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Assessing a Super Priority Diving Ecotourism Destination-Bangka Island, Likupang as an Alternative to Bunaken Marine Protected Area

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ABSTRACT

Likupang, with Bangka Island as its main target area, has been designated as a super-priority tourism destination that will receive spillover tourism from Bunaken National Park, as the carrying capacity of the latter has reached 50%. This study aimed to analyze the suitability and carrying capacity of diving ecotourism areas at six dive sites on Bangka Island from April to December 2023. An explorative descriptive method was employed. Measurements of physical water parameters, such as depth, brightness, and current speed, were conducted *in situ*. Coral data were obtained using the point-intercept transect (PIT) method, while reef fish species were recorded through scuba diving and underwater visual census (UVC) techniques performed by two diving instructors. Data on water parameters, corals, and reef fish were then analyzed to determine the diving ecotourism suitability index and the area's carrying capacity for diving activities. Based on the analysis results, the average percentage of coral cover across the six dive sites on Bangka Island was 64 ± 14%, with 13 types of life forms identified. A total of 225 reef fish species were recorded, with a diversity index of 3.28, an evenness index of 0.71, and a dominance index of 0.07. The physical condition of the waters supports the development of diving ecotourism activities. The average suitability index for diving ecotourism on Bangka Island falls into the "suitable" category, indicating that the area has favorable physical and biological characteristics for diving. Furthermore, the recommended carrying capacity for diving ecotourism activities on Bangka Island is 38 people per day per site per trip.

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INTRODUCTION

Likupang, an administrative division of North Minahasa Regency, North Sulawesi, has been designated as one of Indonesia’s super-priority tourism destinations, alongside Lake Toba, Mandalika, Borobudur, and Labuan Bajo, under the Minister of Tourism and Creative Economy Regulation No. 11/2022 on the Strategic Plan of the Ministry of Tourism and Creative Economy 2020–2024. This strategic government initiative is a deliberate effort to diversify tourism destinations, thereby reducing the overreliance on Bali as the primary tourist hub. The initiative aims to boost the gross domestic product (GDP) of the tourism sector by attracting both domestic and foreign tourists **(Lesmana *et al*., 2022; Mas’ud *et al*., 2025)**.

The development of Likupang as a super-priority destination is particularly significant, since it is expected to benefit from the spillover effects of tourism from Bunaken National Park, a UNESCO World Heritage Site renowned for its rich marine biodiversity and stunning coral reefs **(Syafa'at *et al*., 2024; Ismail *et al*., 2025)**. However, the rising number of tourists visiting Bunaken National Park, particularly Bunaken Island, has raised concerns regarding the potential impact on the coral reef ecosystem, especially given that the carrying capacity has already reached 50% of its maximum limit **(Farhum *et al*., 2021)**. Consequently, implementing visitor management strategies is imperative to ensure the sustainability of Bunaken Island’s coral reef ecosystem **(Ario *et al*., 2021; Anggayasti *et al*., 2025)**. Measures such as restricting tourist access by doubling entrance fees and redirecting visitors to surrounding islands within the national park (BNP) have been proposed **(Kholil & Sulistyadi, 2017)**.

Likupang is characterized by pristine coastal landscapes, featuring white sand beaches, mangroves, and coral reefs, which hold significant potential for marine tourism development. Bangka Island, located within the Likupang region, is distinguished by its well-preserved coral reef ecosystem, making it a premier destination for divers and nature enthusiasts **(Andaria *et al*., 2018; Perwira *et al*., 2020)**.

Coral reefs represent one of the most biodiverse marine ecosystems **(Eider *et al*., 2023)**. In Indonesia, coral reef coverage spans approximately 2.5 million hectares (Pasaribu, 2024), significantly influencing the abundance and diversity of reef fish species **(Darling *et al*., 2017)**. A total of 2,139 reef fish species have been documented in Indonesian waters, reflecting the region’s high marine biodiversity and serving as a bioindicator of coral reef health **(Bintoro *et al*., 2023; Kurniawan *et al*., 2025)**.

Coral reef ecosystems function as natural barriers against coastal abrasion while providing numerous ecological benefits. They serve as habitats, shelters, and nutrient sources for marine biota, as well as spawning and nursery grounds for fish and invertebrates **(Hoeksema, 2017)**. Economically, coral reefs are vital for coastal communities, supporting livelihoods through fisheries and generating foreign revenue via marine tourism **(Cupul-Magaña & Rodríguez-Troncoso, 2017)**. Diving tourism in the Coral Triangle region, encompassing Indonesia and the Philippines, generates an estimated $150 million annually **(De Brauwer *et al*., 2017)**.

Despite the economic and sociocultural benefits of diving tourism, this activity also poses risks to coral reef integrity **(Bhuiyan *et al*., 2020; Kurniawan *et al*., 2024a)**. The damage caused by dive tourism includes physical harm from scuba equipment, direct human contact with corals, and anchoring by vessels **(Giglio *et al*., 2016; Tito & Ampou, 2020)**. To ensure the sustainability of Bangka Island's coral reefs the primary attraction for its diving tourism industry a monitoring system was established to assess reef conditions. This study focused on three key environmental parameters: (1) the ecological status of coral reefs, (2) the suitability of diving ecotourism, and (3) ecotourism carrying capacity. The findings are expected to guide policymakers in developing sustainable diving ecotourism on Bangka Island as part of North Sulawesi's super-priority destination.

MATERIALS AND METHODS

Study area

The research was conducted on Bangka Island, East Likupang District, North Sulawesi Province, from April to December 2023. Six dive sites were selected as sampling locations (Fig. 1), and the coordinates of these locations are presented in Table (1). The study adhered to zoning regulations outlined in Regional Regulation No. 1/2017 on RZWP3K (Coastal and Small Islands Zoning Plan) of North Sulawesi Province (2017–2037) and Decree of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 128/2023 on Marine Protected Areas in the Waters of North Minahasa Regency, North Sulawesi Province, Indonesia.

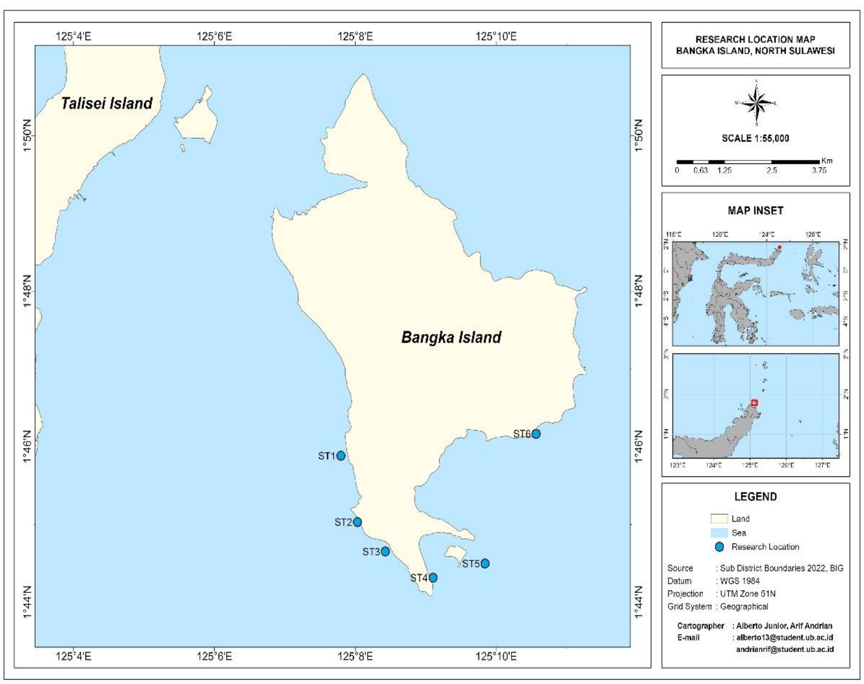

Fig. 1. Map of research location in Bangka Island, Indonesia

Table 1. Zoning, location, coordinates of the observation and observation method

Zone	Location	Coordinate		Observation method
		Longitude	Latitude	
Public facilities zone	Station 1	125.12994	1.76475	Scuba Diving
Tourism zone	Station 2	125.13370	1.75045	Scuba Diving
Fisheries zone	Station 3	125.14044	1.74422	Scuba Diving
Conservation zone	Station 4	125.15196	1.74098	Scuba Diving
Conservation zone	Station 5	125.16432	1.74194	Scuba Diving
Tourism zone	Station 6	125.17611	1.76944	Scuba Diving

Data collection

Reef fish

This research employed an exploratory descriptive methodology **(Sholihah, 2019)**. Data on reef fish and coral cover in the waters of Bangka Island were collected through direct field observations. Reef fish data were obtained using the Underwater Visual Census (UVC) method **(Prato *et al*., 2017)**. Observations commenced with the deployment of a 50-meter transect line parallel to the shoreline, supplemented by imaginary extensions of 2.5 meters to both the left and right (totaling a surveyed area of 150 × 5 m^2). After a five-minute acclimatization period, the first diver recorded species observations following instructions displayed on a whiteboard, while the second diver documented the transect using a GoPro Hero 12 camera.

Fish data collection was conducted from 9:00 AM to 4:00 PM to align with the diurnal activity patterns of most reef fish. Species verification involved direct *in-situ* identification followed by video analysis of the transect line. Final species nomenclature was determined through cross-referencing video and photographic evidence, with taxonomic identification adhering to standardized keys **(Allen *et al*., 2003)**.

Coral reef

A series of observational surveys were conducted to document reef fish assemblages, quantify coral cover, and assess coral-associated biota. The Point-Intercept Transect (PIT) method **(Kuo *et al*., 2022)** was employed to characterize benthic substrate composition, with particular focus on percentage coral cover and associated biotic components. The sampling protocol involved two divers working in tandem: the lead diver captured photographic documentation and video recordings, while the secondary diver systematically recorded all biological categories encountered along the 50-meter transect at 0.5-meter intervals. This sampling procedure was replicated three times to ensure methodological rigor, followed by immediate post-survey taxonomic verification. For reference, Table (2) provides the complete classification scheme of benthic components and their corresponding alphanumeric codes as implemented in our PIT methodology.

Table 2. Category and code for recording biota using the PIT method modified by **Manuputty and Djuwariyah (2009)**

Category	Kode	Description
Hard Coral Life (HCL)	HC	acropora and non-acropora corals
Other Fauna (OF)	SC	corals that do not produce limestone skeletons
	OT	Anemones, sea cucumbers, gorgonians, clams
	SP	*Clathria* sp., *Xestospongia* sp.
	ZO	*Palythoa* sp., *Parazoanthus* sp.
Abiotic Substrate (AS)	R	Rubble
	S	Sand
	RC	Rock
Dead Coral (DC)	DC	coral colonies are still intact, white, not slimy
	DCA	the limestone skeleton is dead and starting to grow fine algae
Macro Algae (MA)	HA	algae from the genus *Halimeda* sp.
	CA	algae that has a chalk structure
	TA	fine-sized algae, resembling fine grass

Data analysis

Coral reef area

The coral reef area quantification on Bangka Island was conducted through analysis of Sentinel-2A satellite imagery acquired in 2024. The data processing utilized SNAP software with the Sen2Cor atmospheric correction algorithm developed by ESA Copernicus. This methodological approach enables accurate benthic habitat mapping through radiometric calibration and atmospheric compensation of satellite data.

Cover of coral reef

Benthic substrate composition and coral-associated biota percentages were quantified using Equation 1 **(Oetama *et al.*, 2024)**. Coral health status was evaluated according to the standardized criteria established in the Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. 4/2001 concerning Coral Reef Damage Standard Criteria (Table 3 for detailed classification thresholds).

$$\%\ component\ cover = \frac{number\ of\ each\ component}{total\ components} x100\% \qquad (1)$$

Table 3. Coral health assessment criteria

Parameter	Standard criteria for coral reef damage (%)	
Percentage of hard coral life	Poor	0 – 24,9
	Moderate	25 – 49,9

	Good	50 – 74,9
	Very good	75 - 100

* Decree of the Minister of Environment and Forestry of the Republic of Indonesia No. 4 of 2001 concerning Standard Criteria for Coral Reef Damage

Coral reef fish

Species diversity was assessed using the Shannon-Weaver diversity index (H'), calculated as:

$$H' = \sum_{i=s}^{s} - P_i \ln P_i \qquad P_i = \frac{n_i}{N} \tag{2}$$

where:
Pi = ni/N (relative abundance of species i)
ni = number of individuals of species i
N = total number of individuals
S = total number of species

This index provides a quantitative measure of community structure that incorporates both species richness and evenness components. The formula to calculate evenness index is using Pielou based on the following formula 3.

$$e = \frac{H'}{ln\ S} \tag{3}$$

Where:
e = evenness index,
H' = the diversity index,
S = the number of species.

The fish dominance index describes the extent to which a species dominates in a community. The formula to calculate fish dominance index value is using Simpson based on the following formula 4.

$$C = \sum_{i=1}^{n} p_i^2 = \sum_{i=1}^{n} \left(\frac{n_i}{N}\right)^2 \tag{4}$$

Where:
C = dominance index,
P_i = the probability the presence of i^{th} species,
n_i = number of i^{th} species, and
N = total individual number of all species.

Analysis of reef fish abundance data was carried out with the following formula 5 **(Bintoro *et al*., 2023);**

$$X = \frac{X_i}{A} \tag{5}$$

Where:

X = reef fish abundance (ind/m^2),

X_i = number of fish on the observed observed (ind)

A = the observed reef fish area (m^2).

Assessment of reef fish condition on Bangka Island based on the diversity index, evenness index, dominance index, and abundance is tabulated in Table (4).

Table 4. Assessment of abundance **(Bintoro *et al.*, 2023)** and community structure **(Oetama *et al.*, 2024)**

Index	Category	Description
Diversity (H')	$H' \leq 1$	low diversity, ecosystem strong pressure
	$1 \leq H' \leq 3$	moderate diversity, ecosystem moderate pressure
	$H' \geq 3$	high diversity, stable ecosystem
Evenness (e)	$0 < e \leq 0.4$	small evenness, stressed community
	$0.4 < e \leq 0.6$	medium evenness, unstable community
	$0.6 < e \leq 1.0$	high evenness, stable community
Dominance (C)	$0 < C < 0.5$	low dominance
	$0.5 < C \leq 0.75$	medium dominance
	$0.75 < C \leq 1.0$	high dominance
Abundance (X)	$0.55 < X \leq 1.54$	low abundance
	$1.55 < X \leq 2.53$	medium abundance
	$2.54 < X \leq 3.54$	higt abundance

Water physical parameters

The physical water parameters included temperature, salinity, water visibility, water depth and current were measured *in situ* at six research stations on Bangka Island **(Costa *et al.*, 2022)**.

Suitability index of diving ecotourism

The suitability of diving ecotourism on Bangka Island was determined based on six parameters, namely coral cover, coral life form types, reef fish species, brightness, reef depth and current velocity (Table 5). Morever, determination of the suitability index of diving ecotourism (ESI) on Bangka Island was calculated using the equation 6, where: ESI is suitability index of diving ecotourism; Qi is quality of parameter I; Si is score parameter I; and n is number of suitability parameters **(Yulianda, 2019)**:

$$ESI = \sum_{i=1}^{n} (Qi \times Si) \quad (6)$$

Table 5. The matrix of suitability of diving ecotourism on Bangka Island **(Yulianda, 2019)**

No.	Parameter	Quality	Category	Score
1.	Coral cover (%)	0.375	>75	3
			>50-75	2
			25-50	1
			<25	0
2.	Number of life form	0.135	>12	3
			>7-12	2
			4-7	1
			<4	0
3.	Number of reef fish species	0.120	>100	3
			50-100	2
			20-<50	1
			<20	0
4.	Brightness (%)	0.150	80	3
			50-80	2
			20-<50	1
			<20	0
5.	Reef depth (m)	0.150	6-16	3
			>15-20; 3-<6	2
			>20-30	1
			>30; <3	0
6.	Current velocity (cm/sec)	0.070	0-15	3
			>15-30	2
			>30-50	1
			>50	0

Table notes: ESI ≥ 2.5 (very suitable); ESI ≤2.0;< 2.5 (suitable); ESI ≤1.0;< 2.0 (unsuitable); ESI <1.0 (very unsuitable).

Carrying capacity of diving ecotourism

The carrying capacity analysis determined the maximum sustainable visitor load that maintains ecological integrity while providing quality recreational experiences. As Bangka Island contains a Marine Protected Area (established under Ministerial Decree No. 128/2023), the carrying capacity calculation followed Equation 7 **(Kaber *et al*., 2023)**, which integrates:

$$DDK = 0{,}1 \left[K \times \frac{Lp}{Lt} \times \frac{Wt}{Wp} \right] \quad (7)$$

Where :

DDK	:	Carrying capacity of the area.
K	:	The visitor ecological potency per unit area.
Lp	:	The square area or the length of area which can be utilized.
Lt	:	Area unit for specific category.
Wt	:	The time provided by the area for tourism activities in a day.
Wp	:	The time spent by visitors on each specific activity.

RESULTS

Coral reef

The area of coral reefs, seagrasses, and sand on Bangka Island was determined through analysis of Sentinel-2A satellite imagery acquired in 2024. The data revealed a total coral reef area of 1,062.98 hectares. ANOVA results showed significant differences ($P < 0.05$) in coral community cover and substrate composition among stations. The percentage of hard coral live (HCL) cover at each station ranged from 16 ± 1.5% to 57 ± 5.5%. Other fauna (OF) - including soft corals (SC), sponges (SP), and additional biota (OT) such as zoanthids, anemones, and sea fans - exhibited considerable variation across research stations (13 ± 2.9% to 48 ± 6.6%). Abiotic substrate (AS) components, comprising coral rubble (R), sand (S), and rocks (RC), varied between 6 ± 3.2% and 43 ± 8.7%. Dead coral (DC) coverage ranged from 4 ± 1.7% to 12 ± 3.7%, while macroalgae (MA) - including Halimeda, coralline algae, and turf algae - showed coverage levels from 0% to 9 ± 1.7% (Table 6). The health status of coral reefs was evaluated based on percentage live hard coral cover, following the classification system established in the Decree of the Minister of Environment No. 4/2001 concerning Standard Criteria for Coral Reef Damage. This assessment framework categorizes reef health status from poor to good based on quantitative analysis of live coral coverage.

Table 6. Percentage of coral life form at Bangka Island

Sampling Sites	Coral Life Forms				
	HCL	**OF**	**AS**	**DC**	**MA**
Station 1	57±5.5	14±2.9	18±6.2	10±4.4	0±0.0
Station 2	47±3,0	13±2.9	33±0.3	6±1.5	0±0.0
Station 3	32±7.9	36±2.8	27±4.2	4±2.0	0±0.0
Station 4	33±1.9	23±3.8	28±3.1	12±3.7	3±1.5
Station 5	40±4.8	48±6.6	6±3.2	4±1.7	1±0.0
Station 6	16±1.5	25±7.1	43±8.7	6±0.8	9±1.7

A total of ten of life form of hard coral life were identified through observations conducted at six research stations on Bangka Island. The presence of Acropora branching (ACB), Acropora digitate (ACD), Acropora submassive (ACS), Acropora tabulate (ACT), Coral branching (CB), Coral massive (CM), Coral submassive (CS), Coral encrusting (CE), Coral mushroom (CMR), and Coral heliopora (CHL) indicates a high degree of coral diversity in the area. Of the ten growth forms of living hard corals, five are consistently observed at each research station: (ACB), (ACS), (CB), (CM), and (CE) (Fig. 2).

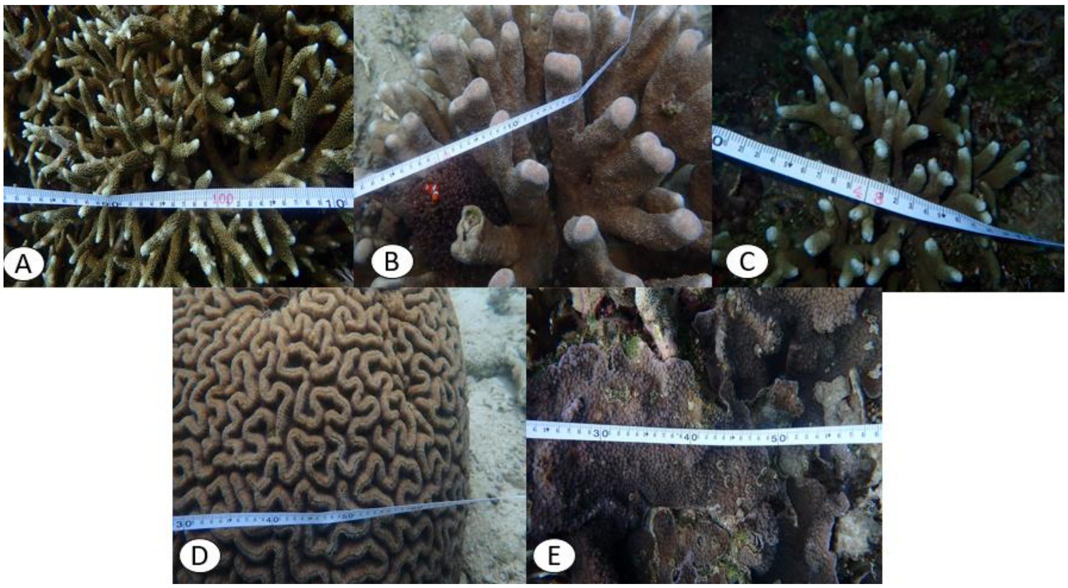

Fig. 2. Life form of hard coral life showing: **A.** *Acropora branching*; **B.** *Acropora submassive*; **C.** *Coral branching*; **D.** *Coral massive*; **E.** *Coral encrusting*

Reef fish

Based on records obtained through the Underwater Visual Census (UVC) method and verified by video analysis, a total of 225 species representing 37 families and 6,987 individuals were documented (Table 7). The target fish identified across all six research stations comprised 14 families, 76 species, and 1,148 individuals, with the Acanthuridae family exhibiting both the highest species richness and abundance among all recorded fish families. The Chaetodontidae family was recognized as the primary indicator group, represented by 21 species and 166 individuals in total. Major reef fish play a vital role in coral reef ecosystems, particularly in regulating trophic dynamics and maintaining ecological balance. Survey data from the six stations identified 22 families, 128 species, and 5,573 individuals categorized as major reef fish. The Pomacentridae family emerged as the most diverse and abundant group, accounting for 44 species and 4,893 individuals, followed by the Labridae and Pomacanthidae families. The relative abundance distributions of target fish, indicator fish, and major fish across all research stations on Bangka Island are presented in Fig. (3).

Table 7. Family of target fish, indicator fish and major fish on Bangka Island

No	Family	Species	Indiv	No	Family	Species	Indiv
Target fish				3	Apogonidae	8	24
1	Acanthuridae	15	382	4	Pomacanthidae	7	99
2	Scaridae	10	118	5	Balistidae	5	69
3	Holocentridae	7	176	6	Tetraodontidae	5	12
4	Siganidae	6	38	7	Monacanthidae	4	13
5	Nemipteridae	6	31	8	Cirrhitidae	3	8
6	Epinephelidae	6	20	9	Blenniidae	2	8
7	Caesionidae	5	144	10	Pinguipedidae	2	7
8	Lutjanidae	5	68	11	Ostraciidae	2	3
9	Mullidae	5	35	12	Pempheridae	1	76
10	Lethrinidae	4	8	13	Zanclidae	1	38
11	Anthiadidae	2	82	14	Centriscidae	1	14
12	Haemulidae	2	12	15	Ephippidae	1	10
13	Carangidae	2	2	16	Aulostomidae	1	6
14	Sphyraenidae	1	32	17	Fistulariidae	1	4
Indicator fish				18	Synodontidae	1	3
1	Chaetodontidae	21	166	19	Priacanthidae	1	3
				20	Gobiidae	1	2
Major fish				21	Ptereleotridae	1	1
1	Pomacentridae	44	4893	22	Scorpaenidae	1	1
2	Labridae	35	379		Total	225	6987

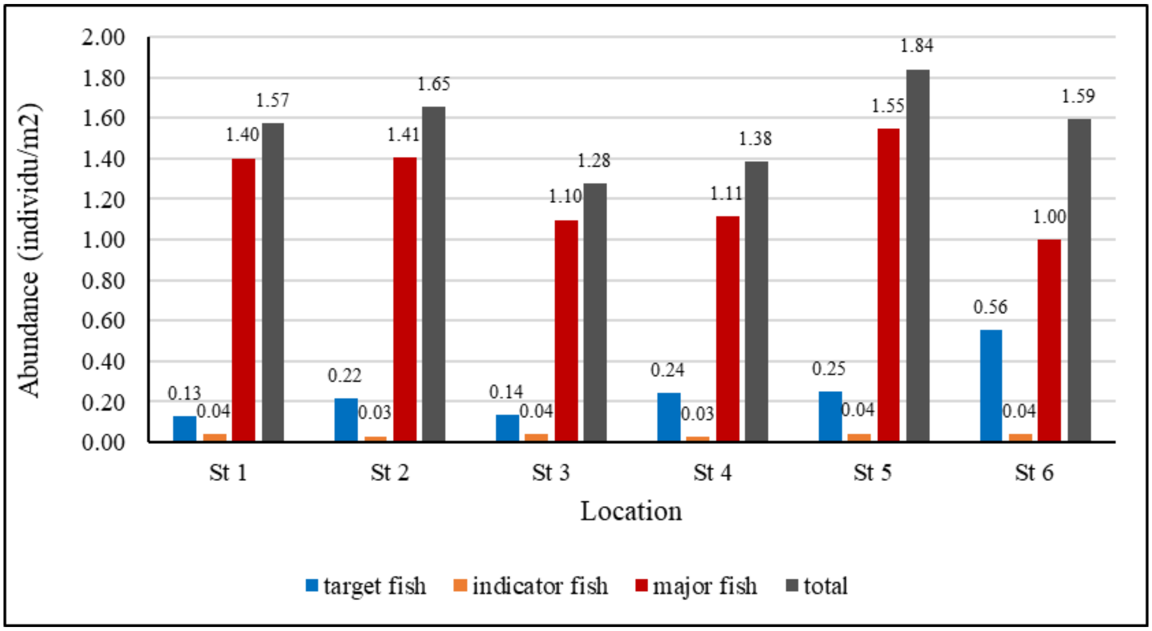

Fig. 3. The total abundance of reef fish on Bangka Island

The diversity index (H') of reef fishes across the six research stations on Bangka Island ranged from 3.06 to 3.65, reflecting high species diversity within the ecosystem. The evenness index (J') values ranged from 0.68 to 0.80, demonstrating a balanced distribution of individuals among species. Dominance index (D) values remained low (0.04-0.09), confirming the absence of any single dominant species in the fish community (Fig. 4).

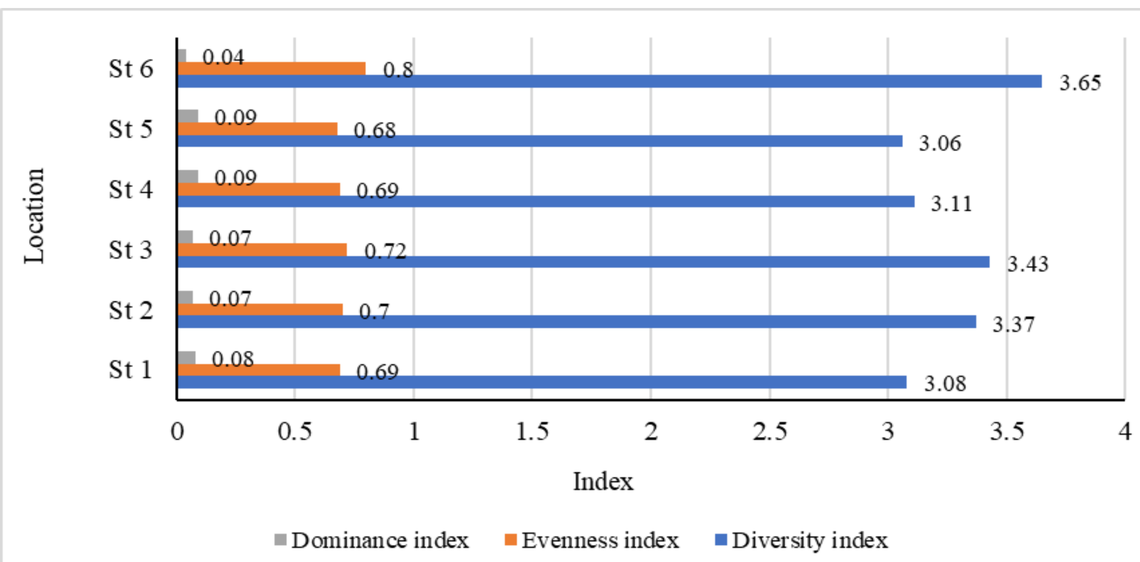

Fig. 4. Reef fish community structure at Bangka Island

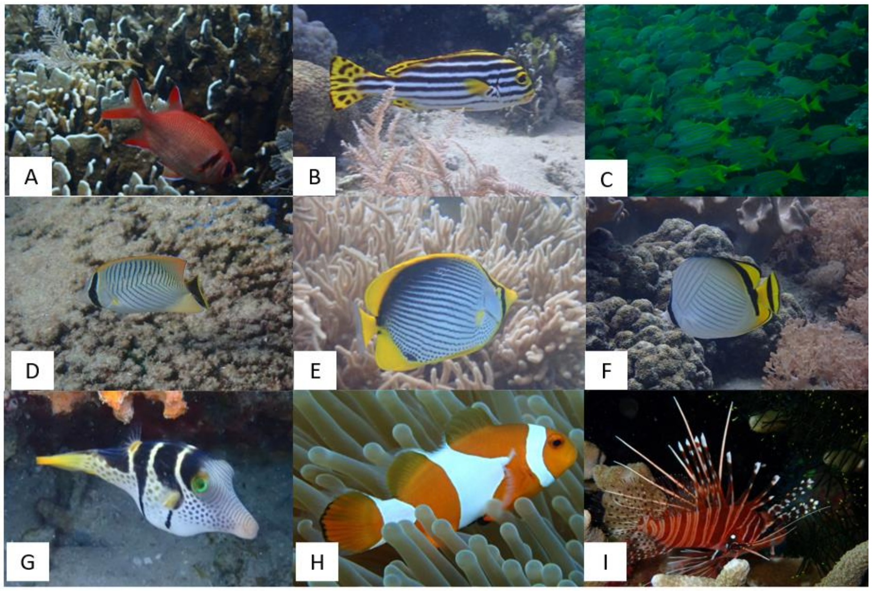

Fig. 5. Species of reef fish in Bangka Island water showing: A. *Caranx melampygus* (Carangidae), B. *Siganus puellus* (Siganidae), C. *Lutjanus kasmira* (Lutjanidae), D. *Chaetodon trifascialis* (Chaetodonidae), E. *Chaetodon melannotus* (Chaetodonidae), F. *Chaetodon vagabundus* (Chaetodonidae), G. *Canthigaster valentini* (Tetratodontidae), H. *Amphiprion ocellaris* (Pomacentridae), I. *Pterois antennata* (Scorpaenidae)

Correlation between hard coral live cover and reef fish abundance

The results of the simple regression analysis showed a positive correlation between hard coral life cover and reef fish abundance, as indicated by the regression equation $y = 0.0033x + 1.4259$ (Fig. 6). The positive regression coefficient (0.0033) indicates that a 1% increase in coral cover corresponds to a 0.0033 unit increase in reef fish abundance. However, the coefficient of determination ($R^2 = 0.0539$) indicates that only approximately 5.39% of the variation in reef fish abundance can be explained by coral cover at Bangka Island.

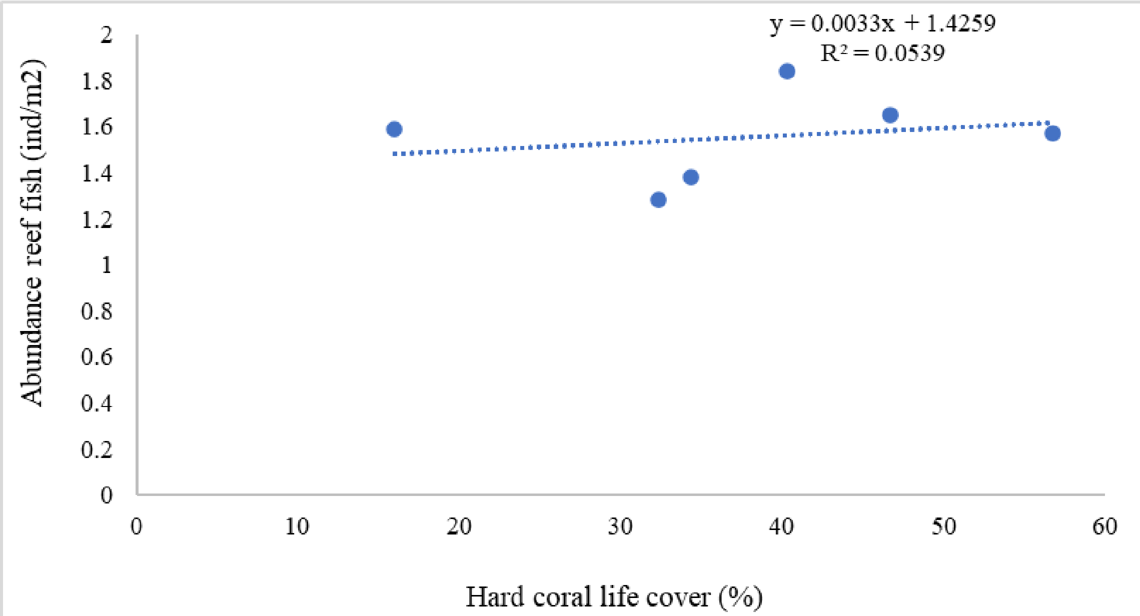

Fig. 6. The Correlation between percentage hard coral life cover and abundance of reef fish at 6 stations on Bangka Island

Seawater physical parameters

Based on the results of field measurements at the 6 research stations, the temperature ranged from 28.32±0.00 to 29.07±0.01°C, the salinity fluctuated between 30.60±0.14 & 31.40±0.01ppm, the current ranged from 10.39 to 21.49cm/ sec, brightness reaching 83.33 to 100%, and the depth of coral reefs was recorded in the range of 4 to 10 meters (Table 8).

Table 8. Seawater physical parameters for Bangka Island

Location	Seawater Quality Parameters				
	Temperature (°C)	**Salinity (ppt)**	**Current (cm/sec)**	**Brightness (%)**	**Coral reef depth (m)**
St 1	28.32±0.00	30.60±0.14	20.69±1.33	100±0.00	5-7
St 2	28.78±0.01	31.18±0.01	10.39±0.30	100±0.00	4-6
St 3	29.07±0.01	31.39±0.00	12.18±0.48	100±0.00	5-7
St 4	28.50±0.02	31.15±0.02	13.89±0.66	100±0.00	5-7
St 5	28.48±0.01	31.04±0.17	21.49±0.53	83.33±0.02	7-10
St 6	28.81±0.01	31.40±0.01	13.58±0.58	100±0.00	5-7

Suitability of diving ecotourism

The development of diving ecotourism requires an assessment of the suitability of resources and coastal environmental conditions in accordance with the required criteria. The assessment of diving ecotourism is determined based on the value of the tourism suitability index (ESI); this index can help identify the most suitable locations for diving tourism activities, taking into account biological parameters (coral community cover and types of life forms, and reef fish species) and seawaters physical parameters (visibility, current and coral reef depth). The suitability of diving ecotourism in the six research locations on Bangka Island is presented in Table (9).

Tabel 9. Suitability index of diving ecotourism for Bangka Island

No	Parameters	Location					
		St 1	St 2	St 3	St 4	St 5	St 6
1	Coral cover (%)	0.75	0.75	0.75	0.75	1.125	0.375
2	Number of life form	0.27	0.41	0.27	0.27	0.27	0.27
3	Number of reef fish species	0.24	0.36	0.36	0.24	0.24	0.24
4	Current velocity (cm/sec)	0.14	0.21	0.21	0.21	0.14	0.21
5	Brightness (%)	0.45	0.45	0.45	0.45	0.45	0.45
6	Reef depth (m)	0.45	0.45	0.45	0.45	0.45	0.45
ESI		**2.3**	**2.6**	**2.5**	**2.4**	**2.7**	**2.0**
Category		**S**	**VS**	**VS**	**S**	**VS**	**S**

*VS: Very Suitable; S: Suitable.

Carrying capacity

Environmental carrying capacity assessment for diving ecotourism activities is important to measure the environment's ability to tolerate human activities and to maintain the authenticity of natural resources. The results of the analysis of carrying capacity for diving ecotourism on Bangka Island are shown in Table (10).

Table 10. Carrryng capacity estimated for diving ecotourism on Bangka Island

Tourism activity	K	Lp (m^2)	Lt (m^2)	Wt	Wp	DDK (person/day/site/trip)
Diving	2	7972355.691	2000	8	2	38

DISCUSSION

Coral reef

The results of this study indicate that Station 1, located within the public facility zone, exhibited the highest percentage of hard coral live (HCL) cover (57±5.5%) and was classified as being in good condition. This high HCL percentage at Station 1 can be attributed to its remote location from human settlements, which minimizes anthropogenic pressures. In contrast, Station 6, situated in the tourism zone, showed significantly lower HCL coverage (16±1.5%), classifying it as poor condition. The reduced HCL at Station 6 results from the predominance of ACB growth forms, which, despite their rapid growth rate (up to 20 cm/year), exhibit structural fragility **(Zurba, 2019)**. Furthermore, inadequate fisheries management and tourism industry practices may contribute to diminished coral cover **(Massei *et al*., 2023)**. Moreover, climate change impacts over recent decades have also driven global coral reef degradation **(Cheng *et al*., 2020; Salamah *et al*., 2024)**.

Stations 2 (tourism zone), 3 (fisheries zone), and 4-5 (marine protected area zone) demonstrated moderate HCL conditions, with percentages of 47±3.0%, 32±7.9%, 33±1.9%, and 40±4.8% respectively (Table 6). Overall, the mean HCL percentage across all six research stations on Bangka Island was 37.5%, classifying it as moderate. This HCL level surpasses those recorded for Samber Gelap Island, South Kalimantan 18.66%, classified as poor **(Iskandar *et al*., 2021)** and Sempu Strait, East Java 6-21.3% **(Bintoro *et al*., 2023)**. The lower HCL percentages in these locations reflect the combined impacts of fisheries, industrial activities, and tourism pressures. In contrast, marine protected areas like the Dampier Strait Raja Ampat, West Papua (64.24% HCL) and Moramo Bay Southeast Sulawesi (53% HCL) maintain good HCL conditions **(Kaber *et al*., 2023; Oetama *et al*., 2024)**. While both fishing and diving activities contribute to coral reef degradation, fisheries pose the more significant threat to reef sustainability **(Bhuiyan *et al*., 2020)**. Consequently, collaborative efforts among stakeholders are essential to implement strategic coral rehabilitation programs, restore damaged reefs, enhance reef quality, and strengthen marine protected area management **(Rinkevich, 2021; Kurniawan *et al*., 2024b)**.

The diverse coral life forms observed across Bangka Island suggest relatively favorable environmental conditions. This morphological diversity enhances ecosystem stability, as different growth forms perform complementary ecological functions **(Darling *et al*., 2017)**. Moreover, coral cover percentage and growth form diversity serve as critical parameters for evaluating diving ecotourism suitability **(Shokri & Mohammadi, 2021)**.

Reef fish

Reef fish can be ecologically categorized into three functional groups: target species, indicator species, and major species. Target fish species represent economically valuable taxa that constitute the primary focus of fisheries activities and serve as important protein sources for local communities **(Tony *et al*., 2020; Al Zamzami *et al*., 2025)**. In North Sulawesi, the families Carangidae, Lutjanidae, Lethrinidae, Caesionidae, Acanthuridae, Siganidae, Mullidae, and Haemulidae form essential components of traditional fisheries **(Utari *et al*., 2024)**. Our surveys documented several target species across all six research stations, including *Myripristis murdjan* (Fig. 5A), *Plectorhinchus vittatus* (Fig. 5B), *Ctenochaetus striatus*, and *Zebrasoma scopas*, while *Lutjanus kasmira* (Fig. 5C) was exclusively recorded in high abundance at Station 5. *Lutjanus kasmira* represents one of the most economically valuable reef fish species in Indonesia, with a broad Indo-Pacific and Atlantic distribution **(Glass *et al*., 2021; Froese & Pauly, 2024)**.

The Chaetodontidae family exhibits strong coral reef dependence, feeding primarily on hard coral polyps, soft corals, and zoanthids, making them reliable bioindicators of reef health **(Ulfah *et al*., 2023)**. We recorded 21 Chaetodontidae species, with three species - *Chaetodon trifascialis* (Fig. 6D), *Chaetodon lunulatus,* and *Chaetodon klenii* - distributed across all six stations. This diversity exceeds that reported from the Moramo Bay Marine Protected Area in Southeast Sulawesi (7 species, 69 individuals) **(Oetama *et al*., 2024)** but matches the 21 species (4 genera) documented in the Spermonde Archipelago near Makassar **(Putra *et al*., 2024)**. The abundance and diversity of Chaetodontidae directly reflect coral reef health and resource availability **(Bintoro *et al*., 2023)**. Dietary specialization divides Chaetodontids into obligate corallivores (e.g., *Chaetodon trifascialis* (Fig. 5D), which preferentially consumes *Acropora* spp. **(Keith *et al*., 2023)** and facultative corallivores e.g., *Chaetodon vagabundus* (Fig. 5F), which can utilize alternative food sources **(Putra *et al*., 2024)**. *Chaetodon melannotus* (Fig. 5E) demonstrates intermediate flexibility, specializing on soft corals **(Pratchett *et al*., 2014)**.

Major reef fish play pivotal roles in maintaining trophic dynamics and ecosystem stability. Our results confirm the Pomacentridae family as the most species-rich and abundant major fish group across Bangka Island's six research stations, consistent with findings from Halang Melingkau Island **(Tony *et al*., 2020)** and Sempu Strait **(Bintoro *et al*., 2023)**. Pomacentrid distribution strongly correlates with habitat complexity, which provides both shelter and feeding opportunities **(Emslie *et al*., 2019)**. Several families, including the vibrantly colored Tetratodontidae (Fig. 5G), Pomacentridae (Fig. 5H), and Scorpaenidae (Fig. 6I), are particularly prized in the ornamental fish trade **(Wiadnya *et al*., 2020)**.

Analysis of our results demonstrates that coral reef fish communities across all six research stations on Bangka Island exhibit high biodiversity, with equitable species distribution contributing to community stability. The consistently high evenness index values (approaching 1.0) indicate balanced distribution of individuals among species, while correspondingly low dominance index values (approaching 0) confirm the absence of dominant species. This observed reef fish diversity pattern reflects the favorable coral reef conditions and supportive environmental parameters in Bangka Island, mirroring findings from the Indo-West Pacific region (Halmahera, Cenderawasih Bay, and Sulu Sea) **(DeVantier & Turak, 2017)**. Our results align with those of **Bachtiar *et al*. (2022)**, who reported similarly high reef fish diversity in Pacific Ocean ecosystems. Conversely, the reduced diversity observed around Samber Gelap Island, South Kalimantan, directly correlates with its limited live coral coverage **(Iskandar *et al*., 2021)**.

Reef fish abundance varied substantially among research stations. Target fish densities ranged from 0.13 to 0.56 individuals/m², peaking at Station 6 and reaching minimum levels at Station 1. Major fish species attained maximum density at Station 5

(1.55 individuals/m²) and minimum at Station 6 (1.00 individuals/m²). Indicator species demonstrated consistently lower abundance (0.03-0.04 individuals/m²) compared to other functional groups. Total reef fish abundance ranged from 1.28 to 1.84 individuals/m², classifying as moderate (Fig. 3). This contrasts sharply with the "low" abundance category reported for Sempu Strait, East Java **(Bintoro *et al*., 2023)**, suggesting greater ecological stress in that region. Bangka Island's moderate abundance levels indicate comparatively favorable conditions for sustaining reef fish populations.

Correlation between hard coral live cover and reef fish abundance

The abundance of reef fish species significantly influences coral reef complexity and structural characteristics **(Darling *et al*., 2017)**. Our research across six stations surrounding Bangka Island demonstrated a positive yet weak correlation between live coral cover percentage and reef fish abundance. Although live coral cover serves as a fundamental ecological parameter - providing essential habitat, reproductive sites, and trophic resources for reef fish - our findings suggest that fish distribution patterns are mediated by multiple factors beyond coral coverage alone. Key additional drivers include: (1) three-dimensional habitat complexity, (2) anthropogenic disturbance levels, and (3) physicochemical water parameters **(Ceccarelli *et al*., 2023)**. These results underscore the necessity for comprehensive, multi-faceted management strategies that address the synergistic interactions of these environmental variables to ensure coral reef ecosystem sustainability.

Seawater physical parameters

Optimal physicochemical water parameters are critical for maintaining coral reef ecosystem health and supporting diving tourism **(Yulianda, 2019; Simarangkir *et al*., 2021)**. Temperature fluctuations directly affect marine organisms' physiological functions, metabolic processes, immune responses, and molecular systems **(Kazmi *et al*., 2022)**. The optimal temperature range for coral growth in tropical waters is 25-29°C (Kaber *et al*., 2023), while 28-30°C is ideal for recreational diving **(De la Hoya *et al*., 2018)**. Our measurements (28.32-29.07°C across all stations) confirm these optimal conditions for both reef ecosystems and diving ecotourism. Comparative data from Halmahera waters (26.6-27.9°C) demonstrates temperature's significant influence on hard coral distribution **(Angkotasan *et al*., 2023)**.

Salinity represents a crucial environmental parameter affecting marine biodiversity. Fluctuations can disrupt physiological processes, cause metabolic imbalances, and increase osmotic stress, ultimately reducing biodiversity. Coral reefs thrive within 25-45 ppt salinity **(Röthig *et al*., 2023)**, and our study confirms that salinity levels remain within this optimal range. Water clarity, measured as light penetration depth, depends on surface irradiance and attenuates with depth **(Prato *et al*., 2017)**. Our results show 100% brightness at 4-7m depth (Stations 1-4,6) and 83.33% at 7-10m (Station 5), ensuring sufficient light for zooxanthellae photosynthesis **(Reimer *et al*., 2022)**. High clarity also benefits diving tourism by enhancing underwater visibility for reef observation and documentation **(Shokri & Mohammadi, 2021)**. Current velocity (10.39-21.49 cm/s across stations) plays multiple roles in reef ecosystems: nutrient distribution, sediment removal, and morphological development (optimal range 10-40 cm/s) **(Kesuma *et al*., 2024)**. For diving safety, currents <15 cm/s (Stations 2-4,6) are ideal for beginners, while stronger currents (20 cm/s at Stations 1,5) suit professional divers **(Yulianda, 2019)**.

Suitability of diving ecotourism

The ecotourism suitability index (ESI) is determined by six key parameters: (1) coral community cover, (2) water clarity, (3) depth, (4) coral life forms, (5) reef fish species, and (6) current velocity, with coral community cover serving as the primary evaluation metric **(Yulianda, 2019)**. Our analysis classified stations 2, 3, and 5 as "very suitable" (S1) and stations 1, 4, and 6 as suitable (S2) for diving ecotourism.

Three factors consistently supported diving activities across all stations: optimal water clarity, appropriate depth, and favorable current conditions. However, the superior ESI ratings at stations 2, 3, and 5 specifically resulted from their exceptional coral community coverage (45-55%), diverse coral life forms (8-10 types), and rich reef fish biodiversity (35-42 species). In contrast, Station 6 showed significantly reduced suitability due to its limited coral cover (22-25%), mirroring constraints observed on Kish Island in the Persian Gulf where low coral coverage similarly restricted dive tourism development **(Shokri & Mohammadi, 2021)**. To address this, we recommend implementing coral reef rehabilitation techniques, particularly coral gardening, which has proven effective in restoring degraded reefs **(Rinkevich, 2021)**. Station 1's suitability was primarily constrained by strong currents (0.25-0.30 m/s), analogous to conditions on Ataúro Island, Timor-Leste, where high current velocities similarly reduced ecotourism potential **(Costa *et al*., 2022)**. These current patterns create ideal conditions for experienced divers but may challenge beginners.

Carrying capacity

The assessment of environmental carrying capacity for diving ecotourism activities is crucial for determining an ecosystem's ability to withstand human pressures while maintaining the integrity of natural resources. In this context, environmental carrying capacity refers specifically to the maximum number of simultaneous visitors a dive site can accommodate without causing environmental degradation **(Yulianda, 2019)**. For Bangka Island, our calculations indicate that 797.24 hectares of coral reef area are suitable for diving ecotourism activities, with a recommended limit of 38 divers per day per site across the island's 21 dive locations. This situation contrasts markedly with Mabul Island, Malaysia, where carrying capacity approaches its maximum threshold, resulting in measurable declines in hard coral quality due to excessive diving activity **(Zhang *et al*., 2016)**. These findings highlight the importance of implementing proactive coral reef management strategies to mitigate degradation risks, including establishing visitor quotas, rotating site usage, and conducting regular ecosystem health monitoring. Such measures will help maintain the ecological balance while supporting sustainable diving tourism development.

CONCLUSION

The coral reef ecosystem of Bangka Island demonstrates favorable ecological conditions for diving ecotourism implementation, as evidenced by three key parameters: (1) adequate coral life form coverage, (2) sufficient reef fish abundance and diversity, and (3) optimal physical water characteristics. These conditions are further supported by the ecotourism suitability index (ESI) assessment, which classifies the area as "suitable" for diving activities. To maintain ecosystem sustainability and marine environmental quality, we recommend adhering to a carrying capacity limit of 38 divers per day per site per trip. For policymakers, we emphasize the critical need to: (a) establish enforceable regulations for dive tourism operations, (b) implement continuous coral reef monitoring programs, and (c) develop community-based conservation initiatives. These strategic measures will ensure the long-term preservation of coral reef ecosystems while supporting sustainable marine tourism development.

Conflicts of interest

We have no conflicts of interest to disclose.

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