row: 115/63) respectively at 13:27, 13:59, 14:10, and 14:17 local time.

Based on the Figure 2.14, between 13:00 and 14:00 (recording time of 4 scenes), the water level on 21 Sept 2014 and 28 Sept.2014 was over 1 m, while on July 10, 2002, and August 29, 1994, the water level was below 1 m. Thus, the graph shows that the sea level varied, which depends on the recording time.

Tides is one of the parameters affecting sea level would determine the depth of water column. Differences in the depth of the sea water, in turn, will influence the results of image analysis since the maximum depth penetration sensor of Landsat satellite is only 10 m (Nurdin et al. 2013).

2.5 Conclusions

Integration of multi-temporal Landsat imagery data and in-situ field data were used to map distribution of coral reefs and to assess changes in coral reef habitats in wide area of the PANGKEP Regency, Spermonde Archipelago, Indonesia. Our multi-temporal Landsat imagery analysis suggests that the coral reef habitats in the PANGKEP Regency, have changed drastically over the 20 years from 1994 to 2014, with a rate of coral reef destruction of 174 ha/yr. The coral reef decline in the study area is presumably caused by destructive fishing practices. The coral reef degradation is also considered to be caused by high total suspended matter concentration which hampers the growth, especially in the inner zone (nearby the mainland).

Coral reef cover is anticipated to decrease if no protection appropriate procedures and management strategies for the coral reefs are implemented in the area. Therefore, prompt strategies in the study area are required to be developed and implemented based on the scientific insights.

Table 2.1 Types and characteristics of Landsat images used in this study. Multi-temporal Landsat imagery data were obtained from the United States Geological Survey (2014)

Satellite and sensor	Acquisition date	Path/row	Spatial Resolution (m)	Acquisition time (UTC+08:00)
Dry season (April-September):				
Landsat 5 TM	August 29, 1994	114/63	30	13:27:27
Landsat 7 ETM	July 10, 2002	114/63	30	13:59:17
Landsat 8 OLI	September 21, 2014	114/63	30	14:10:42
	September 28, 2014	115/63	30	14:17:05
Rainy season (October-March):				
Landsat 5 TM	December 3, 1994	114/63	30	09:24:27
Landsat 7 ETM	December 17, 2002	114/63	30	09:58:23
Landsat 8 OLI	December 26, 2014	114/63	30	10:10:32

Table 2. 2 Classification of benthos in the PIT method

Classes	Description
Live coral (LC)	Acropora and non-Acropora
Dead coral (DC)	dead coral, dead coral algae, and rubble
Biotic (B)	soft coral, sponge, and fleshy weed
Abiotic (A)	sand, silt, and rock
Others	giant clam, <i>Acanthaster planci</i> , <i>Diadema spp.</i> etc.

Table 2.3 Coral cover (%) as a guidance of categorization defined by Gomez and Yap (1988)

Coral cover (%)	Criterion
0.0 – 24.9	Bad
25.0 – 49.9	Moderate
50.0 – 74.9	Good
75.0 – 100.0	Excellent

Table 2.4 Description of classifications. Visually, the coral reef could be sorted into 2 categories (live and dead coral) according to their color. The live coral is generally found far from land, close to the deep water zone, while dead coral is commonly distributed close to the shoreline (COREMAP 2001, cited in Suwargana 2014)

Classes	Description
Sea water	Purple to blue
Live corals	Cyan to light green
Dead corals	Green with clear boundary
Seagrasses	Yellow to red (orange) with unclear boundary
Sand	Yellow and red

Table 2.5 Example of the confusion matrix calculation (from Congalton and Green 2008). In this matrix, N_{ij} is the number of samples classified, where i , j , k and $+$ are the row in the remotely sensed classification and the column in the reference data set (field data), k is the next sample number, $+$ is the total of samples in column or row, respectively. In this case, each column (field data) of the matrix represents the instances in a predicted class while each row (image classification) represents the instances in an actual class and vice versa.

	Field data (j)			Total N_{i+}
	N_{11}	N_{12}	N_{1k}	N_{1+}
Image Classification (i)	N_{21}	N_{22}	N_{2k}	N_{2+}
	N_{k1}	N_{k2}	N_{kk}	N_{k+}
Total N_{j+}	N_{+1}	N_{+2}	N_{+k}	N

Table 2.6 Status of coral reefs in study site based on the result of PIT method at 23 transects in 10 islands

Location (ID)	Transect no.	Latitude; Longitude	Depth (m)	% Coral cover	Status
Saugi (SG)	SG.1	4° 45' 57.87" S; 119° 27' 50.39" E	3	2	Bad
	SG.2	4° 46' 2.36" S; 119° 27' 35.47" E	3	28	Moderate
	SG.3	4° 46' 45.46" S; 119° 27' 44.12" E	3	39	Moderate
Samatellu Lompo (SL)	SL.1	4° 42' 13.07" S; 119° 19' 40.99" E	3	9	Bad
	SL.2	4° 42' 18.21" S;: 119° 19' 50.60" E	3	24	Bad
	SL.3	4° 42' 26.49" S; 119° 19' 34.74" E	10	53	Good
Gondongbali (GB)	GB.1	4° 43' 13.72" S; 119° 3' 42.87" E	3	54	Good
	GB.2	4° 42' 42.55" S; 119° 4' 23.11" E	10	56	Good
Tambakulu (TK)	TK.1	4° 44' 4.14" S; 119° 3' 46.62" E	3	2	Bad
	TK.2	4° 44' 40.67" S; 119° 3' 42.83" E	10	51	Good
Pandangan (PD)	PD.1	4° 43' 26.50" S; 118° 59' 5.50" E	3	6	Bad
	PD.2	4° 43' 11.66" S; 118° 58' 29.04" E	10	15	Bad
Kapoposang (KP)	KP.1	4° 41' 51.94" S; 118° 57' 48.71" E	3	19	Bad
	KP.2	4° 42' 0.81" S; 118° 56' 9.06" E	10	14	Bad
Karanrang (KR)	KR.1	4° 51' 16.71" S; 119° 23' 3.26" E	3	18	Bad

	KR.2	4° 51' 16.69" S; 119° 22' 36.35" E	3	16	Bad
	KR.3	4° 51' 34.04" S; 119° 23' 6.64" E	10	21	Bad
Sarappo Lompo	SR.1	4° 52' 37.32" S; 119° 15' 55.19" E	3	10	Bad
(SR)	SR.2	4° 53' 3.78" S; 119° 16' 5.90" E	10	56	Good
Sanane	SN.1	4° 56' 38" S; 119° 20' 27.50" E	3	20	Bad
(SN)	SN.2	4° 57' 1.83" S; 119° 20' 20.12" E	10	7	Bad
Badi	BD.1	4° 57' 58.16" S; 119° 17' 11.82" E	3	16	Bad
(BD)	BD.2	4° 58' 16.89" S; 119° 17' 2.96" E	10	7	Bad

Table 2.7 Distance of fishing locations from the mainland (before and in 2014) in the study site. The number in columns of "Before 2014" and "In 2014" were the number of fisherman who chose favorite locations for fishing in the period of before 2014 and in 2014, respectively

No.	Fishing location	Distance (km)	Before 2014 (the number of person /yr.)	In 2014 (the number of person /yr.)
1.	Near mainland	3.24	4	10
2.	P. Saugi	6.83	20	18
3.	P. Laiyya	8.87	3	2
4.	P. Karanrang ^{1,2}	13.54	7	6
5.	P. Salemo	14.52	4	2
6.	P. Lamputang	17.64	4	2
7.	P. Palla	18.66	0	2
8.	P. Pangkaiya	18.85	6	2
9.	P. Podang-podang Caddi	19.40	5	5
10.	P. Samatellu Lompo	22.51	0	4
11.	P. Sanane ^{1,2}	22.88	6	5
12.	P. Bontosua ¹	23.39	12	4
13.	P. Sarappokeke ¹	26.66	14	6
14.	P. Sarappo ^{1,2}	26.81	28	32
15.	P. Reangreang ¹	27.27	9	8
16.	P. Badi ^{1,2}	29.00	8	6
17.	P. Lumulumu ^{1,2}	36.47	23	23
18.	Gs. Bonebatang ¹	39.37	11	5
19.	P. Kodingareng Keke ²	41.14	10	7
20.	P. Jangang jangangang ^{1,2}	41.84	19	24
21.	P. Suranti ^{1,2}	43.99	24	31
22.	P. Pamanggangang ^{1,2}	44.50	21	15
23.	P. Tambakulu ^{1,2}	49.29	26	15
24.	P. Gondongbali ^{1,2}	49.57	42	40

25.	P. Lanyukang ^{1,2}	50.33	28	31
26.	P. Langkai ^{1,2}	50.81	36	42
27.	P. Pandangan ^{1,2}	58.62	18	11
28.	P. Kapoposang ^{1,2}	61.22	45	57

¹ Blast fishing is fishing using bombs or explosives

² Cyanide fishing is fishing using cyanide or poisons

Table 2.8 The maximum TSM concentration estimated from the multi-temporal Landsat imagery data in dry (April-September) and rainy (October-March) seasons in the inner zone of the PANGKEP Regency, Spermonde Archipelago

Landsat imagery data	Maximum TSM concentration (mg/L)	
	Dry season	Rainy season
Landsat 5 TM, 1994	120	190
Landsat 7 ETM, 2002	186	221
Landsat 8 OLI, 2014	203	223

Table 2.9 Results of the classification of coral reefs and seabed habitats estimated by the multi-temporal Landsat imagery data in the PANGKEP Regency, Spermonde Archipelago, Indonesia

Class	Landsat 5 TM, 1994			Landsat 7 ETM, 2002			Landsat 8 OLI, 2014		
	Area (ha)	Amount of pixel	Ratio (%)	Area (ha)	Amount of pixel	Ratio (%)	Area (ha)	Amount of pixel	Ratio (%)
Live corals	7,715.67	85,729	71.7	6,885.14	76,501	64.0	4,236.31	47,071	39.4
Dead corals	1,128.17	12,535	10.5	2,210.04	24,556	20.5	4,316.30	47,958	40.1
Seagrasses	655.89	7,287	6.1	846.09	9,400	7.9	906.08	10,067	8.4
Sand	1,264.86	14,054	11.8	823.32	9,148	7.7	1,305.90	14,510	12.1
Total	10,764.59	119,605	100.0	10,764.59	119,605	100.0	10,764.59	119,605	100.0

Table 2.10 Confusion matrix value on the classification of four classes of the seabed habitats in the PANGKEP Regency, Spermonde Archipelago, Indonesia

Field data	Field data				Row total
	Live corals	Dead corals	Seagrasses	Sand	
Live corals	52	8	0	4	64
Dead corals	9	58	0	2	69
Seagrasses	2	0	40	8	50
Sand	3	0	9	48	60
Column total	66	66	49	62	243

Table 2.11 Ratio of producer's accuracy (PA) and the user's accuracy (UA). The calculation was conducted for four marine habitat classifications in the PANGKEP Regency, Spermonde Archipelago, Indonesia. Reference data mean the classes which are classified correctl

Classification	Reference data			Imagery data		
	The total number of correct pixels	The total number of pixels in the field data	Accuracy (%)	The total number of correct pixels	The total number of pixels in the image classification	Accuracy (%)
Live corals	52	66	79	52	64	81
Dead corals	58	66	88	58	69	84
Seagrasses	40	49	82	40	50	80
Sand	48	62	77	48	60	80

Table 2.12 Change in the area of coral reefs from 1994 to 2014 in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The change of area in each class was established based on the overlay of coral reef distribution and condition map derived from Landsat 5 TM (1994), Landsat 7 ETM (2002), and Landsat 8 OLI (2014) images

Classes	Change in the area (ha)	Ratio (%)
From 1994 to 2002:		
Live corals	-831	-10
Dead corals	882	79
Seagrasses	8	1
Sand	-59	-6
From 2002 to 2014:		
Live corals	-2,649	-39
Dead corals	2,306	115
Seagrasses	60	7
Sand	283	28

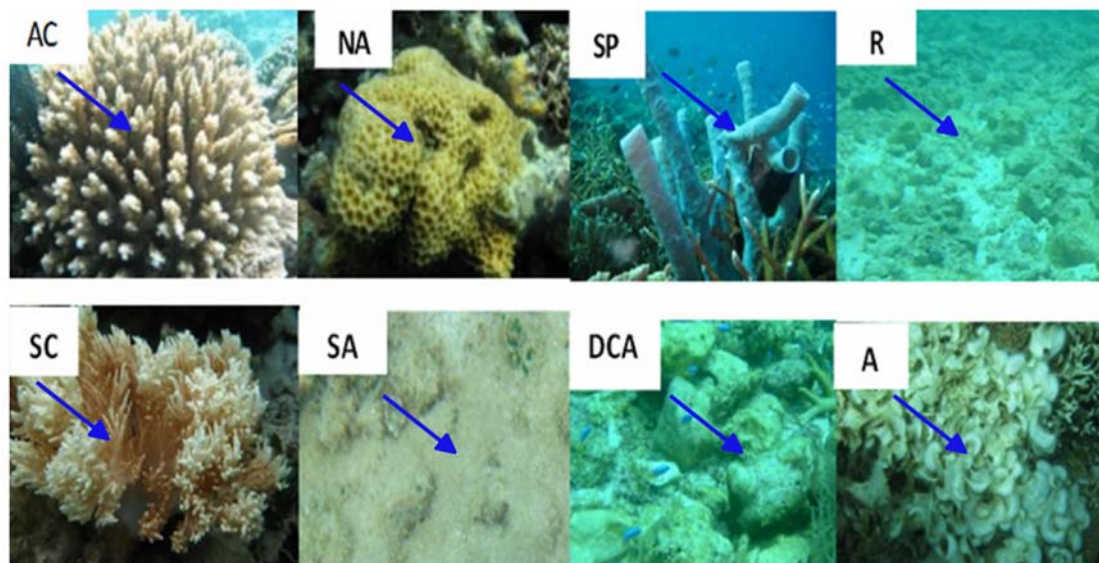


Figure 2.1 Categories used in PIT method. AC: Acropora; NA: Non-Acropora; SP: Sponge; R: Rubble; SC: Soft coral; SA: Sand; DCA: Dead coral algae; A: Abiotic. In this case, the rubble was classified as dead corals

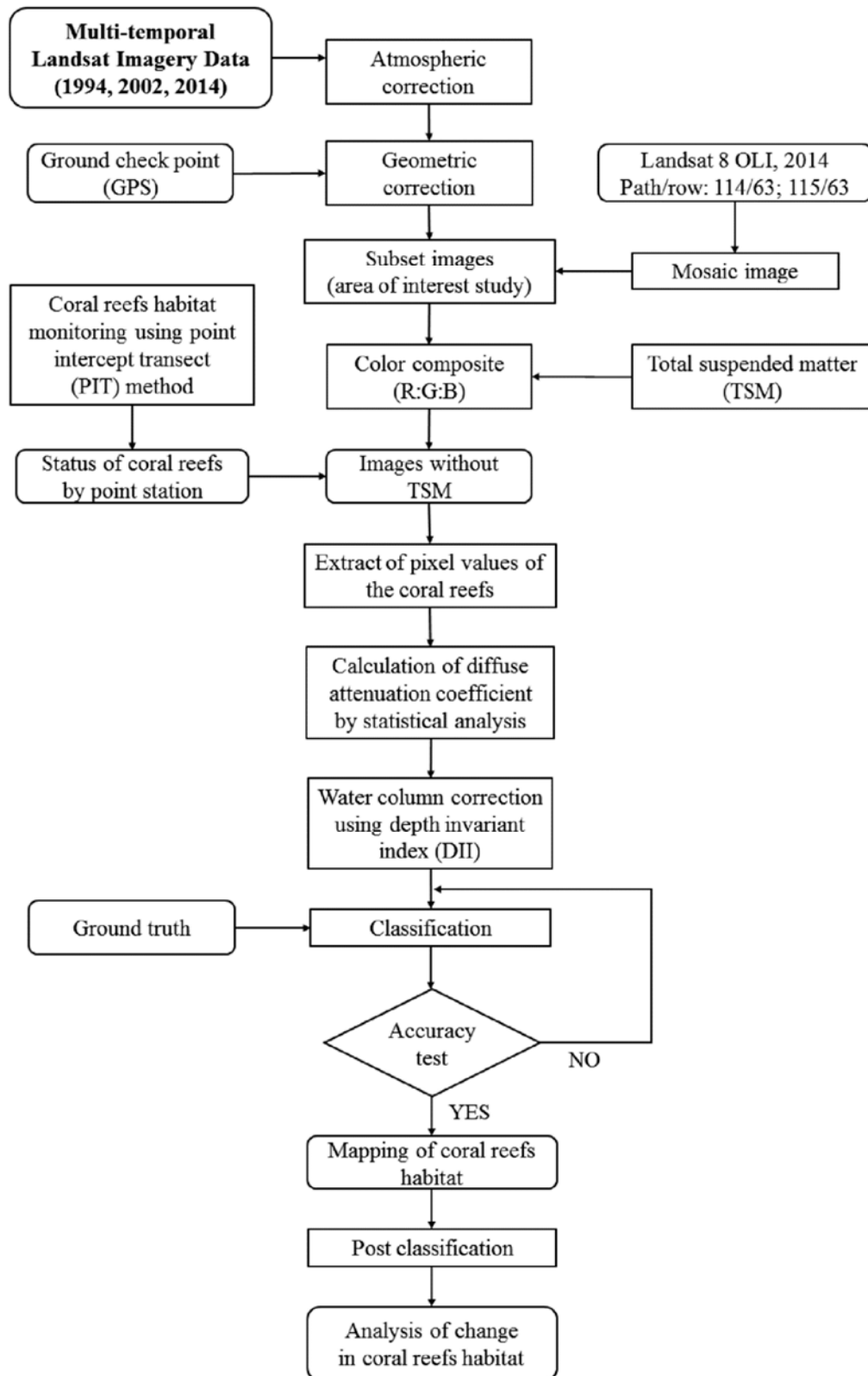


Figure 2.2 Flowchart research on mapping and analysis of changes in coral reefs

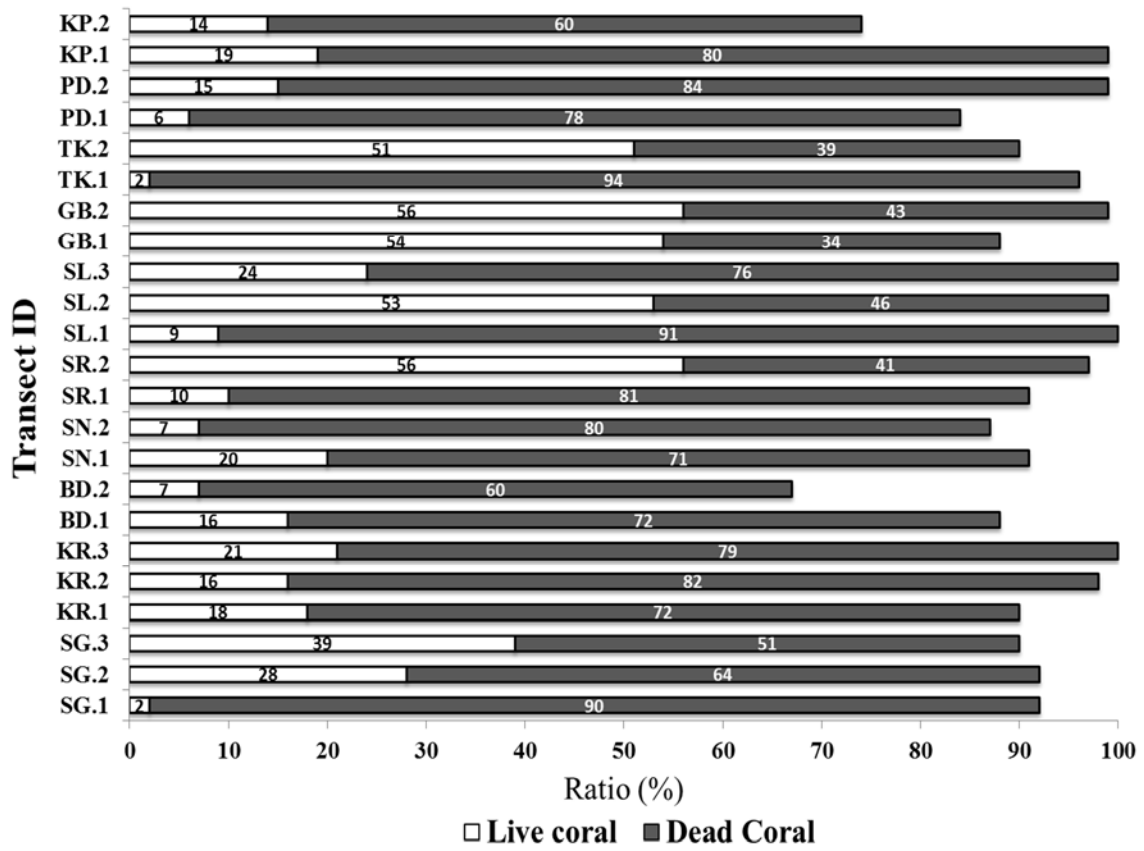


Figure 2.3 Ratio of live corals and dead corals at all sites in the PANGKEP Regency, Spermonde Archipelago, Indonesia. The graph summarizes the calculation for each category obtained by PIT method in each village (2-3 observation transects per village)

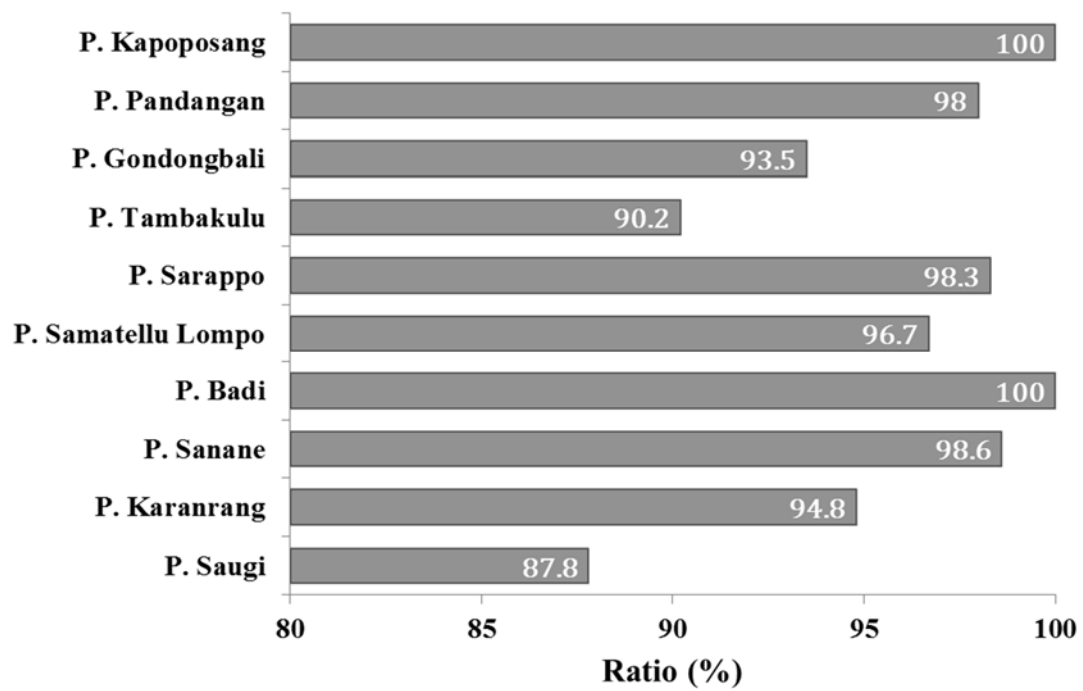


Figure 2.4 Averaged ratio of coral rubbles to total dead corals in the villages in the PANGKEP Regency, Spermonde Archipelago, Indonesia

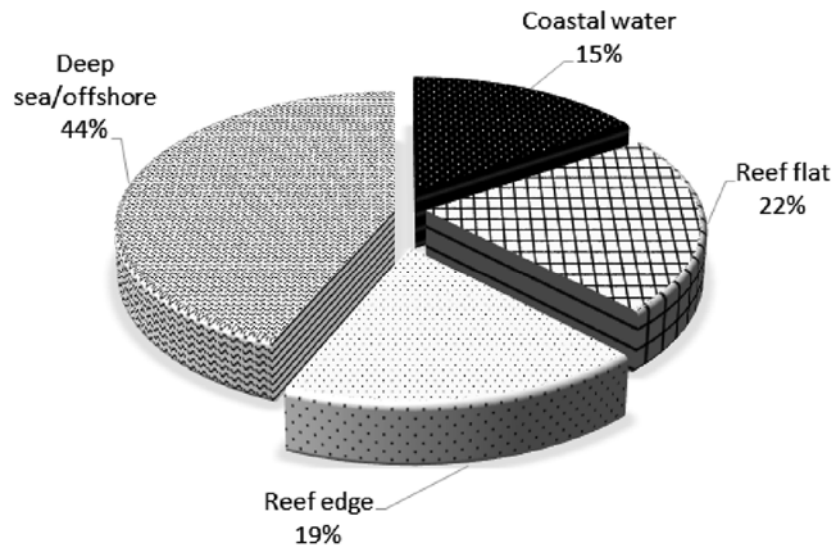


Figure 2.5 Ratio of preferred destructive fishing areas (%) obtained by analyzing the results of questionnaires distributed to 296 respondents, which were strongly linked to the fishing gears used and target fish species frequently caught

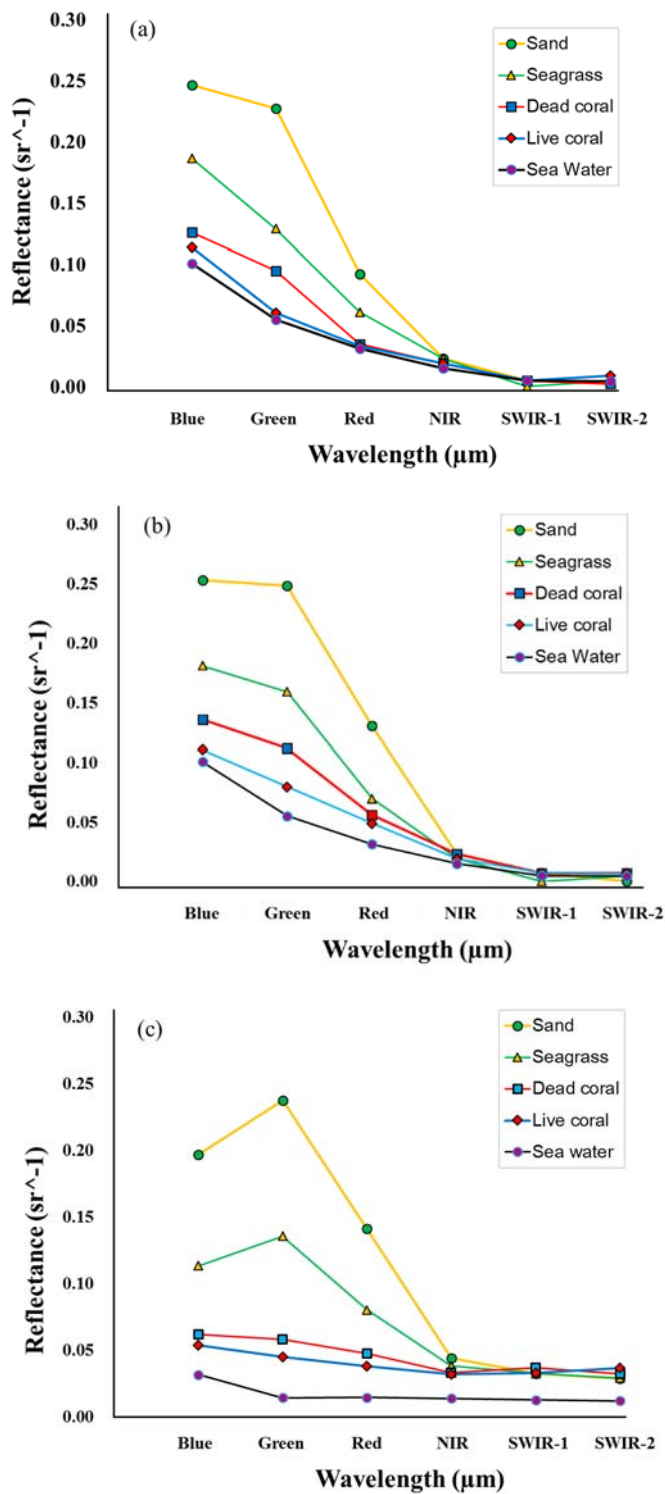


Figure 2.6 Spectral profile of object classes (sand, seagrasses, dead corals, live corals and sea water) on three series Landsat Imagery data: (a) Landsat TM 1994, (b) Landsat 7 ETM 2002, and (c) Landsat 8 OLI 2014

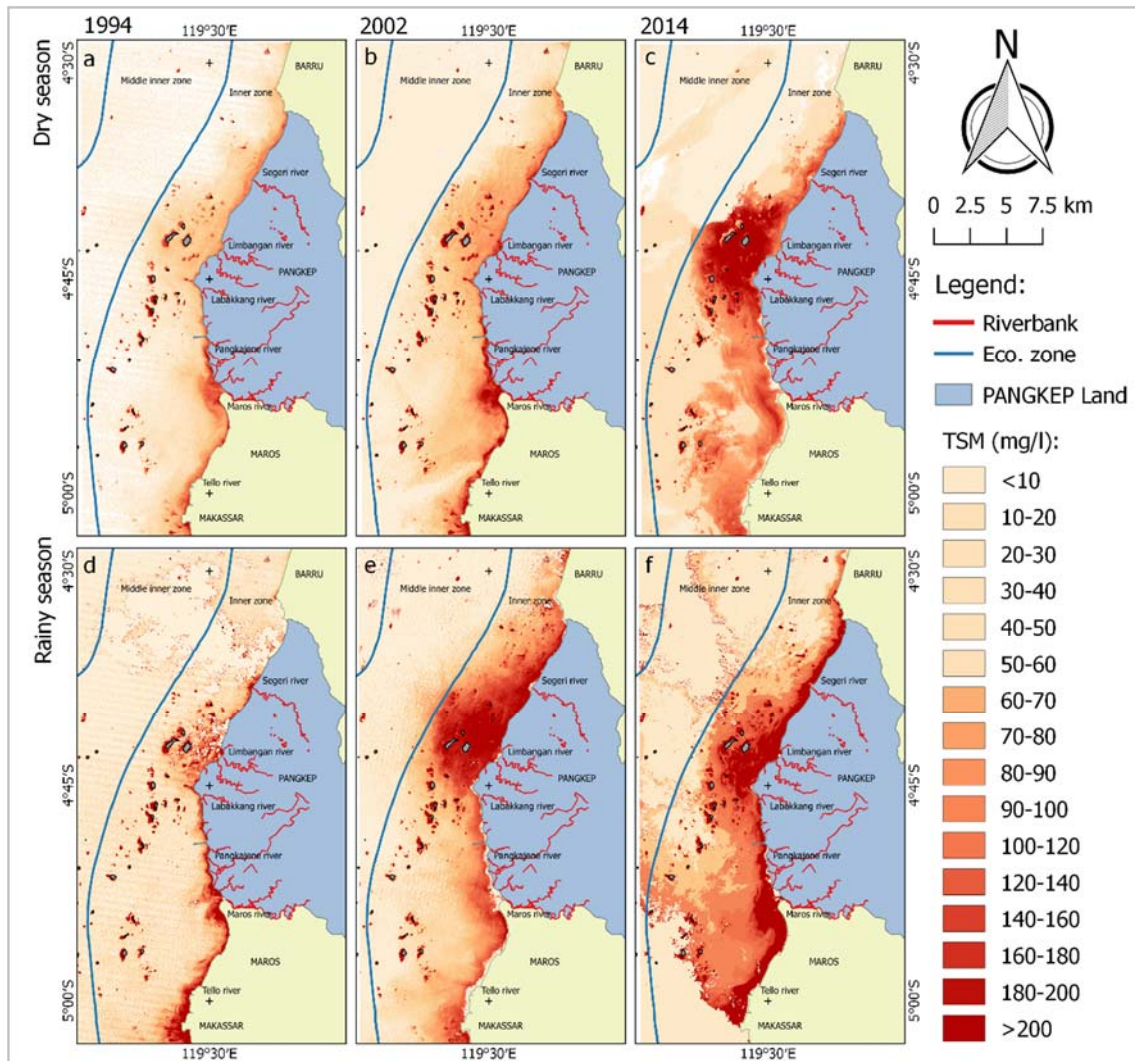


Figure 2.7 Distribution and concentration of total suspended matter (TSM) in dry and rainy seasons in the inner zone: a) dry season in the Landsat 5 TM (in 1994); b) dry season in the Landsat 7 ETM (in 2002); c) dry season in the Landsat 8 OLI (in 2014); d) rainy season in the Landsat 5 TM (in 1994); e) rainy season in the Landsat 7 ETM (in 2002); f) rainy season in the Landsat 8 OLI (in 2014)

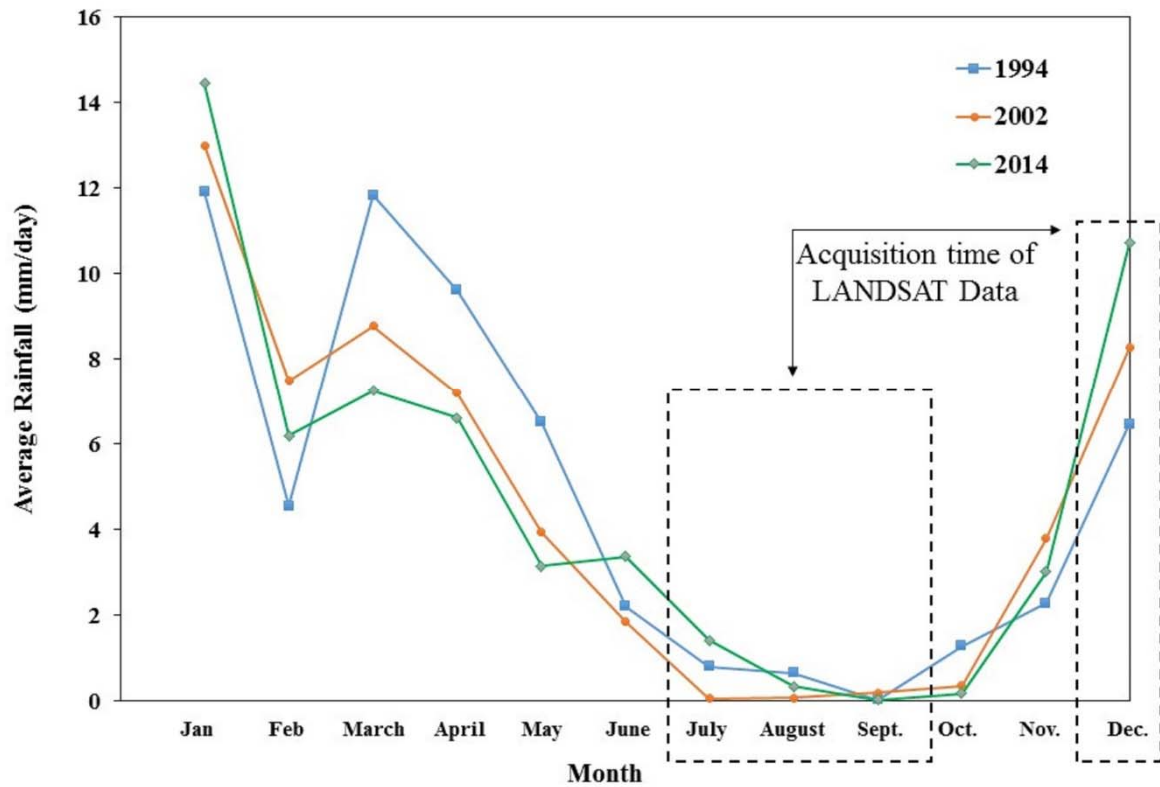


Figure 2.8 Averaged monthly rainfall in 1994, 2002 and 2014 in the study area estimated from the satellite (the Modern-Era Retrospective analysis for Research and Applications, Version 2; MERRA-2) (<https://cds-cv.nccs.nasa.gov/CREATE-V/>).

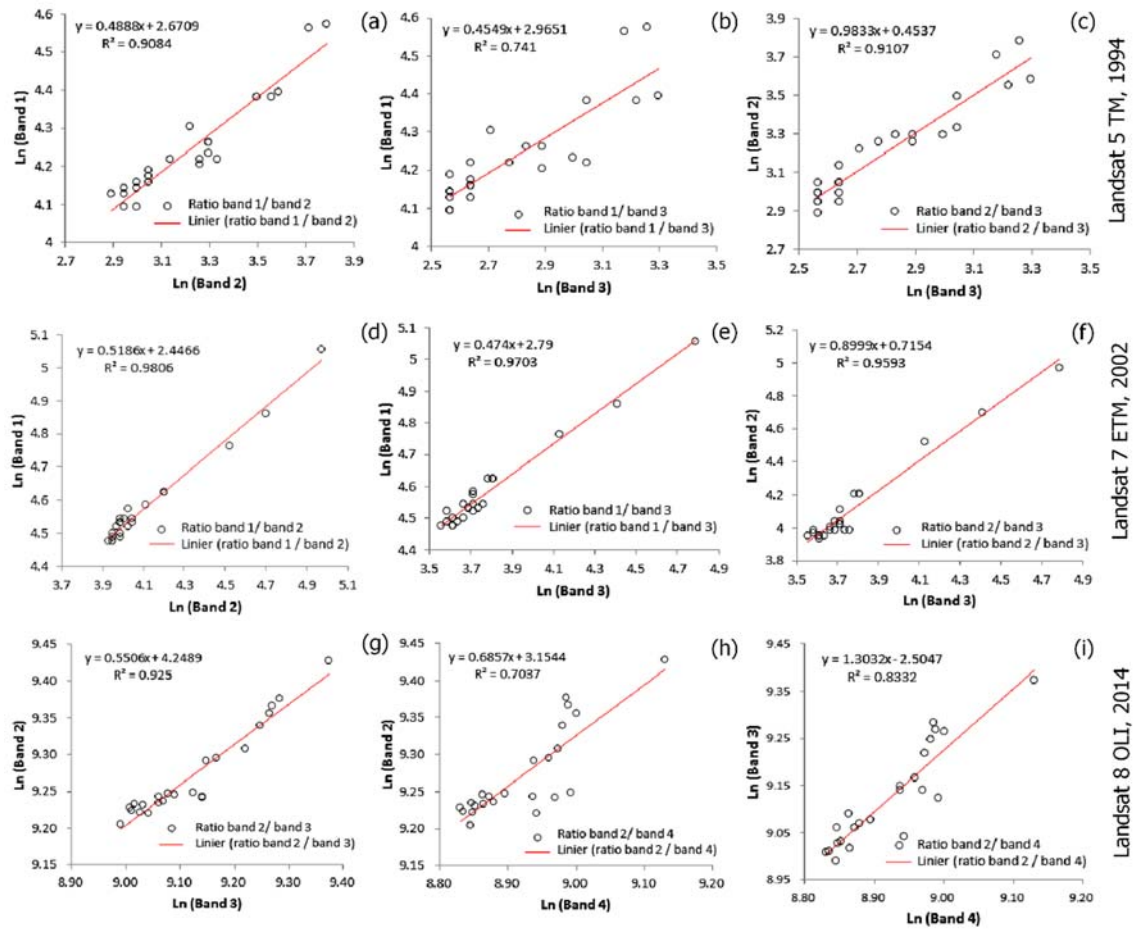


Figure 2.9 Plots of spectral values of the coral reef status obtained by three series of multi-temporal Landsat imagery ((a)-(c) for Landsat 5 TM, 1994; (d)-(f) for Landsat 7 ETM, 2002; (g)-(i) for Landsat 8 OLI, 2014) in the PANGKEP Regency, Spermonde Archipelago, Indonesia. (a) and (d): Band 2 vs. Band 3; (b) and (e): Band 1 vs. Band 3, (c), (f) and (g): Band 2 vs. Band 3; (h): Band 2 vs. Band 4; (i) Band 3 vs. Band 4

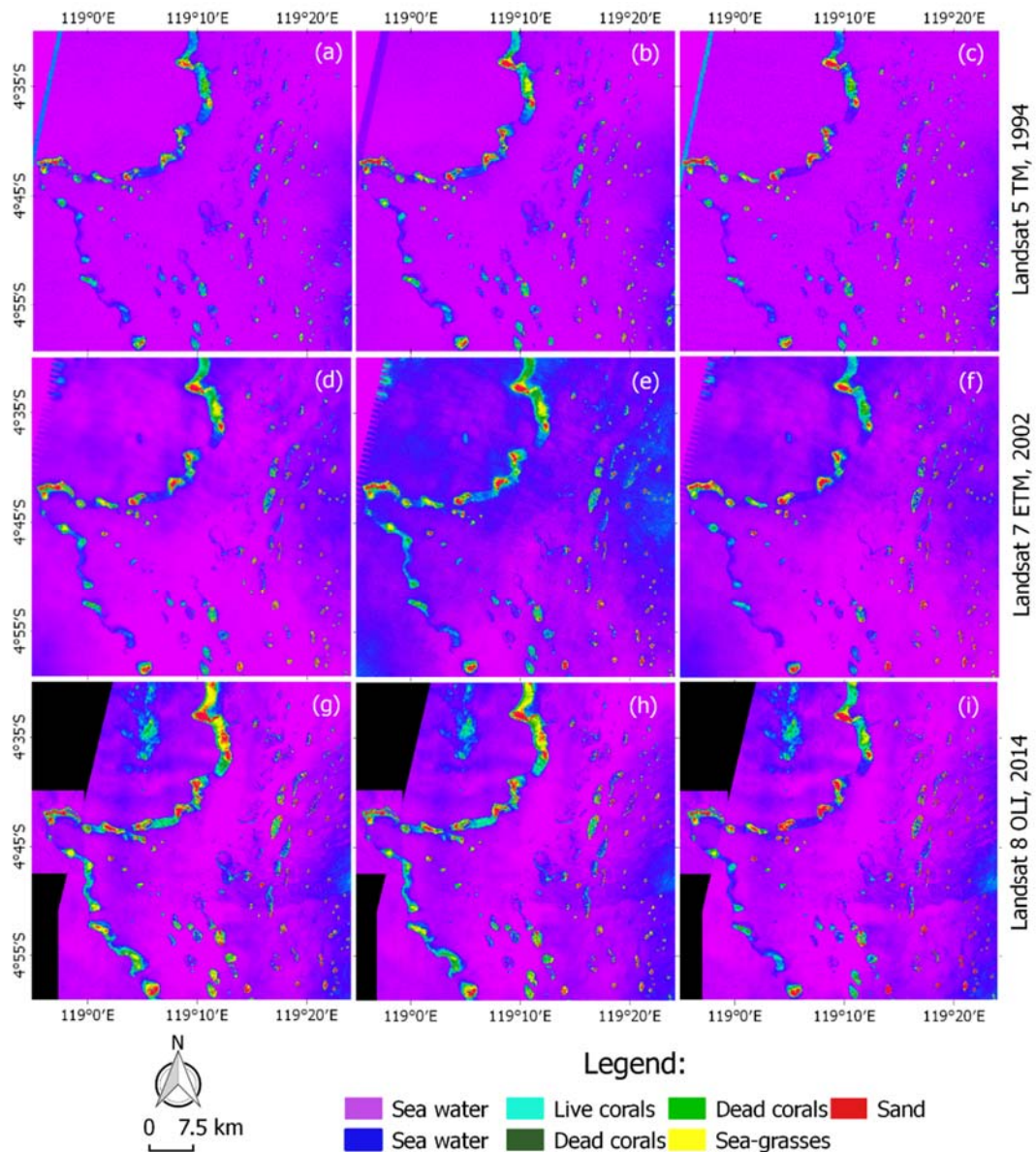


Figure 2.10 Depth invariant index derived from three series of multi-temporal Landsat imagery data ((a)-(c) for Landsat 5 TM, 1994; (d)-(f) for Landsat 7 ETM, 2002; (g)-(i) for Landsat 8 OLI, 2014) in the PANGKEP Regency, Spermonde Archipelago, Indonesia, using gradient of the linier line. (a) and (d): Band 2 vs. Band 3; (b) and (e): Band 1 vs. Band 3, (c), (f) and (g): Band 2 vs. Band 3; (h): Band 2 vs. Band 4; (i) Band 3 vs. Band 4

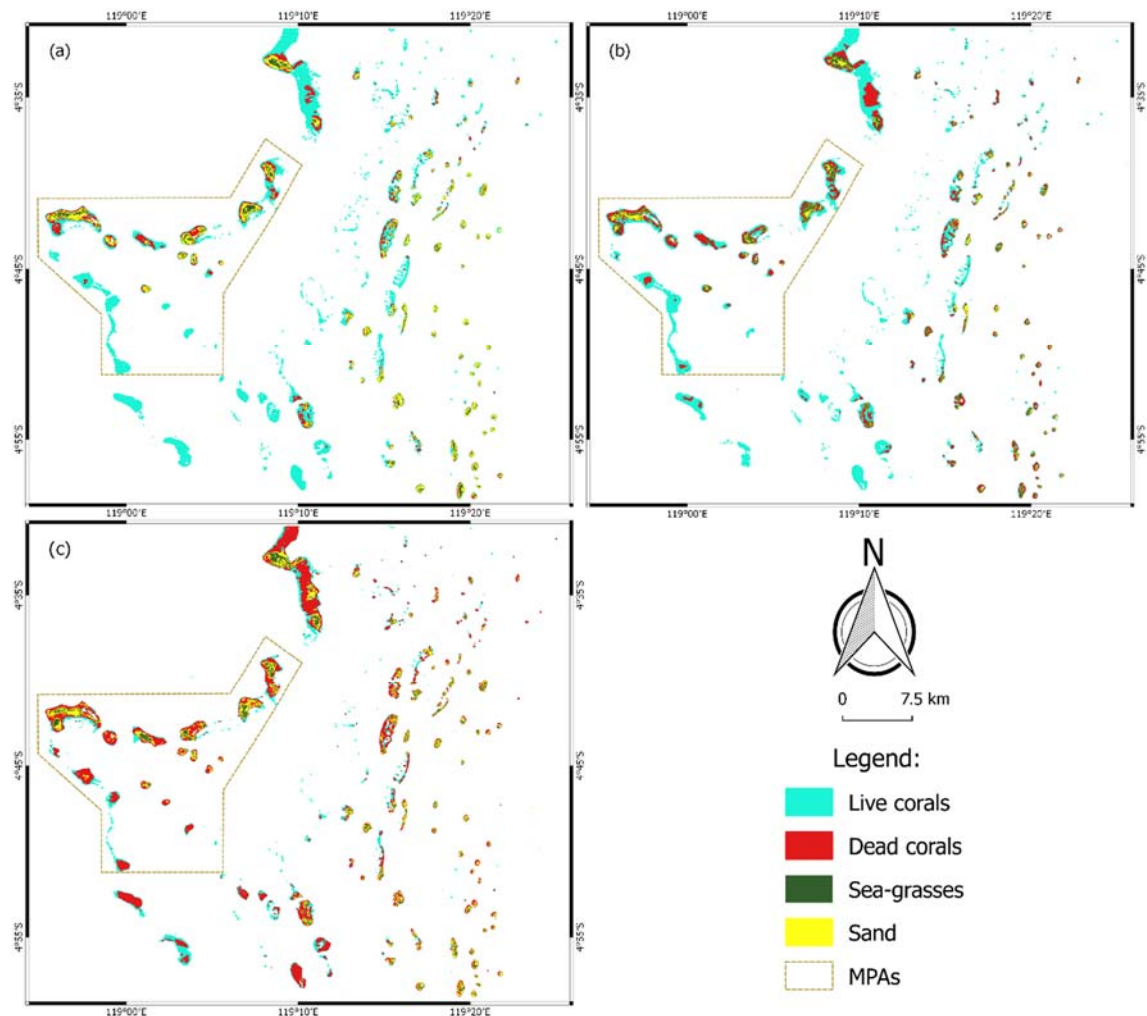


Figure 2.11 Distribution and condition of coral reefs in the PANGKEP, Spermonde Archipelago, Indonesia, obtained from three series multi-temporal Landsat imagery data. (a) Landsat 5 TM, 1994; (b) Landsat 7 ETM, 2002; (c) Landsat 8 OLI, 2014

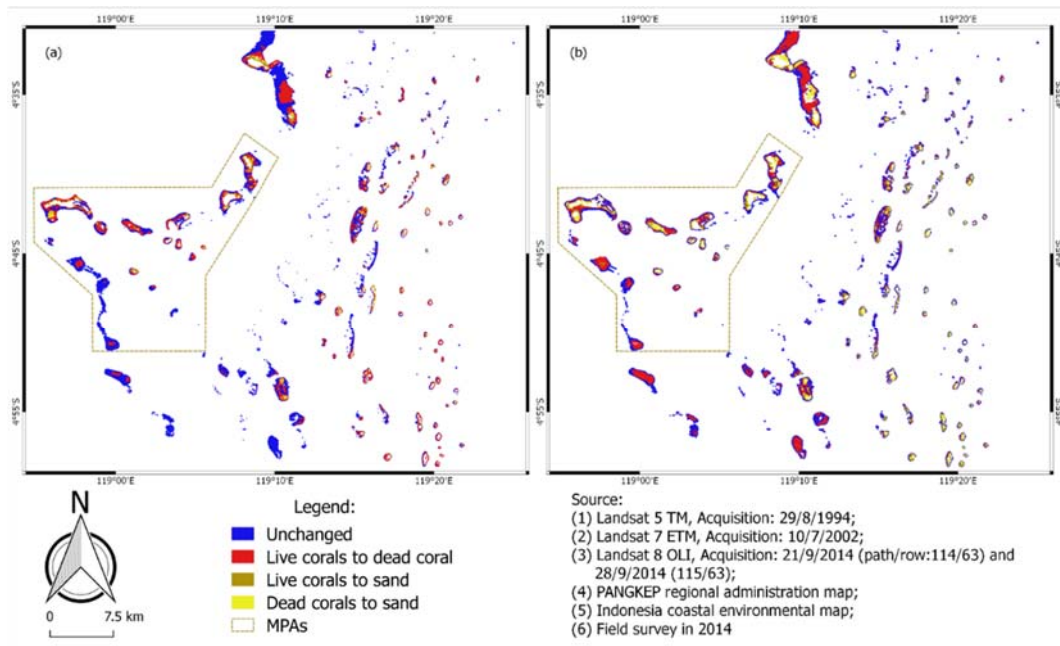


Figure 2.12 Map of change in bottom substrate in the PANGKEP Regency, Spermonde Archipelago, Indonesia: (a) from 1994 to 2002 and (b) from 2002 to 2014. The Kapoposang MPAs is located in the outer zone of the PANGKEP islands which also experienced a drastic decline in coral reef habitats in this period

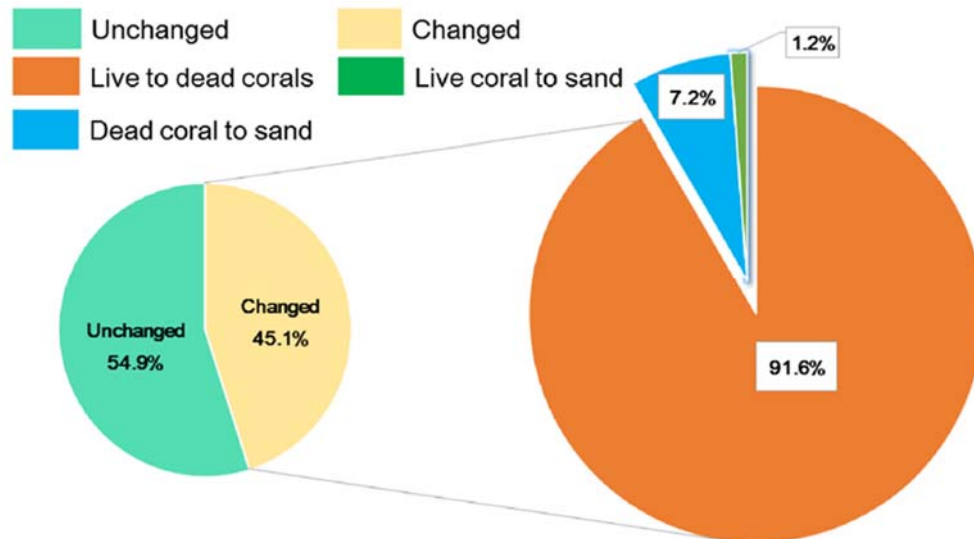


Figure 2.13 Change in composition of coral reefs from 1994 to 2014. During the period, 45.1% of the coral reef area has been transformed (left pie chart): 91.6% from live to dead corals, 7.2% from live corals to sand, and 1.2% from dead corals to sand (right pie chart)

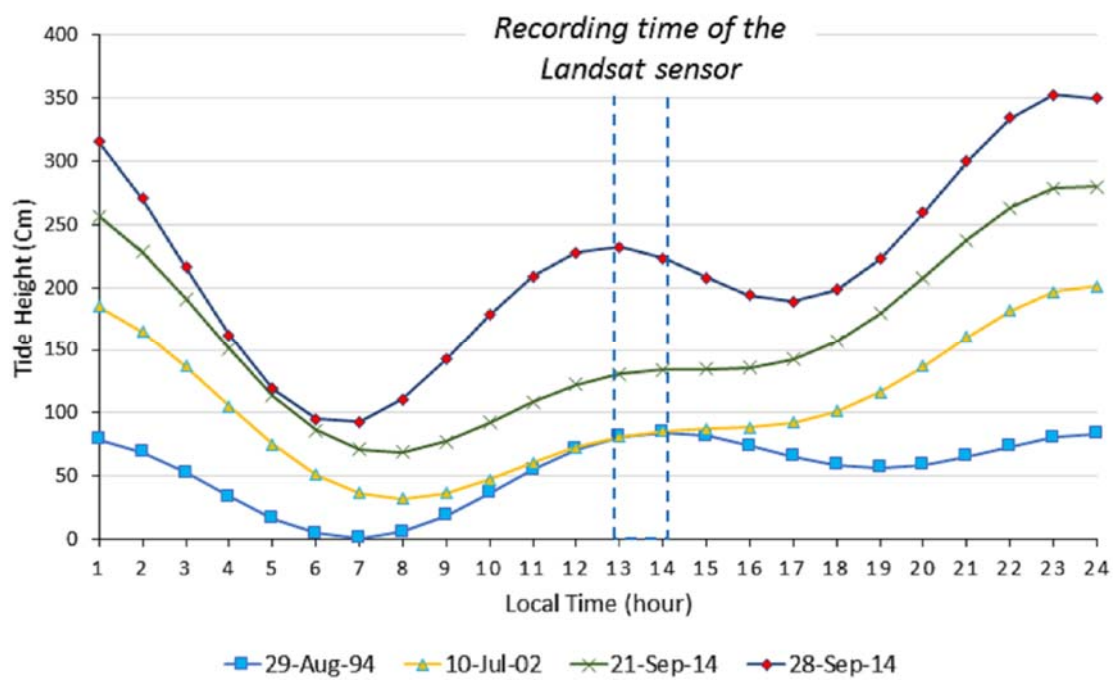


Figure 2.14 Tidal prediction in the PANGKEP Regency, Spermonde Archipelago, Indonesia with a coordinate point of observation: 1190 15'36" S and 40 48'36" E. The data is processed by using the prediction model from http://www.miz.nao.ac.jp/staffs/nao99/index_En.html. Accessed 10 October 2016

Chapter III

Economic assessment of the benefits and losses of goods and services derived from coral reefs: a case study in the Pangkajene and Kepulauan Regency, Spermonde Archipelago, Indonesia

3.1 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 et al. 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 1.1). 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/km²/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/km²/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/km² (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/km²/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).

3.2 Materials and Methods

3.2.1 Data source and materials

3.1.1.1 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.

3.1.1.2 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

(Appendix A1). 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.

3.2.2 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):

$$TEV = UV + NUV = (DUV + NUV) + (BV + EV), \quad (3.1)$$

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.

3.2.2.1 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):

$$DUV = \sum_{i=1}^N Q_i, \quad (3.2)$$

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), Q_2 is the DUV of reef-related tourism (USD/yr), and Q_3 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 (3.3) (Appendix A2):

$$Q = \beta V_1^a V_2^b V_3^c V_4^d, \quad (3.3)$$

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 A2.
- 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 A2.

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.

3.2.2.2 *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:

$$V = L_S \times W_B \times H_B, \quad (3.4)$$

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:

$$SPV = V \times C, \quad (3.5)$$

3.2.2.3 *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):

$$BV(Y_i) = \sum_{Y_i=2005}^{2014} BV_{HA} \times \frac{GDP(Y_i)}{GDP(Y_{i-1})}, \quad (3.6)$$

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 consumers'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:

$$WTP = \beta_0 X_1^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} \dots X_n^{\beta_n}, \quad (3.7)$$

where $X_1, X_2, X_3 \dots X_n$ are the variables of economic and social status among individuals or users of reef-related resources. β_0 is the intercept, whereas $\beta_1, \beta_2, \beta_3 \dots \beta_n$ 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 (3.7) is then transformed into the following equation:

$$\begin{aligned} \ln WTP &= \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \dots \beta_n \ln X_n, \\ &= \{\beta_0 + \beta_1 \ln \bar{X}_1 + \beta_2 \ln \bar{X}_2 + \beta_3 \ln \bar{X}_3 + \dots \beta_n \ln \bar{X}_n\}, \\ &= \beta', \end{aligned} \quad (3.8)$$

where $\bar{X}_1, \bar{X}_2, \bar{X}_3 \dots \bar{X}_n$ 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 (3.8) was then back transformed to its original function to calculate the value of the WTP per capita, using the following equation:

$$WTP = \exp(\beta'), \quad (3.9)$$

- 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:

$$EV = WTP \times N, \quad (3.10)$$

- 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:

$$EVHA = \frac{EV}{L}. \quad (3.11)$$

3.2.3 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):

$$PVEL(Y_i) = \sum_{Y_i=1994}^{2014} EL(Y_i) \times \left(\frac{GDP_{2014}}{GDP(Y_i)} \right), \quad (3.12)$$

where $PVEL(Y_i)$ 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:

$$TEL_{1994-2014} = \sum_{Y_i=1994}^{2014} PVEL(Y_i) \times (1 + r)^{(2014-Y_i)}. \quad (3.13)$$

where $TEL_{1994-2014}$ 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 2002) to obtain the current value of coral reef damage or economic loss.

3.3 Results and Discussion

3.3.1 Use values (UVs) of coral reefs

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

3.3.1.1 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 3.2), the values of the WTP, and consumer surplus (Appendix A3).

Based on the calculation, the total DUV of coral reef-related fisheries was 2.9 million USD/yr (Table 3.1). 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 3.1). 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 total UV of coral reefs 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 3.1). 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). The BV of reef fisheries (675 USD/ha) in the study area was also high compared to the BV of reef fisheries in the Great Barrier Reef MPA (4.2 USD/ha; Driml 1999) and in the Taka Bonerate MPAs (7.8 USD/ha; Sawyer 1992). 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 BV 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. 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.

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 3.2). 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 3.3).

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 3.3). 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).

Based on the responses of the interviewees, there were several factors responsible for the small number of tourists who visited the Kapoposang Marine Park. (1) Kapoposang Island 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.

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.

3.3.1.2 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 m³ was obtained. If the construction cost of the barrier was assumed to be 297 USD/m³, 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.

3.3.2 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.

3.3.2.1 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 3.3). 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.

3.3.2.2 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 A4). 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.

3.3.3 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 high BV indicates that coral reefs can be passed on to future generations as sources of goods and services. However, the threat of coral reef degradation is very high, indicating a significant loss of economic value, which was apparent in the questionnaire respondents' attitudes toward the EV of coral reefs.

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).

3.3.4 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 3.4).

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.

3.4 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, and 5) strict law enforcement and severe penalties to prevent destructive fishing practices.

Table 3.1 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 3.2 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 3.3 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	251,166	59.29	
	– Seaweeds	1,319,939	312.00	
	<i>Subtotal:</i>	2,886,860	675	
	– 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	
Non-Use Value (NUV)	Indirect use values:	16,931,157	3,996.96	
	– Coastal protection			
	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 3.4 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

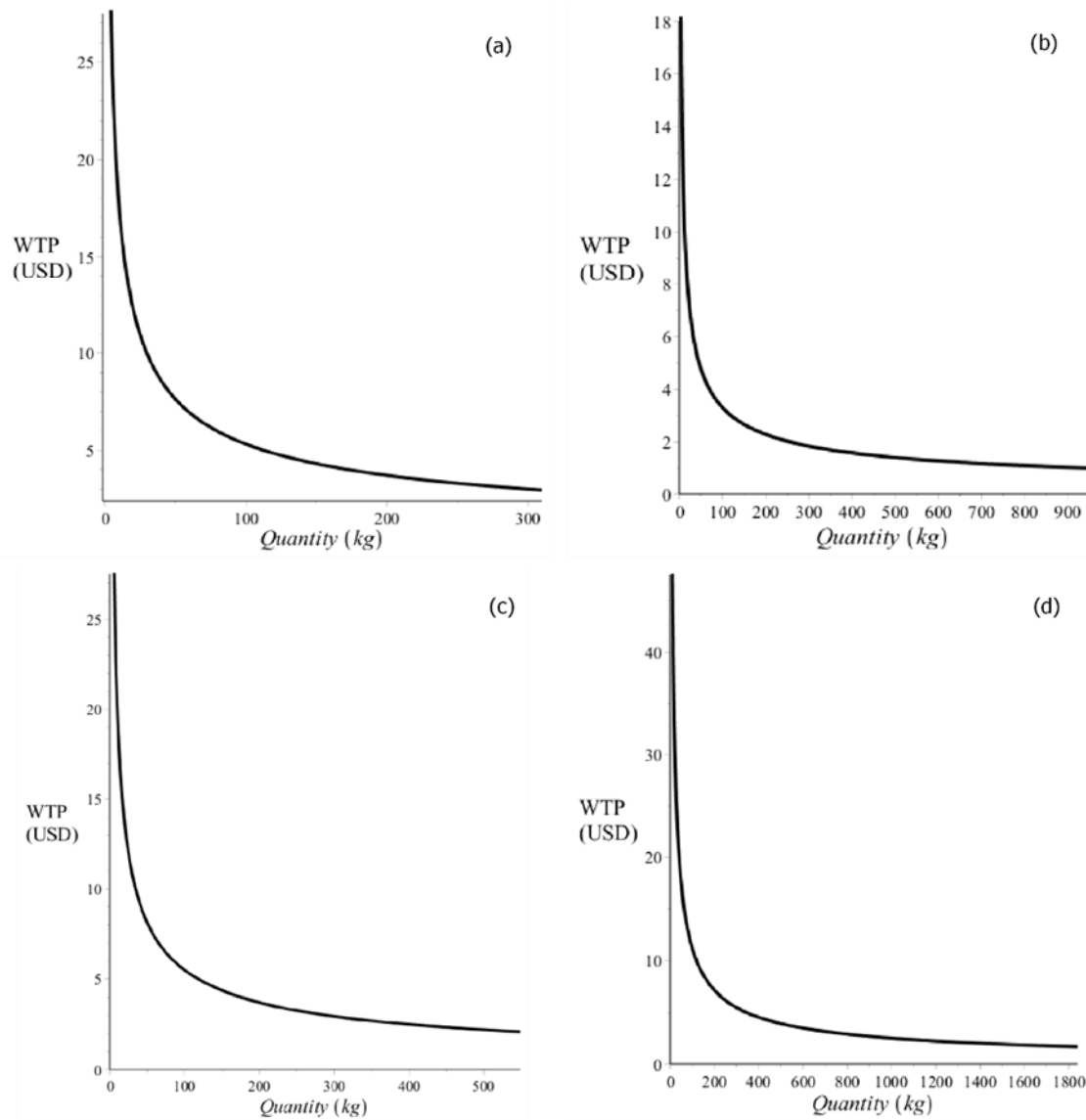


Figure 3.1 Demand function of the coral reef benefits related to the fisheries using the effect on production (EOP) method for: (a) the coral reef fish catch, (b) the crab catch, (c) the squids and octopuses catch and (d) seaweed farming

Chapter IV

General Discussion

4.1 Threats on coral reefs in the PANGKEP Regency

Coral reefs in the Pangkajene and Kepulauan (PANGKEP) Regency are one of the most important ecosystems in the area, as habitats for commercial fish species, tourists' destination, research targets and coastal barriers and so on. Recently these reefs have been under pressure of degradation due to human activities, including destructive fishing practices (DFP), inflow of terrestrial total suspended matter (TSM), ineffective law enforcement, no alternative income and lack of awareness of the fishermen, and rising sea surface temperature (SST).

4.1.1 Destructive fishing issues

Damage of coral reef ecosystems damage due to DFP, was generally prominent within the area far from mainland Sulawesi, from middle inner zone to outer zone. Incidentally, coral reefs in these areas were commonly far from coastal lines, which is difficult to monitor from the land. In contrast, damage of coral reefs close to the mainland Sulawesi (inner zone) was considered to be normally caused by inflow of terrestrial TSM, discharged from 6 estuaries along the coast of mainland Sulawesi between Makassar City and the PANGKEP Regency.

Brant (1984) has classified all the world's fishing methods into 16 major groups, which includes destructive fishing methods. In the Southeast Asia, devices used for destructive fishing activities are generally chemicals (for cyanide fishing) and explosives such as dynamites (for blast fishing). Technically, the cyanide fishing is to paralyze fish through spraying cyanide into coral caves, while the blast fishing is to paralyze fish mechanically by blasting, especially in coral reefs (Brant 1984).

The DFP, historically started in 1945's, the first generation of DFP practitioners were trained by Japanese Army during the World War II and were impressed by the relatively easy operation and low costs to catch a large amount of fish by using dynamite to blast the coral reefs. The type of explosive used has been evolved from dynamite to homemade fertilizer-kerosene bombs. The blasting technique remains one of the main options practiced by many fishermen in Indonesia, notably in the South Sulawesi (Pet-Soede and Erdmann 1998), and these blasting activities were still found despite the status of the area as a part of Coral reef rehabilitation and management program (COREMAP). The existence of marine conservation area in the west part of the South Sulawesi Province i.e. the Kapoposang Marine Protected Areas (MPAs), has yet to be effectively set as a

model of sustainable use of coral reefs, owing to low performance of management in the MPA. The low performance, in turn, was caused by limited facility and lack of human resource.

4.1.2 Law enforcement issues

Other factors including the lack of law enforcement need new resolution especially enforcement related to the Police Institution of the PANGKEP Regency. Based on observation and interview with key stakeholders in the research area, it was found that several police officers were involved indirectly in the DFP as backup or by receiving fisheries products or money as bribes. The corrupted law enforcement system in this area encourages illegal activities. Therefore, leadership to improve the environmental issues in the PANGKEP Police Institution is considered as a key factor for the success of marine law enforcement.

Based on the results above, the following are suggested as possible options to solve the law enforcement institution issues: 1) Improving the guidance of integrity, ability, order and legal awareness to the law officers regarding their duties and responsibilities; 2) Providing legal education, both formal and informal, to the public about the importance of law enforcement in the sea so that people are aware of and follow the prevailing regulations; 3) Improving the welfare of law officers to minimize law enforcers' involvement in corruption cases; and 4) Providing strict sanctions to the law officers who do not perform their duties properly.

4.1.3 Land-based pollution issues

Pollution of the sea by land-based materials including total suspended matter (TSM) has threatened the coral reef ecosystems, especially in the inner zone. Higher TSM concentration than the permissible value (10 mg/L) is considered to disturb coral growth in the 20 years from 1994 to 2014. It was concluded that the highest concentration of TSM in the inner zone had seasonality and was obviously higher around 190-223 mg/L in the rainy season than in the dry season of 120-203 mg/L.

Several activities in the upland such as cement industry by limited liability companies (LLC) (i.e. Semen Tonasa and Semen Bosowa), building residential complexes, rice cropping and aquaculture in coastal areas, are all suspected as sources of sediment materials discharged to the coastal waters. The sediment materials are transported to the sea through river mouths and canals along the coast from Makassar City to the PANGKEP Regency. In this case, rainfall plays an important role in

transporting sediments to the coastal region and subsequently affecting marine ecosystems.

In order to solve the problem regarding to the environmental damage and protection, the Indonesian Government issued several regulations including Environmental Protection and Management Act No. 32 in 2009 and Coastal and Small Island Management Act No. 1 in 2014. These regulations explicitly oblige the corporations or individuals to preserve the environment and to avoid any damages/pollutions, which might occur in all the phases of their business activities, i.e. planning, production and post-production. However, the lack of awareness of corporations or individuals regarding these regulations makes the environmental damages and pollutions still prevalent. Besides, the lack of law enforcement by government bodies also makes the regulations ineffective to prevent the environmental problems.

4.1.4 Socio-economic issues

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. 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.

4.2 Value of coral reefs in the PANGKEP Regency

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 "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.

4.3 Designing effective marine protected areas (MPAs)

To anticipate the progressing coral cover degeneration 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 (Figure 4.1). Even though the expectation had been review in several references (Lauenroth and Burke 2008; Carpenter and Springer 2005; Roberts et al. 2002; Spalding and Green 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.

4.4 Future perspective of the study

Referring to the results and the limitations of this study, several important issues related to stressors for the coral reef ecosystems are found to be solved. Sources of stressors for coral reefs can be divided into two categories, namely natural and anthropogenic factors. Natural factors include high sea surface temperature (SST), rainfall, predators such as the crown-of-thorns starfish (COTs) and so on. Anthropogenic factors include terrestrial industries that change the land-use pattern and causes excessive discharge of the TSM into the sea and destructive fishing as elucidated in this study.

This study found that the dynamics of the TSM in coastal waters were strongly related to land-use patterns and variability of the rainfall in the study sites. However, further studies are necessary to elucidate the detailed changes in the land-use patterns and the relationship with the seasonal change of the TSM concentration in the coastal waters. The presence of the TSM in the coastal waters disrupts coral's growth because the TSM covers coral polyps and inhibit the photosynthesis by the symbiosis which is needed for corals.

High SST is one of the threats that causes coral bleaching and potentially damages the coral reefs in this area. Coral bleaching phenomena were found in the study area from the end of 2009 to mid-2010 (Yusuf and Jompa 2012) and from mid-February to March 2016 (Syafyuddin Yusuf of Hasanuddin University, per. com.). So far, however, the total area of coral bleaching cannot be evaluated in detail in the study site. Therefore, further studies are necessary to clarify the distribution of SST and the relationship with coral reef ecosystems in the study site.

Combination of both natural and anthropogenic stressors on coral reefs has given a massive pressure which ultimately leads to increase in dead corals. Therefore, in the future, combined threats to coral reefs are needed to be studied to develop more comprehensive strategies to balance between saving coral reefs and enhancing local economic growth in the study site.

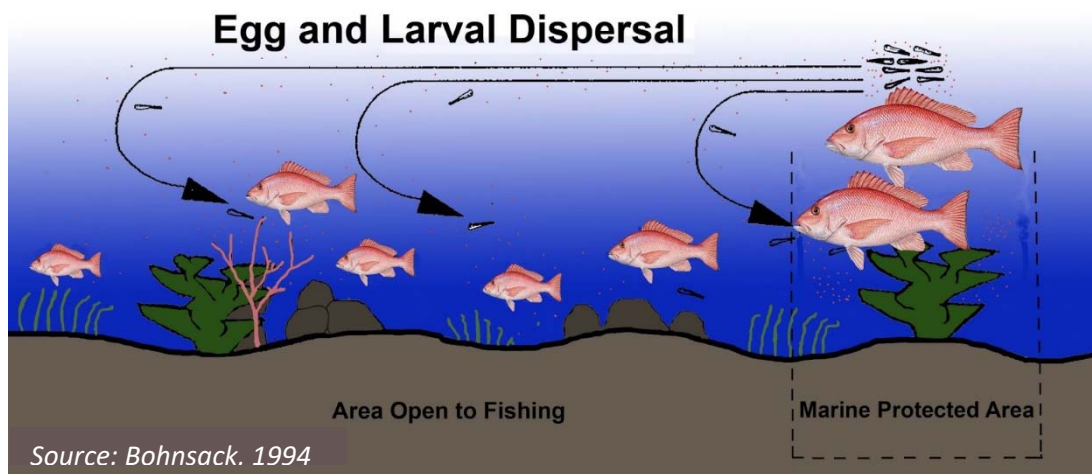


Figure 4.1 Spillover effect in marine protected areas (MPAs) (source: Bohnsack 1994)

Chapter V

Conclusion

This study highlights a comprehensive analysis of the changes of coral reefs in the last 20 years from 1994 to 2014 in the Pangkajene and Kepulauan (PANGKEP) Regency, Spermonde Archipelago in Indonesia. That discusses the changes of coral reef habitats and the causal factors of their changes, total economic benefit values and losses of total direct economic benefit values. The first phase of the analysis conducted in this study was calculation of the area of habitat of coral reefs and their physical changes in the last 20 years using remote sensing technology.

The results of analysis using multi-temporal land satellite (LANDSAT) imagery data that include data derived from LANDSAT 5 thematic mapper (TM 1994), LANDSAT 7 enhanced thematic mapper (ETM 2002) and Landsat 8 operational land imager (OLI 2014) and in-situ measurement data indicate that the inter-annual change of coral cover was substantial. The habitats of coral reefs experienced severer physical damage from 2002-2014 than from 1994 to 2002, suggesting that coral degradation has been accelerated recently. The decrease in coral reef habitats in the PANGKEP Regency, Spermonde Archipelago is considered to be caused by two factors that include over-sedimentation of harmful particles and destructive fishing practices. Spatially, destruction of coral reefs at shoreline areas (inner zone) nearby the Sulawesi Island's mainland was dominated by sedimentation of harmful particles than destructive fishing activities. By contrast, coral reef areas that were quite far away from the Sulawesi's mainland (middle inner zone, middle outer zone and outer zone) were dominated by destructive fishing activities.

Referring to economic dimension, destruction of coral reefs in this area led to significant loss of coral reef benefit value as a source for supplying goods and services. It was estimated that the total economic loss due to coral reef destruction from 1994 to 2014 was USD 1 billion or 50.18 million USD/year. The loss of economic benefit value designated as the total direct benefit value of coral reefs consisted of coral fish catch, crabs catch, squid and octopuses catch, seaweed farming, tourism, scientific research and shoreline protection. Nevertheless, the total economic value of coral reefs (use value and non-use value) was approximately estimated to be USD 12.0 billion or 2.8 million USD/ha. For example, most (99.8%) of the economic value was derived from non-use value. The rest of the economic value was by coastal protection (USD 17 million) followed by coral reef-related fisheries (USD 3 million), tourism and recreation (USD 116 thousand) and researches (USD 16 thousand). It was estimated that the economic

benefit values of coral reefs were declined along with the increase of adverse changes in coral cover in the study area. In fact, it is important to consider particularly the threats to the coral reefs. In order to reduce the threat on coral reefs, several potential practices could be adopted: 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, and 5) strict law enforcement and severe penalties to prevent destructive fishing practices.

Nowadays, many studies including this study give attention to the crises that occurred in coral reef ecosystems. Regarding the research contribution, there were many benefits than can be obtained from this dissertation not only for academic purposes but the practical planning in response to the changing ecosystems of coral reefs and its socio-economic values. Firstly, from the academic perspective, the method used in this dissertation presented a viable framework for analyzing the changes on coral reefs in the wide area with remote sensing approach and economic valuation approach. Secondly, the results of this study can be used as a scientific basis for formulating policy strategies on coral reef ecosystem management. From this perspective, local governments are recommended to build new marine protected areas (MPAs) as one of the coral reef governance strategies, so that coral reefs within MPAs could be managed effectively by using zonation system (i.e., core zones, buffer zones and utilization zones).

Acknowledgments

The author would like to express his gratitude to:

1. Indonesia Endowment Fund for Education Scholarship (LPDP), Ministry of Finance, Republic of Indonesia for immense support during the doctoral course.
2. Ministry of Research, Technology and Higher Education of Republic of Indonesia for their support during the doctoral course.
3. Assoc. Prof. Masahiko Fujii for his guidance and patience as supervisor, and facilitating books and travels needed for research activities.
4. Professors Masahiro Nakaoka, Shunitz Tanaka, Teiji Watanabe, and Masaaki Kurasaki of Graduate School of Environmental Science, Hokkaido University and Associate Prof. Junichi Kurihara of Graduate School of Science, Hokkaido University for their review in order to improve this dissertation.
5. Prof. L.M. Aslan, Prof. Ma'ruf Kasim, Dr. Baru Sadarun of Faculty of Fisheries and Marine Science of Halu Oleo University for their recommendations.
6. Prof. Jamaluddin Jompa, Prof. Sudirman, Dr. Rijal Idrus, Dr. Syafyuddin Yusuf, Dr. Nurjannah Nurdin, Dr. Irwan Muliawan, Dr. Abd Gaffar, Haris Sunendar, M.Sc., Heri Santoso, M.Sc., Ahmad Mauliddin, M.Sc., Hijaz Jalil, M.Si., Urban Elfatih, M.Sc., Amadhan Takwir, M.Si., for their invaluable insights for this research.
7. My parent La Ode Haya and Sitti Safia for the guidance, prayers and all their support for higher education. Also my brothers and sister; La Ode Suryadin, La Ode Hamsar, La Ode Hasrun, Soeherman, Rahmat Hidayat, Alimul Alam, and Neni Ramayanti for all their motivation.
8. Dr. Wa Ode Salma – my wife and my children; Wa Ode Alifya Fatimah Azzahroh, Ilham Wicaksana, Dolfy Saleh, and Cindy Priscilla for being my source of joy, inspiration, and for always encouraging my thoughts with ways to be a better person.
9. Persatuan Pelajar Indonesia (PPI) in Hokkaido, Lembaga Pengelola Dana Pendidikan (LPDP) group in Hokkaido, and Kajian Jumat Malam Fellows, especialy to Eko Siswoyo, Erik Prasetyo Zen, Naufal Rospriandana, Rochim Bakti Cahyono, Suherman, Achmad Syaifuddin, Harri, Ahmad, Lubis, Ade Purwanto, Haryo Edi Wibowo, Lesnanto, Wahyu Kurnia, Freddy, Vecky Kuswandoro, Jamal Musa Hole, Doddy Juli Irawan, Desi Utami, Zetryana, Isma Rosyida, Alfian Helmi, and Akhid Sybli.
10. Team of Marine Science Diving Club (MSDC) of Hasanuddin University, especially to Wawan Mangile, Syamsu Rijal, Tarsan, Neni Asriani, Andi Chaeryah, Nuryanti,

Asirwan, Nur Ismayanti, Nizar Hardiansyah, Januardi Septian. Also, Kapoposang of Marine Protected Areas (MPAs) Crew, especially to Muh. Lukman, Bobby Adirianto, Ilham, and Yaser Sakita.

This study was supported by the "Precise Impact Assessments on Climate Change" of the Program for Risk Information on Climate Change (SOUSEI Program) and the "Integrated Research Program for Advancing Climate Models (TOUGOU Program)" from the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan, the Environment Research and Technology Development Funds (S-15: Predicting and Assessing Natural Capital and Ecosystem Services) of the Ministry of the Environment, Japan, and the Belmont Forum "TSUNAGARI" fund by Japan Science and Technology Agency.

References

- Adrianto L (2006) Synopsis of the Introduction to Concepts and Methodology of Economic Valuation of Coastal and Marine Resources. Center for Coastal and Marine Resources Studies-Working papers, Bogor Agricultural University, Bogor
- Aoun D (2015) Who pays more to preserve a natural reserve, visitors or locals? A confidence analysis of a contingent valuation application. *Environmental Economics and Policy Studies* 17(4): 471-486
- Aronson RB, Precht WF (2001) Evolutionary paleoecology of Caribbean coral reefs. *Evolutionary paleoecology: the ecological context of macro evolutionary change*. Columbia University Press, New York, pp.171-233
- Augustinus PGEF (2001) Sustainable management of the coastal area of SW Sulawesi, Indonesia. In: *Kaleidoscopic View on Social Scientific Global Change Research in the Netherlands*. Netherlands HDP Committee, Royal Academy of Arts and Sciences: 99-107.
- Baboo SS, Devi MR (2011) Geometric correction in recent high resolution satellite imagery: a case study in Coimbatore, Tamil Nadu. *International Journal of Computer Applications* 14: 32-37
- Bohnsack JA (1994) How marine fishery reserves can improve fisheries. *Proc. Gulf Carib. Fish. Inst.* 43: 217-241
- Boschetti L, Flasse SP, Brivio PA (2004) Analysis of the conflict between omission and commission in low spatial resolution dichotomic thematic products: The Pareto Boundary. *Remote Sensing of Environment* 91: 280-292
- Boutwell JL, Westra JV (2013) Benefit transfer: A review of methodologies and challenges. *Resources*, 2(4): 517-527
- Boyd J (2010) Lost ecosystem goods and services as a measure of marine oil pollution damages. *Resources for the Future Discussion Paper*. 25 pp.
- Brander LM, Beukering VP, Cesar HS (2007) The recreational value of coral reefs: a meta-analysis. *Ecological Economics* 63 (1): 209-218

Brandt AV (1984) Fish Catching Methods of the World. Fishing News Books Ltd. London. 534 pp.

Bridge TC, Hughes TP, Guinotte JM, Bongaerts P (2013) Call to protect all coral reefs. *Nature Climate Change* 3(6): 528-530

Brown BE (1997) Disturbances to reefs in recent times. Life and death of coral reefs, pp.354-379

Bruno JF, Selig ER (2007) Regional decline of coral cover in the Indo-Pacific: timing, extent, and sub regional comparisons. *PLoS one*, 2(8): 1-8

Burke L, Reynter K, Spalding M, Perry A (2011) Reefs at risk revisited. World resources Institute, Washington DC. 130 pp.

Burke L, Selig E, Spalding M (2002) Reefs at risk in Southeast Asia World Resources Institute, Washington DC. 72 pp.

Call KA, Hardy JT, Wallin DO (2003) Coral reef habitat discrimination using multivariate spectral analysis and satellite remote sensing. *International Journal of Remote Sensing*, 24: 2627-2639

Campbell J (1987) Introduction to Remote Sensing. Guilford Press, New York. 551 pp.

Carpenter KE, Springer VG (2005) The center of the center of marine shore fish biodiversity: the Philippine Islands. *Environmental biology of fishes*, 72(4): 467-480

Cesar H (1996) Economic analysis of Indonesian coral reefs. World Bank Environment Department Paper. Environment Economics Series. Agriculture Operations Country Department III. East Asia and Pacific Region and Environment Department, The World Bank, Washington DC. 97 pp.

Cesar HS (2000) Coral reefs: their functions, threats and economic value. Collected essays on the economics of coral reefs, pp.14-39

Cesar H, Burke L, Pet-Soede L (2003) The Economics of Worldwide Coral Reef Degradation. Cesar Environmental Economics Consulting, the Netherlands. 24 pp.

Chapin III FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM, Reynolds HL, Mack MC (2000) Consequences of changing biodiversity. *Nature* 405(6783): 234-242

- Chavez PS (1996) Image-based atmospheric corrections-revisited and improved. *Photogrammetric engineering and remote sensing* 62: 1025-1035
- Che N, Price J (1992) Survey of radiometric calibration results and methods for visible and near infrared channels of NOAA-7,-9, and-11 AVHRRs. *Remote sensing of environment* 41: 19-27
- Chee YE (2004) An ecological perspective on the valuation of ecosystem services. *Biol. Conserv.* 120: 549-565
- Chozin M (2008) Illegal but common: Life of blast fishermen in the Spermonde Archipelago, South Sulawesi, Indonesia (Doctoral dissertation, Ohio University)
- Christie P, White, AT (2007) Best practices for improved governance of coral reef marine protected areas. *Coral Reefs* 26: 1047–1056
- Congalton RG, Green K (2008) Assessing the accuracy of remotely sensed data: principles and practices. CRC press, Taylor & Francis group, New York. 210 pp.
- Congedo L, Macchi S (2013) Investigating the Relationship between Land Cover and Vulnerability to Climate Change in Dar Es Salaam. Working Paper. 58 pp.
- Connell JH (1997) Disturbance and recovery of coral assemblages. *Coral reefs*, 16(5): 101-113
- Costanza R, d Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J, Raskin R, Sutton P, Belt VDM (1997) The value of the world's ecosystem services and natural capital. *Nature* 387 (15): 253-260
- D'Angelo C, Wiedenmann J (2014) Impacts of nutrient enrichment on coral reefs: new perspectives and implications for coastal management and reef survival. *Current Opinion in Environmental Sustainability* 7: 82-93
- Davies-Colley R, Smith D (2001) Turbidity, suspended sediment and water quality: a review. *J. Am. Water Works Assoc* 37: 1085–1101
- De'ath G, Fabricius KE, Sweatman H, Puotinen M (2012) The 27–year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences* 109(44): 17995-17999

DFW-Indonesia (2003) Profile of Destructive Fishing in Spermonde Islands. http://dfw.or.id/wp-content/uploads/2011/publikasi/DF_REPORT_SPERMONDE.pdf. Accessed 2 May 2014 (**in Bahasa**)

Driml S (1999) Dollar values and trends of major direct uses of the Great Barrier Reef Marine Park. Research Publication 56. Great Barrier Reef Marine Park Authority, Townsville, Australia. 15 pp.

Eakin CM, Nim CJ, Brainard RE, Aubrecht C, Elvidge C, Gledhill DK, Muller-Karger F, Mumby PJ, Skirving WJ, Strong AE, Wang M (2010) Monitoring coral reefs from space. *Oceanography* 23(4): 118-133

Edinger EN, Jompa J, Limmon GV, Widjatomoko W, Risk MJ (1998) Reef degradation and coral biodiversity in Indonesia: effects of land-based pollution, destructive fishing practices and changes over time. *Marine Pollution Bulletin* 36: 617-630

El-Askary H, Abd El-Mawla S, Li J, El-Hattab M, El-Raey M (2014) Change detection of coral reef habitat using Landsat-5 TM, Landsat 7 ETM+, and Landsat 8 OLI data in the Red Sea (Hurghada, Egypt). *International Journal of Remote Sensing* 35: 2327-2346

ERDAS (2008) ER Mapper User's Guide. ERDAS Inc., United State of America. 278 pp.

Erftemeijer PL, Riegl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: a review. *Marine Pollution Bulletin* 64: 1737-1765

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50: 125–146

Falkowski PG, Jokiel PL, Kinzie RA (1990) Irradiance and corals. In: Dubinsky Z (eds) *Ecosystems of the World 25: Coral Reefs*. Elsevier, Amsterdam, pp. 89-107

FAO (1999) Indicators for sustainable development of marine capture fisheries. FAO Technical Guidelines for Responsible Fisheries No.8. FAO, Rome. 68 pp.

FAO (2000) Application of Contingent Valuation Method in Developing Countries. FAO Economic and Social Development Papers No. 146/200. FAO, Rome. 14 pp.

Fauzi A (2006) *Ekonomi Sumberdaya Alam dan Lingkungan, Teori dan Aplikasi*. Penerbit Gramedia Pustaka Utama. Jakarta. 256 pp. ISBN 9792210423

- Fleiss JL, Cohen J, Everitt BS (1969) Large sample standard errors of kappa and weighted kappa. *Psychological Bulletin* 72: 323–327
- Freeman III, Myrick A, Herriges JA, Kling CL (2014) The measurement of environmental and resource values, theory and methods. RFF Press, New York. 479 pp.
- Gardner TA, Côté IM, Gill JA, Grant A, Watkinson AR (2003) Long-term region-wide declines in Caribbean corals. *Science* 301: 958–960
- Gomez ED, Alino PM, Yap HT, Licuanan WY (1994) A review of the status of Philippine reefs. *Marine Pollution Bulletin* 29: 62-68
- Gomez ED, Yap HT (1988) Monitoring reef condition. In: Kenchington RA, Hudson BET (eds) *Coral Reef Management Handbook*. UNESCO Regional Office for Science and Technology for Southeast Asia (ROSTSEA), Jakarta, pp. 171-178
- Goodman JA, Purkis SJ, Phinn SR (2013) *Coral reef remote sensing: A guide for mapping, monitoring and management*. Springer Science & Business Media, USA. 446 pp.
- Green EP, Mumby PJ, Edwards AJ, Clark CD (2000) *Remote sensing handbook for tropical coastal management*. UNESCO Publishing, Paris. 328 pp.
- Grigalunas TA, Congar R (1995) *Environmental economics for integrated coastal area management: valuation methods and policy instruments*. UNEP Regional Seas Reports and Studies (UNEP). 175 pp.
- Haapkylä J, Unsworth RKF, Flavell M, Bourne DG, Schaffelke B, Willis BL (2011) Seasonal Correction: Seasonal Rainfall and Runoff Promote Coral Disease on an Inshore Reef. *PLoS ONE* 6(3): 1-10
- Hadjimitsis DG, Papadavid G, Agapiou A, Themistocleous K, Hadjimitsis MG, Retalis A, Michaelides S, Chrysoulakis N, Toullos L, Clayton CR (2010) Atmospheric correction for satellite remotely sensed data intended for agricultural applications: impact on vegetation indices. *Natural Hazards and Earth System Sciences* 10: 89-95
- Harbord RM, Higgins JP (2008) Meta-regression in Stata. *Meta*, 8(4): 493-519

Hargreaves-Allen V (2004) Estimating the Total Economic Value of Coral Reefs for Residents of Sampela, a Bajau Community in Wakatobi Marine National Park, Sulawesi. MSc dissertation, Imperial College London

Harley CD, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJ, Thornber CS, and Williams SL (2006). The Impacts of Climate Change in Coastal Marine Systems. *Ecology Letters* 9(2): 228-241

Hedley JD, Roelfsema CM, Chollett I, Harborne AR, Heron SF, Weeks S, Skirving WJ, Strong AE, Eakin CM, Christensen TR, Ticzon V (2016) Remote sensing of coral reefs for monitoring and management: A review. *Remote Sensing* 8(118): 1-40

Hein MY, Lamb JB, Scott C, Willis BL (2015) Assessing baseline levels of coral health in a newly established marine protected area in a global scuba diving hotspot. *Marine environmental research* 103: 56-65

Hill J, Wilkinson C (2004) Methods for ecological monitoring of coral reefs. Australian Institute of Marine Science, Townsville. 117 pp.

Hodgson G (1999) A global assessment of human effects on coral reefs. *Marine Pollution Bulletin* 38: 345-355

Hoeksema BW (2012) Distribution patterns of mushroom corals (Scleractinia: Fungiidae) across the Spermonde Shelf, South Sulawesi. *Raffles Bull Zool* 60: 183-212

Hopley D, Suharsono H (2000) The status of coral reefs in eastern Indonesia. *Australian Institute of Marine Science, Townsville*. 144 pp.

Hourigan TF, Tricas TC, Reese ES (1988) Coral reef fishes as indicators of environmental stress in coral reefs. *Marine organisms as indicators* 1988: 107-135

Howell DC (2016) Fundamental statistics for the behavioral sciences. Nelson Education. 676 pp.

<https://cds-cv.nccs.nasa.gov/CREATE-V/> Accessed on June 2, 2017

<http://kkji.kp3k.kkp.go.id/index.php/en/marine-protected-area-data/details/7/92>. Accessed on June 13, 2016

<https://landsat.usgs.gov/>. Accessed on April 1, 2017

http://www.miz.nao.ac.jp/staffs/nao99/index_En.html. Accessed on October 10, 2016

<http://www.worldwildlife.org/publications/stewarding-biodiversity-and-food-security-in-the-coral-triangle-achievements-challenges-and-lessons-learned>. Accessed on February 15, 2017

Hughes TP (1994) Catastrophes, phase shifts and large-scale degradation of a Caribbean coral reef. *Science* 265: 1547–1551

Hughes TP (1995) Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Biological Conservation* 72(3), 411 pp.

Ishizaka J, Fukushima H, Kishino M, Saino T, Takahashi M (1992) Phytoplankton pigment distribution in regional upwelling around the Izu Peninsula detected by coastal zone color scanner on May 1982. *Journal of Oceanography* 48: 305-327

Jameson SC, Ammar M, Saadalla E, Mostafa HM, Riegl B (1999) A coral damage index and its application to diving sites in the Egyptian Red Sea. *Coral Reefs* 18: 333-339

Jones GP, McCormick MI, Srinivasan M, Eagle JV (2004) Coral decline threatens fish biodiversity in marine reserves. *Proceedings of the National Academy of Sciences of the United States of America* 101: 8251-8253

Jones R, Bessell-Browne P, Fisher R, Klonowski W, Slivkoff M (2016) Assessing the impacts of sediments from dredging on corals. *Marine pollution bulletin* 102: 9-29

Jones R, Ricardo GF, Negri AP (2015) Effects of sediments on the reproductive cycle of corals. *Marine pollution bulletin* 100(1): 13-33

Jupiter S, Roelfsema CM, Phinn SR (2013) Science and Management. In: Goodman JA, Purkis SJ, Phinn SR (eds.) *Coral Reef Remote Sensing A Guide for Mapping, Monitoring and Management*. Springer, London, pp. 403-427

Komyakova V, Munday PL, Jones GP (2013) Relative importance of coral cover, habitat complexity and diversity in determining the structure of reef fish communities. *PloS one* 8: 1-12

Kordi, O'Leary (2016) A spatial approach to improve coastal bioregion management of the north Western Australia. *Ocean & Coastal Management* 127: 26-42

- Krejcie RV, Morgan DW (1970) Table for determining sample size from a given population. *Educational and Psychological Measurement* 30: 607-610
- Lamy T, Galzin R, Kulbicki M, Lison de Loma T, Claudet J (2016) Three decades of recurrent declines and recoveries in corals belie ongoing change in fish assemblages. *Coral reefs* 35(1): 293–302
- Lauenroth WK, Burke IC (2008) *Ecology of the shortgrass steppe: a long-term perspective*. Oxford University Press. 537 pp.
- Lillesand T, Kiefer RW, Chipman J (2004) *Remote sensing and image interpretation*. John Wiley & Sons Inc., New York. 812 pp.
- Lillesand T, Kiefer RW, Chipman J (2014) *Remote sensing and image interpretation*. John Wiley & Sons Inc. 146 pp.
- Lubin D, Li W, Dustan P, Mazel CH, Stamnes K (2001) Spectral signatures of coral reefs: Features from space. *Remote sensing of environment* 75: 127-137
- Luczkovich JJ, Wagner TW, Michalek JL, Stoffle RW (1993) Discrimination of coral reefs, seagrass meadows, and sand bottom types from space: A Dominican Republic Case Study. *Photogrametric Engineering & Remote Sensing* 59: 385-389
- Lyzenga DR (1978) Passive remote sensing techniques for mapping water depth and bottom features. *Applied optics* 17: 379-383
- Lyzenga DR (1981) Remote sensing of bottom reflectance and water attenuation parameters in shallow water using aircraft and Landsat data. *International Journal of Remote Sensing* 2: 71-82
- Maple (2015) *The Essential Tool for Mathematics*.
<https://www.maplesoft.com/products/maple/>. Cited 10 November 2016
- McManus JW (1997) Tropical marine fisheries and the future of coral reefs: a brief review with emphasis on Southeast Asia. *Coral Reefs* 16: 121-127
- Moberg F, Folke C (1999) Ecological goods and services of coral reef ecosystems. *Ecological Economics* 29(2): 215-233. Doi: 10.1016/S0921-8009(99)00009-9
- Moran PJ (1990) The *Acanthaster planci* (L); Biographical data. *Coral Reefs* 9: 95-96

- Moran PJ (1988) Crown-of-thorns starfish: questions, answers. Australian Institute of Marine Science. 35 pp.
- Morton B (1994) Hong Kong's Coral Communities: Status, Threats and Management Plans Marine Pollution Bulletin 29(1-3): 74-83
- Mumby PJ (2001) Beta and habitat diversity in marine systems: a new approach to measurement, scaling and interpretation. *Oecologia* 128: 274-280
- Mumby P, Green E, Edwards A, Clark C (1999) The cost-effectiveness of remote sensing for tropical coastal resources assessment and management. *Journal of Environmental Management* 55: 157-166
- Mumby PJ, Harborne AR (1999) Development of a systematic classification scheme of marine habitats to facilitate regional management and mapping of Caribbean coral reefs. *Biological Conservation* 88: 155-163
- Mumby PJ, Hedley J, Chisholm JRM, Clark CD, Ripley H, Jaubert J (2004) The cover of living and dead corals from airborne remote sensing. *Coral Reefs* 23: 171-183
- Mumby PJ, Steneck RS (2008) Coral reef management and conservation in light of rapidly evolving ecological paradigms. *Trends in ecology & evolution* 23: 555-563
- NASA (2009) Millennium Reef Maps Metadata Updated 11 March 2009 For Landsat images. <http://oceancolor.gsfc.nasa.gov/LANDSAT/HTML/README.html>. Accessed 1 September 2014
- Nasr D (2015) Coral reefs of the Red Sea with special reference to the Sudanese Coastal Area. In *The Red Sea*. Springer Berlin Heidelberg. pp. 453-469
- Nurdin N, Grydehøj A (2014) Informal governance through patron–client relationships and destructive fishing in Spermonde Archipelago, Indonesia. *Journal of Marine and Island Cultures* 3(2): 54-59
- Nurdin N, Komatsu T, AS MA, Djalil AR, Amri K (2015) Multisensor and multitemporal data from Landsat images to detect damage to coral reefs, small islands in the Spermonde archipelago, Indonesia. *Ocean Science Journal* 50: 317-325

Nuridin N, Prasyad H, Akbar ASM (2013) Dinamika Spasial Terumbu Karang pada Perairan Dangkal Menggunakan Citra Landsat Di Pulau Langkai, Kepulauan Spermonde. Jurnal Ilmiah Geomatika 19: 83-89 (**in Bahasa with English abstract**)

Organization for Economic Co-operation and Development – OECD (2016) GDP Implicit Price Deflator in Indonesia.

<https://fred.stlouisfed.org/series/IDNGDPDEFAISMEI>. Cited 12 August 2016

Pagiola S, Bishop J, Ritter VK (2004) Assessing the economic value of ecosystem conservation. Environment Department Paper No.101. The World Bank, Washington DC. 66 pp.

Palandro DA, Andréfouët S, Hu C, Hallock P, Müller-Karger FE, Dustan P, Callahan MK, Kranenburg C, Beaver CR (2008) Quantification of two decades of shallow-water coral reef habitat decline in the Florida Keys National Marine Sanctuary using Landsat data (1984–2002). Remote sensing of environment 112: 3388-3399

Parwati E, Kartasasmita M, Soewardi K, Kusumastanto T, Nurjaya IW (2013) The relationship between total suspended solid (TSS) and coral reef growth (case study of Derawan Island, Delta Berau Waters). International Journal of Remote Sensing and Earth Sciences (IJReSES) 10: 104-113

Pearce D, Moran D (2009) The Economic Value of Biodiversity. IUCN-The World Conservation Union, London. 180 pp. ISBN: 978-1-85383-195-9

Pendleton LH, Hoegh-Guldberg O, Langdon C, Comte A (2016) Multiple Stressors and Ecological Complexity Require a New Approach to Coral Reef Research. Frontiers in Marine Science (3):36 pp.

Pet-Soede C (2000) Options for co-management of an Indonesian coastal fishery. Dissertation, Wageningen University, see <http://library.wur.nl/WebQuery/wurpubs/fulltext/121232>

Pet-Soede L, Erdmann M (1998) An overview and comparison of destructive fishing practices in Indonesia. SPC Live Reef Fish Information Bulletin 4: 28-36

Pet-Soede C, Cesar H, Pet J (1999) An economic analysis of blast fishing on Indonesian coral reefs. Environmental Conservation 26(2): 83-93

Polónia AR, Cleary DF, de Voogd NJ, Renema W, Hoeksema BW, Martins A, Gomes NC (2015) Habitat and water quality variables as predictors of community composition in an Indonesian coral reef: a multi-taxon study in the Spermonde Archipelago. *Science of the total environment* 537: 139-151

Porter JW, Meier OW (1992) Quantification of loss and change in Floridian reef coral populations. *American Zoologist* 32(6): 625-640

Purkis SJ, Pasterkamp R (2004) Integrating *in situ* reef-top reflectance spectra with Landsat TM imagery to aid shallow-tropical benthic habitat mapping. *Coral Reefs* 23: 5-20

Radjawali I (2012) Examining local conservation and development: Live reef food fishing in Spermonde Archipelago, Indonesia. *Revista da Gestão Costeira Integrada* 12(4): 545-557

Research Center for Oceanography, Indonesian Institute of Sciences (2014) Handbook of shallow water habitats mapping.

http://www.coremap.or.id/downloads/gis_1435730309.pdf. Accessed 30 September 2016 (**in Bahasa**)

Roberts CM (1997) Connectivity and management of Caribbean coral reefs. *Science* 278: 1454–1457

Roberts CM, McClean JC, Veron JEN, Hawkins JP, Allen GR, McAllister DE, Mittermeier CG (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* 295 (5558): 1280-1284

Roelfsema C, Phinn S, Dennison W (2002) Spatial distribution of benthic microalgae on coral reefs determined by remote sensing. *Coral Reefs* 21: 264-274

Rogers A, Harborne AR, Brown CJ, Bozec YM, Castro C, Chollett I, Hock K, Knowland CA, Marshall A, Ortiz JC, Razak T (2015) Anticipative management for coral reef ecosystem services in the 21st century. *Global change biology* 21(2): 504-514

Salvat B (1987) Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Mussee, Ecole Pratique des Hautes Etudes, French Polynesia. 253 pp.

Samonte GP, Eisma-Osorio RL, Amolo R, White A (2016) Economic value of a large marine ecosystem: Danajon double barrier reef, Philippines. *Ocean & Coastal Management* 122: 9-19

Saunders M, Lewis P, Thornhill A (2007) *Research Methods for Business Students*. Essex, UK: Pearson, Education Limited. 649 pp. ISBN 978-0-273- 70148-4

Sawyer DA (1992) Taka Bone Rate: management, development and resource valuation of an Indonesian Atoll, MA thesis, Dept Economics, Dalhousie University, Halifax, Nova Scotia

Scopéltis J, Andréfouët S, Phinn S, Chabanet P, Naim O, Tourrand C, Done T (2009) Changes of coral communities over 35 years: Integrating *in situ* and remote-sensing data on Saint-Leu Reef (la Réunion, Indian Ocean). *Estuarine, Coastal and Shelf Science* 84: 342-352

Sekaran U (2003) *Research methods for Business, a skill-building approach*, Fourth Edition. John Wiley & Sons, Inc. ISBN 0-471-20366-1

Sinden JA (1994) A review of environmental valuation in Australia. *Review of Marketing and Agricultural Economics* 62: 337–368

Souter DW, Linden O (2000) The health and future of coral reef systems. *Ocean & Coastal Management* 43(8): 657-688

Spalding M, Ravilious C, Green EP (2001) *World atlas of coral reefs*. University of California Press, Berkeley. 424 pp.

Statistics Indonesia of Pangkajene and Kepulauan Regency (2014) <https://PANGKEPkab.bps.go.id/index.php>. Cited 10 October 2014

Statistics Indonesia of Pangkajene and Kepulauan Regency (2015) <https://pangkepkab.bps.go.id>. Accessed 20 December 2016

Suharsono, Purnomohadi N (2001) International Coral Reef Initiative Country Report: Indonesia, paper presented at the Regional ICRI Workshop for East Asia, Cebu, Philippines. 13 pp.

Sumaila UR, Charles AT (2002) Economic models of marine protected areas: an introduction. *Natural Resource Modeling* 15(3): 261-272

Suwargana N (2014) Analysis of Alos AVNIR-2 imagery for coral reefs mapping (A Case Study: Banyuputih, Situbondo). Proceedings of the National Seminar on remote sensing, Indonesian National Institute of Aeronautics and Space (LAPAN). pp. 588-596. http://sinasinderaja.lapan.go.id/wp-content/uploads/2014/06/bukuprosiding_588-596.pdf. Accessed 10 October 2014 (**in Bahasa with English abstract**)

Tseng WWC, Hsu SH, and Chen CC (2015) Estimating the willingness to pay to protect coral reefs from potential damage caused by climate change-The evidence from Taiwan. *Marine pollution bulletin* 101(2): 556-565

UNEP (2006) *Marine and Coastal Ecosystems and Human Well-Being: A Synthesis Report Based on the Findings of the Millennium Ecosystem Assessment*. UN Environment Programme, Nairobi. 76 pp.

Unsworth RE and Petersen TB (1995) *A manual for conducting natural resource damage assessment: the role of economics*. Industrial Economics Incorporated. <https://www.fws.gov/policy/NRDAManualFull.pdf>. Cited 13 June 2016

United States Geological Survey (2014) Data sets. <https://earthexplorer.usgs.gov/>. Accessed on 20 December 2014

Wahiddin N, Siregar VP, Nababan B, Jaya I, Wouthuyzen S (2015) Change detection of coral reef habitat using Landsat imagery in Morotai Island North Maluku Province. *Jurnal Ilmu dan Teknologi Kelautan Tropis* 6: 507-524 (**in Bahasa with English abstract**)

Wahyudin Y (2007) *An Economic Value of the Natural Seaweed Resources*. Available at SSRN 1678973. <http://dx.doi.org/10.2139/ssrn.1678973>

Ward TJ, Hegerl EJ (2003) *The benefits of marine protected areas*. Department of the Environment and Heritage, Commonwealth of Australia. 77 pp.

Wawo M, Adrianto L, Bengen DG, Wardiatno Y (2014) Valuation of Seagrass Ecosystem Services in Kotania Bay Marine Nature Tourism Park, Western Seram, Indonesia. *Asian Journal of Scientific Research* 7(4): 591-600

Weeks R, Russ GR, Alcala AC, White AT (2010) Effectiveness of marine protected areas in the Philippines for biodiversity conservation. *Conservation Biology* 24(2): 531-540

Weil E, Smith G, Gil-Agudelo DL (2006) Status and progress in coral reef disease research. *Diseases of aquatic organisms* 69(1): 1-7

- Weinberg S (1976) Submarine daylight and ecology. *Marine Biology* 37: 291-304
- Wells S (2009) Dynamite fishing in northern Tanzania—pervasive, problematic and yet preventable. *Marine Pollution Bulletin* 58(1): 20-23
- Wilkinson CR (1992) Coral reefs of the world are facing widespread devastation: can we prevent this through sustainable management practices? *Proc. 7th International Coral Reef Symposium* 1: 11–21
- Wilkinson CR (1996) Global change and coral reefs: impacts on reefs, economies and human cultures. *Global Change Biology* 2(6): 547-558
- Wilkinson CR (2008) Status of Coral Reefs of the World: 2008 Global Coral Reef Monitoring Network and Reef and Rainforest Research Center. Townsville, Australia. 296 pp.
- White AT, Vogt HP, Arin T (2000) Philippine coral reefs under threat: the economic losses caused by reef destruction. *Marine Pollution Bulletin* 40(7): 598-605
- Wooldridge SA, Brodie JE (2015) Environmental triggers for primary outbreaks of crown-of-thorns starfish on the Great Barrier Reef, Australia. *Marine pollution bulletin* 101(2): 805-815
- World Bank (2015) World Bank Supports Indonesia's Coral Reefs and Coastal Communities. <http://www.worldbank.org/en/news/press-release/2014/02/21/world-bank-indonesia-coral-reefs-coastal-communities>. Accessed 15 July 2015
- World Wild Fund (2016) Coral Triangle. <http://www.worldwildlife.org/places/coral-triangle>. Accessed 20 December 2016
- Yasir Haya LM, Fujii M (2017) Mapping the Change of Coral Reefs Using Remote Sensing and *in situ* Measurements; A Case Study in PANGKEP Regency, Spermonde Archipelago, Indonesia. *Journal of Oceanography*. DOI: 10.1007/S10872-017-0422-4
- Yusuf S (2008) Outbreak Phenomenon of *Acanthaster planci* and its predatory due to Scleratinian living preferences in Kapoposang Island, South Sulawesi. *Proceeding of Indonesian Coral Reef Symposium*, 235-243
- Yusuf S, Jompa J (2012) Indonesia First Quantitative Assessment of Coral Bleaching on Indonesian Reefs. In: *Proceedings of the 12th International Coral Reef Symposium*.

Cairns, Australia.

http://www.icrs2012.com/proceedings/manuscripts/ICRS2012_17D_6.pdf

Zheng Z, Li Y, Guo Y, Xu Y, Liu G, Du C (2015) Landsat-Based Long-Term Monitoring of Total Suspended Matter Concentration Pattern Change in the Wet Season for Dongting Lake, China. Remote Sensing 7: 13975-13999

Appendices

Appendix A1. Questionnaire sheet and list interview of the coral reefs in the Pangkajene and Kepulauan (PANGKEP) Regency, Spermonde Archipelago, Indonesia

A.1.1. Questionnaire survey of the utilization of coral reef ecosystems among fisheries

a. Identity of respondents

Name :

Age : years old

Gender : male/female*)

Most recent education : Elementary school/ middle school/ high school/
Diploma/ Bachelor/ Master/ Doctoral *)

Marital status : single/married/widow/widower

Number of family members : (Person)

 a. Child : (Person)

 b. Adult : (Person)

 c. Address :

Primary occupation **)

- | | |
|--|---|
| ☐ Government employee | ☐ Fisher |
| ☐ Private employee | ☐ Ornamental-coral fisher |
| ☐ Entrepreneur | ☐ Building-coral fisher |
| ☐ Crop farmer | ☐ Coral-ecosystem fisher |
| ☐ Fishpond-fisher | ☐ If others, please specify..... |

Supplementary occupation **)

- | | |
|--|--|
| ☐ Government employee | ☐ Fisher |
| ☐ Private employee | ☐ Ornamental-coral fisher |
| ☐ Entrepreneur | ☐ Building-coral fisher |
| ☐ Crop farmer | ☐ Coral-ecosystem fisher |
| ☐ Fishpond-fisher | ☐ If others, please specify |

b. Target Respondents: Fishers

1. Do you catch fish in this area?¹

- ☐ Yes
- ☐ No

*) Please cross each unnecessary item out of your choice

**) Please put a tick (✓) in the box to the answer of your choice

¹ Please put a tick (✓) in the box to the answer of your choice. If you answer "yes" to question 1, please continue to the next items. If your answer "no" to question 1, the questionnaire is discontinued.

2. The occupation experience in fisheries (yr)
3. Fishing gear
 - a. Type :
 - b. Size : length overall (LOA) m; width.....m; height:.... m
 - c. Number : (unit)
 - d. Purchasing price : IDR / unit
 - e. Life service² :(yr)
4. Fishing vessel/boat
 - a. Size : length overall (LOA)..... m; width: m; height: .. m
 - b. Gross weight : gross tonnage
 - c. Number : unit
 - d. Purchasing price : IDR..... / unit
 - e. Life service³ : (yr)
5. Driving engine of vessel/boat⁴
 - ☐ Sailboat
 - ☐ Out-board engine
 - a. Type of engine (manufacturer) :
 - b. Engine power : (horse power)
 - c. Number : (unit)
 - d. Purchasing price : IDR /unit
 - e. Life service : (yr)
 - ☐ In-board engine
 - f. Type of engine (manufacturer) :
 - g. Engine power : (horse power)
 - h. Number : (unit)
 - i. Purchasing price : IDR /unit
 - j. Life service : (yr)

6. Other fishing supplementary tools and equipments

No.	Type	Size Specification	Number of Equipment	Unit	Cost of Fishing Tools and Equipments	Life service ⁵
-----	------	-----------------------	------------------------	------	--	------------------------------

² Life service is operational serviceable of engine used to operate fishing gear

³ Life service is operational serviceable of engine used to operate vessel or boat

⁴ Please choose according to the type of selected driving engine

⁵Life service is operational serviceable of engine used to operate vessel or boat

	/purchasing price per unit (IDR/unit)
a.	
b.	
c.	
7. Number of employees per fishing operation	
a. Owner..... (person)	
b. Captain.....(person)	
c. Mechanic.....(person)	
d. Steersman.....(person)	
e. Cook.....(person)	
f. Crew (boy) (person)	
8. Status of the ownership : owned/partnership/fisheries company ⁶	
9. Current status of the operational structure: owner/captain/crew/	
10. Fishing ground	
a. Fishing area :	
b. Distance from shoreline : nautical miles	
c. Total cruising hours : hours	
11. Time zone of fishing gear operation: morning/afternoon/night	
12. Number of days for fishing operational activities per trip : days	
13. Trip average of fishing operational time period : trip per week/month /yr ⁷	
14. Non-fishing season in a yr:....month, ⁸ : 1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11 / 12	
15. Month duration of fishing season	
a. Peak season : until (month)	
b. Normal season : until (month)	
c. Low season : until (month)	
16. Method of fish storage and preservation during fishing operation	
☐ Hold and ice	
☐ Hold without ice	
☐ Without hold and ice, but put fish on the deck	
☐ If others please specify	
17. Volume and value of catch production in fishing season by species	
a. Peak fishing season	

⁶Please cross each unnecessary item out of your choice

⁷Please cross each unnecessary item out of your choice

⁸Please circle an item or more based on your choice

Catch Composition by Species	Production Volume by Catch (kg/trip)	Production Value by Price (IDR/kg)
1.		
2.		
3.		
4.		
5.		

b. Normal fishing season

Catch Composition by Species	Production Volume by Catch (kg/trip)	Production Value by Price (IDR/kg)
1.		
2.		
3.		
4.		
5.		

c. Low fishing season

Catch Composition by Species	Production Volume by Total Catch (kg/trip)	Production Value By Price (IDR/kg)
1.		
2.		
3.		
4.		
5.		

18. Profit share between the owner and hired employees

- a. Owner : proportion / percent
- b. Hired employee : proportion / percent

19. Operational cost per fishing trip

No	Items	Number	unit	Purchasing (IDR)/Unit	Total Cost (IDR)
a.	Diesel fuel		liter		
b.	Ice		block of ice		
c.	Salt		kg		
d.	Fishing supplies		trip		
e.	Retribution		percent		
f.	Others, specify.....				

20. Maintenance Cost

- a. Vessel/boat : IDR..... per month /yr
- b. Vessel/boat engine : IDR.....per month/yr
- c. Fishing gear : IDR.....per month/yr
- d. Others : IDR.....per month/yr/

c. Target Respondents: Fish pond fishers

1. The occupation experience in fisheries (yr)
2. Status of the ownership: a) owned b) hired employee c) lease
3. Category of the livelihood: a) primary occupation b) supplementary occupation
4. The previous occupation before changes your current occupation.....
5. Fishpond area/ production unit:
6. Status of the ownership: owned/lease/profit share/others.....
7. Commodities produced:
8. Harvest yield for one yr:
9. Investment cost of fish breeding

Type of Investment	Unit	Price (IDR /unit)	Total Cost (IDR)
1.			
2.			
3.			

10. Cost of production inputs per fish harvest season

No	Items of production inputs	Unit Price	Number (Unit)	Total Cost (IDR)
1.	Preparation cost of seaweed farming plots			
2.	Maintenance cost			
3.	Medicines			
4.	Natural breedings			
5.	Artificial breedings			
6.	Salary for hired employees			
7.	Cost of handling during harvest			
8.	Others, specify.....			

11. Fixed costs of fish breeding

Type of Cost	Cost/unit (IDR/unit)	Total Cost (IDR)
1. Mariculture permission letter		
2. Land and building tax		
3. Fishpond plot handling		
4. Reparation of tools and equipment		

12. Yield (volume and value of production) per fish harvest season

Type	Price/kg	Total Revenue (IDR)
1.		
2.		
3.		
4.		
5.		

d. Target Respondent: Seaweed Farmers

1. The occupation experience in fisheries (yr)
2. Status of the ownership: a) owner b) hired employee c) lease
3. Category of the livelihood: a) primary occupation b) supplementary occupation
4. Previous occupation before changing your current occupation:
5. Seaweed plot area/ production unit:
6. Status of the ownership: owned/lease/profit share/others.....
7. Commodities produced:
8. Harvest production for one year:
9. Investment cost of seaweed cultivation

No	Investment Cost	Unit	Volume (Unit)	Price (IDR /unit)	Total Cost (IDR)
1.	Rope	Bale			
2.	Anchor	Unit			
3.	Floating materials	Unit			
4.	Net	M			
5.	Others:				

10. Cost of operational inputs per seaweed harvest season

No	Operational Cost	Sat	Volume (Unit)	Price (IDR /unit)	Total Cost (IDR)
1	Seaweed seedlings	kg			
2	Hired employee salary to tie and stretch along the ropes	Plot			
3	Maintenance cost	Plot			
4	Cost of handling during harvest	Plot			
5	Cost for seaweed processing	Day			
6	Others:				

11. Fixed cost

No	Fixed Cost	Unit	Volume (unit)	Price Unit (IDR /unit)	Total Cost (IDR)
1.	Tax				
2.	Retribution				
3.	Others.....				

12. Production cost

No	Cost	Unit	Volume (kg)	Price Unit (IDR)
1	Wet seaweed	Kg		
2	Dried seaweed	Kg		
3	Others:			

A.1.2. Questionnaire survey of the utilization of coral reef ecosystem among tourists and researchers

a. *Identity of Respondents*

1. Name:
2. Age :
3. Origin of place:
4. Most recent education : Elementary school/ middle school/ high school/
Diploma/ Bachelor/ Master/ Doctoral
5. Household income:
 - a. IDR 500.000 – 1.000.000
 - b. IDR 1.000.000 – 2.000.000
 - c. IDR 3.000.000 – 4.000.000
 - d. IDR 4.000.000 – 5.000.000
 - e. More than IDR 5.000.000

b. *Tourist/researcher Activities*

1. How many visitors who recreate with you in this area (tourism group) persons
2. Tourism cost in this area
 - a. Transportation : IDR/person
 - b. Lodging : IDR/person
 - c. Food/Beverage : IDR/person
 - d. Entrance ticket : IDR...../person
 - e. Rent for entertainment facilities : IDR..... /person
 - f. Charge for the use of public utilities (WC and others): IDR...../person
 - g. Others, ... : IDR...../person
3. What your perception based on your tourism experience in this area?
 - ☐ Positive
 - ☐ Neutral
 - ☐ Negative
4. Number of your visits in this area visit/yr
5. How long do you spend your tourism experience per trip?(day)
6. Probably you lose your productive time for spending your time in this area. How many your productive loses converted into money?
IDR.....

7. Is there any tourism destination as an alternative besides this tourism area?⁹

☐ No

☐ Yes

7a) If your answer to question 7 is “yes”, how much cost you spend at that tourism destination

a. Transportation : IDR/person

b. Lodging : IDR/person

c. Food/Beverage : IDR/person

d. Entrance ticket : IDR...../person

e. Rent for entertainment facilities : IDR...../person

f. Charge for the use of public utilities (WC and others): IDR...../person

g. Others, ... : IDR...../person

7b) How many times do you go to that tourism destination?

A.1.3. Questionnaire survey of local people living at the surrounding areas of coral reef ecosystems

a. Characteristics of Respondents

Name :

Age : (yr)

Most recent education : Elementary school/ middle school/ high school/ Diploma/
Bachelor/ Master/ Doctoral

Number of family members : (person)

Current occupation :

Household income: IDR./yr

b. Knowledge/Perception of Respondents on Coral Reefs

1. Do you aware that the existence of coral reefs gives benefits to local peoples in this area?

a. Strongly aware

b. Aware

c. Neither aware nor unaware

d. Unaware

e. Strongly unaware

If your answer to question 7 is “no“, this questionnaire is discontinued, whereas, if your answer to question 7 is “no“, the next questions is continued to no.7a) and 7b)

2. Do you agree that coral reefs have the ecological, economical and sociological roles in this area?
 - a. Strongly agree
 - b. Agree
 - c. Neither agree nor disagree
 - d. Disagree
 - e. Strongly disagree
3. Do you agree that coral reefs offer benefits to you?
 - a. Strongly agree
 - b. Agree
 - c. Neither agree nor disagree
 - d. Disagree
 - e. Strongly disagree
4. Do you agree that coral reefs are being treated in this area?
 - a. Strongly agree
 - b. Agree
 - c. Neither agree nor disagree
 - d. Disagree
 - e. Strongly disagree
5. Do you agree that coral reefs should be depleted in this area?
 - a. Strongly disagree
 - b. Disagree
 - c. Neither agree nor disagree
 - d. Agree
 - e. Strongly agree
6. Do you agree the need for the preservation of coral reefs for your benefits in this area?
 - a. Strongly agree
 - b. Agree
 - c. Neither agree nor disagree
 - d. Disagree
 - e. Strongly disagree
7. Do you agree to share contribution for the preservation of coral reefs in this area?
 - a. Strongly agree
 - b. Agree
 - c. Neither agree nor disagree
 - d. Disagree

- e. Strongly disagree
- 8. How much money (IDR) you spend for retribution in favor of the preservation of coral reefs in this area in a yr? Please specify
- 9. What percent of your income spent for retribution in a year in favor of the preservation of coral reefs in this area?
 - a. 1%
 - b. 2%
 - c. 3%
 - d. 4%
 - e. 5%
 - f. 6%
 - g. 7%
 - h. 8%
 - i. 9%
 - j. 10%
 - k. More than 10% (.....%)

c. *Complemental Data*

Total populations living at surrounding areas of coral reef ecosystem

Area of coral coverage at surrounding areas

A.1.4. List question for interview

1. Do you have specific ties with your commercial-fisher?
 - a. Yes b. No
2. If your answer to question 1 is “yes“, what factors that motivate you to relate with your commercial-fisher?
 - a. Credits for fishing investment (vessel/boat, fishing gear, etc), please specify.....(IDR)
 - b. Credits for equipment supplies, please specify(IDR /trip)
 - c. If others please specify
3. What benefits you have by to do social relation with your commercial-fisher? (yes/no). If your answer is “yes“, please chose one or more the following items
 - a. Credit (money) used for lack of something important
 - b. Health benefit
 - c. Bonus receive near Holidays
 - d. If others please specify, ...

What detriments have you by to do social relation with your commercial-fisher?

(yes/no). If your answer is “yes“, please specify

Appendix A2. 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):

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

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:

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

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

$$= \beta' + a \ln V_1, \quad (A3)$$

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.

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

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:

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

as written in the following equation:

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

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

$$Q = \alpha X_I^\sigma. \quad (\text{A7})$$

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:

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

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:

$$\frac{EV}{ha} = \frac{CS \times N}{L}. \quad (A12)$$

Appendix A3. Calculation of direct use values (DUVs) using the effect on production (EOP) method

A3.1 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 A3.1.

Table A3.1 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 (R²) 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 R² illustrates the value of R² that adjusted. This value is always smaller than R² 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).

A3.2 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:

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

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 A3.2.

Table A3.2 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	Price	Age	Family member	Education	Income

	(β)	(a)	(b)	(c)	(d)	(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 A3.2) are substituted into Equation (A13), it is modified in the following:

a. Fish coral:

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

b. Crabs:

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

c. Squids and Octopuses:

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

d. Seaweeds:

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

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

a. Coral Fish:

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

b. Crabs:

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

c. Squids and Octopuses:

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

d. Seaweeds:

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

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:

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

b. Crabs:

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

c. Squids and Octopuses:

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

d. Seaweeds:

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

Furthermore, from the function A22 through A25, several values as shown in Table A3.3 were obtained.

Table A3.3 The result of calculation of some component of value in the EOP method

Types of	Utility	Average	Payable	Consumer
----------	---------	---------	---------	----------

fisheries production	value (U) in USD	WTP in USD	value (PQ) in USD	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 A4. 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 A4.1.

Table A4.1 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 A4.2.

Table A4.2 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 A4.2, then the WTP values could be estimated as follows:

$$\begin{aligned} \ln \text{WTP} &= 13.67 \\ &= 866,059.138 \text{ (1 USD = 13,000 IDR)} \\ &= 66.62 \text{ USD /person.} \end{aligned} \quad (\text{A27})$$