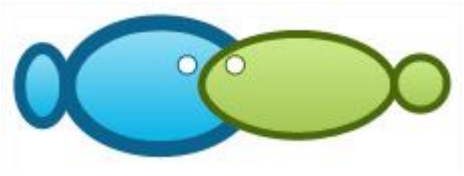

Socio-ecological system of carbon-based mangrove ecosystem on the coast of West Muna Regency, Southeast Sulawesi-Indonesia

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Abstract. Generally, the coastal areas and the mainland are social-ecologically interrelated with varying characteristics. This research, therefore, aims to determine the socio-ecological system and its connectivity related to the dynamics of mangrove carbon. Data were obtained through interviews, field observations, and logical framework, with the spidergram and Drive-Pressures-State-Impact-Response (DPSIR) methods used for its analysis. The results showed that the density and carbon stock associated with the degradation of mangrove ecosystems was due to the use of land for infrastructural development especially ponds, settlements, roads and docks. Connectivity between infrastructure on the degradation of mangrove stock and density was in the strong and very strong categories. Its use on cultivated land had strong and negative connectivity to the reduction of carbon and the density of mangroves especially for *Bruguiera cylindrica, Bruguiera gymnorhiza* and other species. The use of mangroves as tourism land had moderate and positive connectivity to stock and density.
Key Words: carbon stock, DPSIR, socio-ecological system, West Muna Regency.

Introduction. The characteristics of the coastal areas differ from those of the mainland, however, they are social-ecologically interrelated. The coastal area is located between land and sea with a unified ecosystem. In addition, it consists of activities/interactions of natural (resources) and human systems (socio-economic) known as the SES (Socio-Ecological System). Berkes & Folke (1994), Berkes et al (2003), Constanza (1999), Constanza et al (2000), and Glaeser & Glaser (2010) stated that socio-ecological connectivity is defined as functional interdependence between social and ecological change. It is important to discuss the socio-ecological integrated management system and approach with regards to the anthropogenic concept (Virapongse et al 2016; Kanwar 2018).

One of the ecological systems found in coastal areas is mangrove ecosystems which are often utilized by humans. The excessive use of mangroves leads to ecological pressures and damage due to land conversion as ponds, settlements and firewood which leads to carbon loss due to decreased absorption rate and increased concentrations of greenhouse gases resulting from the decomposition of litter (De Wilde & De Bie 2000; Allen et al 2007; Biswas et al 2007; Davidson 2009; Dunne et al 2013; Harley et al 2015; Castillo et al 2017; Tullberg et al 2018).

Studies on the socio-ecological system were carried out on the seagrass ecosystem, Salura Island, and in coastal cities by Sjafrie (2016), Susiloningtyas (2015), and Amri (2017), respectively. However, studies of socio-ecological systems related to carbon are still very minimal in Indonesia and the world. Therefore, this research analyzes the socio-ecological system that plays a role in the absorption and release of mangrove carbon.

Material and Method

Description of the study sites. West Muna Coast is one of the mangrove ecosystem habitats found in Muna Island, Southeast Sulawesi Province, Indonesia. This research was conducted from January to December 2019 in Maginti Sub-district (station I), Central Tiworo Sub-district (station II), Archipelago Tiworo Sub-district (station III) and Sawerigadi Sub-district (station IV) West Muna Regency (Figure 1).

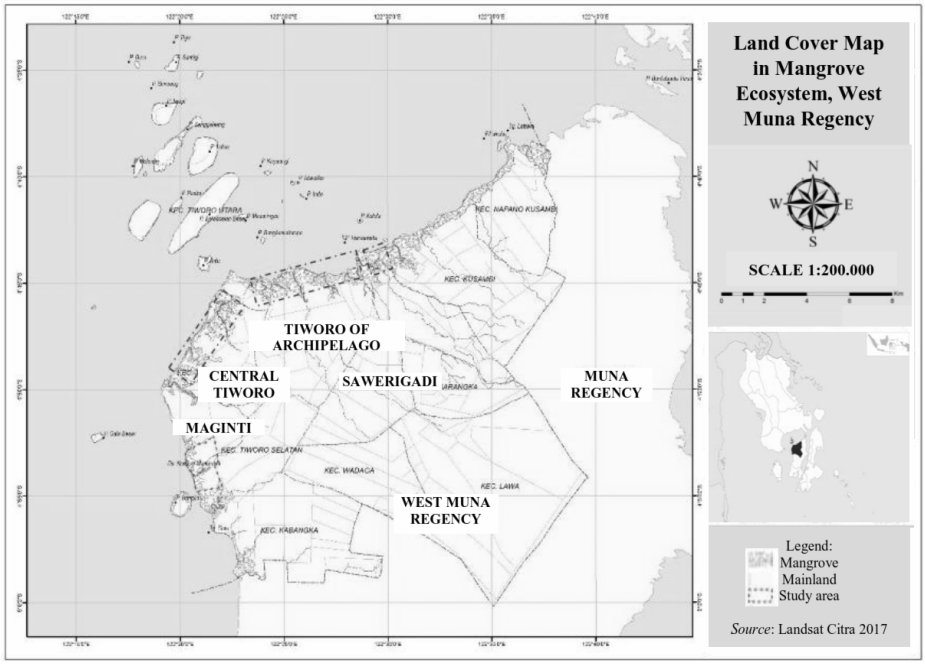

Figure 1. The location of mangrove ecosystems at West Muna, Southeast Sulawesi.

Procedures of data collection. Data were ecologically and socially obtained from 200 respondents by using interviews and questionnaires.

Data analysis

Socio-Ecologycal System (SES) analysis with the Drive-Pressures-State-Impact-Response (DPSIR) approach. The DPSIR framework was widely adopted to analyze environmental problems related to the connectivity of social and natural systems. DPSIR analysis was used to determine the relationship of the factors that caused pressure on mangrove ecosystems, especially those related to the addition or reduction of carbon stocks. Figure 2 shows the modified DPSIR framework used in this analysis in accordance with Baldwin et al (2016).

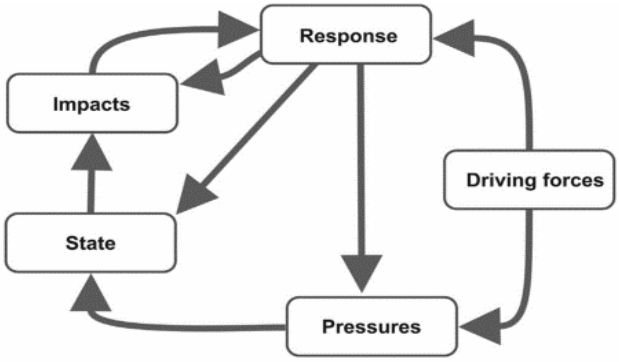

Figure 2. Schematic outline of DPSIR framework (Baldwin et al 2016).

Analysis of the SES connectivity. Analysis of the SES connectivity network of mangrove ecosystems based on carbon was carried out using the modified spidergram approach (Wildenberg 2015). The levels were each marked with red, orange yellow, green and blue, which means no, low, moderate, strong and very strong connectivity, respectively

(Muliani 2017). The types of connectivity related to the increase and decrease of carbon stocks were marked (+), and (-), respectively. The provision of connectivity categories was based on the results of observations, interviews, and logical thinking frameworks.

Results

Mangrove density. Mangrove density in each observation station ranged from 621 to 853 trees ha^{-1} with an average of 735 trees ha^{-1} (Table 1).

Table 1

Mangrove density on the Coast of West Muna Regency

Species	Density (trees ha^{-1})				
	I	*II*	*III*	*IV*	*Average*
Bruguiera cylindrica	93	38	34	7	43
Bruguiera gymnorrhiza	105	59	34	32	57
Rhizophora apiculata	180	106	144	75	126
Rhizophora mucronata	120	74	121	65	95
Rhizophora stylosa	225	178	137	282	205
Sonneratia alba	130	162	177	302	193
Xylocarpus granatum	0	4	0	0	1
Ceriops tagal	0	0	0	25	6
Scyphiphora hydrophyllacea	0	0	0	28	7
Calophyllum inophyllum	0	0	0	5	1
Total	853	621	646	820	735

The density value was lower than Rahman et al (2014) analysis on the coast of West Muna Regency at 1500 trees ha^{-1}. The number of mangrove species on the coast of West Muna Regency was higher than reported by Kaunang & Timbal (2009) in Bunaken National Park, Ledheng et al (2009) in coastal of Bastian Cape – East Nusa Tenggara, Darmadi & Ardhana (2010) in Ngurah Rai Mangrove Forest, Darmadi et al (2012) in Cantigi-Indramayu, Imanuddin & Simarangkir (2012) in Muara Badak Bay, Fuady et al (2013) in Anambas Island, Haya et al (2015) in Joronga Island, Hilmi et al (2015) in Anakan Ocean-Cilacap, Febrianysah et al (2018) in Baai Island-Bengkulu, and was less than reported by Jamili et al (2009) in Kaledupa Island, Ardiansyah et al (2012) in Sebatik Island, and Rizwany et al (2016) in Nine Island.

DPSIR framework of mangrove SES. In general, the socio-ecological system framework of mangrove ecosystems related to carbon dynamics is presented in Figure 3.

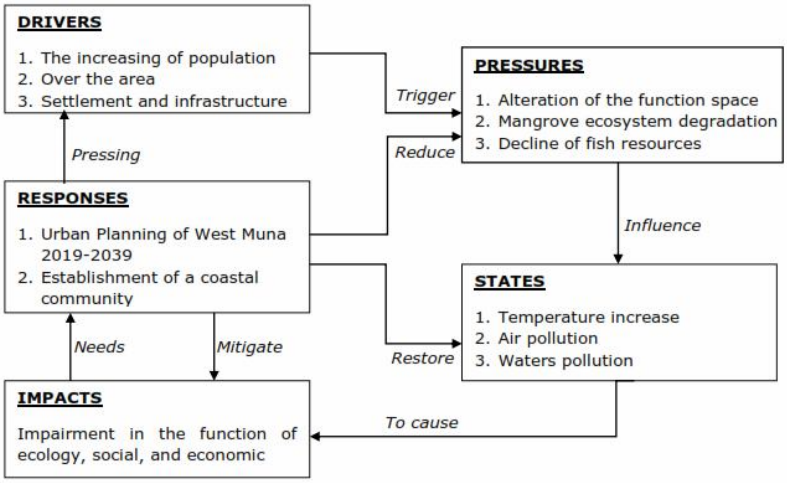

Figure 3. Schematic of DPSIR framework in West Muna Regency.

The networks of SES connectivity. In general, the connectivity of the socio-ecological system in the mangrove ecosystem at the four stations is presented as follows in Figures 4-7.

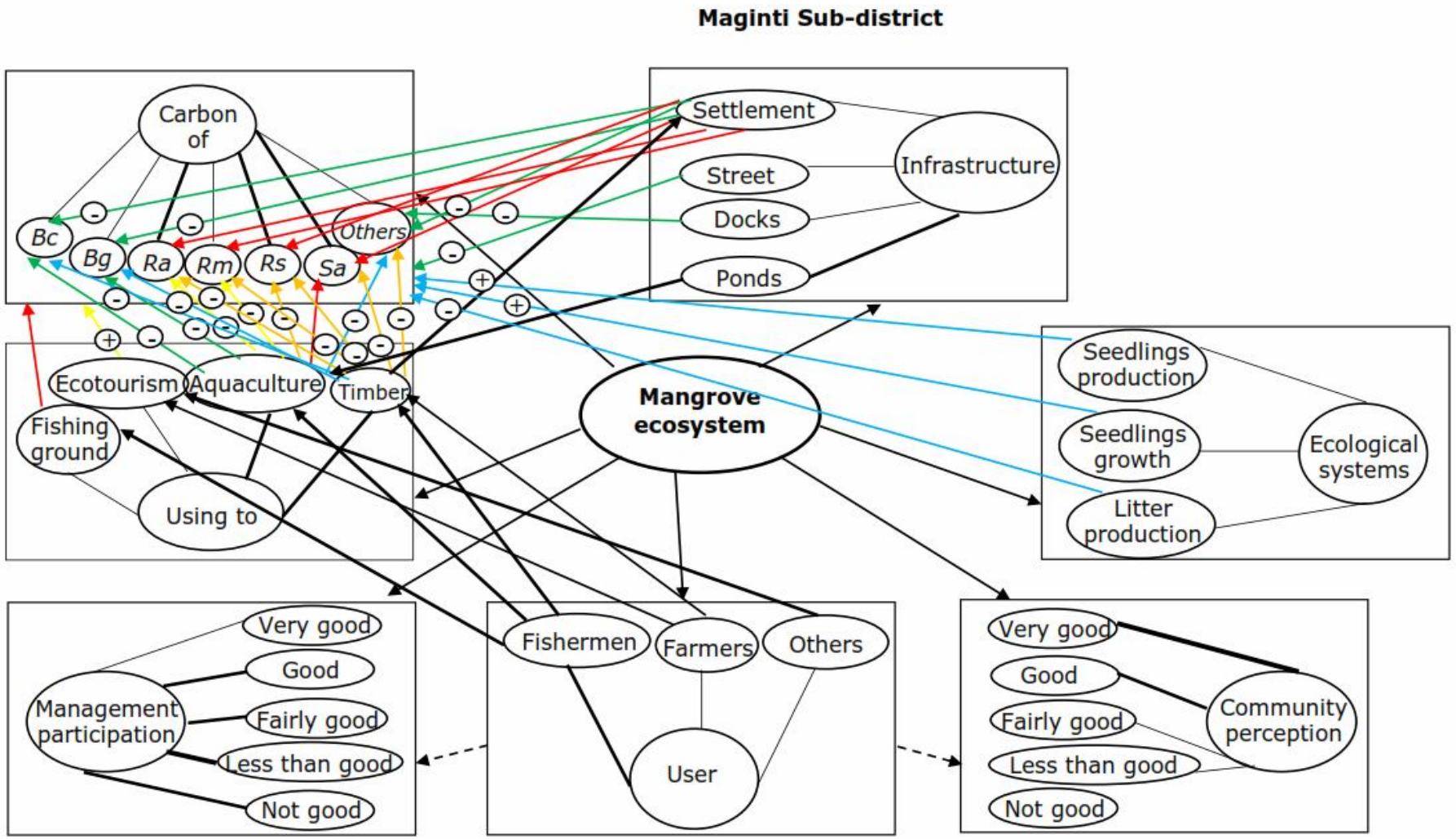

Figure 4. The network of socio-ecological system connectivity of carbon-based mangrove ecosystems in Maginti Sub-district. Remarks: *Bc* = *Bruguiera cylindrica, Bg* = *Bruguiera gymnorrhiza, Ra* = *Rhizophora apiculata, Rm* = *Rhizophora mucronata, Rs* = *Rhizophora stylosa, Sa* = *Sonneratia alba*; red line = no connectivity, orange line = low connectivity, yellow line = moderate connectivity, green line = high connectivity, blue line = very high connectivity; thin black line = small amount, medium black line = moderate amount, thick black line = large amount, dashed black line = supplementary information; (+) = positive connectivity to carbon storage, (-) = negative connectivity to reduce the carbon stock.

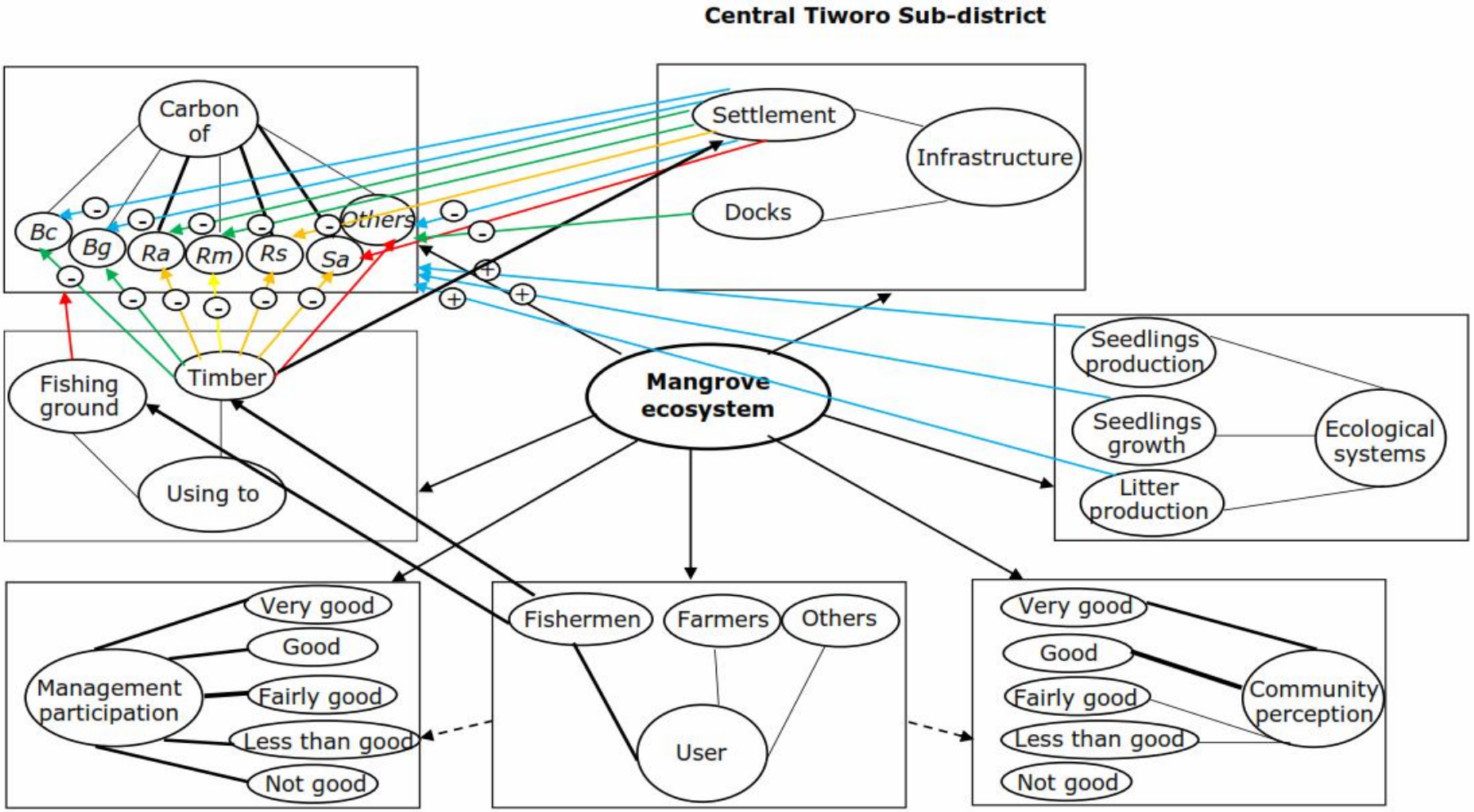

Figure 5. The network of socio-ecological system connectivity of carbon-based mangrove ecosystems in Central Tiworo Sub-district. Remarks: *Bc* = *Bruguiera cylindrica, Bg* = *Bruguiera gymnorrhiza, Ra* = *Rhizophora apiculata, Rm* = *Rhizophora mucronata, Rs* = *Rhizophora stylosa, Sa* = *Sonneratia alba*; red line = no connectivity, orange line = low connectivity, yellow line = moderate connectivity, green line = high connectivity, blue line = very high connectivity; thin black line = small amount, medium black line = moderate amount, thick black line = large amount, dashed black line = supplementary information; (+) = positive connectivity to carbon storage, (-) = negative connectivity to reduce the carbon stock.

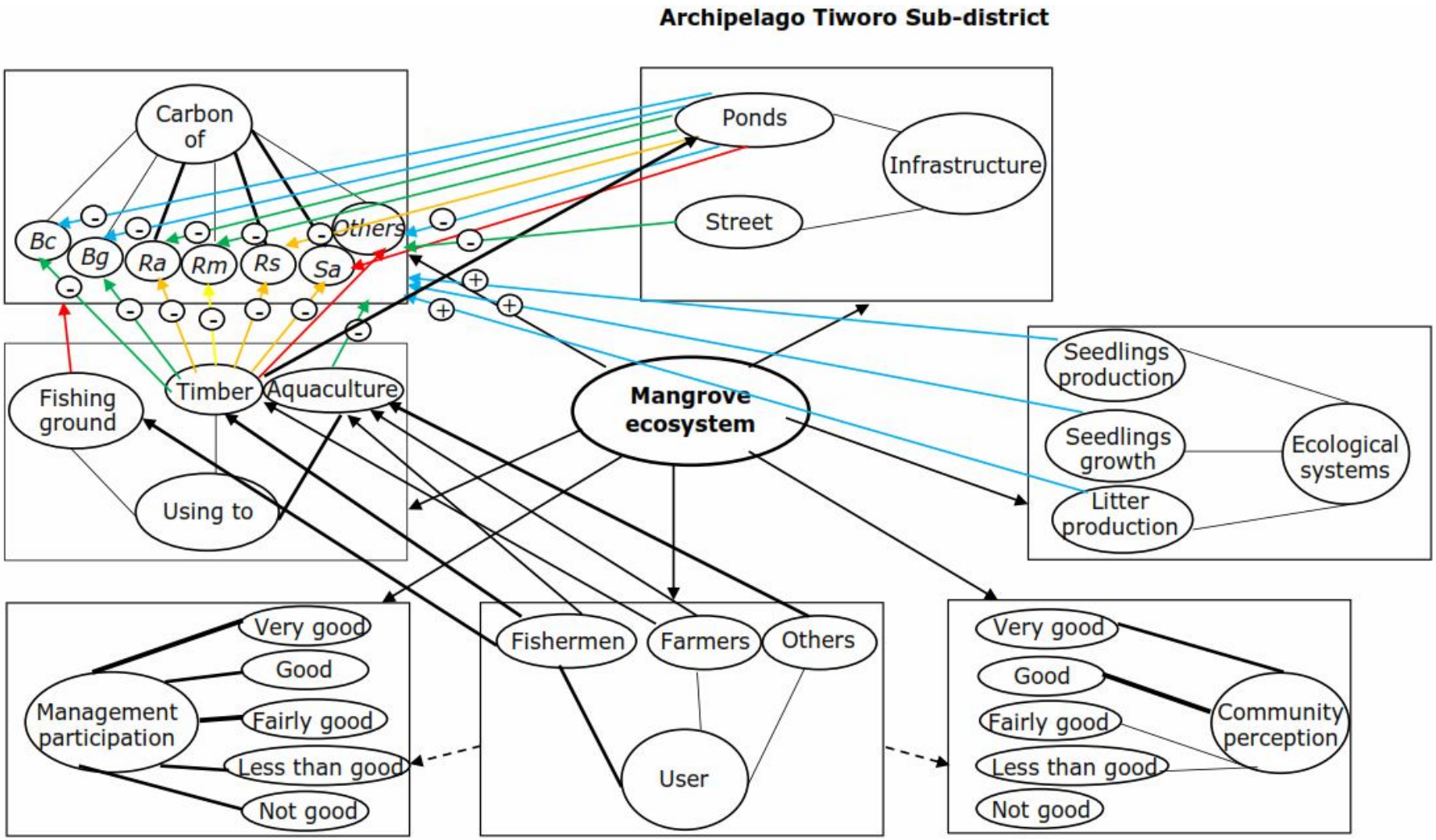

Figure 6. The network of socio-ecological system connectivity of carbon-based mangrove ecosystems in Archipelago Tiworo Sub-district. Remarks: *Bc = Bruguiera cylindrica, Bg = Bruguiera gymnorrhiza, Ra = Rhizophora apiculata, Rm = Rhizophora mucronata, Rs = Rhizophora stylosa, Sa = Sonneratia alba*; red line = no connectivity, orange line = low connectivity, yellow line = moderate connectivity, green line = high connectivity, blue line = very high connectivity; thin black line = small amount, medium black line = moderate amount, thick black line = large amount, dashed black line = supplementary information; (+) = possitive connectivity to carbon storage, (-) = negative connectivity to reduce the carbon stock.

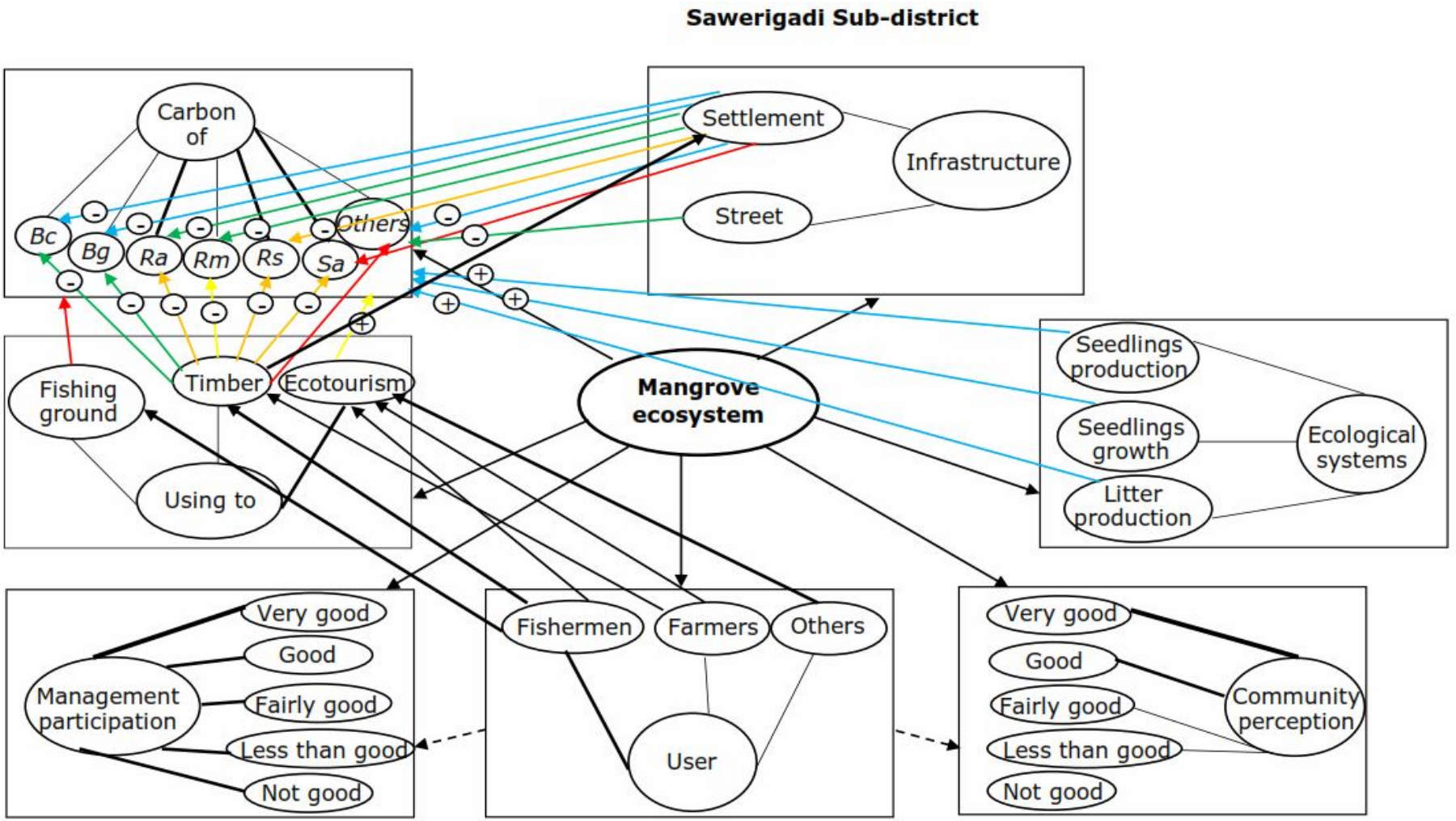

Figure 7. The network of socio-ecological system connectivity of carbon-based mangrove ecosystems in Sawerigadi Sub-district. Remarks: *Bc* = *Bruguiera cylindrica, Bg* = *Bruguiera gymnorrhiza, Ra* = *Rhizophora apiculata, Rm* = *Rhizophora mucronata, Rs* = *Rhizophora stylosa, Sa* = *Sonneratia alba*; red line = no connectivity, orange line = low connectivity, yellow line = moderate connectivity, green line = high connectivity, blue line = very high connectivity; thin black line = small amount, medium black line = moderate amount, thick black line = large amount, dashed black line = supplementary information; (+) = possitive connectivity to carbon storage, (-) = negative connectivity to reduce the carbon stock.

Discussion

SES problems. Based on interviews with respondents, literature review, and field observations using the DPSIR analysis approach, it was found that the driving factors in the socio-ecological system of mangrove carbon were changes in land use, increased in the number of population, settlements and infrastructure. The magnitude of these driving factors triggered pressure on the mangrove ecosystems and other coastal systems. Furthermore, the pressure influenced the increase in air temperature and pollution which ultimately impacted on the social, ecological and economic systems of the society. Efforts made by the government to reduce the impact of mangrove ecosystem degradation was by setting a Regional Spatial Plan (RTRW) 2019-2039. In addition, the government also continued to guide the community to continue to maintain and preserve mangrove ecosystems. However, these efforts were limited by the transfer of mangrove ecosystem management policies to the provincial government, which needs to be revoked to the district level in accordance with the local community's wisdom and regulations.

In generally, the SES problems in this study are the same as the SES problems in mangrove ecosystem on the coast of Subang regency (Muliani et al 2018). In addition, Muliani et al (2018) reported that the goverment of Subang Regency resolved the SES problems by a setting a Regional Spatial Plan (RTRW) 2011-2031, Plan Zonation of Coastal Areas and Small Islands (RZWP3K) West Java Province, mangrove rehabilitation, and conservation. The policy are able to increase the resilience of mangrove ecosystem, especially in the Blanakan villages (2017).

SES connectivity. The results of the socio-ecological analysis, in relation to mangrove dynamics showed strong connectivity at Maginti Sub-district, Central Tiworo Sub-district, Archipelago Tiworo Sub-district, and Sawerigadi Sub-districts, regarding the type of carbon used in each mangrove species. Its utilization in the production of aquaculture ponds, docks, roads and settlements caused degradation of carbon density such as especially *Bruguiera cylindrica, Bruguiera gymnorrhiza*, *Xylocarpus granatum, Ceriops tagal, Scyphiphora hydrophyllacea,* and *Calophyllum inophyllum*. Strong pressure on these species occurred because their habitat was closer to community settlements, was on brackish salinity towards the land (Noor et al 2016).

The use of mangrove wood has strong and negative connectivity to *B. cylindrica, B. gymnorrhiza, R. apiculata*, *R. mucronata, R. stylosa,* and *S. alba* species because it is more widely used in the construction of houses and agricultural fences by communities.

The ecological system and use of mangrove ecosystems as ecotourism areas have very strong and moderate connectivity with a positive value on mangrove stocks and densities. The higher the production and growth of seedlings, the greater the carbon density and stock (Rahman et al 2019). Similarly, better management of mangrove ecotourism leads to a higher protection of stocks and densities.

Conclusions. The degradation of the carbon density and stock of mangrove ecosystem was due to the conversion of land into several infrastructures, such as ponds, settlements, roads and docks, with its connectivity in the strong and very strong categories. The use of mangroves as cultivated land had strong and negative connectivity to the reduction of carbon and density, especially for *Bruguiera cylindrica, Bruguiera gymnorrhiza*, *Xylocarpus granatum, Ceriops tagal, Scyphiphora hydrophyllacea,* and *Calophyllum inophyllum.* However, its use as a tourist land has strong, moderate and positive connectivity to stocks and densities.

Acknowledgements. The first author would like to express the highest gratitude to the Indonesian Endowment Fund for Education (LPDP) as the main sponsor of this research so that the research could be conducted successfully.

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Received: 06 January 2020. Accepted: 24 February 2020. Published online: 07 March 2020.
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How to cite this article:
Rahman, Wardiatno Y., Yulianda F., Rusmana I., 2020 Socio-ecological system of carbon-based mangrove ecosystem on the coast of West Muna Regency, Southeast Sulawesi-Indonesia. AACL Bioflux 13(2):518-528.