COST-BENEFIT ANALYSIS OF MANGROVE CONSERVATION VERSUS SHRIMP AQUACULTURE IN BINTUNI BAY AND MIMIKA, INDONESIA

Climate Economic Analysis for Development, Investment and Resilience

Contract No.: AID-OAA-I-12-00038, Task Order AID-OAA-TO-14-00007

March 6, 2020

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Front photo source: Mangrove forest, Bintuni, Indonesia. Photo by Ben Brown.

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March 6, 2020

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ACRONYMS

BAU	Business-as-usual
CBA	Cost-benefit analysis
CEADIR	Climate Economic Analysis for Development, Investment and Resilience
CO_2	Carbon dioxide
E3	Bureau for Economic Growth, Education and Environment (USAID)
EP	Economic Policy Office (USAID/E3)
GCC	Global Climate Change Office (USAID/E3)
Ha	Hectares
HDI	Human Development Index
IDR	Indonesian rupiah
Km	Kilometers
Km_2	Square kilometers
NOAA	National Oceanic and Atmospheric Administration (United States)
NPV	Net present value (present value of net benefits)
PT BUMWI	PT Bintuni Utama Murni Wood Industries
tCO_2e/ha	Metric tons of carbon dioxide equivalent per hectare
tCO_2e	Metric tons of carbon dioxide equivalent
USAID	United States Agency for International Development
VSL	Value of a statistical life
WFP	World Food Programme
WRI	World Resources Institute

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EXECUTIVE SUMMARY

This cost-benefit analysis (CBA) focused on two mangrove areas in the Papua and West Papua regions of eastern Indonesia -- Bintuni Bay and Mimika. These sites were selected because of their global importance as large contiguous areas of mangroves with high productivity and biodiversity (Alongi 2007). The Bintuni site had a mangrove wood harvesting concession that has operated since 1988. The Mimika site was adjacent to a large mangrove area in the Asmat Regency.

The CBA considered two scenarios. The *Business-as-usual (BAU) scenario* assumed that the low, existing mangrove conversion rate of 0.05 percent per year would continue at both sites, leading to a 2.8 percent reduction in mangrove area over 50 years. Most of this mangrove conversion has been for human settlements and infrastructure, not aquaculture. The *Alternative scenario* assumed that an additional 0.75 percent of the mangrove area would be converted to shrimp aquaculture each year resulting in a 54 percent net reduction in the mangrove area over 100 years, after regrowth of abandoned aquaculture areas.

Information on the costs and benefits of activities supported by the mangroves (near-shore fishing, farming, hunting and gathering, wood harvesting, and collecting mangrove palm products for roofing materials, food, and beverages) was collected through a survey of 120 households in three villages at each of the two sites. Although mangroves are also important spawning and nursery areas for off-shore fisheries, no data were available to quantify these benefits.

The economic analysis also included the value of mangroves for carbon storage and reducing damage from cyclones and tsunamis. Carbon sequestration estimates were available for Bintuni Bay and Mimika. Since there was no history of cyclones or tsunamis in either of the study sites, the base case analysis assumed that that these events would not occur during the study period.

Shrimp ponds in former mangrove areas typically have short usable lives of 10 years or less. It can take ten years or more for mangroves to be re-established in abandoned shrimp ponds. Shrimp pond revenues are eventually outweighed by annual losses in income-generation from mangrove-supported activities (fishing, hunting and gathering, and wood extraction).

At a 12 percent real discount rate over a 50-year time horizon, the financial net present value (NPV) from partial conversion of mangroves for shrimp aquaculture was only 1.9-4.2 percent higher than mangrove conservation for near-shore fishing and harvesting of other wild products. For Bintuni Bay, the financial NPV was $701 million under the BAU scenario (mangrove conservation) and $731 million under the Alternative scenario (partial conversion for shrimp aquaculture). For Mimika, the financial NPV was $845 million under the BAU scenario and $861 million under the Alternative scenario. These small differences could easily be offset by other uncounted benefits, such as spawning and nursery areas for deep sea fish.

With a lower discount rate or longer time horizon, the financial NPVs were lower for partial mangrove conversion to aquaculture than for mangrove conservation. Just reducing the discount rate to three or seven percent resulted in a higher financial NPV for mangrove conservation in Mimika. The financial NPV was higher for mangrove conservation in Bintuni Bay when a three percent discount rate was combined with a 100-year time horizon.

When the social cost of carbon was valued at between $5 and $25 per tCO_2e in an economic analysis, mangrove conservation had a 5.5-5.6 percent higher NPV at the 12 percent discount rate than partial conversion to aquaculture. The economic desirability of mangrove conservation was even larger at higher values of the social cost of carbon, lower discount rates, and/or the 100-year time horizon. For example, at a $25/tCO$_2$e social cost of carbon, three percent discount rate, and 100-year time horizon, mangrove conservation had an economic NPV 18-22 percent higher than partial conversion to aquaculture.

A Monte Carlo analysis considered the effects of risk and uncertainty in population growth rates, shrimp pond revenues, and sustainable mangrove wood harvesting rates over 10,000 simulation runs. This analysis generated average NPV values and ranges within two standard deviations of the average.

The two study areas had a low historical risk of cyclones and tsunamis, which made them less representative of many mangrove areas in Indonesia and other countries. To make the findings more relevant for other locations, the Monte Carlo analysis also included an annual risk of 0.5 percent for cyclones and 0.5 percent for tsunamis. It also included probability distributions for the value of statistical lives lost and housing damage when a cyclone or tsunami occurred.

When no monetary value was placed on the carbon sequestration, mangrove conservation was only more valuable than partial aquaculture conversion in 23-37 percent of the model runs at the 12 percent discount rate. When the value of carbon sequestration was included, mangrove conservation was more valuable than partial conversion in 99.8-99.9 percent of the cases. The financial NPV for the Alternative scenario was most sensitive to the assumptions about shrimp pond revenues per hectare and the life of the shrimp pond, There was a considerable likelihood that the financial NPV could be higher for mangrove conservation than partial conversion due to the risks of lower profits from shrimp aquaculture or a shorter life for the ponds.

When the social cost of carbon was included, the lower economic NPV was almost entirely driven by the mangrove conversion rate. There was essentially no likelihood that the economic NPV could be higher for partial conversion to aquaculture than mangrove conservation when the social cost of carbon was at least $5/tCO$_2$e. The assumptions about the impacts of cyclones and tsunamis on human mortality and housing damage made virtually no difference to the financial or economic NPVs in this analysis.

This CBA did not value other mangrove ecosystem services (such as water quality improvement, biodiversity protection, and option and existence values) due to a lack of biophysical and economic data on these complex relationships. Inclusion of these additional ecosystem service values would increase the economic superiority of mangrove conservation over partial conversion to aquaculture.

1. INTRODUCTION

1.1. PURPOSE OF THE STUDY

Worldwide, there were approximately 81,000 square kilometers (km^2) of mangroves in 2014 (Hamilton and Casey 2016). However, approximately 35 percent of the world's mangrove forests were cleared and converted to other uses or substantially degraded between 1980 and 2000 (Giri *et al.* 2011). Mangrove clearing continued after 2000, although at a slower rate. Between 2000 and 2012, approximately two percent of the global area of mangroves was cleared (Hamilton and Casey 2016).

Indonesia lost 40 percent of its mangroves over the past three decades, an average annual loss rate of 1.13 percent. The main driver of mangrove loss in Indonesia has been conversion to aquaculture, particularly for shrimp ponds (Murdiyarso *et al.* 2015; Proisy *et al.* 2017; Richards and Friess 2016). Between 2000 and 2012, Indonesia lost approximately 749 km^2 of mangroves, constituting almost half of total global mangrove deforestation (Hamilton and Casey 2016). The main driver of mangrove conversion in Indonesia has been aquaculture, mainly for shrimp ponds. Mangrove conversion for aquaculture has expanded rapidly in the country since 2000. The area of active aquaculture ponds, including shrimp, finfish, and other shellfish, was 650,000 hectares (ha) in 2012. Shrimp aquaculture generated nearly 40 percent of total revenues from fisheries in Indonesia (Murdiyarso *et al.* 2015).

Indonesia has also experienced substantial deforestation from conversion of terrestrial forests to oil palm plantations (Vijay *et al.* 2016). There have been some reports of mangrove conversion to palm oil, particularly in North Sumatra. Approximately 5.17 percent of the 22,000 ha of mangroves cleared in Indonesia between 1990 and 2015 were converted to oil palm plantations (Basyuni and Sulistiyono 2018). Since mangroves occur only on sites with saline or brackish water, mangrove soils are generally unsuitable for oil palm plantations due to their salinity.

Mangroves can have national or local importance as sources of woodfuels, polewood, and nonwood products. In Indonesia, mangrove palm (*Nypa fruticans*) fronds are used as a roofing material and the sap from the inflorescence is used for foods and beverages. Mangroves serve as spawning and nursery areas for many finfish and shellfish fish species, which was one of the highest-valued benefits found in a similar analysis for Quelimane, Mozambique (Narayan *et al*. 2017). Mangroves can also help maintain water quality for human consumption and aquatic species and provide habitat for animals that are hunted. An important but harder to quantify benefit is that mangroves can reduce the risk of deaths, injuries, and infrastructure damage from cyclones or tsunamis due to their coastal protection benefits.

Mangroves also have global climate change mitigation benefits, providing carbon storage in biomass and soils and habitat for maintaining biodiversity. Donato *et al.* (2011) reported that mangroves can store as much as 14-73 billion metric tons of carbon dioxide equivalent (tCO_2e), including aboveground and belowground biomass and soil carbon. In comparison, the annual global carbon dioxide (CO_2) emissions in 2014 were 49 billion metric tons (WRI 2019).

The common perception of policy makers and resource users that mangroves have a relatively low value is one of the contributing factors in mangrove deforestation (Merrill and Edwardsen 2015). To test the validity of these perceptions, the USAID's Economic Policy (EP) and Global Climate Change Offices (GCC) asked the Climate Economic Analysis for Development, Investment and Resilience (CEADIR) Activity to conduct a cost-benefit analysis (CBA) of mangrove conservation versus partial conversion for shrimp aquaculture in Indonesia. Converting mangroves to agriculture would require costly earthmoving equipment and dike construction to exclude tidal water and reduce soil salt concentrations.

As a result, this analysis did not consider conversion of mangroves to oil palm plantations or other agricultural uses.

1.2. FOCUS OF THE STUDY

CEADIR selected two locations in Eastern Indonesia with some of the largest intact areas of mangroves in the world -- Bintuni Bay in West Papua and Mimika in Papua (FIGURE 1). However, there were some important differences between the two areas. Bintuni Bay has experienced decades of mangrove logging at a sustainable extraction rate, whereas there has been minimal anthropogenic impact on mangroves in Mimika. Both areas still had high productivity confirmed by measurements of mangrove carbon stocks (Alongi 2007).

Together, Papua and West Papua comprise the traditional area called Tanah Papua. Both regions had special autonomous status under Indonesian law (Indrawan *et al.* 2019). Tanah Papua had seven customary areas and at least 250 indigenous ethnic groups, including some uncontacted tribes. Tanah Papua held half of Indonesia's total biodiversity, including 20,000 plant species (55 percent endemics found nowhere else), 602 bird species (52 percent endemics), 125 mammal species (58 percent endemics), 329 species of reptiles and amphibians (35 percent endemics), 250 freshwater fish species, and 1,200 marine fish species (Indrawan *et al.* 2019).

Papua and West Papua had 38 percent of Indonesia's remaining primary forest in 2012 (Andriansyah *et al.* 2018). Annual deforestation rates in Papua increased from an average of 20,000 ha between 2001 and 2010 to over 100,000 ha in 2014-2015 (Chitra, Wijaya and Firmansyah 2017). Most of the deforestation was due to large-scale legal, logging and illegal cutting in legal concessions; road construction; oil and gas and mining; agriculture (especially oil palm), and urban and public infrastructure. Land use conflicts were also a problem in Papua, which had registered 102 mining permits, 25 palm oil licenses, and 35 logging permits covering 2,627,099 ha of forest that overlapped with conservation areas and protected forests (Indrawan *et al.* 2019).

Government policy targeted 70 percent of West Papua for natural forest conservation, but 64 percent of the land area had also been declared available for cultivation (Indrawan *et al.* 2019). In 2015, the Government of West Papua designated the area as the world's first conservation province. In 2018, the governor of West Papua decided to review all logging and plantation licenses.

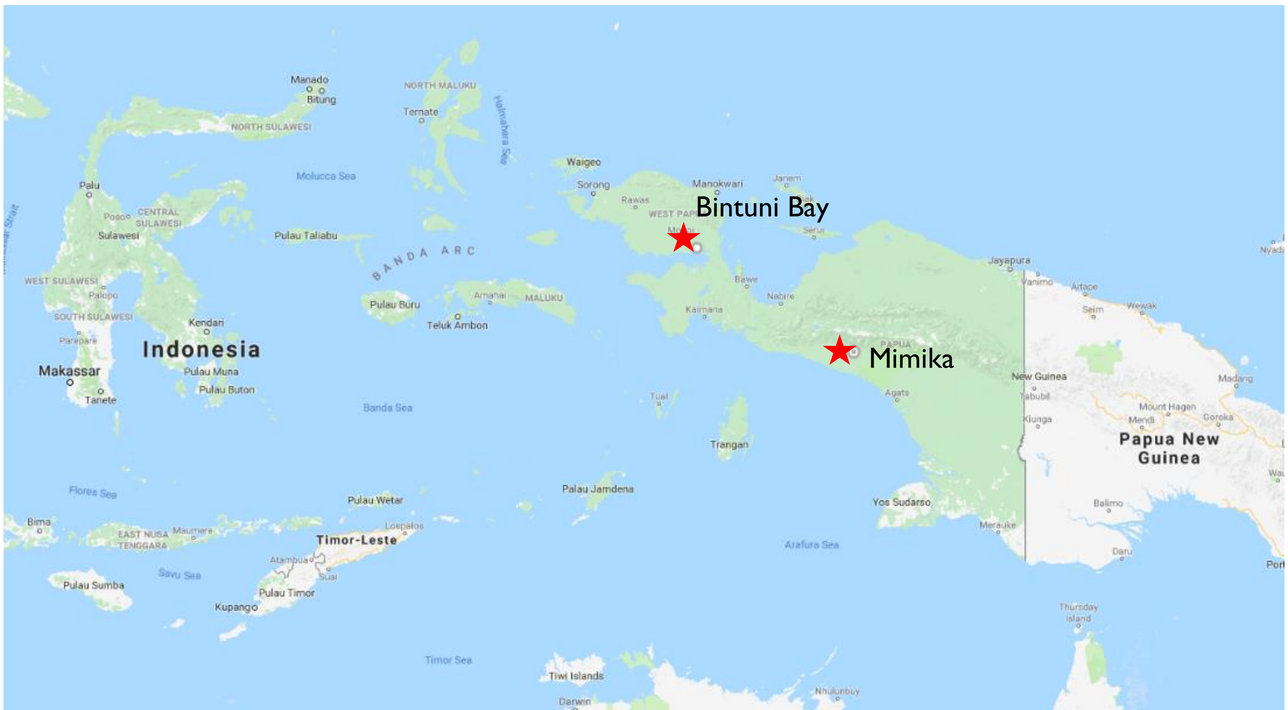
The mangrove harvesting concession for wood chip production in Bintuni Bay began operations in 1988. This concession has logged about 25 percent of the mangrove area, though it remains largely intact apart from forest structure changes. On March 21, 2019, the Provincial Parliament of West Papua passed a law placing sustainability at the center of development planning for the province and this included Bintuni Bay (Gribi 2019). The mangroves in Mimika District were largely intact and adjacent to another large mangrove area in the Asmat Regency.

This report discusses the methods and findings of the financial and economic analyses and Monte Carlo simulation modeling for the CBA. The *financial analysis* reflected the perspective of the local communities in Bintuni Bay and Mimika while the *economic analysis* adopted the national and global perspectives. This CBA built on the findings of an earlier CEADIR literature review on mangrove valuation (Smith *et al.* 2018).

Section 2 of this report describes the methods and assumptions used in the analysis. Section 3 presents the results of the cost-benefit analysis under the base case, sensitivity analysis, and Monte Carlo analysis. Section 4 summarizes the conclusions. Annex A contains the questionnaire used in the household survey of villagers in the Bintuni Bay and Mimika regions. Annex B contains the questions used in focus group discussions with key stakeholders. Annex C discusses the methods and findings from the survey and focus groups.

1.3. STUDY AREAS

FIGURE 1. BINTUNI BAY AND MIMIKA



Source: Google Maps.

1.3.1. BINTUNI BAY

Bintuni Bay is in the Bintuni Regency of West Papua Province, Indonesia. It had approximately 260,000 ha of mangrove forests in 2017. This comprised nine percent of the total mangrove area in Indonesia and 1.9 percent of the world total (Sillanpää *et al.* 2017). FIGURE 2 contains a satellite view of the Bintuni Bay Region.

The Bintuni Bay study area had a population of approximately 60,400 in 2014. Over 37,220 people lived in areas with mangroves, districts adjacent to mangroves, or districts with river connections to mangroves in 2014 (BPS Teluk Bintuni 2016). Over 40 percent of the population in the Bintuni Bay region had incomes below the poverty line in 2014 (2015). The Human Development Index (HDI) for Bintuni Bay was 0.604 in 2013 (BPS Teluk Bintuni 2016).[1] This index value was well below the national was average of 0.694 in 2017 (UNDP 2018). The Food Security and Vulnerability Atlas classified Bintuni

1 UNDP's Human Development Index health, life expectancy at birth, education (mean years of schooling for adults 25 years old or more and expected years of schooling for children entering school age), and the logarithm of gross national income per capita on a scale between zero and one. The HDI is the geometric mean of the index values for each of the three dimensions.

Bay as highly vulnerable to food insecurity due to the high poverty rate, inadequate access to electricity and clean water, and high proportion of underweight young children (WFP 2015). Only 11 percent of households had electricity and 28 percent lacked access to clean water (WFP 2015).

PT Bintuni Utama Murni Wood Industries (PT BUMWI) is a private company that has operated an 82,120 ha mangrove concession in the district since 1988. It produced mangrove wood chips for sale to pulp and paper producers. The Forest Stewardship Council has certified that this concession meets its criteria for sustainable forest management practices. PT BUMWI was the largest mangrove concession in the world with a sustainability certification (World Wild Fund for Nature 2018).

The district's economy was dominated by mining and manufacturing, which generated 91 percent of the value of final goods and services (BPS Teluk Bintuni 2016).[2] This included a large and expanding liquefied natural gas development. Only six percent of the value of final goods and services was from agriculture or fisheries, but these sectors were their important for the incomes of most households (BPS 2017). CEADIR conducted a household survey in the villages of Ausoy, Taroy, and Sidomakmur in Bintuni Bay.

FIGURE 2. Satellite View of the Bintuni Bay Region

Source: Google Earth, 2°22'19.64"S 133°27'37.44"E; image date -- December 31, 2016.

1.3.2. MIMIKA REGENCY

Mimika Regency is located in Papua Province. It had 244,000 ha of mangroves in 2016 (Aslan *et al.* 2016). This constituted 8.3 percent of the total mangrove area of Indonesia and 1.8 percent of the world total. The mangroves in Mimika were largely intact, although there has been some low-level

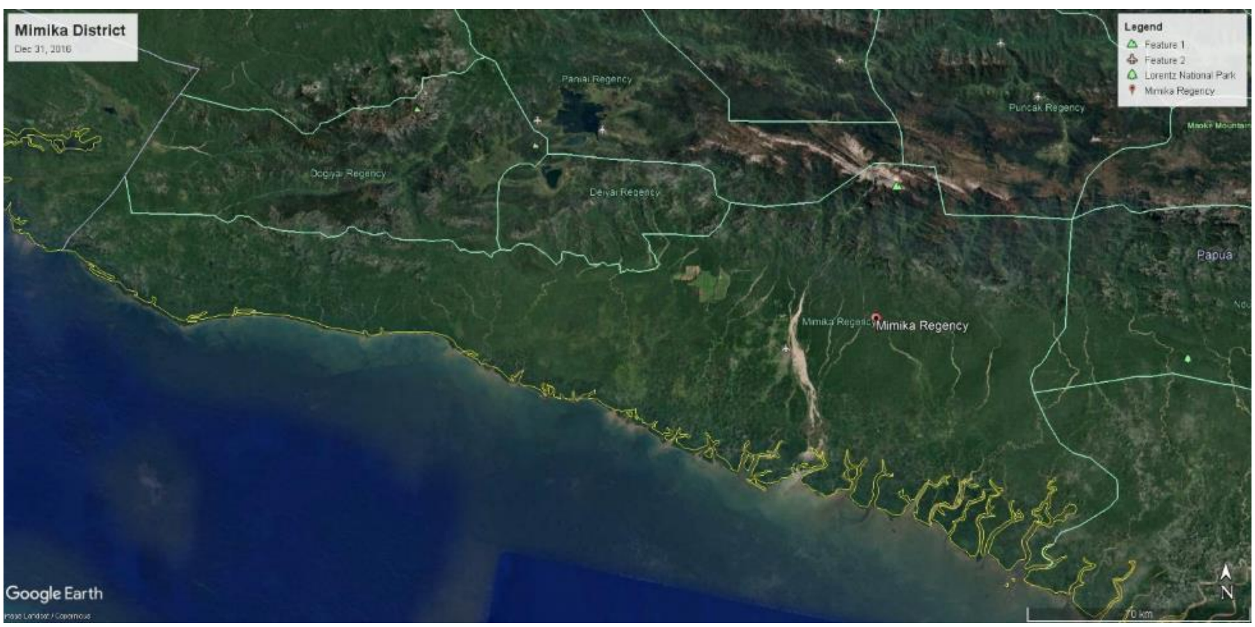
2 The BP Tangguh facility had an annual production capacity of 7,600,000 t of natural gas, which was expected to increase to 11.4 million tt (Energi Dan Sumber Mineral 2016).

pressure for conversions from infrastructure development, tailings disposal from the mining sector, and illegal logging. FIGURE 3 contains a satellite map of the province. The mangroves in Mimika are connected to mangrove areas in Kaimana District to the west and Asmat, Mappi, and Merauke Districts to the east. Together, these areas constituted the second largest contiguous mangrove in the world, after the Sunderbans in Bangladesh and India.

Mimika had a population of almost 224,000 in 2014. Over 92,300 people lived outside the city of Timika in districts within or adjacent to mangroves or along rivers connected to mangroves (BPS 2017). CEADIR team conducted a household survey in the villages of Pigapu, Atuka, and Ohotya in Mimika. Over 20 percent of the population in the Mimika region had incomes below the poverty line in 2014 (WFP 2015). The UNDP Human Development Index for Mimika was 0.704 in 2013, which was slightly above the national average (BPS Mimika 2015). The Food Security and Vulnerability Atlas classified Mimika as highly vulnerable to food insecurity due to the poverty rate, inadequate access to electricity and clean water, and proportion of underweight young children (WFP 2015). Seventy-one percent of households lacked access to clean water and 11 percent had no electricity (WFP 2015).

Mining contributed 92 percent of the value of final goods and services in Mimika Regency (BPS Mimika 2015). The Grasberg mine above Timika was the world's largest gold mine and second largest copper mine (Jamasmie 2017). However, most people in Mimika earned their income from fishing, hunting, and gathering.

FIGURE 3. Satellite View of Mimika



Source: Google Earth, 4°26'17.30" S 136°26'48.07" E; Image date -- December 31, 2016.

2. DATA COLLECTION AND ANALYSIS METHODS

2.1. FOCUS GROUPS AND HOUSEHOLD SURVEYS

CEADIR FACILITATED PARTICIPATORY GROUP DISCUSSIONS IN THREE VILLAGES IN EACH OF THE TWO STUDY AREAS AFTER THE GROUP DISCUSSIONS, THE FIELD TEAM CONDUCTED IN-PERSON HOUSEHOLD SURVEYS. CEADIR SURVEYED 120 HOUSEHOLDS IN THREE VILLAGES IN EACH OF THE TWO STUDY AREAS TO GATHER DATA ON THE COSTS AND REVENUES FROM ACTIVITIES SUPPORTED BY MANGROVES.

TABLE 1 compares the mangrove-related activities in the two areas. The survey included questions on the types and amounts of goods collected or harvested, frequency of the activity, amounts sold versus retained for home consumption, and selling prices. It also asked about collection or production costs per unit of the activity (such as a typical fishing trip). These costs included equipment, transport fuel, food, and water.

TABLE 1. Mangrove-Related Activities in the Two Study Areas

Mangrove Activity	Bintuni Bay	Mimika
Fishing	✓	✓
Farming	✓	✓
Hunting and gathering	✓	✓
Mangrove wood harvesting	✓	
Mangrove palm product harvesting	✓	

The team ecologist identified the commercial finfish and shellfish species that inhabited the local mangroves and tidal creek for at least a portion of their lives. Local people collected some mollusks from the mangroves by hand. They caught crabs and fish in traps, cast nets, and set nets. They used hooks and line for estuary and near shore fish. Hunters and gatherers harvested water snakes, boars, tree kangaroos, cockatoos, ant nests, turtles and turtle eggs, and medicinal herbs from mangrove ecosystems.

CEADIR estimated the average annual net revenues per household involved in each activity. The team calculated total net revenues from each activity separately for each study area. CEADIR assumed net revenues from each mangrove-supported activity under the Alternative scenario decreased linearly with the mangrove conversion rate. However, it is unlikely that this simplifying assumption accurately reflected the relationship between the ecosystem services provided by mangroves. Data were not available for more accurate modeling of these dynamics.

Table 2 contains survey data on the importance of mangrove-related activities for household incomes in the two study areas, including the revenues and costs of these activities for participating households.

TABLE 2. Importance of Activities Supported by Mangroves- for Household Incomes in Bintuni Bay and Mimika in 2018 (U.S. Dollars)

Activity	Bintuni Bay			Mimika		
	Percent of Households Involved	Average Revenues per Household	Average Costs per Household	Percent of Households Involved	Average Revenues per Household	Average Costs per Household
Fishing	45	447.8	261.8	59	212.5	81.9
Farming	7	72.3	4.7	12	13.7	0.1
Hunting and gathering	4	76.7	0.3	17	316.3	8.2
Mangrove wood harvesting	2	1,248.1	17.9	0	n/a	n/a
Mangrove palm product harvesting	1	2.8	0.0	0	n/a	n/a

2.2. COST-BENEFIT ANALYSIS DATA AND ASSUMPTIONS

CEADIR followed the USAID (2015) CBA guidelines, which used a 12 percent real discount rate to calculate the net present values NPVs in an economic analysis. CEADIR also conducted a sensitivity analysis for the economic CBA at two lower real discount rates -- three percent and seven percent. The USAID guidelines allow a different real discount rate in a financial analysis, based on the costs of loan financing to the client groups. The financial and economic analyses were based on a 50-year time horizon and a sensitivity analysis was conducted with a 100-year time horizon. The analysis was conducted in Indonesian rupiah (IDR) and converted to U.S. dollars at the July 29, 2018 exchange rate of IDR 14,371 per U.S. dollar (www.oanda.com)

The CBA considered two scenarios. The *Business-as-usual (BAU) scenario* assumed that the existing low mangrove conversion rate of 0.05 percent per year would continue at both sites. This conversion rate would result in a 2.8 percent reduction in the total mangrove area over 50 years. The business-as-usual scenario assumed that this conversion was for human settlements and infrastructure, rather than aquaculture.

The *Alternative scenario* assumed that 0.75 percent of the mangrove area would be converted to aquaculture each year. This would result in a 52 percent reduction in the mangrove area over 100 years, after accounting for the natural regeneration of mangroves in abandoned aquaculture ponds.

The financial analysis considered the costs and benefits of activities supported by the mangroves, including near-shore fishing, farming, hunting and gathering, wood harvesting, and collection of mangrove palm products for roofing materials, food, and beverages.

CEADIR estimated carbon sequestration rates associated with the area of mangroves under each scenario. The economic analysis placed a monetary value on the carbon sequestration benefits. The financial analysis did not include the value of carbon sequestration. Carbon is released when mangroves are converted to other land uses and the potential carbon sequestration from intact mangroves in future years is also foregone. CEADIR valued the greenhouse gas emission (GHG) reductions in the economic analysis to reflect the social cost of carbon. However, CEADIR did not value carbon sequestration benefits in the financial analysis because it may be difficult for the two communities to sell carbon credits.

Mangroves can reduce human mortality risks and property damage in coastal areas from cyclones and tsunamis. The two study areas for this CBA were atypical because their low historical risks of cyclones and tsunamis. To make the results of the economic analysis more applicable to other locations, CEADIR applied historical storm and tsunami damage rates from other parts of Indonesia in some scenarios in the economic analysis, but not the financial analysis. This report presents the results of the economic analysis with and without the coastal protection benefits that are likely to occur at other mangrove sites.

The financial analysis included tax payments as a cost to the local producers. The economic analysis did not count tax payments as a cost because they fund government services that contribute to the gross domestic product. CEADIR applied a 10 percent value-added tax to the costs of equipment and gasoline, but not food and water. There were no significant subsidies for mangrove products that required any adjustments in the economic analysis.

Mangroves help support the livelihoods of many local households and are generally not privately owned. Users do not generally have the rights to sell mangrove areas, but may capture some use or transfer rights for mangroves converted to aquaculture ponds. This CBA did not separate the returns to labor from the returns to the land and related water resources because the net income from mangroves is a joint product of the labor and the sites.

2.2.1. MANGROVE CONVERSION TO AQUACULTURE

The Mimika mangroves had a low baseline rate of conversion to aquaculture—0.05 percent per year (Merrill and Edwardsen 2015). Since no information was available on the baseline rate of mangrove conversion to aquaculture in Bintuni Bay mangroves, CEADIR assumed that it was similar to Mimika's rate.

PT BUMWI has managed an 82,120 ha mangrove concession in the Bintuni Bay region since 1988. In recent years, it has harvested approximately 500 ha of mangrove per year. The company could increase the harvested area to 2,100 ha and still maintain the 30-year rotation period required under the concession. PT BUMWI shared information on the costs and revenues of its concession. It has maintained the total mangrove area, except for a limited area needed for the log yard, wood chipping facility, and dock infrastructure.

The Business-as-usual case assumed no mangrove conversion for aquaculture, just a continuation of the low baseline conversion rate of 0.05 percent for human settlements and infrastructure. The Alternative scenario assumed a mangrove conversion rate of 0.75 percent per year for aquaculture eplus the 0.05 percent annual loss rate for other uses.

CEADIR relied on data on the net revenues from shrimp aquaculture in other areas of Indonesia because there has been little aquaculture to date in former mangrove areas of Bintuni Bay and Mimika. The average annual net revenue from aquaculture ponds in Demak in Central Java Province and Tanjung Panjang in Gorontalo Province was $861/ha in 2017 (Brown 2017). CEADIR adjusted this value to $886/ha to account for Indonesia's inflation rate between 2017 and 2018, based on data from Trading Economics (2019).

The usable life of a shrimp pond converted from mangroves is relatively short because poor management typically leads to water quality problems. Proisy *et al.* (2017) used remote sensing data to estimate an average life of 10 years for shrimp ponds in Bali, Indonesia. CEADIR assumed that new aquaculture ponds in Bintuni Bay and Mimika would remain productive for 10 years and then be abandoned. It would take 10 years for the mangroves to regrow after pond abandonment (Di Nitto *et al.* 2013). However, the regrowth rate could be slower if the abandoned ponds block tidal flows.

2.2.2. CARBON STOCKS AND SEQUESTRATION RATES

Murdiyarso *et al.* (2015) estimated that the baseline carbon stocks in mangroves were 5,122 tCO_2e/ha in Bintuni Bay and 4,676 tCO_2e/ha in Mimika. These estimates included the carbon in aboveground and belowground biomass as well as the soil.

Alongi (2012) estimated that undisturbed mangroves can sequester 6.38 tCO_2/ha per year.[3] If mangroves are converted to aquaculture ponds, 89 percent of the accumulated carbon stock will be released in the conversion (Kauffman *et al.* 2014). In addition, the annual carbon sequestration potential of cleared mangroves will be lost until the mangroves reach their mature height again after aquaculture pond abandonment.

In the economic analysis, CEADIR valued the carbon stored by mangroves at \$5/tCO_2e in the base case. The team also conducted sensitivity analyses at four other carbon prices—\$0, \$8, \$15, and \$25/tCO_2e. CEADIR selected this range of carbon prices after reviewing prices from the Regional Greenhouse Gas Initiative, the California Cap-and-Trade Market, and the voluntary carbon markets.

2.2.3. COASTAL PROTECTION BENEFITS

Mangroves typically provide some protection from extreme coastal events, such as tsunamis and cyclones. Laso Bayas *et al.* (2011) estimated an eight percent reduction in the severity of impacts of the 2004 tsunami in coastal areas with mangroves.

However, the two study areas included in this CBA lacked recent records of any from tsunami or cyclones damage The U.S. National Oceanic and Atmospheric Administration (NOAA) maintains a database summarizing historical records of the impact of tsunamis worldwide (NOAA 2018). This database showed many areas in Indonesia with tsunami impacts, none were listed in the Papua and West Papua Regions. The NOAA database contained historical, country-specific estimates of deaths and property damage from tsunamis. On average, a tsunami in Indonesia has caused 15 premature deaths and destroyed 400 houses.

The Australian Bureau of Meteorology (2018) has maintained a database of cyclone tracks in the southern hemisphere since 1969. None of the cyclones in this database have come close to the study areas for this CBA. Tropical cyclones are generally rare within five degrees of the equator due to the weak Coriolis effect from the Earth's rotation (Prentice and Hope 2007). Bintuni Bay and Mimika are both close to the equator, between three and four degrees south.

The base case assumed that the annual risk of either a tsunami or major cyclone was zero to reflect the historical experience in the study area. The team also conducted a sensitivity analysis based on more typical tsunami and cyclone risks in other parts of Indonesia. Mangroves may have a higher economic value of mangroves in places subject to these risks. CEADIR's Monte Carlo analysis assumed an annual

[3] CEADIR converted the original estimate of 174 grams of carbon per square meter per year to tCO_2/ha, using the conversion factors of 3.67 grams CO_2e per gram of carbon, 10,000 m per ha, and 1 million grams per metric ton.

risk of 0.5 percent for a tsunami and 0.5 percent for a major cyclone. The NOAA database did not provide any information on the average impacts of a cyclone in Indonesia. Consequently, CEADIR assumed that a cyclone would have the same average impact as a tsunami.

Ideally, the value of statistical lives lost prematurely would be included in a financial analysis or an economic analysis. However, it is difficult to place a monetary value on local community perceptions of these losses. As a result, CEADIR only valued statistical lives lost in the economic analysis. CEADIR estimated the societal value of a statistical life (VSL) using the following formula from Milligan *et al.* (2014):

$$VSL = 1.3732 \times 10^{-4} \times GDP\ per\ capita^{2.478}$$

This formula estimated a value of $87,365 per statistical life in Indonesia.

Housing prices varied in the two areas. In 2016, the average value of a house in Bintuni Bay was $8,017, based on data from the Bintuni Regency Department of Social Affairs. The average value of a house in Mimika was $16,814, based on data from the Mimika Regency Department of Transmigration and Social Housing. CEADIR updated these housing prices to $8,505 in Mimika and $17,837 in Bintuni Bay to account for inflation between 2017 and 2018 (Trading Economics 2019).

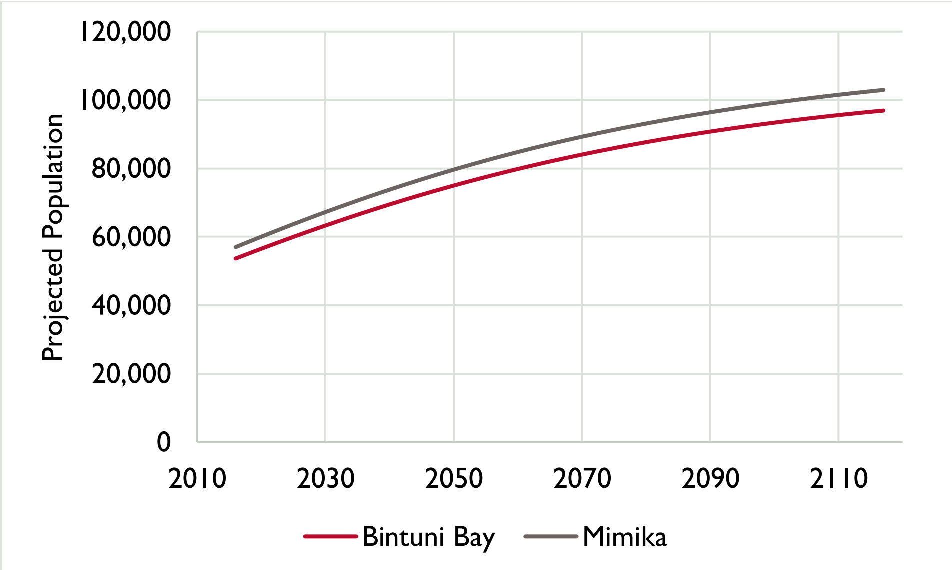
2.2.4. OTHER BENEFITS EXCLUDED FROM THE ANALYSIS

Mangrove ecosystems provide other tangible environmental services, such as improving local water quality and maintaining biodiversity. They may also provide other less tangible economic benefits from option and existence values. CEADIR did not include the value of the water quality or biodiversity benefits in the financial or economic analyses due to inadequate local data on the magnitude of these site-specific impacts. The analyses did not rely on benefit transfers based on values obtained from studies in other locations. CEADIR also excluded option and existence values due to concerns about the validity, reliability, and bias of contingent valuation approaches. As a result, the actual economic benefits are likely to be higher than the lower-bound estimates in this analysis.

2.2.5. POPULATION PROJECTIONS

The team assumed that the benefits from fishing and other resource-extracting activities were limited by the availability of labor rather than resource stocks. This assumption was realistic, as Bintuni Bay and Mimika had relatively large and stable mangrove areas. As a result, the CBA projected that the fish catch and harvests of other natural resources would increase in proportion to population growth. This assumption would not be appropriate for other locations with degrading or disappearing mangroves. CEADIR projected that the population in both locations would initially grow 1.4 percent per year and then slow to two percent per year over the study period. These parameters approximated the World Bank (2018) population projections for Indonesia that extended through 2050. CEADIR applied these population growth rate assumptions, rather than the World Bank projections, for two reasons. First, it made it easier to vary these assumptions for the Monte Carlo analysis. Second, it enabled CEADIR to extrapolate population projections for 50 and 100-year periods instead of through 2050.

FIGURE 4. Projected Population in Bintuni Bay and Mimika, 2018 to 2117



3. RESULTS OF THE COST-BENEFIT ANALYSIS

3.1. BASE CASE

The financial analysis only included monetary values for productive uses of resources supported by mangroves. The economic analysis also valued the carbon sequestration benefits from mangroves at \$5/tCO_2e**.** TABLE 3 shows the base case results of the financial and economic analyses in the business as usual (BAU) and Alternative scenarios. The financial analysis found that the NPV was only 1.9-4.2 percent lower for mangrove conservation than for partial conversion of mangroves to shrimp aquaculture. The differences between the two NPVs were small and the range of uncertainty in the assumptions was large.

Both study areas had extensive baseline areas of carbon-rich mangroves. Inclusion of carbon storage benefits in the economic analysis changed the preferred outcome to mangrove conservation, even at a relatively low carbon price. At a social cost of carbon of \$5/tCO_2e, the economic NPV of mangrove conservation was 5.5-5.6 percent higher than the NPV for partial conversion to shrimp aquaculture. The economic advantages of mangrove conservation were much larger at higher carbon prices.

In the base case, the economic analysis did not include any benefits from mangroves in reducing the impacts of tsunamis or cyclones on human mortality or coastal property damage due to the low historical risks of these events in the two study areas. However, the economic benefits of mangrove conservation would be higher in other parts of Indonesia or other countries that commonly face the risks of cyclones or tsunamis.

TABLE 3. Net Present Values in the Base Case, 50-Year Time Horizon, 12 Percent Discount Rate, and \$5/tCO2e Carbon Price (Millions of U.S. Dollars)

\$Type of Analysis	Bintuni Bay			Mimika		
	BAU Scenario	Alternative Scenario	Difference	BAU Scenario	Alternative Scenario	Difference
Financial	701	731	-30	845	861	-17
Economic	56,406	53,455	2,950	48,562	46,027	2,534

3.2. SENSITIVITY ANALYSIS

CEADIR CONDUCTED SOME SENSITIVITY ANALYSES TO ASSESS THE ROBUSTNESS OF THE CBA RESULTS UNDER DIFFERENT ASSUMPTIONS.

Table 4 lists the parameters that varied in the sensitivity analyses.

TABLE 4. Assumptions That Varied in the Sensitivity Analyses

Parameter	Base Case	Sensitivity Cases
Time horizon (years)	50	100
Real discount rate (percent)	12%	3% and 7%
Social Cost of Carbon ($/t$CO_2$e)	$5	$0, $8, $15, and $25

Table 5 presents the results of the sensitivity analysis for the financial and economic analyses for Bintuni Bay. Table 6 contains the sensitivity analysis results for Mimika. The social cost of carbon assumption had a large effect on the economic NPV values. The economic advantages of mangrove conservation (BAU scenario) over partial conversion to aquaculture (Alternative scenario) increased substantially at higher social costs of carbon. Lower discount rates increased the financial and economic superiority of mangrove conservation over partial conversion, even at a carbon price of zero.

The impact of a longer time horizon varied with the discount rate. At a 12 percent discount rate, there was little difference between the financial and economic NPVs for 50 years versus 100 years. At a three percent discount rate, the NPVs were much higher over 100 years than 50 years.

TABLE 5. Sensitivity Analysis Results for Bintuni Bay: Net Present Values (Millions of U.S. Dollars)

Discount Rate (Percent)	Time Horizon (Years)	Type of Analysis	Social Cost of Carbon	Bintuni Bay		
				BAU Scenario	Alternative Scenario	Difference
3%	50	Financial	$0	$2,393	$2,376	$17
		Economic	$0	$2,506	$2,473	$33
			$5	$176,306	$155,333	$20,973
			$8	$280,586	$247,049	$33,537
			$15	$523,906	$461,053	$62,854
			$25	$871,506	$766,772	$104,734
	100	Financial	$0	$3,121	$2,872	$249
		Economic	$0	$3,268	$2,990	$278
			$5	$218,133	$179,438	$38,696
			$8	$347,052	$285,306	$61,746
			$15	$647,863	$532,332	$115,531
			$25	$1,077,593	$885,227	$192,366
7%	50	Financial	$0	$1,215	$1,247	-$32
		Economic	$0	$1,273	$1,299	-$26
			$5	$94,087	$86,522	$7,565
			$8	$149,775	$137,656	$12,119
			$15	$279,714	$256,968	$22,747
			$25	$465,342	$427,413	$37,929
	100	Financial	$0	$1,272	$1,288	-$16
		Economic	$0	$1,333	$1,342	-$9
			$5	$97,411	$88,554	$8,857
			$8	$155,058	$140,882	$14,176
			$15	$289,568	$262,979	$26,588
			$25	$481,725	$437,405	$44,320

TABLE 5. (Continued)

Discount Rate (Percent)	Time Horizon (Years)	Type of Analysis	Social Cost of Carbon	Bintuni Bay		
				BAU Scenario	Alternative Scenario	Difference
12%	50	Financial	$0	$701	$731	-$30
		Economic	$0	$734	$762	-$28
			$5	$56,406	$53,455	$2,950
			$8	$89,809	$85,071	$4,737
			$15	$167,749	$158,842	$8,907
			$25	$279,093	$264,229	$14,864
	100	Financial	$0	$704	$733	-$29
		Economic	$0	$737	$764	-$27
			$5	$56,609	$53,585	$3,024
			$8	$90,132	$85,277	$4,855
			$15	$168,352	$159,225	$9,127
			$25	$280,095	$264,866	$15,229

TABLE 6. Sensitivity Analysis Results for Mimika: Net Present Values (Millions of U.S. Dollars)

Discount Rate (Percent)	Time Horizon (Years)	Type of Analysis	Social Cost of Carbon	Mimika		
				BAU Scenario	Alternative Scenario	Difference
3%	50	Financial	$0	$2,887	$2,783	$104
		Economic	$0	$2,980	$2,863	$117
			$5	$152,039	$134,002	$18,037
			$8	$241,474	$212,685	$28,790
			$15	$450,157	$396,279	$53,878
			$25	$748,276	$658,557	$89,719
	100	Financial	$0	$3,767	$3,366	$401
		Economic	$0	$3,888	$3,463	$425
			$5	$188,358	$155,056	$33,302
			$8	$299,039	$246,012	$53,028
			$15	$557,296	$458,242	$99,055
			$25	$926,235	$761,427	$164,808
7%	50	Financial	$0	$1,466	$1,464	$1
		Economic	$0	$1,513	$1,507	$6
			$5	$81,059	$74,557	$6,502
			$8	$128,788	$118,387	$10,400
			$15	$240,153	$220,658	$19,495
			$25	$399,246	$366,759	$32,488

TABLE 6. (Continued)

Discount Rate (Percent)	Time Horizon (Years)	Type of Analysis	Social Cost of Carbon	Mimika		
				BAU Scenario	BAU Scenario	BAU Scenario
7	100	Financial	$0	$1,535	$1,512	$22
		Economic	$0	$1,584	$1,556	$28
			$5	$83,944	$76,329	$7,615
			$8	$133,360	$121,193	$12,167
			$15	$248,664	$225,874	$22,789
			$25	$413,384	$375,420	$37,964
12%	50	Financial	$0	$845	$861	-$17
		Economic	$0	$872	$886	-$15
			$5	$48,562	$46,027	$2,534
			$8	$77,175	$73,112	$4,064
			$15	$143,941	$136,309	$7,632
			$25	$239,321	$226,591	$12,730
	100	Financial	$0	$849	$864	-$15
		Economic	$0	$876	$890	-$14
			$5	$48,738	$46,140	$2,598
			$8	$77,455	$73,290	$4,164
			$15	$144,461	$136,641	$7,820
			$25	$240,185	$227,142	$13,043

3.3. ASSUMPTIONS AND RESULTS OF THE MONTE CARLO ANALYSIS

CEADIR used Oracle's Crystal Ball software (an add-on to Excel) for a Monte Carlo analysis that modeled the effects of risks and uncertainty on the outcomes of the mangrove management decisions. The team defined the key risks and uncertainties and estimated the base value, range of uncertainty, and probability distribution for these parameters. The software calculated the potential financial and economic outcomes over 10,000 simulation runs. Each simulation run used a specific value for each parameter based on the range and probability distribution. The software calculated the outcomes for each simulation and the range and average NPV across the whole set of runs.

Table 7 lists the assumptions that varied in the Monte Carlo analysis. CEADIR selected appropriate probability distributions for the various parameters. The analysts assumed a normal probability distribution when available data allowed estimation of the standard deviation of the distribution. A triangular distribution was used when the base value was most likely, the probability of other values declined linearly, and data did not support estimation of the standard deviation. CEADIR selected a log-normal distribution for risks that have a relatively low probability, but severe impacts (such as premature deaths and housing damage from tsunamis and cyclones.

The Monte Carlos analysis estimated the probabilities of obtaining larger or smaller differences in the NPVs between the BAU and Alternative scenarios as a result of the combined effects of varying the key parameters. A positive difference reflected a higher NPV for the BAU scenario. Conversely, a negative difference indicated a lower NPV for the mangrove conservation scenario.

Table 7 shows the assumptions that varied in the Monte Carlo Analysis and their assumed probability distributions, base values, ranges, and data sources. The Crystal Ball software computed the average financial and economic NPVs over the 10,000 simulation runs.

Table 8 contains the Monte Carlo results for the financial and economic analyses expressed as averages ranges within two standard deviations of the averages. These ranges accounted for 95 percent of the variation in the distribution of results. The Monte Carlo analysis found higher financial NPVs for partial conversion for aquaculture than for mangrove conservation at both sites. However, there was substantial overlap in the ranges of the financial NPVs in the Alternative and BAU scenarios. The high end of the range for the BAU scenario for Bintuni Bay was $834 million while the low end of the range for the Alternative scenario was $581 million. Therefore, there was a 23 percent probability that the financial NPV for Bintuni Bay could be higher under the BAU scenario than the Alternative scenario. There was a 35 percent probability that the financial NPV for Mimika could be higher under the BAU scenario than the Alternative scenario.

However, the economic NPVs were higher for mangrove conservation than partial conversion to aquaculture at both sites. Furthermore, the economic NPV ranges did not overlap for the BAU and Alternative scenarios. For example, the high end of the range for the economic NPV of the Alternative scenario in Bintuni Bay was $54.3 billion, which was below the low end of the range for the BAU scenario, $56.3 billion. Consequently, there was a 95 percent confidence level at both sites that the economic NPV was higher for mangrove conservation than partial conversion to aquaculture.

TABLE 7. Assumptions That Varied in the Monte Carlo Analysis

Assumption	Distribution Shape	Base Value	Range	Data Source
Population growth rate	Triangular	1.4%/year	0.0-2.8%/year	World Bank (2018)

Assumption	Distribution Shape	Base Value	Range	Data Source
Population growth deceleration rate	Triangular	2.0%/year	0.0–4.0%/year	World Bank (2018)
Annual net revenue from shrimp ponds	Triangular	$886/ha	$0–$1,722/ha	Brown (2017)
Useful life of a shrimp pond	Triangular	10 years	2–18 years	Proisy *et al.* (2018)
Annual mangrove logging rate in a sustainable concession	Triangular	500 ha	400–1,000 ha	CEADIR estimate based on PT BUMWI data
Mangrove fishing revenue annual variation factor	Triangular	1	0.8–1.2	CEADIR estimate
Annual probability of a tsunami	Triangular	0.0%	0.0–0.5%	NOAA (2018)
Annual probability of a major cyclone	Triangular	0.0%	0.0–0.5%	Australian Bureau of Meteorology (2018)
Average number of premature deaths from a tsunami	Log-normal	15	Standard deviation = 15	NOAA (2018)
Average number of premature deaths from a cyclone	Log-normal	15	Standard deviation = 15	Assumption extrapolated from tsunami data
Average number of houses destroyed by a tsunami	Log-normal	400	Standard deviation = 400	NOAA (2018)
Average number of houses destroyed by a cyclone	Log-normal	400	Standard deviation = 400	Assumption extrapolated from tsunami data

TABLE 8. Monte Carlo Analysis Results (Millions of U.S. Dollars)

	Financial NPVs		Economic NPVs	
	BAU	Alternative	BAU	Alternative
Bintuni Bay	708 (581-834)	735 (600- 69)	56,413 (56,284-56,658)	53,458 (52,639--54,278)
Mimika	847 (735- 59)	861 (742-980)	48,564 (48,450- 8,679)	46,028 (45,332- 6,724)

Table 9 shows the effects of changing individual parameters of the Monte Carlo analysis on the financial NPVs for both sites. Table 10 shows the effect of changes in the individual parameters of the Monte Carlo analysis on the economic NPVs. Positive values indicated increases in the NPV of the BAU scenario versus the Alternative scenario. Two parameters (annual net revenues per ha of aquaculture and the average life of a shrimp pond), accounted for over 97 percent of the difference in the financial NPV between the two scenarios in both areas. Lower values for these two parameters increased the NPV of mangrove conservation while higher values were more favorable for partial aquaculture conversion.

The financial NPV results were somewhat sensitive to the population growth rate and the annual revenue adjustment factor for fishing. A higher population growth rate increased the value of all mangrove-supported production. A higher annual revenue adjustment factor for fishing increased the value of mangroves. However, the financial NPV of mangrove conservation was far less sensitive to the fishing parameters than the aquaculture parameters.

TABLE 9. Effects of Changing Monte Carlo Analysis Parameters on the Financial Net Present Values (Percentages)

Parameter	Bintuni Bay	Mimika

Annual net revenues of aquaculture per ha	-81.70%	-81.90%
Shrimp pond life	-16.10%	-17.10%
Population growth rate	1.5%	0.3%
Annual revenue adjustment factor for fishing	0.7%	0.7%

The mangrove conversion rate assumption had the largest impact on the economic NPV results due to the value of the carbon sequestration benefits when the social cost of carbon was positive. As mangrove conversion rate increased, the economic NPV for partial aquaculture conversion decreased except when the social cost of carbon was zero.

TABLE 10. Effects of Changing Monte Carlo Analysis Parameters on the Economic Net Present Values (Percentages)

Parameter	Bintuni Bay	Mimika
Mangrove conversion rate	99.40%	99.10%
Annual net revenues of aquaculture per ha	-0.40%	-0.60%
Shrimp pond life	-0.20%	0.30%

4. CONCLUSIONS

Shrimp ponds in former mangrove areas typically have short usable lives of 10 years or less. It can take ten years or more for mangroves to be re-established in abandoned shrimp ponds. Shrimp pond revenues are eventually outweighed by annual losses in income-generation from mangrove-supported activities (fishing, hunting and gathering, and wood extraction).

At a 12 percent real discount rate over a 50-year time horizon, the financial net present value (NPV) from partial conversion of mangroves for shrimp aquaculture was only 1.9-4.2 percent higher than mangrove conservation for near-shore fishing and harvesting of other wild products. For Bintuni Bay, the financial NPV was $701 million under the BAU scenario (mangrove conservation) and $731 million under the Alternative scenario (partial conversion for shrimp aquaculture). For Mimika, the financial NPV was $845 million under the BAU scenario and $861 million under the Alternative scenario. These small differences could easily be offset by other uncounted benefits, such as spawning and nursery areas for deep sea fish.

With a lower discount rate or longer time horizon, the financial NPVs were lower for partial mangrove conversion to aquaculture than for mangrove conservation. Just reducing the discount rate to three or seven percent resulted in a higher financial NPV for mangrove conservation in Mimika. The financial NPV was higher for mangrove conservation in Bintuni Bay when a three percent discount rate was combined with a 100-year time horizon.

When the social cost of carbon was valued at between $5 and $25 per tCO_2e in an economic analysis, mangrove conservation had a 5.5-5.6 percent higher NPV at the 12 percent discount rate than partial conversion to aquaculture. The economic desirability of mangrove conservation was even larger at higher values of the social cost of carbon, lower discount rates, and/or the 100-year time horizon. For example, at a $25/$tCO_2e$ social cost of carbon, three percent discount rate, and 100-year time horizon, mangrove conservation had an economic NPV 18-22 percent higher than partial conversion to aquaculture.

A Monte Carlo analysis considered the effects of risk and uncertainty in population growth rates, shrimp pond revenues, and sustainable mangrove wood harvesting rates over 10,000 simulation runs. This analysis generated average NPV values and ranges within two standard deviations of the average.

The two study areas had a low historical risk of cyclones and tsunamis, which made them less representative of many mangrove areas in Indonesia and other countries. To make the findings more relevant for other locations, the Monte Carlo analysis also included an annual risk of 0.5 percent for cyclones and 0.5 percent for tsunamis. It also included probability distributions for the value of statistical lives lost and housing damage when a cyclone or tsunami occurred.

When no monetary value was placed on the carbon sequestration, mangrove conservation was only more valuable than partial aquaculture conversion in 23-37 percent of the model runs at the 12 percent discount rate. When the value of carbon sequestration was included, mangrove conservation was more valuable than partial conversion in 99.8-99.9 percent of the cases. The financial NPV for the Alternative scenario was most sensitive to the assumptions about shrimp pond revenues per hectare and the life of the shrimp pond, There was a considerable likelihood that the financial NPV could be higher for mangrove conservation than partial conversion due to the risks of lower profits from shrimp aquaculture or a shorter life for the ponds.

When the social cost of carbon was included, the lower economic NPV was almost entirely driven by the mangrove conversion rate. There was essentially no likelihood that the economic NPV could be higher for partial conversion to aquaculture than mangrove conservation when the social cost of carbon was at least $5/$tCO_2e$. The assumptions about the impacts of cyclones and tsunamis on human mortality and housing damage made virtually no difference to the financial or economic NPVs in this analysis.

This CBA did not value other mangrove ecosystem services (such as water quality improvement, biodiversity protection, and option and existence values) due to a lack of biophysical and economic data on these complex relationships. Inclusion of these additional ecosystem service values would increase the economic superiority of mangrove conservation over partial conversion to aquaculture.

ANNEX A. METHODS AND FINDINGS FROM THE HOUSEHOLD SURVEYS AND GROUP INTERVIEWS

The field team conducted focus group discussions followed by individual household surveys. Annex B lists the discussion questions for the focus groups. Annex C contains the survey questionnaire.

The focus group discussions included 116 people. Twenty percent were women, though women only participated in the villages of Ausoy (Bintuni Bay) and Pigapu (Mimika). Almost all of the participants in Pigapu village were women. Overall, the participants were mainly fishers, traders, and village leaders, who were able to provide a comprehensive picture of mangrove uses and seasonality in the village. The focus group participants provided their views on the benefits of mangroves and sketched village maps showing settlements, roads, facilities, and the locations of mangroves.

CEADIR then surveyed 120 households to assess the direct use values of mangrove-related products and indirect values of mangrove services. Although the households were randomly selected, the field team made greater efforts to include women as respondents in the villages where women had not been in the focus group discussions. Table A-1 shows the locations of the surveyed households that were randomly selected, which included 75 men and 45 women. Approximately 31 percent of the respondents were between 31 and 40 years of age and over 28 percent were older than 50.

Nearly 86 percent of the respondents depended on fisheries as their main source of income. Approximately 11.7 percent earned most of their household income from paid employment or small-scale enterprises. Only 1.7 percent earned most of their income from hunting or gathering and 0.8 percent from farming.

TABLE A-1. Respondent Characteristics

Sites/ Villages	Population	Total Households	Surveyed Households	Percent of Area Households Surveyed
Bintuni Bay				
Ausoy	1,747	329	28	8.51%
Sidomakmur	1,276	187	20	10.70%
Taroy	537	97	12	12.37%
Mimika District				
Pigapu	411	97	21	21.65%
Atuka	909	194	20	10.31%
Ohotya	562	105	19	18.10%
Total			**120**	

The survey included questions on the specific products obtained from mangrove areas, seasonality of harvesting, amounts sold, amounts consumed within the household, and the sales prices received by the households. For products that were not sold in markets, the field team obtained data on the prices of close substitutes from household interviews and market price checks. The survey included questions on the amount and species of fish caught, prices received by the fishing households, the costs of fuel and maintenance for fishing boats and fishing gear, and the labor time spent in fishing. This analysis did not separate the returns from unpaid labor and land and related water resources. The costs of paid laborers were deducted along with other input costs. CEADIR used this information to estimate the net annual returns from near-shore fisheries.

The survey also asked about other products collected from the mangroves, including wood, shellfish, medicinal plants, wild game, and nypa palm. It include questions on the amount and types of products obtained, seasonality of collection and use, amounts sold, amounts consumed within the household, and seasonal variation in sales prices. It also asked households about storm and tsunami damage costs such as property damage and lost cash or in-kind income. The survey also included questions on the sociocultural value of mangroves.

ANNEX B: DISCUSSION QUESTIONS FOR THE FOCUS GROUPS

Preparation:

1. Prepare for logistic, picture of mangrove tree
2. Invite participant through village leaders
3. Women and men groups are separated

Process:

1. Introduction (Procedure, purpose, voluntary)
2. Facilitator prepare picture of mangrove tree and distribute color papers for game during FGD (yellow for root, blue for branch, green for leave)
3. Questions:
    a. What is the use of mangrove?
    b. Root, branch, leave and fruit. Other species in mangrove forest (Please stick the color paper on the mangrove tree)
    c. How do you collect those?
    d. Since when do you collect them?
    e. What is the purpose of collecting them?
        - Consumption/ for sell?
        - Quantity
        - Price
    f. Would you rank the most important for your family?
    g. What is the cause for destruction?
        - Is there any?
        - What is the cause?
        - Who did?
        - What is impact to community?
    h. Disaster
        - Any? Flood/storm?
        - Frequency
        - Intensity
        - How did you cope?
        - Is there any support from outsiders?
    i. Ecotourism
        - Is there any visitor?
        - When/purpose?
        - Is there any direct benefit for community? In what form?
    j. Conversion
        - Is the any conversion to other form of use? Concession/plantation/settlement?
        - Is there any compensation received? What form?
        - What do you think of mangrove? What does it mean to your life?
    k. Water?

- Source
- Quality: tasty/color/smell?
- Quantity: # of family use the water? Frequency
- The use of water:
- If the quality is not good, what do you do before using it?
- Are there any diseases related to water? How long does it need to recover from the water related disease?

l. Habitat for indigenous people
   - What value related to mangrove?
   - Do you know the history of mangrove forest in this area?
   - Any ritual related to mangrove?
   - What do you think of mangrove forest?
   - Are there any local leaders who know about the cultural value of mangrove forest?

m. Appreciation of species
   - Is there any story about animal/plant?
   - Any taboo related those animal and plant?
   - What is the taboo?
   - Still exist?
   - Any animal/plant used for ritual?

4. Facilitators are taking notes while discuss.
5. Facilitators greet the participants

Post

- Facilitators clean up the information
- Verify the information with local leaders

ANNEX C. HOUSEHOLD SURVEY QUESTIONNAIRE

General Information

A. Respondents Information

- Name :
- Gender and Age :
- Village :
- Source of Livelihoods :

Checklist (√)

Source of Livelihoods	Fishers	Farmers	Hunters	Others (…..?)

B. Household:

1. Number of household members :
2. In detail:

Wife	: …………………………….	(person)
Children	: …………………………….	(person)
Siblings	: …………………………….	(person)

3. Family Information

Relationship	Gender	Age (year)	# of family in one house	Education level	Marriage status (married/not)	Source of livelihoods
Head of household						
Spouse						
Child 1						
Child 2						
Child 3						
Child 4						
Child 5						
Siblings						

4. House status (own, rent, other):

<table>
<tr><th rowspan="2">House status (√)</th><th>Own</th><th>Rent</th><th>Owned by family</th><th>Given (by who?)</th><th>Other</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">How long have you lived in this house?</td></tr>
<tr><td colspan="6">Price of house?</td></tr>
<tr><td colspan="6">Has it been renovated?</td></tr>
</table>

C. Income, Expenditure and Assets

1. What do you collect from mangrove forests?

Activity	Timber	Fruit	Leaves	Fish	Shrimp	Shells	Crab	Others
Check list (√)								
Uses? (e.g., food, housing, or medicine)								

D. Source of Livelihoods: Fish

1. What fish do you catch? (Fish, shrimp, mud crab)

2. What is the purpose of fish caught? Consumption, share with families, sold where and the price?

3. Checklist (√)

Species of fish	Consumed (%)	Shared (%)	Sold (%)	Sold to where?
Scad				
Mullet				
Snapper				
Shrimp				
Shells				
Crab				

4. The quantity of fish per one catch in average: bunch/kg (please convert to kg)

5. How many weeks had a medium catch last year?

6. What is the highest catch last year?

7. How many weeks of high catch last year?

8. What is the lowest catch over a week?

9. How many weeks of low catch last year?

10. How many weeks with no fishing?

11. How many weeks had a medium catch last year?

12. Fish quantity over a season

Species of fish	Average catch (bunch/kg)	Price (IDR in kg/piece)	Time of average catch			Highest catch (bunch/kg)	Time of highest catch			Price (IDR in kg/piece)	Lowest catch (bunch/kg)	Time of lowest catch			Price
			Days/ week (D)	Weeks (W)	Months (M)		D	W	M			D	W	M	
Scad															
Mullet															
Snapper															
Shrimp															
Crab															
Other shellfish															

13. How long does it take to catch fish? (ask about seasonality in catching fish)

Item (fish/collecting shrimp/shells/crab)	Hour	How was the frequency of catch last year?		
		Is it the same with this year?	Better catch	Less catch

14. What gear is used for catching fish?

15. What is the price of the gear?

    - If it is self-made, and how long did you make it?

Please check list (√)

Gear	Material	Duration	Market price	Note

16. Do you use a canoe?

17. Who owns the canoe?

18. How much is the cost of the canoe?

19. How long does the canoe last?

20. If you rent, how much is the rental fee? For what unit of time?

21. Operational cost for catching the fish? For what unit of time?

    - Fuel:

    - Logistics (Food, cigarettes, betel nuts)

22. Checklist (√)

Canoe? (Yes/No)	Canoe ownership (owned/rent)	Canoe price (IDR)	If self-made, the cost? (IDR)	Rental fee (IDR)	Fuel (IDR)	Logistic (Food, cigarette, beetle peanut) IDR

23. Who catches fish?

- Who is the most proficient at catching fish/collecting shells/crab/shrimp?
- Who else joins the trip?

24. Checklist (√)

Item (fish/collecting shrimp/shells/crab)	The main actor		Labor/Crew
	Male	Female	

D. Source of Livelihoods: Hunting/Gathering

1. What animal do you hunt?

   - Quantity?

2. Do you collect fruit from mangrove forests?

   - What kinds?

   - Quantity per one collection?

   - Any range of quantity collected through a year?

3. Do you collect any medicine from the mangrove forest?

4. If you or family members are sick, where do you go? Traditional healers/doctor?

5. Do you collect ant nests?

   - Frequency?

   - What is the purpose?

   - Quantity per one collection?

   - Any range of quantity collected through a year?

4. Do you collect any other food from the mangrove forest?

5. Checklist (√)

Check list (√)	Hunting (Yes/No)	Fruit (Yes/No)	Medicine (Yes/No)	Ant Nest (Yes/No)	Others	Quantity (Kg)	
						One collection	How many times per year?
Yes/No							
What?							

6. What gear do you use for hunting/collecting material from mangrove forests?

7. What is the cost of the gear?

8. How long does the gear last?

9. Check list (√)

Gear for hunting	Gear for collecting fruit	Gear for collecting medicinal plant	Gear for collecting ant nest	Gear use for other purpose	Price estimation	How long the gear lasts?

10. What is the purpose of hunting/collecting? Selling/consumption?

11. What is the selling price?

12. Checklist (√) (Subsistence (Sub.), Social (Soc.), Commercial (Comm.)

	Hunting			**Collecting**			**Fishery**			**Rice estimation**			**Price estimation** ***Information could be collected from traders***	**Sold/ consumed**
	Sub.	**Soc.**	**Comm.**	**Sub.**	**Soc.**	**Comm.**	**Sub.**	**Soc.**	**Comm.**	**Sub.**	**Soc.**	**Comm.**		
Item														
Item														

10. Where do you harvest/hunt?

11. How long does it take to hunt/collect from mangrove forests? How many times per year do you hunt?

12. Who is the main actor in hunting/collecting from mangrove forests?

13. Who else participates in this activity?

Checklist (√)

	Location	Duration	Who is the main actor	Who participate in the trip?
Hunting				
Collecting fruit				
Collecting medicinal plant				
Collecting ant nest				
Collecting other things for food				

E. Sources of Livelihoods: Farming

1. Do you have farming plot?
    - Number of ha:
    - Own? Rent?
    - What is the rental system?

2. What crops do you grow?

3. What crops do you harvest the most?

4. What is the cost to harvest?

5. Checklist (√)

Crops	Areas (ha)	Status			Harvesting Frequency	Quantity Harvested	Cost of Farming
		Own	Rent	Rental System			

6. What gear is used for farming?

7. What is the price of the gear?

   - How often does it need to be replaced?

8. Checklist (√)

Gear	Cost	Life of Gear	Price (IDR) – Market Price

9. Is the harvest for family consumption or sold?

- Where do you sell?

- What is the price?

Checklist (√)

Farm	Cassava	Banana	Sweet Potato	Yam	Others
Check list					
Quantity (kg)					
Consumption/sold?					
Where to sell?					
What is the price? (IDR)					

10. How long does it take to farm? How often do you go to farming area?

11. Who farms?

12. Who participates in the farming?

13. Checklist (√)

Duration	Hour	Days	Week	Frequency per month	Labor

F. Sources of Livelihood: Other

1. Do you collect wood? Yes/No

    a. What do you use the wood for?

    b. When do you collect them?

    c. Quantity over time?

    d. If it is sold, how much is the price?

e. Where do you sell?

2. Checklist (√)

The use of wood (fuel/ construction/canoe/etc.)	Quantity/one trip (kg)	Frequency			Price	Where to sell
		Days/week	Week/month	Month/year		

3. Do you have other activities?

    - Collecting Honey/fruit/nypa?

4. When do you collect them?

5. What is the quantity? (Kg)

6. What is the purpose of collecting them? Consumption/sold?

    - Where do you sell?
    - Price?

7. Checklist (√)

Other Activities	Purpose			Frequency Collecting			Quantity (Kg) per Trip	Price (IDR)	Where to Sell
	Subsistence	Social	Commercial	Days/week	Week/month	Month/year			
Honey									
Nypa									
Other									

8. What gear do you use?

9. What is the price of the gear?

Gear	Life of the gear	Price (please check in the market)

10. Where do you conduct the activity?

11. Time for conducting the activity

    - Frequency per week?

    - Frequency per month?

    - For how long?

12. Who is the main actor?

13. Who participates?

14. Checklist (√)

Location	Hour	Days	Week	Month/Year	Main actor	Labor involved

15. Are there any family members who work in other places?

   - If yes, where and what is the role?
   - Income:
   - Number of days work/month:

16. Have you received any support from others?

   - From where?
   - What type of the support?
   - If it is cash, how much?
   - If not cash, what type?

(Notes for surveyor for family income, please refer to excel)

G. Expenditures

1. What is the family expenditure for these items? (Please calculate per month)

    - Food:
    - Betel nut/cigarettes:
    - Cloth:

2. Education?

    - SD/Primary school:
    - SMP/Junior High School:
    - SMA/Senior High School:

3. Utilities and fuels? (per month)

    - Electricity:
    - Water:
    - Fuel: Rp
    - Other:

4. Expenditure for social purpose (related to customary, religious activity, and other)

    - Frequency per year:
    - Type of activity:
    - How much do you spend for this purpose?

5. Savings

    - Cash:
    - Jewelry:

- Land: area (ha)

H. Water Management: Improved Water Quality

1. Source of water?

2. Quality?

    - Quality = tasty/smell/colour?

    - Quantity = how many family members collect the water from the same source? Frequency?

3. What do you use the water for?

    - Washing : without process?

    - Bathing : process?

    - Drink : process? Salt?

4. If the quality is not good:

    - Do you know the cause?

    - Any suffer from water? Please check to health staffs

    - What is the disease related to water?

I. Indigenous People Rights and Roles

1. What value does the community have related to mangroves?

2. Do you know the relationship your ancestor with mangroves?

3. Is there any customary ritual related to mangroves?

4. What do you think of mangrove forest?

(If they do not know please ask if any local leaders know about this)

J. Appreciation of species

1. Is there any story about mangroves?

2. Is there any taboo with the animal/plant?
3. Why is there such a taboo?
4. Is the animal/plant still exist?
5. Is the animal/plant still used for customary ritual?

REFERENCES

Alongi, Daniel. 2007. "Mangrove Forests of Papua." *Ecology of Papua* 1: 824-857.

———. 2012. "Carbon Sequestration in Mangrove Forests." C*arbon Management* 3 (3): 313-322. DOI: 10.4155/cmt.12.20

Andriansyah, Muhamad; Rizky Firmansyah; Arief Wijaya; and Josefhine Chitra. 2018. "Indonesia's Last Forest Frontier: Three Facts to Know About Papua. " Washington, DC: *World Resources Institute blog*. https://www.wri.org/blog/2018/11/indonesias-last-forest-frontier-3-facts-know-about-papua

Aslan, Aslan; Abdullah Rahman; Scott Robeson; and Matthew Warren. 2016. "Mapping Spatial Distribution and Biomass of Coastal Wetland Vegetation in Indonesian Papua by Combining Active and Passive Remotely Sensed Data." *Remote Sensing of Environment* 183: 65-81.

Australian Bureau of Meteorology. 2018. "Southern Hemisphere Tropical Cyclone Data Portal." Melbourne: Australian Bureau of Meteorology. http://www.bom.gov.au/cyclone/history/tracks/

Basyuni, Mohammad and Nurdin Sulistiyono. 2018. "Deforestation and Reforestation Analysis from Land-Use Changes in North Sumatran Mangroves, 1990-2015." *IOP Conference Series: Materials Science and Engineering* 309. https://iopscience.iop.org/article/10.1088/1757-899X/309/1/012018/pdf

BPS Teluk Bintuni (Indonesia Central Bureau of Statistics). 2016. *Kabupaten Teluk Bintuni dalam Angka 2014*. Teluk Bintuni: Government of Indonesia.

———. 2017. *Statistik Indonesia 2017*. Jakarta: Government of Indonesia https://www.bps.go.id/publication/2017/07/26/b598fa587f5112432533a656/statistik-indonesia-2017.html

Brown, Benjamin. 2017. "Cost Benefit Analysis for Mangrove Forest Landscape Rehabilitation in Indonesia." PowerPoint presented at the IUCN Mangrove Specialist Group Symposium in Bremen, Germany, September 12.

BSP Mimika (Indonesia Central Bureau of Statistics Mimika). 2015. *Kabupaten Mimika Dalam Figure 2014*. Mimika: Government of Indonesia.

Chitra, Josefhine, Arief Wijaya, and Rizky Firmansyah. 2017. "Balancing Development and Forest Protection in Papua." Washington, DC: World Resources Institute, blog. https://www.wri.org/blog/2017/10/balancing-development-and-forest-protection-papua

Di Nitto, Diana; J. van Beek; Farid Dahdouh-Guebas; Paul Erftemeijer; L. Higazi; Nico Koedam; Katrien Quisthoudt; and Jayatissa Pulukkuttige. 2013. "Modelling Drivers of Mangrove Propagule Dispersal and Restoration of Abandoned Shrimp Farms." *Biogeosciences Discussions* 10 (1): 5095–5113.

Donato, Daniel; J. Boone Kauffman; Markku Kanninen; Sofyan Kurnianto; Daniel Murdiyarso; and Melanie Stidham. 2011. "Mangroves Among the Most Carbon-Rich Forests in the Tropics." *Nature Geoscience* 4: 293-297.

Energi Dan Sumber Mineral. 2016. "Perjanjian Pembiayaan Proyek LNG Tangguh Train 3 Ditandatangani." Kementerian Energi Dan Sumber Daya Mineral. https://migas.esdm.go.id/post/read/perjanjian-pembiayaan-proyek-lng-tangguh-train-3-ditandatangani

Giri, Chandra; Norman Duke; Tomas Loveland; Jeff Masek; Edward Ochieng; Ashbindu Singh; Larry Tieszen; and Zq Zhu. 2011. "Status and Distribution of Mangrove Forests of the World Using Earth Observation Satellite Data." *Global Ecology and Biogeography* 20 (1): 154-159.

Gribi, Niki. 2019. "West Papua Becomes Indonesia's First Conservation Province." Conservation Strategy Fund, April 4. https://www.conservation-strategy.org/en/news/west-papua-becomes-indonesia%E2%80%99s-first-conservation-province#.XSjIQpNKi71

Hamilton, Stuart and Daniel Casey. 2016. "Creation of a High Spatio-Temporal Resolution Global Database of Continuous Mangrove Forest Cover for the 21st Century (CGMFC-21)." *Global Ecology and Biogeography* 25: 729-738.

Indrawan, Mochamad; Agus Sumule; Arief Wijaya; Noak Kapisa; Frans Wanggai; Mubariq Ahmad; Benja Mambai; and Charlie Heatubun. 2019. "A Time for Locally Driven Development in Papua and West Papua." *Development in Practice*. 29 (6): 817-823. DOI: 10.1080/09614524.2019.1609907

Jamasmie, Cecilia. 2017. "Freeport to Yield Control of Giant Grasberg Copper Mine to Indonesia." Mining.com, August 29. https://www.mining.com/freeport-to-yield-control-of-giant-grasberg-copper-mine-to-indonesia/

Kauffman, J. Boone; Chris Heider; Jennifer Norfolk; and Frederick Payton. 2014. "Carbon Stocks of Intact Mangroves and Carbon Emissions Arising from Their Conversion in the Dominican Republic." *Ecological Applications* 24 (3): 518–527.

Laso Bayas, Juan; Georg Cadisch; Gerd Dercon; Sonya Dewi; Laxman Joshi; Carsten Marohn; Meine van Noordwijk; and Hans Piepho. 2011. "Influence of Coastal Vegetation on the 2004 Tsunami Wave Impact in West Aceh." *Proceedings of the National Academy of Sciences* 108: 18612-18617.

LESTARI. 2016. *Kajian Ketahanan Sosial-Ekonomi-Ekologi (Resilience Assessment) di Mimika dan Asmat dan Pengembangan Rencana Aksi Lorentz Lowlands Landscape (Annex)*. Jakarta: Tetra Tech, Prepared for USAID.

Milligan, Craig; Said Dahdah; Andreas Kopp; and Jeannette Montufar. 2014. "Value of a Statistical Life in Road Safety: A Benefit-Transfer Function with Risk-Analysis Guidance Based on Developing Country Data." *Accident Analysis and Prevention* 17: 236-247.

Merrill, Reed and Matthew Edwardsen. 2015. *ESTARI Landscape Baseline Analysis Plan*. Burlington: Tetra Tech, Prepared for USAID.

Murdiyarso, Daniel; Daniel Donato; J. Boone Kauffman; Haruni Krisnawati; Sofyan Kurnianto; Solichin Manuri; Joko Purbopuspito; Sigit Sasmito; Sartji Taberima; and Matthew Warren. 2015. "The Potential of Indonesian Mangrove Forests for Global Climate Change Mitigation." *Nature Climate Change* 5: 1089-1092.

Narayan, Tulika; David Cooley; Lindsay Foley; Jacqueline Haskell; and Eric Hyman. 2017. *Cost-Benefit Analysis of Mangrove Restoration for Coastal Protection and an Earthen Dike Alternative in Mozambique*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

NOAA. 2018. "Global Historical Tsunami Database." Silver Spring, MD: National Oceanic and Atmospheric Association.

Prentice, Michael and Geoffrey Hope. 2007. "Climate of Papua." In *Ecology of Papua, Ecology of Indonesia*. Singapore: Periplus Editions (HK) Ltd., 177-195.

Proisy, Christophe; Ariani Andayani; James Enright; Stéphane Guitet; Niken Gusmawati; Frida Sidik; and Gaëlle Viennois. 2018. "Monitoring Mangrove Forests After Aquaculture Abandonment Using Time Series of Very High Spatial Resolution Satellite Images: A Case Study from the Perancak Estuary, Bali, Indonesia." *Marine Pollution Bulletin* 131: 61-71.

Richards, Daniel and Daniel Friess. 2016. "Rates and Drivers of Mangrove Deforestation in Southeast Asia, 2000-2012." *Proceedings of the National Academy of Sciences* 113: 344-349.

Sillanpää, Mériadec; Daniel Friess; and Juliana Vantellingen. 2017. "Vegetation Regeneration in a Sustainably Harvested Mangrove Forest in West Papua, Indonesia." *Forest Ecology and Management* 390: 137-146.

Smith, Gordon; Lindsay Foley; Eric Hyman; and Charlotte Mack. 2018. *Mangrove Ecosystem Valuation: Methods and Results*. Washington, DC: Crown Agents USA and Abt Associates, Prepared for USAID.

Trading Economics. 2019. Indonesia Inflation Rate. https://tradingeconomics.com/indonesia/inflation-cpi

UNDP. 2017. "Table 2. Human Development Index Trends, 1990-2017." *Human Development Report*. New York: United Nations Development Programme. http://hdr.undp.org/en/composite/trends

USAID. 2015. *USAID Guidelines: Cost-Benefit Analysis*. Washington, DC: United States Agency for International Development.

Vijay, Varsha; Clinton Jenkins; Stuart Pimm; and Sharon Smith. 2016. "The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss." *PloS One* 11 (7): e0159668.

WFP. 2015. *Food Security and Vulnerability Atlas of Indonesia*. Rome: World Food Programme.

World Bank. 2018. "Data Catalog: Population Estimates and Projections." Washington, DC: World Bank. https://datacatalog.worldbank.org/dataset/population-estimates-and-projections.

World Wide Fund for Nature. 2018. *New Hope for New Guinea's Forests*. Gland, Switzerland: World Wide Fund for Nature.

WRI. 2019. "Climate Watch Data Explorer." *CAIT Climate Data Explorer*. Washington, DC: World Resources Institute. https://www.wri.org/our-work/project/cait-climate-data-explorer