Optimizing the utilization of mangrove coastal resources through the application of intercropping ponds/silvofishery in Sinjai Regency, Indonesia

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Abstract. The study aimed to determine the optimal ratio of pond area and mangrove stands in mangrove forest conservation areas. Several ecological aspects in the mangrove forest conservation area were studied, determining the carrying capacity of the coastal environment, and the feasibility of pond cultivation in the mangrove forest conservation area. Based on the analysis of biophysical and chemical factors of the coastal waters in Sinjai Regency, the area of ponds that can be operated, based on the carrying capacity of coastal waters in Sinjai Regency, is 2,276 ha. Based on the results of the analysis of the economic valuation of fish ponds in Sinjai Regency, 54% are ponds and 46% are mangroves.
Key Words: optimization, coastal resources mangrove, silvofishery, cultivation.

Introduction. The coastal protection and socio-economic functions of the mangrove forests must be balanced (Wamnebo et al 2018). However, the problem that often arises is that if the role of conservation is taken as the sole interest, social issues may arise. On the other hand, if social and economic roles are the main considerations, then ecological problems will threaten the mangroves sustainability. Consequently, it is necessary to determine a model for integrating the various stakeholders' interests, in the mutual advantage. To achieve a balanced, integration, the management of mangrove forest ecosystems should promote a rational exploitation by involving all directly concerned communities around the mangrove forest areas. Tumpangsari (silvofishery) is a fairly good technical approach, which consists of a series of integrated activities of fish/shrimp farming, planting, maintaining, managing and preserving mangrove forests. This system has a simple technology, can be carried out without destroying existing mangrove forests and can be carried out as an intermediary activity while trying to reforest green belt areas in critical coastal areas (MENKLH 1988). This pattern is expected to enhance the mutually beneficial cooperation between smallholders and forestry parties. The implementation of silvofishery activities should prevent the destruction of the mangrove forest ecosystem by the local community, because it provides an alternative source of income. There are two main trends in the management of mangrove forests, focusing either on conservation or on utilization functions. These two tendencies will work synergistically if there is a management model that takes into account the appropriate eco-biological and socio-economic principles. The integration between ecology and economy can be harmonized and optimized to meet the needs of today's society without destroying or reducing the ability of these ecosystems, and can provide the needs for future generations. The principle for an optimization of the cultivation technique in ponds located in mangrove forest conservation areas is to seek a combination of ecological and economic integration. In order to balance the need for ponds on mangrove land and the maintenance of the ecological function of mangroves, it is necessary to study the optimal area of ponds to be cultivated on mangrove forest conservation areas. This research aimed at determining the optimal area partitioning between pond sand mangrove stands, on the mangrove forest conservation areas, through structured studies examining several ecological aspects, determining the carrying capacity of the coastal environment (mangrove forests and coastal waters) for fish farming activities, and analyzing the feasibility of the pond farming business on mangrove forest conservation lands.

Material and Method

Litter production. The productivity of mangrove forest was measured as follows:
a. The litter was collected using trapping methods
b. The sample were put into a cardboard box, then air-dried and weighed.
c. The litter samples were put in the oven at 80°C for 48 hours, at the Pangkep State Agricultural Polytechnic Soil Laboratory. Then the litter was weighed again and a constant dry weight was obtained.

Mangrove community structure. Data on species, number of stands and tree diameter were further processed to obtain species density, namely the number of stands of species on a unit area. It was calculated by the equation (Sachlan 1982):

$$D_i = n_i / A$$

Where:
D_i - density of species i;
n - total number of stands of species i;
A - sampling area (plot).

Water sampling. Water sampling was carried out during the active phytoplankton photosynthesis process. According to Boyd (1999), the photosynthesis begins to be active in the morning and increases until noon, then decreases towards the afternoon. On this basis, water samples were taken during the day (11.00-13.00). Observations were carried out in the pond forest areas stocked with milkfish or/and shrimp. Phytoplankton were taken from four places, namely water in the pond (two points) in the corner and two other points in the center of the pond. For each sampling point, 5 L of water were taken, so that from one sampling location there were 20 L of sampled water, which were poured into plankton net bag (number 25). Portions of filtered water were accommodated in a 10 mL glass and 5-6 drops of preservative were added, then the sample was put in a closed bottle and analyzed in the Water Quality Laboratory of the Pangkep State Agricultural Polytechnic. Water samples for analysis of physical and chemical parameters were taken together with water samples for composite phytoplankton examination.

Approach/analysis model
Ecological component

Litter production. The mean (average) litter production for each observed plot was determined by the formula (Sachlan 1982):

$$Xi = \sum_{j=1}^{n} Xj$$

Where:
Xj - average litter production per plot in a certain time period;
Xi - litter production for the i^{th} (i = 1,2,3,…n) plot in a certain time period (g m^{-2} $month^{-1}$)
n - Number of litter traps

The average value of litter production for each forest pond and for each observation is determined by the formula (Sachlan 1982):

$$x = \sum_{j=1}^{n} Xj / M$$

Where:
X - average litter production per forest pond for a certain time
Xj - average litter production per plot, for the period (g m^{-2} $month^{-1}$)
M - number of sample units per pond forest.

Phytoplankton community structure index
Total number of individuals. Phytoplankton examination carried out in the laboratory was identified to the genus level and classified. Meanwhile, water samples for chemical and physical parameters that can be stored will be analyzed in the laboratory. To support the interpretation of the data from the physico-chemical examination of water and to get a more precise description of the condition of the aquatic environment in each class of forest pond, an analysis of the structure of the phytoplankton community was carried out. The abundance of phytoplankton is expressed in the number of individuals per liter. Plankton counting was carried out in 20 fields of view using the micro-transect method.
To calculate it, the following equation was used (Sachlan 1982):

$$\text{Total number of individuals} / L^{-1} = \frac{Oi}{Op} \times \frac{1}{Vs} \times \frac{n}{p}$$

Where:
Oi - area of the cover glass (mm^2);
Op – area of one field of view (mm^2);
Vs - volume of water filtered by plankton nets (L);
n - number of plankton in the entire field of view;
p - number of observed fields of view.

Species diversity. Diversity index is based on the importance of the species in the community. The Shannon-Wiener diversity index was calculated with the equation (Sachlan 1982):

$$H' = \sum_{i=1}^{n} pi \frac{ni}{N} \log \frac{ni}{N} pi$$

Where:
H' - Shannon-Weiner diversity index;
Pi - ni /N;
ni - number of individuals of the i-th species;
N - total number of individuals.

Economic component
Feasibility analysis of fish pond culture/mangrove conservation business. To find out the prospect of developing pond culture/mangrove conservation, a business feasibility analysis is carried out. In assessing the feasibility of a business, it is necessary to carry out a cost benefit analysis (Rustam et al 2021). Thus, the entrepreneurs/farmers (cultivators) can determine the profit and loss balance and evaluate the (risks and uncertainties related to the business being developed.
The feasibility of the fish pond culture/mangrove conservation business results from the formula (Kasmir 2014):

$$\Pi = TR - TC$$
$$R/C \text{ ratio} = TR/TC$$

Where:
Π – profit;
TR - total revenue in a certain period;
TC- total cost used in one production cycle.

If the R/C ratio > 1, then the business can be profitable;
If the R/C ratio < 1, then the business is losing;
If the R/C ratio = 1, then the business is neither profitable nor losing.

Optimization of land use. Analysis of the land use optimization is carried out based on economic aspects. The economic aspects that are taken into consideration are the value of the R/C ratio. Economic analysis is looking for the optimal partition of the land area between the pond and the mangrove forest, in the intercropping pond (silvofishery).

Analysis of the carrying capacity of coastal waters. The analysis of the carrying capacity of these waters is based on the limits of the waters as waste recipients. The quantity of receiving water is a determinant of how much waste a water body can receive so that the quality is still feasible for sustainable aquaculture activities. This analysis is based on the assumption of Allison (1981) which states that to maintain the quality of the waters still suitable for aquaculture, the receiving waters of liquid waste from aquaculture activities must have a volume of 100 times the volume of liquid waste discharged into the waters.

Results. Observation results of the biophysical and chemical characteristics of the tides, waves and currents of Coastal Waters in Sinjai Regency are presented in Table 1.

Table 1

Physical condition of coastal waters in Sinjai Regency

Parameters	*Values*
Tidal hight (h)	126 cm
Beach width (x)	670 m
Beach longitude (y)	17 km
Tidal pattern	2 high tides 2 low tides
Beach slope (θ)	0.45

Based on the assumptions above, the area of the pond that is feasible to operate for intensive tiger shrimp cultivation in order to remain sustainable is as follows (Table 2).

Table 2

Calculation of sustainable pond area by coastal water volume in Sinjai Regency

Elevation (degrees)	*Coastal water volume (Vo) (m^3)*	*Tide frequency*	*Vo available (m^3 day^{-1})*	*Maximum waste volume in pond (m^3)*	*Pond water volume (m^3)*	*Sustainable area of pond (ha)*
0.107	14.225.289	2	28.450.578	284.506	2.845.057	284,5

The data from the identification of phytoplankton species at different pond and mangrove stations are presented in Table 3 and Figure 1.

Table 3

Composition by species (%) and abundance of phytoplankton (ind L^{-1}) at pond and mangrove stations in the coastal waters of Sinjai Regency

Observation station	*Bacllariophyceae*	*Chlorophyceae*	*Cyanophyceae*	*Phaeophyceae*	*Euglenophycea*
Station 1 (ind L^{-1})	48,370	5,370	32,250	10,750	21,500
Station 1 (%)	40,90	4,54	27,27	9,09	18,19
Station 2 (ind L^{-1})	127,875	139,740	21,490	0	16,130
Station 2 (%)	41,89	45,78	7,05	0	5,28
Station 3 (ind L^{-1})	123,610	91,375	37,620	80,620	0

Observation station	*Bacllariophyceae*	*Chlorophyceae*	*Cyanophyceae*	*Phaeophyceae*	*Euglenophycea*
Station 3 (%)	37,09	27,43	11,29	24,19	0
Station 4 (ind L^{-1})	198,855	48,355	26,870	5,370	0
Station 4 (%)	71,16	17,30	9,62	1,92	0

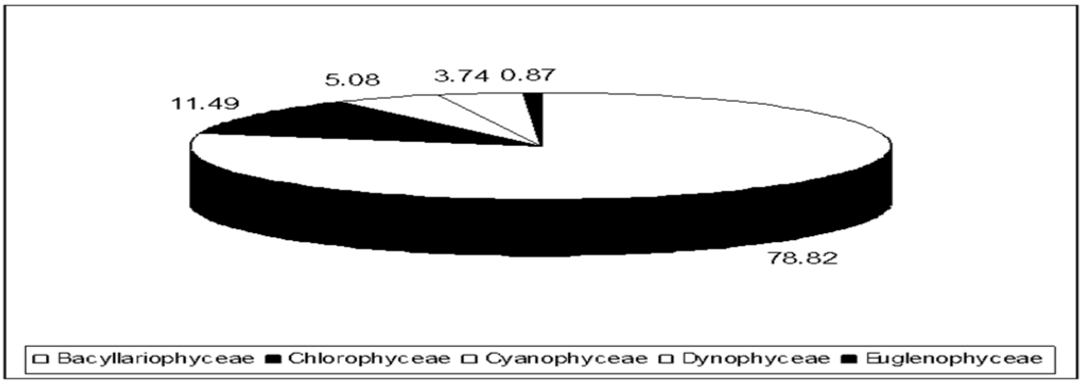

Figure 1. Species composition based on abundance of each class of phytoplankton in coastal waters at mangrove station.

The characteristics of mangrove forest vegetation at the silvofishery ponds in Sinjai Regency are presented in Table 4.

Table 4

Condition of mangrove forest vegetation at silvofishery ponds in Sinjai Regency

Location	*Plot*	*Density (ind 100 m^{-2})*	
		Tree	*Saplings*
Station 1 (control)	0	0	0
Station 2	1	55	62
	2	76	37
	3	64	5
Station 3	1	117	-
	2	123	7
	3	114	18
Station 4	1	136	21
	2	148	-
	3	152	5

Station 1 (control); Station 2 (25% mangrove: 75 ponds); Station 3 (50% mangrove: 50% pond); Station 4 (75% mangrove: 25% pond).

The area of shrimp ponds that can be operated based on the type of applied technology is presented in Table 5.

Table 5

Areas of ponds eligible for exploitation, (based on the applied technology)

Location	*Production capacity (kg)*	*Pond area (ha) based on production target*		
		Intensive (4 tons ha^{-1})	*Semi Intensive (2 tons ha^{-1})*	*Traditional (kg ha^{-1})*
Sinjai Regency	4 tons	284.5	569.0	2.276

Table 6

Calculation of R/C ratio for pond (silvofishery) maintenance in Sinjai Regency

Location	Observation			Average
	1	2	3	
I	1.04	1.25	1.01	1.10
II	1.23	1.10	1.22	1.22
III	1.57	1.46	1.47	1.47
IV	1.06	1.18	1.16	1.16

Based on this analysis, the optimization from the economic aspect is 54% embankment ditch ponds and 46% mangrove forests (Figure 2).

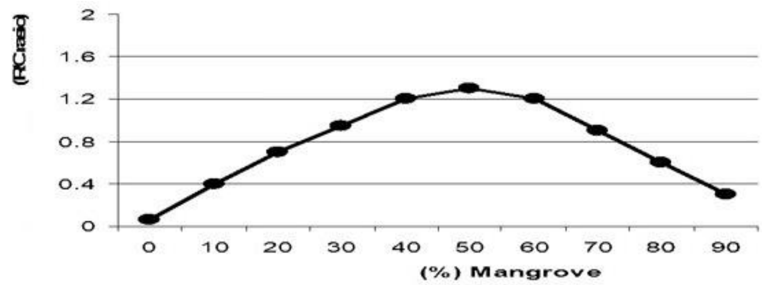

Figure 2. Results of the analysis of the optimization of pond farming business from the economic aspect.

Discussion. The physical conditions of coastal waters Sinjai Regency (Table 1) are as follows: tidal hight 126 cm, beach width 670 m, beach longitude 17 km, tidal pattern 2 times a day, and beach slope of 0.45 degrees. Measurements of water parameters were also carried out during the research in Sinjai Regency and obtained temperatures of 29–32°C, pH 7.35–7.98, salinity 30–32‰, DO 3.52–4.85, NO_3 0.08–0.154. These water quality parameters are still within the proper range for marine biota according to seawater quality standards for marine biota (fish farming) stipulated in the Decree of the Minister of the Environment No. Kep-02/MNKLH/I/1988, concerning guidelines for setting environmental quality standards (Poernomo 1992; Widigdo 2000, 2001, 2002). The dynamic nature of the sea and coast causes the physico-chemical parameters of coastal water to largely range. The movement of water masses results in changes in water quality, the circulation of sea water results in the mixing of water masses and the distribution of nutrients and waste in the waters. In addition, the sea and beaches have a great ability to purify themselves (self-purification), so that everything that happens in seawater can change in a short time (Dahuri 1996, 1998, 1999, 2002). This makes it difficult to assess the quality of sea and coastal waters. However, regardless of the magnitude of the changes, the results of the instantaneous inspection obtained in testing the quality of marine and coastal waters are a real picture of the state of the aquatic environment. This is a reflection of the situation in the longer term.

Plankton. Phytoplankton are microscopic plant organisms that live floating in water and are primary organisms in the food chain. Phytoplankton is one of the biological parameters to determine the level of water fertility (Odum 1971). Figure 1 and Table 3 above shows that at the mangrove forest station Bacyllariophycea is the dominant type of phytoplankton (78.82%), then Chlorophycea with a composition of 11.49%, Cyanophyceae with a composition of 5.08%, Dyanophycea and Euglenophycea each at 3.74.% and 0.87%. Several species of Bacyllariophycea (diatoms) such as Chaetoceros, Nitschia, Cosconodicus and Rhizosolenia are species that have a fairly high frequency of occurrence and abundance. Chaetoceros and Nitschia are types of diatoms favored by fish and shrimp. The types of Chlorophyceae that appear frequently are Coelastrum, Oocystis, Oodegenium, Ulothrix and Microsphora. The types of Cyanophyceae obtained were Calothrix, Oscillatoria, Trichodesmium and Spirulina. From the class Dynophyceae, the types that are often obtained are Ceratium and Noctiluca. While in the Euglophyceae class, the types obtained are Euglena. Based on the results of phytoplankton identification, it is known that there are at least 5 classes of phytoplankton found in Sinjai Regency, namely Bacillariophycea, Chlorophycea, Cyanophycea, Phyopphyceae and Euglenophycea. The data from the identification of these types of phytoplankton were obtained in ponds with Station 1 (control), and Station 2, 3, 4, each with Station 2 25% mangrove: 75% ponds, Station 3 50% mangrove 50% ponds and Station 4 75% mangrove ponds: 25% difference in ponds as presented in Table 4. The lowest diversity value was found in Station 1 (control) and the highest in Station 4 75% mangrove: 25% ponds. According to Odum (1971), the value of type diversity 1-3 is included in the moderate level of diversity. Besides diversity, the uniformity of phytoplankton is an indicator of the level of water pollution. According to Lee et al (1978), the uniformity index between 1.0-2.0 is lightly polluted and >2.0 is not polluted. Based on the uniformity index, the observation area in Sinjai Regency is included in the moderate level of diversity with the category of unpolluted and lightly polluted areas. Meanwhile, the value of the species uniformity index (I) from all observation stations obtained a value in the range of 0.592-0.651. According to Odum (1971), the uniformity index is between 0.5–1.0, so the distribution of individuals between species is relatively even. Based on this, the condition of phytoplankton at each station in the aquaculture and silvofishery forest areas showed an even distribution of individuals. In addition to the abundance of phytoplankton, according to Hartinah & Rustam (2018) that several mangrove species (*Rhizophora apiculata*, *Bruguiera gymnorhyza*, *Avicennia alba*, *Nypa fruticans*) have antimicrobial effects against Vibrio bacteria (Effendi 1998). Vibriosis disease is caused by the gram negative Vibrio bacteria, namely: *Vibrio parahaemolyticus*, *Vibrio alginolyticus*, and *Vibrio anguillaru*, are one of the causes of the increased carrying capacity of mangrove waters for shrimp culture in the sylvofishery system. The carrying capacity of coastal areas for fish/shrimp cultivation activities is strongly influenced by the availability of water volume. The volume of water available on the beach is calculated using the approach Widigdo et al (2001), that the volume of water is determined based on the length of the shoreline, tidal range, slope of the waterbed and distance from the shoreline at the time of the highest tide and at the lowest tide. Based on the calculated data in the waters of Sinjai Beach (Table 2), the volume of water available on the beach (Vo) was 14,225,289 m^3 and the volume available per day was 28,450,578 (2 tides). The carrying capacity of coastal waters as waste recipients is a determining factor for how much waste will be accepted so that the quality is still suitable for shrimp/fish farming activities. In connection with this, the determination of the carrying capacity of coastal waters for shrimp aquaculture activities can be determined using the approach of several expert opinions in aquaculture and environmental experts which can be used as a basis for reference. Dahuri (2002) stated that in order to maintain the quality of public waters that are still suitable for aquaculture, waters receiving liquid waste from aquacultural activities must have a volume between 60-100 times the volume of liquid waste discharged into public waters. Boyd (1998, 1999) stated that the maximum feed capacity for 1 ha of intensively managed ponds is 100-150 kg day^{-1}. Moreover, the water will no longer be able to maintain its quality. In shrimp farming in ponds, the maximum feed is given when the shrimp is approaching harvest weighing between 30-35 g $head^{-1}$. At this size, the dose of feed given is 2.2-2.5% day^{-1}. This condition is intended for intensive shrimp farming with a weight (biomass) of about 4 tons ha^{-1} (Widigdo 2002). The average daily water discharge is 10% of the total pond water volume. Based on this value, it was found that in Sinjai Regency, the optimum area of ponds could be operated by intensive cultivation of 284.5 ha with a production capacity of 3.5–4.0 tons ha^{-1}. Semi-intensive shrimp farming is 569 ha with a production target of 1.5–2.0 tons ha^{-1} MT^{-1}, traditional shrimp farming with a production target of 500 kg ha^{-1} MT^{-1}, the area of the pond that can be operated is only 2,276 ha.

Mangrove ecosystem in Sinjai Kabupaten Regency. Mangrove ecosystem is a coastal ecosystem composed of various types of vegetation that have specific biological and physiological adaptations to environmental conditions that are varied. The mangrove ecosystem is generally dominated by several true mangrove species including *Rhizophora* sp., *Avicennia* sp., *Bruguiera* sp. and *Sonneratia* sp. These mangrove species can grow well in shallow water ecosystems, because of the form of roots that can help to adapt to the aquatic environment, both from the influence of tides and other factors. Other environmental factors that influence are temperature, salinity, dissolved oxygen, sediment, pH, currents and waves.

Mangrove type and density composition. In general, the types of plants that make up the mangrove ecosystem at the research site consist of true mangrove species and associated mangroves. The true mangrove species in question include: *Rhizophora* sp., *Avicennia* sp., *Bruguiera* sp., *Sonneratia* sp., *Ceriops* sp., *Fruticans* sp. and *Acanthus ilicifolius*. Meanwhile, the associated mangrove species consisted of *Ipomoea pes-caprae*. The condition of the mangrove forest on the coast of East Sinjai in 1985 was in a damaged state, and the east coast was open. At that time, strong and open winds hit the fishermen's settlements on the coast. The condition of the muddy beach reaches a depth of 0.5–1 m, this condition arises in the community's thinking to carry out the planting of Rhizophora mangroves independently. The condition of mangrove forests in the East Sinjai area in Tongke-Tongke and Samataring villages is quite good. This is supported by the local governments policy which issued a Regional Regulation on Mangrove Forests in 1999.

Economic valuation of ponds. Based on the economic valuation of ponds in Sinjai Regency (Table 6) with various patterns applied by assessing the Total Revenue (TR) and Total Cost (TC), the R/C ratio of ponds (silfovishery) in various patterns in Sinjai Regency, the value of the R/C ratio in the ponds varies between 1.1–1.57. In general, the economic valuation of each pond pattern is more than 1.0. This means that the embankment ditch pond business is feasible. Based on the analysis of variance, the R/C ratio showed a significantly different value from the regression analysis (Figure 2) with the equation Y = 0.598 + 0.030X - 0.00027 X2. The maximum value of the R/C ratio produced is 1.40, which is 54% or the composition of 54% water and 46% mangrove forest. Based on the results of polynomial analysis of the economic aspect, the optimum R/C ratio value is 1.40 with a pond area of 54%. Based on this analysis, the optimization from the economic aspect is 54% embankment ditch ponds and 46% mangrove forests.

Conclusions. Based on the bio-physical and chemical factors of the coastal waters of Sinjai, the area of the pond that can be operated based on the maximum environmental carrying capacity of the coastal waters in Sinjai Regency is a maximum of 2,276 ha. Based on the results of the economic valuation analysis for ponds/ponds in the Sinjai area, the production of milkfish monoculture ponds earns a profit of USD 68.03 ha^{-1} $season^{-1}$ with an R/C ratio of 1.265 and the production of polyculture shrimp and milkfish ponds provides a profit of USD 163.15 ha^{-1} $season^{-1}$ with a value of R/C ratio=1.614. Based on the results of the economic valuation, the comparison value between the area of mangrove forest and the area of fish/shrimp rearing in silvofishery ponds in Sinjai Regency is 54% of ponds and 46% of mangroves.

Conflict of interest. The authors declare no conflict of interest.

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