System’s approach to municipal water use allocation

G P L Abella\(^1\), A M P Alberto\(^1\), J M Tubay\(^2\), Z P M Cario\(^1\)

\(^1\)Institute for Climate Change and Environmental Management, Central Luzon State University, Science City, Nueva Ecija, Philippines, 3120
\(^2\)Institute of Mathematical Science and Physics, University of the Philippines Los Banos, College, Laguna, Philippines, 4031

E-mail: gplabella@clsu.edu.ph

Abstract. Human activities in aquatic and terrestrial ecosystems can cause the depletion of coastal resources. The study aimed to develop a decision support system for the municipality of Palauig, Zambales as the basis for coastal resource management. Water use allocation was done in a systems approach, using Gurobi® - mathematical optimization solver, considering priority goals of Palauig, goal 1 is to maximize mangrove use in minimizing disaster risk, goal 2 is maximizing water suitability and goal 3 is maximizing the total economic value of resources. The municipal water map was divided into 1-ha grids. Optimization run results showed that disaster risk fronting shoreline would be canceled by mangrove allocated on those areas. The area allocation of 331 ha mangrove, 1 ha coral, 1,573 ha seagrass, 50 ha fish cage, 33 ha MPA and 17,942 ha fishing area, the water uses would have economic values of Php 2.9B, Php 20.8M, Php 1.7B, Php 4.1B, Php 323M, and Php 33.9B, respectively. The area allocated for the fish cage did not exceed the allowable area set hence, its environmental impacts would be manageable. Production of 2.3MT would meet Palauig’s consumption requirement for fish.

1. Introduction

Coastal resources provide economic goods and ecosystem services. However, degradation exists because of multi-dimensional threats and pressures from human activities in land and water. In the Philippines, coastal resource issues include overfishing, destructive fishing, the encroachment of industrial fishing on municipal water, untreated waste disposal and sedimentation, and mangrove deforestation [1].

The Coastal zone is part of the municipal water. In the Philippines, the management of municipal water was mandated to local government units by virtue of Republic Act 7,160 or the Local Government Code. Republic Act 8,550 or the Fisheries Code of the Philippines defines municipal water as marine waters included between two lines drawn perpendicular to the general coastline from points where the boundary lines of the municipality touch the sea at low tide and a third line parallel with the general coastline including offshore islands and 15 kilometers from such coastline. It is delineated to protect the small-scale or municipal fisherfolks.

The coastal ecosystems of Palauig, specifically mangrove forest, seagrass bed, and coral reef, obtained low to very low faunal and floral diversity. The presence of coliform and heavy metals were also determined. The fish stock assessment revealed a low yield of fish in the area. Based on the study conducted by this program, eutrophication, dynamite fishing, oil spill, mine drainage pollution, and solid wastes posed major impacts on the coastal ecosystem of Palauig. The degradation was exacerbated by the presence of fish cages covering 25 hectares in 2002 [2].
The absence of proper valuation of the coastal resources triggers the degradation. The failure of existing methods to properly account for the results in undervaluation of total benefits, thus having the tendency of overexploitation and conversion of resources to immediate but unsustainable options [3]. Efforts have been made on the rehabilitation of coastal ecosystems. However, some rehabilitation projects can be considered a failure. Poor survival rates of mangroves can be attributed to two major factors: inappropriate species and site selection [4]. The site suitability for seagrass restoration was pointed out by [5] as one of the factors for the project’s failure. After a decade, researches had significantly improved the methods of selecting the best site for seagrass restoration [5]. The absence of site suitability analysis in coral reef rehabilitation and establishment of marine protected areas (MPA) also result in a failure of those projects.

Coastal resource management is in dire need to protect and maintain the huge natural and economic resources in the country as regards food supply, livelihood, and environmental quality. Through coastal resource management, humans can see to it that there would be prevention with further damage and overexploitation of the coastal ecosystem along with the natural capability to produce at the extent of causing permanent damage to the system and their products [6].

This study aimed to develop a decision-support system as a basis for water use allocation on the municipal water of Palauig, Zambales. This is done in a systems approach in a way that it is not only the biophysical characteristics of the coastal ecosystem that is being considered but also the socio-economic aspects of it. This is an avenue to manage the coastal ecosystem, given the limited resources of the local government unit.

2. Study area
Palauig, Zambales is a third class municipality located at 15°27′07.96″N and 119°57′17.11″E. It is bounded on the north by the municipality of Masinloc, on the south by the municipality of Iba, on the east by Mt. Tapulao, and on the west by the West Philippine Sea. It is composed of 16 coastal and 3 non-coastal barangays. Palauig is also part of the Masinloc and Oyon Bay Protected Seascapes.

3. Methods
3.1. Identification of development goals
The local government unit of Palauig through the Municipal Councilors (Sangguniang Bayan) and the group of village leaders (Association of Barangay Captains) were asked to identify their goals through focus group discussion.

3.2. Model formulation
The identified priority goals were translated to objective functions and mathematical formulas and were processed through multiple goal linear programming software, Gurobi®. Six water uses were considered in the municipal water of Palauig, namely, 1) mangrove forest; 2) coral reef; 3) seagrass bed; fish cage; 5) Marine Protected Area (MPA); and 6) municipal fishing area (MFA). MFA is where the small-scale municipal fishers can fish using fishing vessels of three (3) gross tons.

The first goal is to minimize disaster risk by maximizing the use of mangroves (1). The presence of mangrove can attenuate the impacts of storm surge [7] thus, the sites that would be allocated with mangroves were assumed to have reduced disaster risk. A summation of the binary variable of each grid assigned to mangrove ($X_{g,m}$), multiplied with the storm surge risk score of each grid ($DR_g$) is obtained.

**Goal 1: Maximize mangrove use to minimize disaster risk**

$$\text{Maximize mangrove use} = \sum_{g=1}^{ng} X_{g,m} \times DR_g$$
Water suitability and total economic value of water uses were targeted to be maximized to improve the economic status of the people in Zambales. Maximizing water suitability (2) can be computed by getting the summation of the binary variable of each grid assigned to water use options \(X_{g,u}\) multiplied by the suitability rating of each grid of that water use option assigned \(ST_{g,u}\).

Goal 2: Maximize water suitability

\[
\text{Maximize water suitability} = \sum_{g=1}^{ng} X_{g,u} \times ST_{g,u}
\]

For the third objective function, maximizing economic value (3) is calculated by getting the summation of the binary variable of each grid assigned to water use options \(X_{g,u}\) multiplied by the total economic value of each grid \(EV_{g,u}\).

Goal 3: Maximize the total economic value

\[
\text{Maximize total economic value} = \sum_{g=1}^{ng} X_{g,u} \times EV_{g,u}
\]

3.3. Setting of constraints

Constraints are restrictions on the decision variables. It limits the value of the decision variables, so that it cannot go above (setting a maximum or \(\leq\)) or below (setting a minimum or \(\geq\)) a certain value of the variable.

There were six (6) initial constraints set for water use allocation.

a. Rehabilitation/conservation cost of mangrove forest, coral reef and seagrass bed and establishment of MPA (4) – This ensured that the rehabilitation or establishment cost \(RC_u\) of the water use \(X_{g,u}\) that will be assigned by Gurobi will not go beyond the total rehabilitation fund \(RF\) allotted by the local government unit. Rehabilitation or establishment costs were obtained from literatures and management plans of the selected coastal region.

\[
\sum_{g=1}^{ng} X_{g,u} \times RC_u \leq RF
\]

b. One assignment, one grid (5) – This ensured that there is only one land use assigned to one grid.

\[
\sum_{g=1}^{ng} X_{g,u} = 1
\]

c. There should be at least one grid for seagrass beds, coral reefs, and mangrove forests (6). This was set to ensure that there would be a grid assigned to the water use with ecological and economic importance.

\[
\sum_{g=1}^{ng} X_{g,u} \geq 1
\]

d. Additional MPA needed (including coral reef and seagrass bed) (7) - This was set to ensure that the part of the municipal water is allocated to MPA \(MPA_{\text{min}}\).

\[
\sum_{g=1}^{ng} \text{size}_g \times (X_{g,5} + X_{g,3} + X_{g,2}) \leq MPA_{\text{min}}
\]

e. Minimum fish production requirement (8) – This ensured that the area allotted for the fish cage will have a production (FP) that will not go below the fish consumption requirement (FR). The demand for fish was determined using the per capita consumption of fish multiplied with the population of the study site.
\[
\sum_{g=1}^{ng} X_{g,u} \times size_g \times FP \geq FR
\]

f. Maximum area for the fish cage (9) – This ensured that the water use \((X_{g,u})\) that will be assigned by Gurobi will not go beyond the maximum allowable area for the fish cage \((FC_{max})\). The maximum allowable area for a fish cage depends on the analysis of the Fisheries Office or carrying capacity assessment.

\[
\sum_{g=1}^{ng} X_{g,u} \times size_g \leq FC_{max}
\]

3.4. Data gathering
The disaster risk score in relation to storm surge was used in determining the disaster risk value of the first three grids of the municipal water from the shoreline. The data were obtained from the disaster risk assessment conducted. Total economic values (TEVs) of the mangrove forest, coral reefs, and seagrass beds are computed through economic valuation. Fish caught in municipal water is drawn from the fishery office of the study site.

Table 1. Weights of the factors influencing water suitability for different water use of the municipal water of Palauig, Zambales.

| Factors Influencing Water Suitability | Weight of Factors |
|---------------------------------------|-------------------|
| Mangrove forest                       |                   |
| Tidal rate                            | 0.52              |
| Bathymetry                            | 0.21              |
| Type of shoreline                     | 0.27              |
| Coral reef                            |                   |
| Temperature                           | 0.20              |
| Salinity                              | 0.20              |
| Phosphate                             | 0.14              |
| Bathymetry                            | 0.16              |
| Sediment                              | 0.10              |
| Proximity to existing corals          | 0.20              |
| Seagrass bed                          |                   |
| Current seagrass distribution         | 0.29              |
| Proximity to a natural seagrass bed   | 0.17              |
| Sediment                              | 0.15              |
| Water quality (TSS)                   | 0.18              |
| Bathymetry                            | 0.20              |
| Fish cage                             |                   |
| Topographical criteria                | 0.37              |
| Physical criteria                     | 0.28              |
| Chemical criteria                     | 0.23              |
| Biological criteria                   | 0.11              |
| MPA                                   |                   |
| Relative naturalness                  | 0.27              |
| Representativeness                    | 0.31              |
| Biodiversity                          | 0.20              |
| Vulnerability                         | 0.13              |
| Fisheries value                       | 0.09              |
Parameters of suitability for mangrove forestation or rehabilitation were tidal rate, bathymetry, and type of shoreline [8]. Water suitability for coral reef establishment or restoration was based on temperature, salinity, phosphate, bathymetry, sediment, and proximity to existing corals [9]; according to [10] discussed the parameters of the water suitability for seagrass beds.

UNDP/FAO (1989) recommended a set of site suitability criteria in establishing fish cages. It includes the topographical criteria (depth or bathymetry), physical criteria (temperature and turbidity), and chemical criteria (nitrite). Establishing a marine protected area (MPA) requires ecological, social, and economic preparedness of the community. Ecological criteria include relative naturalness, representativeness, biodiversity, vulnerability, and fisheries value [11,12]. The rest of the municipal water is considered a fishing area; thus, the grids were scored automatically with 2. The weight of factors influencing the water suitability for the different water uses was evaluated employing AHP (table 1). Seven marine science experts were asked to do the evaluation.

3.5. Data encoding and running the model
Data needed for water use allocation, namely, the total economic value of water uses, disaster risk score pertaining to storm surge, and the water suitability scores of the water use, were encoded in spreadsheets.

All equations were written in the Solver Studio interface following the steps: 1) encoding and defining the decision variables; 2) encoding the objective function equations; 3) encoding the constraint equations; 4) entering the command to view the model output; 5) running the model using Gurobi® (license # 194cd782-22ab-11e9-856d-02e454ff9e50); and 6) visually presenting the optimization results through ArcGIS (license # 872908)

4. Results
4.1. Disaster risk
The disaster risk assessment conducted by this program showed that the villages affected by storm surge risk were Libaba, Alwa, Macarang, Magalawa, Locloc, Santo Tomas, Lipay, San Juan, East Poblacion, Bato, Garreta, and West Poblacion. The first three grids of the municipal water fronting the said villages adopted their storm surge risk scores which ranged from 2 to 3.

4.2. Water suitability
A small percentage (1.49% or 296 hectares) of the municipal water of Palauig was classified as highly suitable for mangrove forests. Another small portion, 0.17% or 34 hectares, and 1.95% or 389 hectares, were considered moderately and marginally suitable. Water suitability for coral reefs in the municipality of Palauig, Zambales, consists of 1.40% or 279 hectares highly suitable, 1.13% or 225 hectares moderately suitable, 7.30% or 1,456 hectares marginally suitable, and 90.17% or 17,972 hectares not suitable. A very small portion, 0.05% or 9 hectares, was scored as highly suitable for seagrass beds. Whereas, 0.24% or 49 hectares and 2.43% or 485 hectares, were found to be moderately and marginally suitable. Most of the municipal water (97.27% or 19,387 hectares) was classified as not suitable.

Water suitability for fish cage area in the municipality of Palauig Zambales recorded 1.21% each for highly and moderately suitable with 242 hectares. A small portion, 1.77% or 353 hectares, was classified as marginally suitable. The majority of the municipal water, 95.8% or 19,094 hectares, was graded as unsuitable for the establishment of the fish cage. The water suitability classification of the municipal water of Palauig for the marine protected area was 0.46% or 91 hectares highly suitable, 0.52% or 103 hectares moderately suitable, and 1.33% or 266 hectares marginally suitable. A huge part of the municipal water, 97.7% or 19,472 hectares, was classified as unsuitable for MPA.

4.3. Total economic value of coastal resources
Based on the economic valuation conducted by this program, the total economic value of mangrove amounted to Php 6,585,087 per hectare or Php 724,359,583 for the entire mangrove forest area of Palauig (table 2). This considered its use (market goods, carbon sequestration service fee, and flood control ability) and non-use values (bequest and option values). The ecosystem services of breeding and nursery grounds, the refuge protection having obtained other species, its inherent aesthetic value, and its
scientific research value, generated the total economic value of coral reef of Php 20,829.06 per hectare or Php 7,259,259 in Palauig.

Seagrass bed has several functions such as the provision of permanent habitat, a temporary nursery area for the development of the juvenile stage, a feeding area for various life stages, and a refuge from predation. The seagrass ecosystem was estimated to have a total economic value of Php 1,084,735 per hectare or Php 29,471,475 in the entire municipal water of Palauig. Adding the total economic value of those three coastal resources, the value of MPA was estimated at Php 7,691,244.69 per hectare or Php 12,885,296,054 in Palauig.

| Water Use                  | Total Economic Value (Php/ha) |
|----------------------------|-------------------------------|
| Mangrove forest            | 6,585,087.12                  |
| Coral cover                | 20,829.06                     |
| Seagrass bed               | 1,084,735.62                  |
| Fish cage                  | 23,183,750.00                 |
| Marine protected area      | 7,691,244.69                  |
| Municipal fishing area     | 12,760.64                     |

The fish cage gave an economic value of Php 23,183,750 or Php 369,548,975 for the 16-hectare coverage of the fish cage in Palauig water. Considering the fish catch of small-scale fisherfolks, the municipal fishing area yielded an amount of Php 12,760 per hectare or Php 254,330,146 for the entire Palauig water.

4.4. Decision-support system on municipal water use allocation

The priority goals set by the Sangguniang Bayan and Association of Barangay Captains of the municipality of Palauig were translated into: (Goal 1) maximize mangrove use to minimize disaster risk; (Goal 2) maximize water suitability; and (Goal 3) maximize total economic value. The disaster risk score of 943, in relation to storm surge, was canceled out of the protection service of the mangrove (table 3). The total water suitability scores of the water uses (39,921) allocated by the model were said to have been maximized since it is much higher than the lowest potential suitability score of 20,636. The total economic value that can be gained from the optimum water use allocation is Php 243,049,093,725.19. Having the largest allocation of 17,942 hectares for the municipal fishing area, the area where small-scale fisherfolks can do fishing, the economic value can reach Php 33,958,167,000. The second-largest allocation of 1,573 hectares or 7.89%, in addition to the existing area of 42 hectares, was obtained by seagrass bed. With this allocation, the total economic benefits from seagrass cover would amount to 1,707,373,862. Whereas, 331 hectares of mangrove forest, in addition to the existing area of 110 hectares, would gain an economic value of Php 2,910,608,507. The coral cover which obtained the lowest allocation of 1 hectare, in addition to the existing 498 hectares, would gain a total economic value of Php 20,829.
Table 3. Optimization run results pursuing Goals 1 to 3 in the municipal water of Palauig, Zambales.

| Goals                                                                 | Item                     | Unit | Current/Potential | Optimum     |
|-----------------------------------------------------------------------|--------------------------|------|-------------------|-------------|
| 1. Maximizing mangrove use in minimizing disaster risk                | Mangrove                 | Php  | 2,910,608,507.04  |             |
|                                                                        | Coral cover              | Php  | 20,829.06         |             |
|                                                                        | Seagrass bed             | Php  | 1,707,373,862.32  |             |
|                                                                        | Fish cage                | Php  | 4,149,891,250.00  |             |
| 2. Maximize water suitability                                         | Marine protected area    | Php  | 323,032,276.78    |             |
|                                                                        | Municipal fishing area   | Php  | 33,958,167,000.00 |             |
| 3. Maximize the economic value of water uses                          | Total economic value     | Php  | 243,049,093,725.19|             |

| Constraints                                                           | Minimum area for MPA     | ha    | 1,607.38          | 32.91       |
|                                                                      | Rehabilitation           | Php  | Fund             | Cost        |
|                                                                      | Mangrove                 | Php  | 2,210,000.00     |             |
|                                                                      | Coral cover              | Php  | 100,000.00       |             |
|                                                                      | Seagrass bed             | Php  | 2,046,200.00     |             |
|                                                                      | Marine protected area    | Php  | 2,100,000.00     |             |
|                                                                      | Total rehabilitation     | Php  | 4,568,852.61     | 6,456,200.00|
|                                                                      | Maximum area for fish cage| ha  | 50.00            | 49.92       |
|                                                                      | Minimum production requirement | kg | 470,386.62       | 2,285,849.69|

Though the allocation of 32.91 hectares for MPA, in addition to the existing 1,675 hectares, was not able to meet the minimum area set in the study, it would still earn a total economic value of Php 323,032,277. The total rehabilitation cost of different water uses (Php 6,456,200) allocated by the model exceeded the rehabilitation fund set in this study, which was 20% of the development fund of the local government of Palauig or Php 4,568,853. The allotted area for the fish cage did not go beyond the maximum allowable area for the fish cage (50 hectares) set in this study. With this area allocation, the fish production of 2,285,850 kg would be able to meet the fish demand (470,386 kg) of the people of Palauig.

The water use allocation provided in the model shows that 90% of the municipal water was allocated for the fishing area, 8% for seagrass beds, 1.66% for mangrove forests, 0.25% for fish cages, and 0.16% for MPA (figure 1). One grid was assigned for coral cover.

5. Discussion
Storm surge risk is a function of storm surge hazard susceptibility, exposure, sensitivity, and adaptive capacity. The majority of the barangays are highly susceptible to storm surges because they are coastal barangays. The population in the coastal communities exposed to storm surges was high. The sensitivity of areas was also high because of the location of settlements, the extent of agricultural areas, beaches, and coastal shores to be affected by the storm surge. The municipality of Palauig also had low adaptive capacity against storm surge due to the absence of an early warning system and weak social network on disasters. Further, the mangrove forest in the area is dwindling making it insufficient to protect the coastal communities.

The bathymetry of the water was the major factor for the suitability of mangrove forests [8]. The higher the bathymetry level of the area, the lower the chance for the area to become suitable for
mangrove forest, thus the majority of the municipal water was classified as not suitable. Temperature, phosphate, and salinity are among the most important factors for considering the suitability of coral reefs. Excessive amount/exposure to high temperature could induce bleaching and can lead to mortality. The area with low salinity when exposed to high temperature can be bleached and the area with low phosphate can eventually make the coral bleaching. The area with a good amount of phosphate, salinity, and temperature are the most suitable for coral reef areas [9]. Only a small portion of the municipal water of Palauig was able to satisfy these parameters.

![Figure 1. Water use allocation in the municipal water of Palauig, Zambales.](image)

For the suitability of seagrass bed, knowing the current seagrass distribution in the area is important because possible seagrass transplanting should be done near an area where seagrass is already present. The bathymetry and the sediments have the major influence for the growth and spread of seagrass, lower bathymetry level means it is more suitable for the seagrass and area with sediments that are free of pebbles is most likely be more suitable than area with rocky seabed sediment [10]. The high sedimentation load in Palauig water made it impossible to get high suitability for seagrass bed.

All the parameters have to be assessed for the suitability of fish cage. Considering the turbidity of the area can help prevent run off causing soil erosion, leaching of heavy metals, and reduction of salinity. Also, excessive amount of nitrate in the area may lead to the toxification of fish due to oxidation and may help phytoplankton to bloom excessively. Bathymetry is also a factor for the suitability of fish cage. Fish cage requires to be enclosed all except the top. The higher the bathymetry level the bigger are the materials for the fish cage to be enclosed [13].

The highly suitable area for MPA Palauig municipal water was located around the existing area of coral reef [11]. Coral reef naturally has high diversity and fish value. The MPA requires to be located where seagrass, mangrove, and coral are present. All the parameters needed for the suitability of establishing MPA were found in the aforementioned areas.

The relative low total economic value of mangrove forest, coral reef, seagrass bed and MPA, compared to the fish cage, may be attributed to the low valuation that people placed on non-use values. The site for rehabilitation of mangrove forest was allocated based on its function of minimizing disaster risk
against storm surge, its suitability and economic value. A study was conducted on how mangroves affect the surge height, increase surface roughness and reduce height of surface wind waves [14]. Coral reef received the smallest allocation due to its high rehabilitation cost of Php 100,000 per hectare or even more. Further, it has relatively low economic value and low suitability. Seagrass, on the other hand, received the largest allocation because of its low rehabilitation cost of P1,500 per hectare only. Moreover, it has also high economic value.

Though the allocation was not able to meet the minimum area for MPA set in the study, more so the ideal 15% recommended by the 1998 Fisheries Code, it was able to assign an additional 32 hectares, as constrained by the low rehabilitation fund. The MPA establishment cost of Php 5,000.00 used in this study was far below than those host municipalities which allocated Php 25,000 to Php 600,000 in 2005 [15]. The allocation was not able to cover the minimum area for MPA set in this study which is 1,607 hectares. This can be attributed to low rehabilitation fund of Php 4,568,852, which is 20% of the development fund. Study revealed that LGUs are faced with a need to allocate limited funds for many sectors and services [15]. Coastal resource management and establishment of marine protected area do not always get the highest priority.

The setting of maximum allowable area for fish cage was done to minimize the negative environmental impacts brought by this, namely, organic matter being settled on sea bed may lead to production of toxic gases, sediment oxygen demand is enriched, changes in macrobenthic community structure, decrease in dissolved oxygen, localized eutrophication and development of resistance in bacterial pathogens of fish [16]. Pursuant to Section 51 of RA 8550, the LGUs shall ensure that allotted area for aquaculture shall not exceed 10% of the suitable water source area and that the LGU shall determine the maximum allowable number. In this study, the establishment of fish cages in the municipal water was constrained to a minimum to inhibit the environmental impacts but can still meet the fish consumption requirement of the two municipalities.

6. Conclusion and recommendations

The water use allocation options provided by Gurobi, a multiple goal linear programming software, serve as decision support system to policy makers or Sangguniang Bayan of Palauig, with regard to their coastal resource management. The allocation was done in a systems approach since the total economic values, suitability of the water for different uses, the disaster risks on storm surge, were considered holistically. The allocation on the rehabilitation or establishment of coral reef, seagrass bed, marine protected area and fish cage was based mainly on suitability and total economic value. Establishment of fish cage is also based on suitability and economic value. However, there are environmental impacts related to fish cages. Thus, it was constrained to a maximum allowable area. Coastal resource management can be attained through proper water use allocation of the municipal water while gaining full economic benefits and reducing disaster risk. The assignment of water use according to science-based data could strengthen decisions of policy-makers and law enforcers.

References
[1] Parras D A 2001 Coastal resource management in the Philippines: A case study in the Central Visayas region J. Environ. Dev. 10(1) 80–103
[2] Cesar B and Vera A 2004 The Struggle of the Small-Scale Fisherfolk of Masinloc and Oyon Bay for Good Governance in a Protected Seascape 1–15
[3] Aguero, Max and X Flores 1996 Valuation Concepts and Techniques with Applications to Coastal Resources. In Valuation of Tropical Coastal Resources: Theory and Application of Linear Programming ICLARM Stud. 9–16
[4] J H Primavera and J M A Esteban 2008 A review of mangrove rehabilitation in the Philippines: Successes, failures and future prospects Wetl Ecol Manag 16 (5) 345–58
[5] E I Paling, M Fonseca, M M van Katwijk, and Mvan Keulen 2009 Seagrass Restoration Coast Wetl - An Integr. Ecosyst. Approach 687–713
Acknowledgements

This research is an output of the Project 4 of the program titled, “Coastal Resource Management Integrating Coastal Resource Assessment and Valuation, Carrying Capacity, Climate Change Adaptation and Disaster Risk Reduction in the Province of Zambales (CRM in C3DZ): A Systems Approach”. We are grateful to the Commission on Higher Education (CHED), Philippines, under DARETO program, for the research funding which provided key support to the project.

[6] A T White and A Cruz-Trinidad 1998 The Values of Philippine Coastal Resources: Why Protection and Management are Critical 96
[7] S Dasgupta, M S Islam, M Huq, Z H Khan, and M R Hasib 2019 Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh PLoS One 14(3) 1–14
[8] B Suprakto and D Arfiati 2014 Development of Mangrove Conservation Area Based on Land Suitability and Environmental Carrying Capacity (Case Study from Probolinggo Coastal Area, East Java, Indonesia) Inter. J. Ecosys. 4(3) 107–18
[9] Y Guan, S Hohn, and A Merico 2015 Suitable environmental ranges for potential Coral reef habitats in the tropical ocean PLoS One 10 (6) 1–17
[10] Lanuru M, Mashoreng S, and Amri K 2018 Using site-selection model to identify suitable sites for seagrass transplantation in the west coast of South Sulawesi J. Phys. Conf. Ser. 979 012007
[11] K D Saputra, S Sukandar, H Muliawati, U C Satrya, and P Pratama 2017 The GIS Application of Marine Protected Area Site Selection, in Trenggalek, East Java Province 79 268–74
[12] K Post 2016 Increasing the Resilience of Marine Ecosystems: Creating and Managing Marine Protected Areas in the Philippines 1–32
[13] FAO 2015 Aquaculture operations in floating HDPE cages 593, Fisheries and Aquaculture 176
[14] A Mcivor, T Spencer, and I Möller 2012 Storm Surge Reduction by Mangroves Natural Coastal Protection Series: Report 2
[15] Toribio, B M Zita, P M Alino, and ES Guiang 2009 C-b s mp a : if in. Philipp. Agric. Sci. 92(2) 153–69
[16] RSS Wu 1995 The environmental impact of marine fish culture: Towards a sustainable future Mar. Pollut. Bull. 31 159–66.