Socio-ecological network analysis of Bima Bay, West Nusa Tenggara Province, Indonesia

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Abstract. Bima Bay is a socio-ecological system (SES) with semi-closed water, located between 2 local governments, encompassing Bima Regency and Bima City. The total population in the coastal area was 185419 and 190736 people, in 2016 and 2018, respectively, featuring a 1.03% increase. However, about 5097 people (0.02%) of Bima Bay depend on the fisheries sector as a source of livelihood. The purpose of this study, include: (1)mapping the SES of Bima Bay, adopted from the conceptual model in the socio-ecological system; (2) obtaining quantitative data using network analysis between the socio-ecological system components. The analysis tools used are the mapping of the SES conceptual model and social network analysis (SNA). The results based on the highest degree are the following: fisheries business - 17 degrees; fish - 14 degrees; shrimp - 12 degrees; and local regulation - 11 degrees. The highest betweenness value (41.98) was observed in local regulation and number of visits, while the value for market and fisheries business was 39.3. The lowest value (2.06) was recorded for fish and shrimp. Therefore, 6 groups of relationships were established in the SES of Bima Bay, on the basis of cluster or community detection.
Key Words: betweenness, cluster, community detection, degree, social-ecological system.

Introduction. Bima Bay is a semi-closed water body directly connected to the Flores Sea, characterized by an area of 184 km^2 and 78 km in length (DirPolAir NTB 2017). The coastal area is currently faced with rapid progression, alongside the concept of developing the City of Bima as a "Waterfront City" and a tourism village, through the NTB Governor Decree Number 050.13-366 in 2019, concerned with the development of 99 tourist locations in West Nusa Tenggara Province. In addition, the idea is feared to put pressure on the sustainability of coastal ecosystems, and also to impact spatial use, observed in both direct and indirect changes in patterns. These modifications are related to the function and distribution of designation, including industrial estates, settlements, warehousing, and transportation systems, which influence the quality and quantity of regional infrastructure, and coastal reclamation. Furthermore, the transformations observed in land areas, alongside the diminution of coral reefs, mangrove regions and sedimentations result in silting. This phenomenon is exacerbated by the non-environmentally friendly use of spaces, and the accumulation of domestic waste load.

The policy is expected to encourage land use and increase the population of the Bima Bay area, consequently yielding to an increase in activities. In addition, there are implications on the coastal ecosystem and water quality, encompassing mangroves, seagrass and coral reefs (Asyiawati et al 2010).

The aforementioned characteristics show the need for proper management in order to attain sustainable utilization. This expectation requires adequate supervision and an understanding of the interaction between social and ecological systems, being one of the management solutions concerning ecological and socio-economic sustainability.

Furthermore, the inability to build a functional system is bound to negatively impact the existence of the already limited bay resources, even though the areas and community application are currently open. These areas allegedly feature a continuing rise in utility, in efforts to improve the economy of the surrounding regions, alongside negative impacts, in terms of environmental and coastal ecosystem destruction.

The interactions between ecological and social systems are known as socio-ecological systems (SES), as described in some research (Anderies et al 2004; Costanza 1999; Berkes et al 2000; Constanza et al 2000; Abram & Dyke 2018). According to Gunderson et al (2006), SES is a broad concept of human and nature, where the ecological system is related to and influenced by one or more social systems. SES refers to the collaboration between social structures and processes with ecosystem units, including coastal areas, mangroves, seagrasses, coral reefs, beaches and upwelling structures (Adrianto 2009).

The complexity of the SES is rooted in the results of the node activity, which is connected by network topology (Hu et al 2017). This study is centered on the relationships between social and ecological systems in sustainable management of the Bima Bay area, and it aims to ascertain the influencing units. The purpose of this study, therefore, is to map the SES of Teluk Bima, and analyze the relationship between the SES components in the network of Bima Bay, located in West Nusa Tenggara Province.

Material and Method

Description of the study sites. The study site is located between 2 autonomous government areas of Bima City and Bima Regency, West Nusa Tenggara, and is surrounded by 6 subdistricts, at the coordinates 118°41’33.265”E and 8°28’40.732”S (Figure 1). The population of the coastal area was 185419 and 190736 in 2016 and 2018, respectively, featuring an increase of 1.03% (Statistic of Bima Regency 2019; Statistic of Bima Municipality 2019).

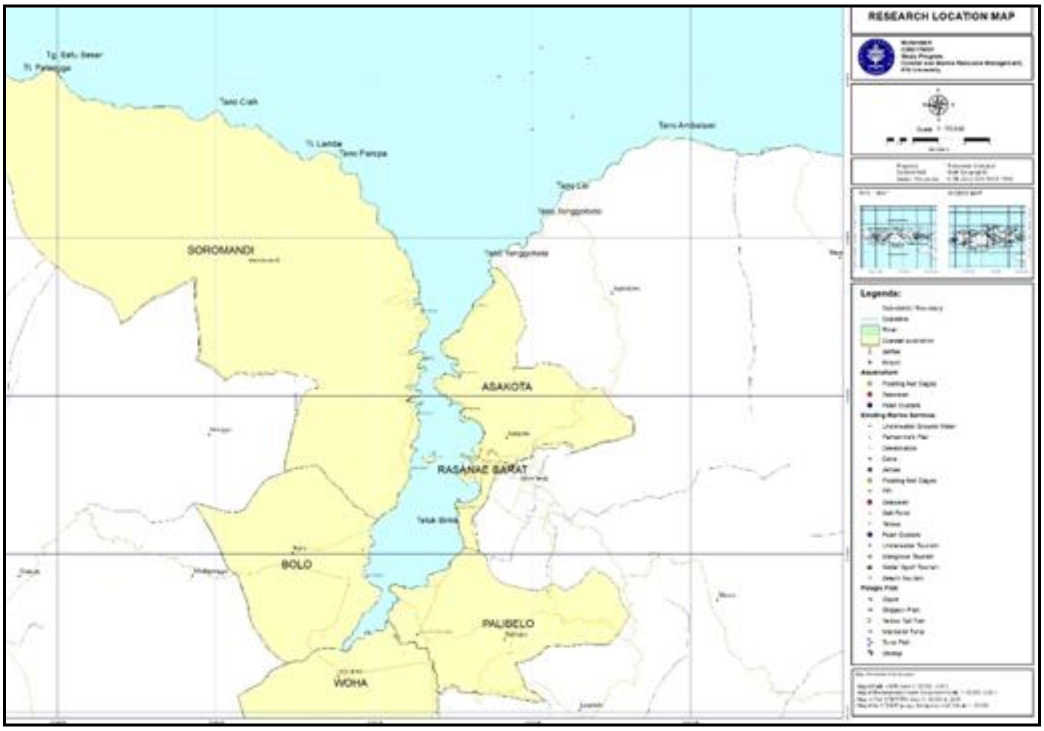

Figure 1. Research location - Bima Bay.

The direction of the development policy in Bima City is based on the presence of a waterfront, while Bima Regency takes advantage of the Bay area as a tourist village. Bima Bay has broad access to other areas in the archipelago, especially the eastern and western regions of East Nusa Tenggara and Bali Province, respectively. Bima Bay has the potential of being utilized for capture fisheries, aquaculture (brackish and marine water cultivation), and tourism. However, proper management has not been integrated due to the current focus on development in each sector, with disregard for others. This perception is reinforced by the NTB Province local regulation number 12 of 2017, concerning the Coastal and Small Island Zoning Plan (RZWP3K), which establishes Bima Bay as vicinity for public use in tourism and port zones. Furthermore, the alleged impact of this regulation is observed in the development of capture fisheries and aquaculture.

This perspective is assumed to produce changes in the Bima Bay system, both ecologically and socially. These indicate a threat to the environment, resources and lives of people in the surrounding community, both directly and indirectly. The sketch of the bay ecosystem is understood from the standpoint of socio-ecological system.

Raw material and data analysis. This study required the collection of primary data, obtained directly through in-depth interviews with questionnaires, and secondary data, in the form of results and based on information made available at the local governments. These sources are translated based on a conceptual framework model adopted from Anderies et al (2004) (Figure 2). The populations in this study include fishermen, farmers, collectors and related agencies, totaling 40 interviews conducted using the purposive sampling method. The selection was based on certain criteria (Sugiyono 2013), including: small and traditional fishermen involved in fishing activities at the Bima Bay area; indigenous pond farmers and floating net cages; collectors; related institutions (regional development planning agency Bappeda, fisheries, marine and tourism services).

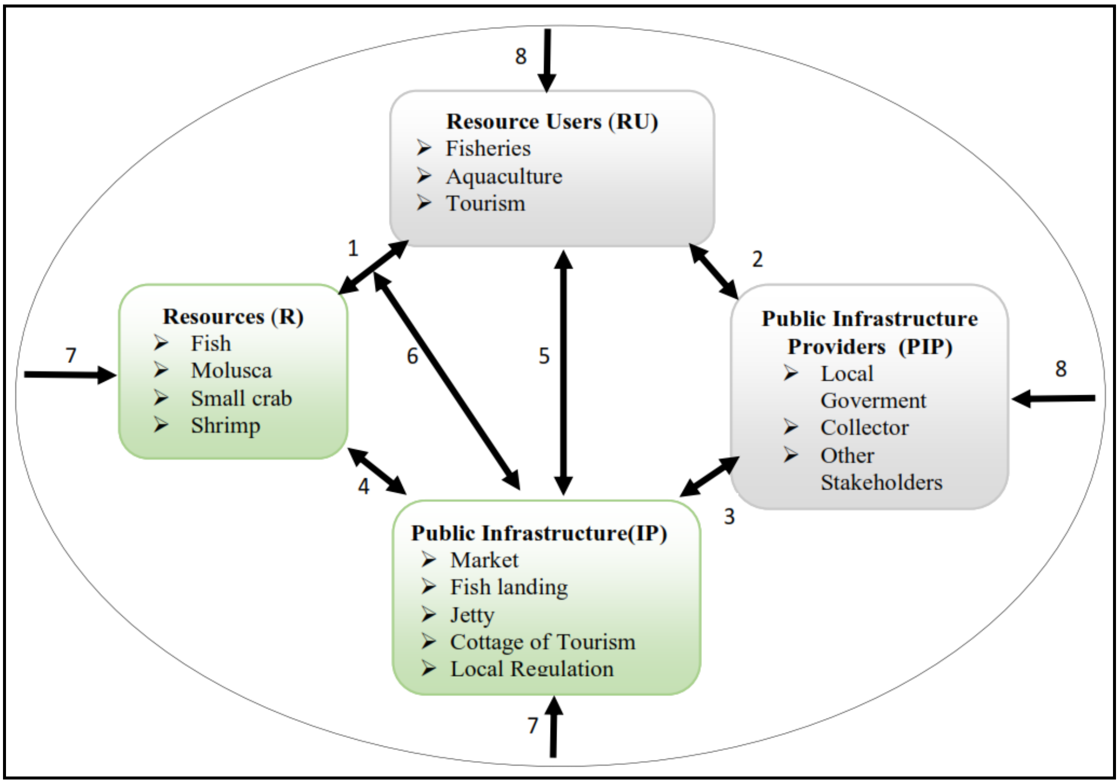

Figure 2. Socio-ecological system framework of Bima Bay.

In the perspective of an ecological system, Bima Bay is an interaction between biotic and abiotic components, including the physico-chemical parameters of the substrate and water. There is, however, a possibility of optimal development when there is less pressure from fishing activities or environmental changes (sedimentation, solid and liquid waste, etc).

Table 1 shows the composition of resource users.

Table 1

Components of resource users

No	Resource use	Definition and characteristics
1	Fishermen	Fishermen include all the people with the livelihood of fishing (Law of the Republic Indonesia 2016). Those in the research location are divided into 3 classes based on working time, including full, main sideline and additional part-time. fishermen. Most boats used to catch fish at the Bima Bay do not have engines, although some possess engines that are outboard or with capacities up to 10 gross tons. The fishermen in Bima Bay are included in the category of small and traditional fishermen.
2	Collector	A collector is any person that acts as a collector or a marketer, and is known to buy fishery commodities from fishermen and farmers.
3	Cultivator	Cultivators are individuals that make a livelihood from cultivating fresh, brackish, and sea water fish (Law of the Republic of Indonesia 2016). Cultivation in Bima Bay waters requires the use of floating net cages and traditional ponds with polyculture systems. Water generally has a bad condition for brackish water cultivation during the dry season (July-September). During the dry season, the cultivator changed the traditional fish ponds to salt ponds.
4	Tourism	Includes sightseeing in the area (Bibin et al 2017).

Public infrastructures are set up to support the interests of the community. This encompasses the input of individuals and institutions in providing facilities for public purposes at the study area. In addition, the providers of infrastructure include the local government, which provides public infrastructure to support the activities of fishermen, farmers, tourists and fish processing groups, and also helps selling the catch, and the access to travel. The other providers of infrastructure are the collectors, which provide space for fishermen and farmers to sell the catch and cultivation products.

The public infrastructure at the study area consists of 2 components: physical and non-physical. Physical components are jetty piers, tourist cottages, fish landings, market. The non-physical component available in the study area represents local regulation of (Perda) West Nusa Tenggara Province number 12 of 2017, concerning zoning plans for coastal areas and small islands (RZWP3K).

Social network analysis is the basis for recognizing the relationships existing between important individuals/groups and the constraints of social environment or challenges for individual actions (Kluger et al 2015). The base of network analysis is represented by the relations associated with the nature of connections established between individuals, groups and organizations. Furthermore, the social nodes are possibly represented as individuals, groups or other public units, and the process of identifying those that are suitable for social network analysis is often complex. This is due to the connection between different sectors, levels of development and variations in interests. In addition, the concept of relationships has the dimensions of strength, symmetry, transitivity, reciprocity, and multiplexity (Kluger et al 2015). SNA usually uses adjacency matrices, where the values in each cell show information about the relationships and degree of closeness between actors, individuals, or nodes. The outcome is based on the values existing in each cell (Putri et al 2018), and this study used measurement scale values of -1, 0 and 1, where -1 represents a negative relationship, 0 represents the absence of any association and 1 designates a positive relationship. Moreover, Dijkstra's algorithm is used to identify the shortest of all possible paths and trace the initial location to the destination (Susanto et al 2012). The social network analysis is then used to evaluate networks between components or units in the R SNA package, with R tools (Butts 2019). In addition, 3 levels of individuals are used to obtain an understanding, including degree, betweenness and cluster or community detection.

The degree analysis is used to comprehend the number of relationships between nodes and others in the network (Kluger et al 2015). This is also applied in calculating the number of interactions owned by a node, and the degree value is obtained using the formula:

$$C_D(n_i) = d(n_i)$$

Where: C_D - degree centrality; $d(n_i)$ - the amount of interactions owned by node n_i with other nodes in the network.

The betweenness analysis is conducted on the relationships of node or edge positioned between others in the network. This is also used to calculate the frequency of being passed by another prior to reaching a certain node or edge. Furthermore, the value of betweenness serves to determine the role of actors that function as bridges of interaction in the network (Setatama & Tricahyono 2017), calculated using the formula:

$$C_B(n_i) = \sum g_{jk}(n_i) / g_{jk}$$

Where: C_B - betweenness centrality; $g_{jk}(ni)$ - the number of the shortest paths from node j to node k that pass through node i; g_{jk} - the number of shortest paths between 2 nodes in the network.

Clusters have been explained many times in various contexts, including from the perspective of community detection, groups, subgroups, subnetworks, cohesion groups and modules. Cluster analysis refers to the grouping of network interests into several subgroups, which is natural, depending on the nature of the node, and its relationship in the network. This association is then measured based on the similarity matrix (Setatama & Tricahyono 2017). Community detection in social networks is understood as the tendency of actors or nodes to form groups with closely related connections. This study uses grouping approach based on community detection methods, and cluster analysis, adopted to enhance identification and understanding. Furthermore, community detection is applied in a graphical technique to find cluster nodes, understood as the magnitude or strength of ties in the community. Alamsyah et al (2014) reported cluster analysis as a tool for measuring nodes that are closely connected to nodes in other networks. The following formula was used to calculate the value within the network (Hansen et al 2011).

$$CC = \sum_{i=1}^{n} \frac{2\,e_i}{k_i\,(k_i - 1)}$$

Where: CC - closeness centrality; k_i - the number of nodes in a group; e_i - the number of relationships between nodes in a group.

Furthermore, community detection analysis is node-centric, applied with nodal degree grouping. The proximity of actors in a group with a large number of other members was evaluated with the k-plex containing a maximum subgraph of ns nodes, where each is located adjacent to the ns-k in a subgraph. Also, there is a respective absence of ties prior to reaching the k group members. Therefore, k-plex is bound on instances where k=1 and k-core is a sub-structure of each node (vi), connecting at least k members in the group (Wang et al 2020).

$$N_s(i) \geq k \forall v_i \in v_s$$

Where: N_s – node centric; vs - node to s; vi – each node; ns - number of nodes up to s; vs - number of each nodes up to s; k-plex number of group sizes to ns, also (ns-k) cores.

Results and Discussion

Social network analysis. 4 components of the socio-ecological system (SES) were identified, including resources, resource users, public infrastructure providers and public infrastructure. The social network analysis was based on the results of in-depth interviews, questionnaires and field observations, which were then streamlined to the following components: resources, including fish, molluscs, small crabs and shrimp; users, which consist of capture fisheries, aquaculture and tourism; public infrastructure providers, encompassing the local governments, collectors and other stakeholders; public infrastructure, including fish markets, fish landing sites, jetties, tourist huts and local regulations. The results were translated into sub-units, and subsequently into nodes, based on the relationships and linkages with existing sub-components/units (Figure 3).

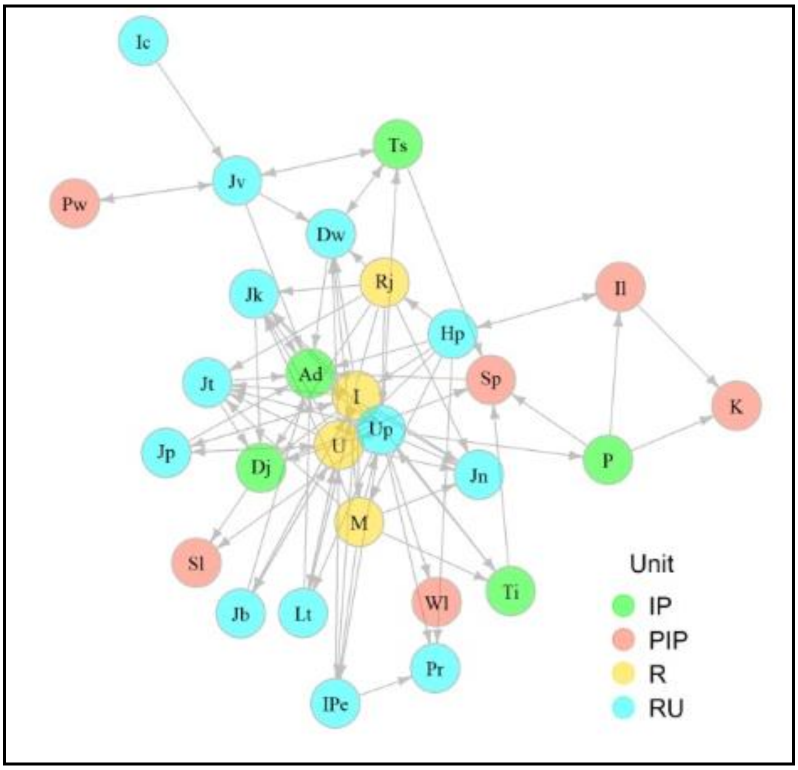

Figure 3. Basic model of network analysis. Nodes are labeled as public infrastructure (IP), public infrastructure providers (PIP), resources (R), resource users (RU), fisheries business (Up), fish (I), local regulations (Ad), shrimp (U), molluscs (M), small crabs (Rj), jetties (Dj), tourist destination (Dw), fishery products (Hp), number of ships (Jk), number of visits (Jv), cottage (Ts), infrastructure (Sp), tourism income (Ic), commodity (K), market (P), others stakeholder (Sl), domicile area (Wl), tourism manager (Pw), price (Pr), number of fishermen (Jn), fishery income (IPe), construction of public facilities (Sp), area of cultivation (Lt), fish landing (Ti), collecting income (Il), type of cultivation (Jb), number of cultivators (Jp), number of fishing gear (Jt).

Degree analysis. Degree analysis determines the number of links to other actors in the network. The results of Bay Bima SES degree analysis showed a significant relationship between fisheries business (Up) and other nodes, with a degree value of 17. Furthermore, the fish node (I), with a degree value of 14, indicates the importance attributed to the existence of fish resources as a source of livelihood for coastal communities. This also shows the presence of a relationship with other nodes in the network. Conversely, the shrimp node (U), with a degree value of 12, also shows a high level of association with others. This occurs due to the presence of many traditional fish farmers in the coastal area of Bima Bay, alongside the practice of polyculture systems between milkfish and shrimp. The local regulations (Ad) connected with 11 other components in the basic network model. This is concerned with the coastal zoning plans and small islands (RZWP3K) being one of the points mentioned as a tourism area, with other nodes also contributing adequately. Conversely, the bay utility as an area for tourism leads to the development of a good relationship for future progress, in addition to the fisheries business (Up), fish (I) and shrimp (U). In addition, the lowest degree value (1) was recorded in tourism income (Ic), tourism management (Pw) and domicile area (Wl). Figure 4 shows the node size, based on the magnitude of the SES degree value in Bima Bay.

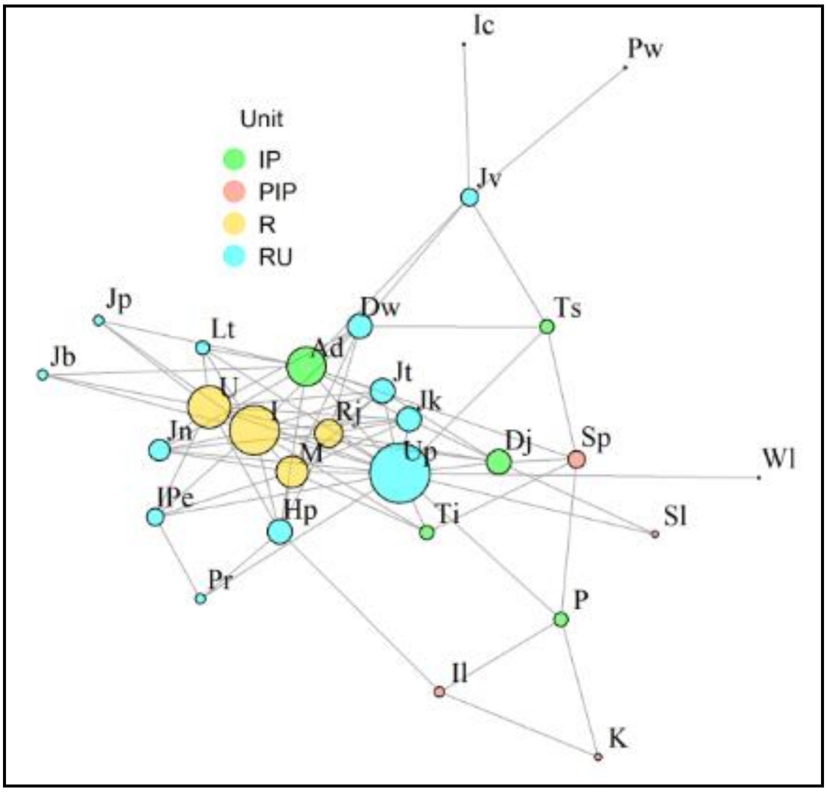

Figure 4. Node size based on degree value. Nodes are labeled as public infrastructure (IP), public infrastructure providers (PIP), resources (R), resource users (RU), fisheries business (Up), fish (I), local regulations (Ad), shrimp (U), molluscs (M), small crabs (Rj), jetties (Dj), tourist destination (Dw), fishery products (Hp), number of ships (Jk), number of visits (Jv), cottage (Ts), infrastructure (Sp), tourism income (Ic), commodity (K), market (P), others stakeholder (Sl), domicile area (Wl), tourism manager (Pw), price (Pr), number of fishermen (Jn), fishery income (IPe), construction of public facilities (Sp), area of cultivation (Lt), fish landing (Ti), collecting income (Il), type of cultivation (Jb), number of cultivators (Jp), number of fishing gear (Jt).

Betwenness analysis. Betweenness analysis determines the extent of a relationship between the position of one node and another in the network. The results show the highest value of 41.98 in the association between the local regulation node (Ad) and the number of visits node (Jv). This indicates the tendency for automatic increase in number of tourist visits, when the area is used as a tourism site, in accordance with the rules of utilization. The relationship between market and fisheries business nodes has a betweennes value of 39.3 and ranks second. This shows the strong influence of fisheries business improvement by the presence or absence of the market. This is needed to accommodate the agricultural output, which is assumed to further develop, and this is not greatly influenced by the existence of the market. The third highest betweenness value of 27 regards the nodes of tourism income (Ic) and the number of visits (Jv), alongside the number of visits (Jv) and the tourism management node (Pw), as well as the fisheries business (Up) and domicile area (Wl). This shows the ability for increasing the number of nodes related with visits to provide a good contribution towards the tourism income. Furthermore, more tours at Bima Bay are expected to cause an upsurge in the amount of local revenue attained in terms of retribution, which consequently encourages local governments to improve service and physical facilities. In addition, an increase in the number of visit nodes is assumed to increase the activity of tour managers in providing services for tourists. The relationship between fisheries business (Up) and the administration area is relatively close. This is because the Bay is located between 2 autonomous domicile areas, encompassing Bima City and Bima Regency, and the existence of a fisheries business depends on the domicile location. Figure 5 shows the node and edge size, based on the value of betweenness.

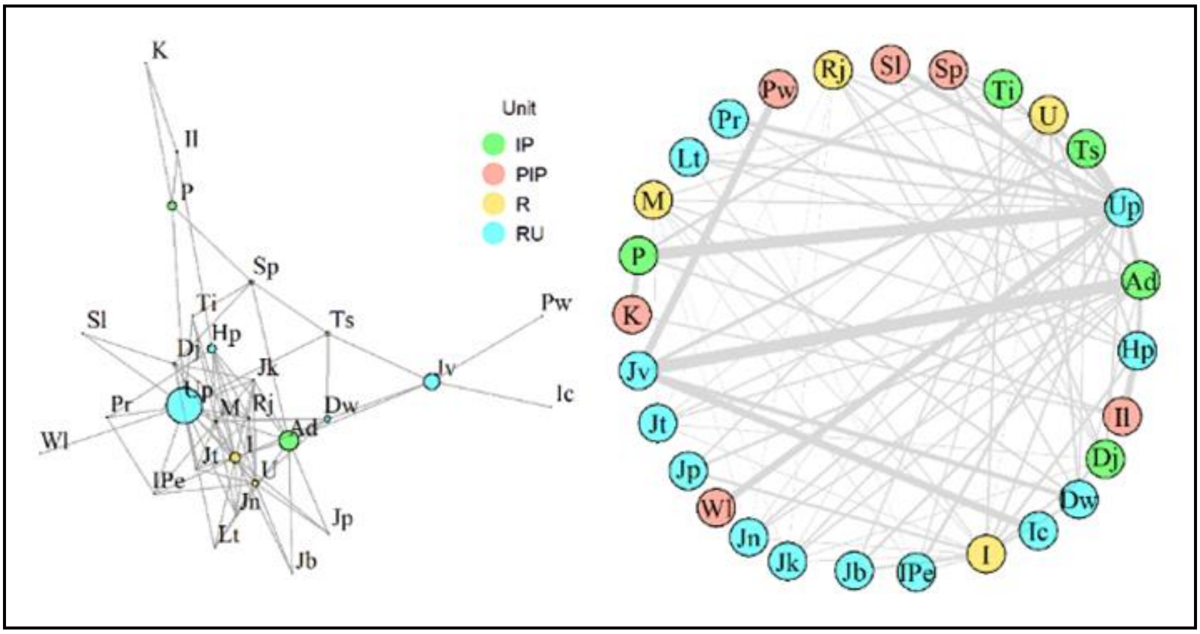

Figure 6. Size of the node and edge based on the magnitude value of betweenness. Nodes are labeled as public infrastructure (IP), public infrastructure providers (PIP), resources (R), resource users (RU), fisheries business (Up), fish (I), local regulations (Ad), shrimp (U), molluscs (M), small crabs (Rj), jetties (Dj), tourist destination (Dw), fishery products (Hp), number of ships (Jk), number of visits (Jv), cottage (Ts), infrastructure (Sp), tourism income (Ic), commodity (K), market (P), others stakeholder (Sl), domicile area (Wl), tourism manager (Pw), price (Pr), number of fishermen (Jn), fishery income (IPe), construction of public facilities (Sp), area of cultivation (Lt), fish landing (Ti), collecting income (Il), type of cultivation (Jb), number of cultivators (Jp), number of fishing gear (Jt).

Cluster and community detection analysis. The cluster analysis results with social network analysis naturally grouped the data based on similarity in the pattern of relationship structure and characteristics. These often appear simultaneously in the same associations. Figure 6 presents a dendrogram of the graphical node cluster and community detection.

The act of grouping with cluster analysis and community detection in Bima Bay, which was based on node relationships, showed the presence of 6 clusters in a network. These were measured by observing the similarity matrices, as seen in vertex, and also edge betweenness. Furthermore, the values obtained for community detection relationship were displayed as a color cluster, and node or edge relationship levels of the Bima Bay socio-ecological system was calculated based on the value of degree, betweenness and clusters, as shown in Table 2.

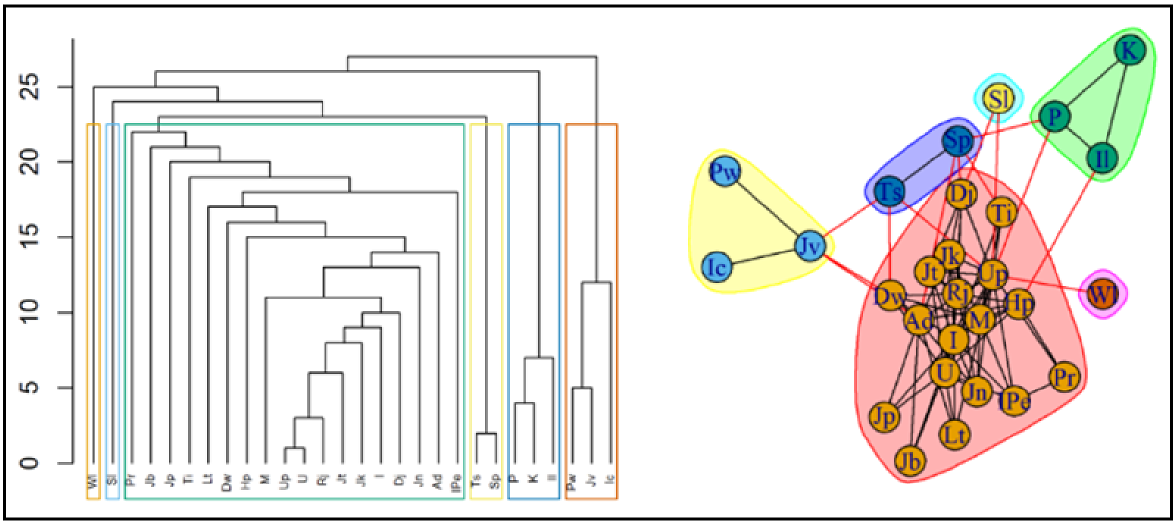

Figure 6. Cluster and community detection of the Bima Bay social network. Nodes are labeled as public infrastructure (IP), public infrastructure providers (PIP), resources (R), resource users (RU), fisheries business (Up), fish (I), local regulations (Ad), shrimp (U), molluscs (M), small crabs (Rj), jetties (Dj), tourist destination (Dw), fishery products (Hp), number of ships (Jk), number of visits (Jv), cottage (Ts), infrastructure (Sp), tourism income (Ic), commodity (K), market (P), others stakeholder (Sl), domicile area (Wl), tourism manager (Pw), price (Pr), number of fishermen (Jn), fishery income (IPe), construction of public facilities (Sp), area of cultivation (Lt), fish landing (Ti), collecting income (Il), type of cultivation (Jb), number of cultivators (Jp), number of fishing gear (Jt).

Table 2

The degree, betweenness and cluster values of Bima Bay

Node	*Degree*	*Edge betweenness*	*Node*	*Node betweenness*	*Node*	*Cluster*
Up	17	41.98	Up	113.85	Up	1
I	14	39.30	Ad	62.51	Ad	1
U	12	27.00	Jv	51.58	I	1
Ad	11	27.00	I	33.98	Jv	2
M	9	27.00	Hp	27.02	Ic	2
Rj	8	24.76	P	27.02	K	3
Dj	7	24.73	U	21.55	P	3
Dw	7	22.00	Dw	20.01	Sl	4
Hp	7	20.34	Ts	14.28	Ts	5
Jk	7	20.32	Sp	13.13	Wl	6

Note: Up - fisheries business; I - fish; Ad - local regulations; U - shrimp; M - molluscs; Rj - small crabs; Dj - jetties; Dw - tourist destination; Hp - fishery products; Jk - number of ships; Jv - number of visits; Ts - cottage; Sp - infrastructure; Ic - tourism income; K - commodity; P - market; Sl - others stakeholder; Wl - domicile area; Pw - tourism manager.

The degree value in fisheries business (Up) shows the high importance attributed to this node, known to influence the relationship between others. Furthermore, the introduction of changes is expected to affect the SES of Bima Bay. Hence, the absence of the fisheries node is expected to create an imbalance within the network. This shows its dominance in establishing relationships with other actors (Kluger et al 2015). Meanwhile, the betweenness value concerning the node of regional regulation and the number of visits has the highest relationship value. Therefore, in accordance with the rules of utilization, the bay application as a tourism area is expected to encourage visitations from local or regional communities, and also instigate an automatic increase in the number of tourist trips (Perda NTB Province 2017). Grouping by cluster analysis is displayed in the form of a hierarchical diagram, and the community detection results show the presence of 18 nodes in orange (Figure 6). This group is assumed to dominate the relationship structure in the SES of Bima bay. However, the green and yellow feature 3 nodes, while the blue has 2, and the red as well as light blue groups have 1 node. Conversely, the level of network analysis, using the cluster method, shows grouping results that are similar with community detection, although only the grouping form tends to be based on a hierarchy.

Based on the results of this study, interaction between people and resources in the coastal area of the bay is very important for understanding it as a socio-ecological system. A holistic understanding of the complex interactions between humans, wildlife, and habitats is essential for the design of sustainable wildlife policies (Dressel et al 2018). Interactions in socio-ecological systems are complex, because different types of fisheries interact with ecosystems. Understanding connectivity within these systems (i.e. among social and ecological actors) helps in establishing meaningful management strategies for the sustainable use of marine resources (Kluger et al 2019). The interaction of socio-ecological systems in coastal areas will reduce the ecological impact caused by increasing human activities. According to Muliani et al (2018) socio-ecological system interactions in coastal villages often cause problems, from declining ecological quality to social conflicts. One solution for reducing these impacts is to expand the analysis of the coupled socio-ecological system as a whole, not only increasing the number of elements and relationships, but also exceeding established disciplinary boundaries (Kluger et al 2015). Coastal management approach based on socio-ecological systems provides basic knowledge for systematically addressing complex issues in integrated coastal management, and for developing a knowledge-based strategy in understanding the processes of ecological and social dimensions of the system on a different scale (Hafsaridewi et al 2018). However, policy design will be effective when the ecological process in accordance with social institutions is responsible for managing human-environmental interactions (Leslie et al 2015).

Conclusions. The results of the social network analysis, based on the degree value, was 17 for the fisheries business node, which is an important factor in identifying the number of relationships and interactions with other nodes in the network. It was closely followed by fish, at 14 degrees, shrimp at 12 and regional regulations at 11 degrees. In addition, the betweenness value is 41.98 for the node of regional regulation and the number of visits (Ad│Jv), while the relationship between fisheries businesses had the highest value. This indicates the importance of fisheries business node between others in the network, which is followed by regional rules, number of visits and fish. Conversely, the cluster analysis based on grouping at the density level in the network recognized the presence of 6 network clusters in the SES of Bima Bay.

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