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The Socio-Ecological System Interactions in the Coastal Region of West Bali

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ABSTRACT

Interactions within coastal socio-ecological systems frequently give rise to various challenges, ranging from ecological degradation to the emergence of social conflicts. This study aims to analyze the socio-ecological systems present along the West Bali coastline and to examine the connectivity networks among the integrated socio-ecological systems of coastal villages. Data were collected through interviews, field observations, and analyzed using the Driver–Pressure–State–Impact–Response (DPSIR) framework. The findings indicate that the degradation of mangrove ecosystem density is primarily driven by land conversion for aquaculture ponds, residential development, and other infrastructure projects. The connectivity within this socio-ecological system is categorized as strong to very strong. Furthermore, the utilization of mangrove areas for aquaculture (ponds) and agricultural activities exhibits a strong and negative connectivity with the decline in mangrove density.

INTRODUCTION

The western coastal region of Bali encompasses the shoreline along the western part of the island, including the area within the West Bali National Park (Taman Nasional Bali Barat, TNBB) (**Suardana *et al.*, 2023; As-syakur *et al.*, 2025**). This area features a mosaic of ecosystems, including mangrove forests, seagrass beds, coral reefs, and coastal habitats, all of which provide essential ecosystem services such as supporting local fishers' livelihoods, carbon sequestration, and coastal protection (**Choudhary *et al.*, 2024; Lovelock *et al.*, 2025; Noveanda *et al.*, 2025; Wirabuana *et al.*, 2025**). The presence of the TNBB also renders this coastal region significant for the conservation of endemic and migratory species, as well as for nature-based tourism (**Yudasmara, 2010; Tito & Hastuti, 2020**).

Despite its ecological richness, the West Bali coast is facing a range of environmental and socio-economic pressures. Recent shoreline monitoring studies have revealed that Bali has experienced a significant trend of coastal erosion in recent years, affecting the coastline's length, coastal habitats, and infrastructure in coastal communities (**Hidayati, *et al.*, 2017; Hafizah, 2022; Aryasatya & Pujianiki, 2024; Hastuti *et al.*, 2024**).

Human–environment interactions in West Bali’s coastal areas have also created management challenges, including access conflicts between traditional fishers and conservation zones, the need for mangrove rehabilitation, and coral reef restoration to enhance the resilience of coastal ecosystems. Coastal villages exhibit a high degree of complexity in both their social and ecological systems. These ecological problems may evolve dynamically, either due to natural processes or as a result of human activities. The complexity of ecological systems becomes further compounded when socio-ecological interactions between villages emerge in a non-harmonious manner (**Hafsaridewi *et al.*, 2018; Muliani *et al.*, 2018**).

The socio-ecological system (SES) is a broad conceptual framework that views humans and nature as interdependent, where human and ecological systems are functionally interconnected. Socio-ecological connectivity is defined as the functional interdependence between social change and ecological change. Discussions surrounding connectivity and socio-ecological system approaches are essential for promoting integrated management (**Herrero-Jáuregui *et al.*, 2018; Cinner & Barnes, 2019**).

Several SES-related studies have been conducted in various coastal regions, including coastal urban SES (**Amri, 2017**), SES in mangrove ecosystems (**Rahman *et al.*, 2020**), and fisheries resources (**Arief, 2023**). However, none of these studies have examined SES within coastal villages or explored the connectivity networks among villages that give rise to an integrated SES. Investigating the integration of SES connectivity in coastal villages is therefore crucial in order to understand the interactions between villages and their relationship with ecological systems (**Fujitani *et al.*, 2020; Gain *et al.*, 2020; Haraldsson *et al.*, 2020; Nagel & Partelow, 2022**).

MATERIALS AND METHODS

1. Study site description

The western coastal region of Bali encompasses the shoreline along the island’s western edge and falls within the administrative boundaries of Jembrana Regency, with part of the area included in the West Bali National Park (Taman Nasional Bali Barat, TNBB), located in the province of Bali, Indonesia. This study was conducted between June and September 2025 at five observation sites: Station I: Karang Sewu, Gilimanuk; Station II: Tuwed Village; Station III: Perancak/Budeng Village; Station IV: Delod Berawah Village; Station V: Yeh Embang Village, all within Jembrana Regency (Fig. 1).

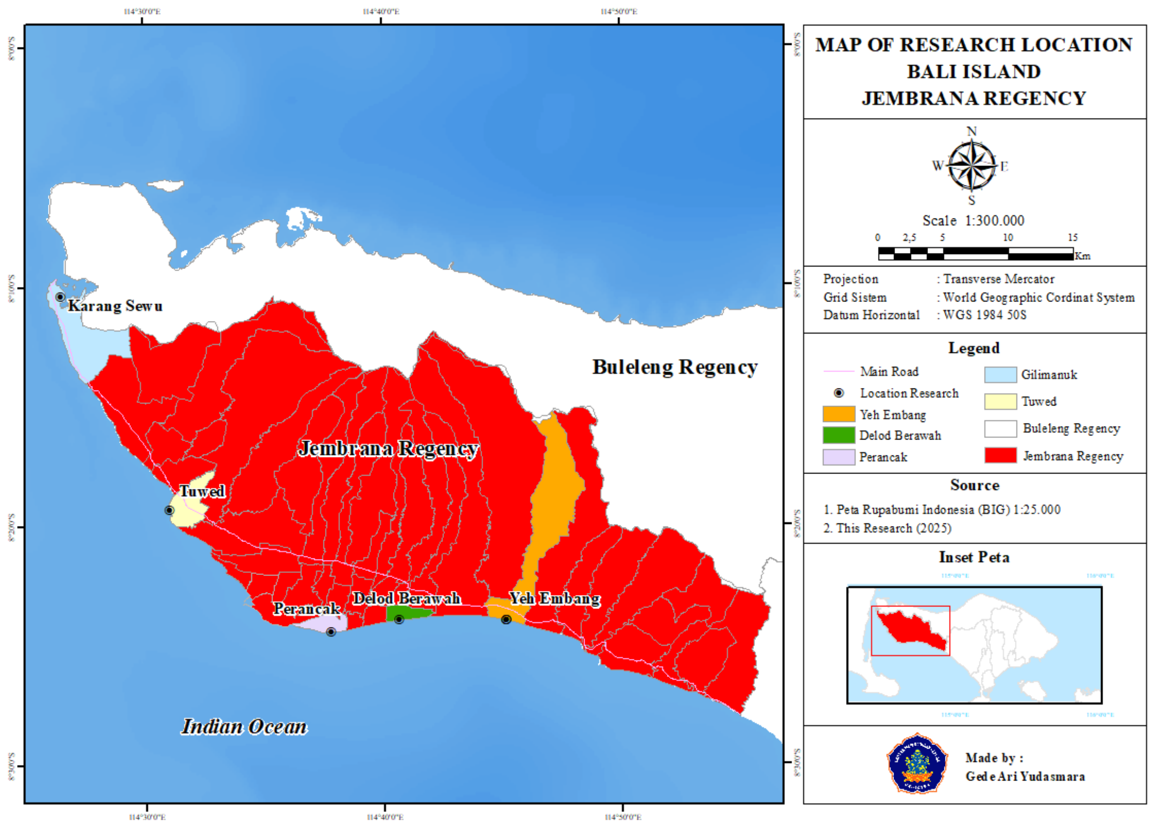

Fig. 1. Map of the study sites

2. Data collection procedures

The data used for the analysis of the socio-ecological system (SES) comprised both primary and secondary sources. Primary data were collected through direct observation and semi-structured interviews with 100 respondents relevant to the study, including capture fishers, aquaculture farmers, and community leaders. Secondary data were obtained through a literature review of relevant scientific publications, reports, and institutional documents.

3. Data analysis

The analysis of the socio-ecological system (SES) was conducted using the DPSIR framework (Drivers–Pressures–States–Impacts–Responses). This approach was employed to examine the interrelationships among the driving factors that contribute to ecosystem pressures, thereby enabling an assessment of the intensity of resource utilization by human activities in coastal areas, as well as the interconnectedness between ecological and social systems (SES). Ecosystem pressure assessments were carried out through a system-wide and integrative approach, focusing on the ecosystem's structure, composition, and function, analyzed using spatial indicators including landscape features, water use patterns, and biodiversity (**Yee *et al.*, 2014**). The conceptual framework for the DPSIR-based analytical method is illustrated in Fig. (2).

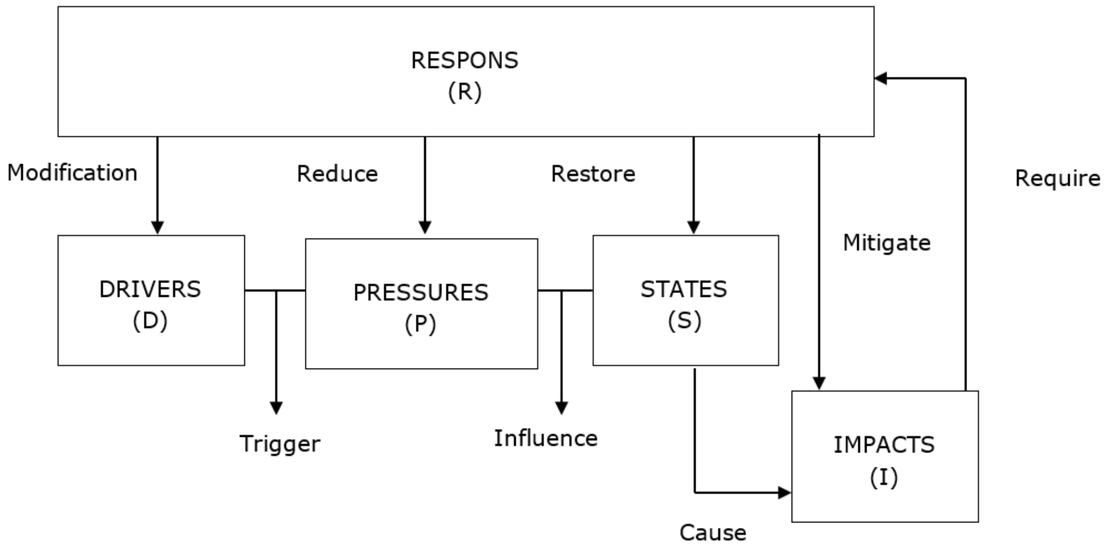

Fig. 2. Conceptual framework for the DPSIR approach to SES analysis

The SES analysis was conducted using a descriptive-quantitative approach, whereby quantitative data were presented in diagrammatic form. The analysis of SES connectivity networks was based on the connectivity pattern model developed by **Muliani *et al.* (2018)**. This approach allowed for the identification and visualization of the interlinkages among social and ecological subsystems within and across villages, providing insight into the degree and structure of connectivity that influences the dynamics of integrated SES.

RESULTS

1. Mangrove canopy density

Based on field observations, the distribution of mangroves along the West Bali coast is relatively limited, with a noticeable trend of reduction compared to previous conditions—except in Karang Sewu, Gilimanuk, which remains stable due to its location within a national park area. The decline in mangrove coverage is strongly associated with land-use conversion, particularly for activities such as aquaculture (e.g., shrimp and milkfish ponds), agriculture, plantations, and the development of water bodies. In 2014, the total area of mangrove canopy density was recorded at 215,811m². By 2025, this area was projected to be degraded by 176,246m², indicating a significant loss of mangrove cover (Table 1).

Table 1. Changes in mangrove canopy density

No	Location	Canopy Density Degradation (m^2)
1	Karang Sewu Gilimanuk	0
2	Tuwed Village (Tukad Aya Barat dan Pebuahan)	1,798
3	Budeng Village and Perancak Village	154,662
4	Delod Berawah Village	4,496
5	Yeh Embang Village	15,289
Total (m^2)		176,246

2. SES analysis using the DPSIR framework (Drivers–Pressures–States–Impacts–Responses)

The results of the DPSIR analysis indicate that the primary drivers in the socio-ecological system of West Bali's coastal region include: 1. Land-use change; 2. population growth and 3. expansion of residential settlements. These driving forces generate significant pressures on the ecological system, particularly affecting mangrove ecosystems and the broader coastal environment. Subsequently, these ecological pressures lead to increased pollution and environmental degradation, which in turn produce cascading impacts on the social, ecological, and economic systems of coastal communities. The overall DPSIR framework for the West Bali coastal SES is presented in Fig. (3).

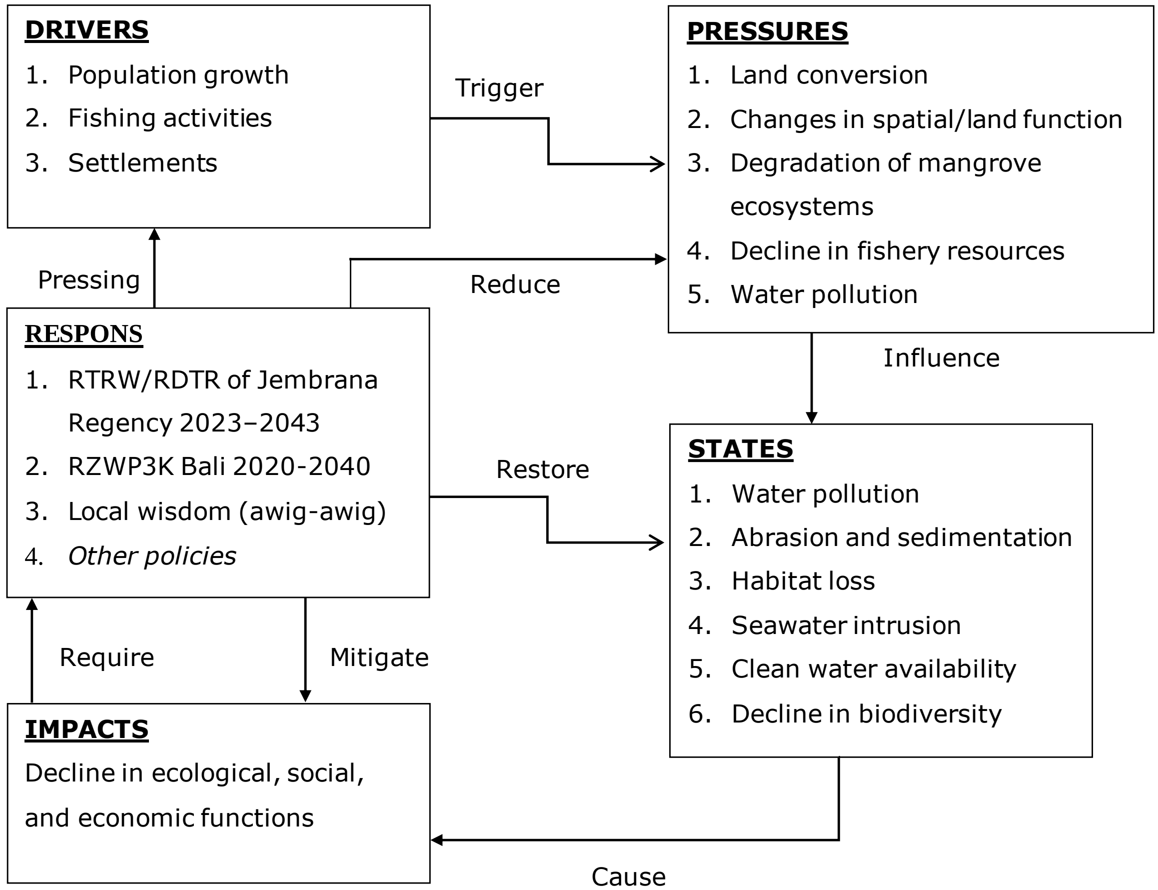

Fig. 3. General DPSIR framework for the socio-ecological system of the West Bali coast

3. SES connectivity analysis

Central Bangka Habitat

In general, the connectivity of the socio-ecological system (SES) along the West Bali coast is illustrated through the integrated relationships between ecological and social subsystems across coastal villages. The overall connectivity framework of this coastal SES is presented in Fig. (4).

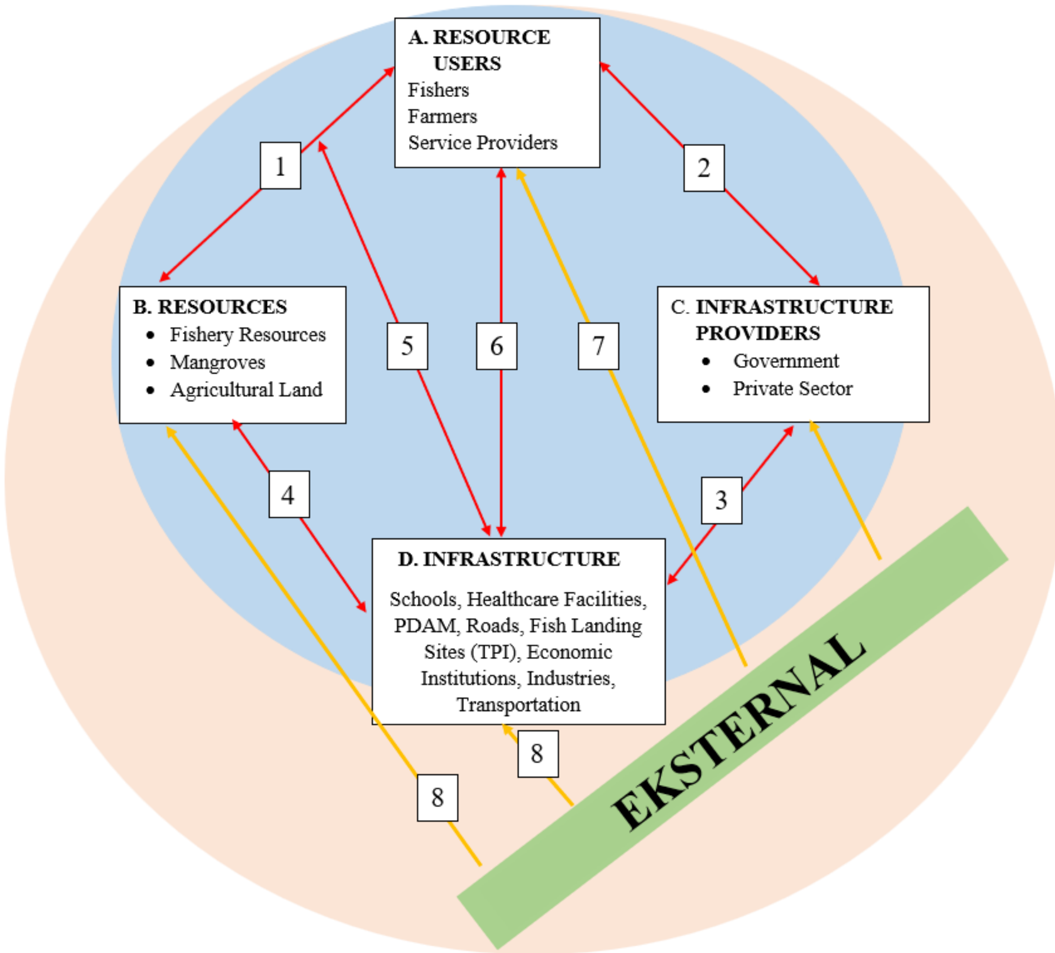

Fig. 4. Framework model of the socio-ecological system (SES) in coastal villages of West Bali

DISCUSSION

Based on interviews with respondents, literature reviews, and field observations using the DPSIR analysis framework, it was found that the main drivers within the socio-ecological system (SES) of the West Bali coast include land-use change, population growth, and urban settlement expansion (**Gunawan *et al.*, 2024**).

The magnitude of these driving forces has exerted significant pressure on mangrove ecosystems, fisheries resources, agricultural land, and other coastal systems (**Gashaw *et al.*, 2018; Velástegui-Montoya *et al.*, 2025**). These pressures have led to increased coastal erosion, seawater intrusion, habitat loss, water pollution, limited access to clean water, and a decline in biodiversity, all of which have substantial impacts on the social, ecological, and economic dimensions of local communities (**Bhowmik *et al.*, 2022**; **Hagger *et al.*, 2022**; **Ginting & Rauf, 2023; Maulana *et al.*, 2023; Apriani & Delistiani, 2025)**.

In response to these challenges, the government has implemented planning policies such as the Regional Spatial Planning (RTRW) 2023–2043 and the Coastal Zone and Small Islands Zoning Plan (RZWP3K) of Bali Province 2020–2040. These initiatives are consistent with the findings of **Muliani *et al.* (2018)** which emphasize that the establishment of government policies on resource management is a key strategy in addressing resource-related pressures and enhancing the resilience of mangrove ecosystems.

Furthermore, government authorities continue to encourage local communities to engage in the preservation and protection of coastal ecosystems, particularly mangrove forests (**Redi *et al*., 2020**; **Mursyid *et al*., 2021; Winatha *et al*., 2023**). However, these efforts are constrained by the administrative transfer of mangrove ecosystem management authority to the provincial level, which—according to local customary laws and governance traditions—should ideally remain under the jurisdiction of regency-level authorities to ensure context-specific and community-aligned management practices.

The interaction and connectivity of the socio-ecological systems in the coastal villages of West Bali are shaped by a complex web of relationships. Within the internal systems of each village, social interactions are formed between resource users and infrastructure providers, while ecological interactions occur between aquatic ecosystems and mangrove ecosystems, as well as in community adaptation and response to environmental changes (**Munawar *et al*., 2020**).

Socio-ecological interactions emerge from the interface between resources and resource users, and are further extended through external inter-village connectivity. This external connectivity is built through educational social interactions, the influence of fishing systems on education systems, fisherfolk institutions, and shared infrastructure, which together create a networked SESR (Socio-ecological system resilience) across coastal villages.

CONCLUSION

The degradation of mangrove ecosystem density in West Bali is primarily driven by land conversion for aquaculture ponds, residential development, and other infrastructure. The connectivity of these socio-ecological interactions is categorized as strong to very strong. The utilization of mangrove areas for aquaculture and agriculture exhibits a strong and negative connectivity with the decline in mangrove canopy density.

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