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Macroinvertebrates as Bioindicators of Water Quality in Karang Beach, Bali

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Abstract: Karang Beach is a shallow water with a sandy substrate mixed with coral fragments and seagrass beds that support the life of benthic organisms. This study aims to determine the water quality at Karang Beach using macroinvertebrates as bioindicators. Sampling was conducted on November 1 and 25, 2025, using field survey methods (in situ) and laboratory analysis (ex situ). Water quality parameters measured included temperature, pH, turbidity, and current velocity. The measurement results showed relatively stable water conditions with an average temperature of 25.5°C, pH 8.1, and turbidity ranging from 3.3–4.8 NTU. The macroinvertebrates found came from the families Toxopneustidae, Grapsidae, and Holothuriidae. Analysis using the Family Biotic Index (FBI) at stations 1 to 4 showed that the water quality at Karang Beach was in a moderately stressed to poor condition, characterized by the dominance of organisms tolerant to environmental disturbances.

Keywords: Bioindicators; Famili Biotic Index (FBI); Karang Beach; Macroinvertebrates; Water Quality.

Introduction

Coastal ecosystems represent vital global marine environments that drive biogeochemical cycling, support primary productivity, and host immense biodiversity (Nybakken, 2001; Odum & Barrett, 2005). Within these shallow-water habitats, macroinvertebrate communities serve as fundamental ecological components, bridging secondary production with higher trophic levels. The distribution, abundance, and diversity of these benthic organisms are intimately coupled with structural habitat complexity—such as sandy substrates, coral rubbles, and seagrass beds—which provide critical refugia, breeding grounds, and foraging resources (Supono & Nadiarti, 2017). Consequently, understanding macroinvertebrate community dynamics is essential for evaluating the overall ecological health and functioning of coastal marine ecosystems worldwide.

To assess ecosystem integrity, biological indicators (bioindicators) have emerged as powerful tools in environmental monitoring (Aulia et al., 2020). Macroinvertebrates, or macrozoobenthos, are particularly effective bioindicators because their low mobility and relatively long lifespans force them to integrate the continuous effects of environmental stressors, functioning as key indicators of aquatic health (Minggawati, 2013; Rosenberg & Resh, 1993). While conventional water quality monitoring relies heavily on physico-chemical parameters—such as temperature, pH, turbidity, and current velocity—these measurements only capture instantaneous abiotic conditions at the moment of sampling. In contrast, biological indices, such as the Modified Family Biotic Index (FBI), utilize the differential pollution tolerance levels of benthic families to diagnose cumulative organic enrichment and long-term ecological degradation (Arisandi, 2012).

Despite its ecological significance, Karang Beach in Sanur, South Denpasar, Bali, faces increasing anthropogenic pressure driven by intense coastal tourism, recreational activities, and localized urban runoff (Asadi et al., 2018). Although the surface waters of Karang Beach appear clear and sheltered, nutrient loading and organic waste deposition severely threaten the underlying benthic habitat. A critical research problem arises from the frequent discrepancy observed in coastal management: visual and snapshot physico-chemical measurements often classify water quality as acceptable, masking underlying biological stress and habitat degradation (Halpern et al., 2008). Without evaluating the biological response of resident benthic communities, the true extent of organic pollution and ecosystem impairment at Karang Beach remains poorly understood.

To address this knowledge gap, this study establishes a baseline biomonitoring framework by integrating localized abiotic measurements with the Family Biotic Index (FBI) across multiple sampling stations at Karang Beach. While macrozoobenthic studies exist across Indonesian waters, the application of biological tolerance indices to detect silent anthropogenic stress in heavily visited tourism zones like Sanur represents a critical state of the art in local coastal assessment. Therefore, the primary objective of this research is to evaluate the water quality status of Karang Beach using macroinvertebrates as bioindicators and to correlate benthic community structure with environmental parameters. The urgency of this study lies in providing empirical, biological evidence to guide integrated coastal zone management, mitigate wastewater impacts, and align local conservation efforts with Sustainable Development Goal 14 (Life Below Water) (United Nations, 2015).

Materials and Methods

Research Location and Time

This research was conducted in Karang Beach, Sanur, South Denpasar, Bali. The research utilized a descriptive approach through direct field observation and laboratory analysis. The research location was divided into four observation stations representing differences in environmental conditions and activities in the Karang Beach area.

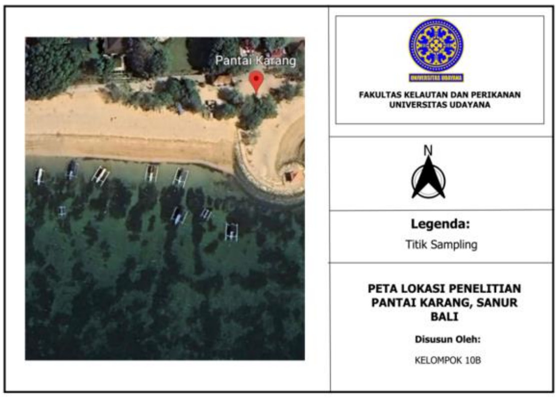

Figure 1. Research Location

Data Collection

In situ observations were carried out directly at the research site. Current velocity was measured at each station using a floating meter. In addition, observations were made on macroinvertebrates found at stations 1 to 4. The collected macroinvertebrates were identified, and their number and species were recorded. The presence and composition of macroinvertebrates were used as biological indicators of water quality because these organisms are relatively sedentary and possess different tolerance levels to environmental changes and pollution stress.

Ex situ measurements were conducted in the laboratory by analyzing water quality parameters from samples taken at each station. The parameters measured included turbidity, pH, and temperature. Turbidity was measured to determine the clarity of the water and the amount of suspended particles that could affect the life of benthic organisms. Temperature was measured to determine the thermal conditions influencing the metabolic activity and distribution of macroinvertebrates. Meanwhile, pH was measured to determine the chemical conditions supporting or limiting the presence of aquatic organisms.

Data Analysis

Data analysis in this study utilized the Family Biotic Index (FBI). According to Arisandi (2012), the calculation of the benthic macroinvertebrate biotic index using the Modified Family Biotic Index (FBI) has been widely used to indicate the level of organic pollution in waters, where each macroinvertebrate family has a specific score

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indicating its tolerance level to organic pollution. In this method, each group of aquatic organisms is given a tolerance score between 0 and 10, showing their ability to survive in polluted conditions. The calculation formula is:

$$FBI = \sum_{i-1}^{i=n} \frac{xi.ti}{N}$$

where *FBI* is the benthic macroinvertebrate index value, *xi* is the number of individuals in the i-th family group, *ti* is the tolerance level of the i-th family group, and *N* is the total number of individuals composing the community. A higher FBI value indicates poorer water quality.

Table 1. Water Quality Classification based on the Family Biotic Index (FBI)

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00 – 3.75	Excellent	Organic pollution unlikely
3.76 – 4.25	Very Good	Possible slight organic pollution
4.26 – 5.00	Good	Some organic pollution
5.01 – 5.75	Fair	Fairly significant organic pollution
5.76 – 6.50	Fairly Poor	Significant organic pollution
6.51 – 7.25	Poor	Very significant organic pollution
7.26 – 10.00	Very Poor	Severe organic pollution

Although the FBI was originally developed by Hilsenhoff for freshwater systems, its conceptual framework is applied here with adjustments. For marine contexts, indices like AZTI'S Marine Biotic Index (AMBI) (Borja et al., 2000) are typically more specific, but the FBI classification was utilized as an initial baseline assessment in this study.

Results and Discussion

Macroinvertebrate Community Structure and Trophic Dynamics

Based on the observations (**Table 2**), there was a severe limitation in the macroinvertebrate diversity, with only one individual species identified for each station, originating from the families Holothuriidae, Toxopneustidae, and Grapsidae. The limited number of species found caused the abundance value to be critically low, which strongly indicates a compromised ecosystem. The low number of individuals was partially influenced by the high tide conditions during sampling, which altered the distribution and accessibility of benthic organisms. However, from an ecological perspective, a persistently low diversity and abundance in a coastal ecosystem typically indicate prolonged environmental stress.

According to Odum and Barrett (2005) in their foundational text Fundamentals of Ecology, stressed or disturbed ecosystems often exhibit reduced species richness, where only a few highly tolerant, opportunistic species can survive and dominate the habitat. This phenomenon is further explained by the classic Pearson and Rosenberg (1978) model of macrobenthic succession, which posits that as organic enrichment and pollution increase, complex benthic communities are replaced by a few resilient taxa.

Table 2. Identified Macroinvertebrates

Species	St I	St II	St III	St IV
Tripneustes gratilla	1	-	-	-
Grapsus albolineatus	-	-	-	1
Holothuria atra	-	1	-	1

The presence of these specific taxa provides significant insight into the trophic dynamics of Karang Beach. The sea urchin Tripneustes gratilla (Family: Toxopneustidae) is a benthic organism commonly found in intertidal ecosystems, particularly coral reefs and seagrass beds. It possesses a round body with short and relatively blunt spines. The short and sparse spines indicate that it is less protected from extreme environmental stress, such as increased turbidity, high sedimentation, or organic pollution. Internationally, Muthiga and McClanahan (2007) highlighted that T. gratilla plays a crucial herbivorous role in controlling algal epiphytes in seagrass beds. Its sparse population in Karang Beach might indicate suboptimal grazing habitats or vulnerability to localized anthropogenic runoff that degrades seagrass quality.

Grapsus albolineatus (Family: Grapsidae) has a circular dorsal carapace, indicating a strong and protective body structure that allows it to withstand physical pressures in the coastal environment, such as wave action. Morphologically, this reflects a high tolerance ability towards declining water quality. Therefore, the family Grapsidae can be categorized as a species with a high tolerance value in the FBI assessment, often indicating disturbed aquatic conditions. This is supported by Kennish (2002), who stated that highly mobile brachyuran crabs are often opportunistic scavengers capable of thriving in organically enriched or physically disturbed coastal zones where more sensitive species fail to survive.

Holothuria atra (Family: Holothuriidae) features a soft, thick, black body with elastic tentacles around the mouth that serve to capture food, indicating strong adaptation to benthic life on sandy substrates. In the context of FBI, its presence typically reflects an organism with a low tolerance to pollution, indicating relatively unpolluted micro-habitats. As deposit feeders, *Holothuria atr*a is highly dependent on the sediment quality; heavy metal contamination, microplastics, or anoxia in the substrate drastically limits their distribution (Purcell et al., 2012; Rudi et al., 2012). Their presence suggests that while the water column may carry pollutants, parts of the sandy substrate still retain sufficient ecological integrity to support deposit-feeding guilds,

Environmental Water Quality Parameters and Anthropogenic Stress

Table 3 presents the results of water quality parameters, including current velocity, turbidity, temperature, and pH across all stations. The temperature measurement at Karang Beach was consistent across all stations at 25.5°C. Temperature is a crucial factor for marine organisms, affecting metabolic and reproductive activities. This value meets standard quality thresholds and remains slightly below the optimal limit for biota life, which is 28-32°C. The measured pH value was consistent at 8.1 across all stations. According to standard environmental thresholds for marine biota, a pH range of 7-8.5 is optimal. Highly acidic or alkaline conditions can disrupt metabolic and respiratory processes. The uniformity in temperature and pH indicates a homogeneous aquatic environment, driven by shallow waters, close station proximity, and adequate wave mixing. Tomascik et al. (1997) emphasized that shallow coastal waters in Indonesia typically exhibit high physicochemical homogeneity due to continuous diurnal tidal flushing.

Table 3. Water Quality Measurement Results

Parameter	St I	St II	St III	St IV
Current Velocity (m/s)	0.27	0.60	0.38	0.63
Turbidity (NTU)	3.3	4.0	4.8	3.3
Temperature (°C)	25.5	25.5	25.5	25.5
pH	8.1	8.0	8.1	8.1

Turbidity levels ranged from 3.3 to 4.8 NTU, which is generally low. Lower turbidity allows deeper light penetration, enhancing photosynthesis for aquatic vegetation and thus increasing dissolved oxygen availability. Current velocity varied between 0.27 m/s and 0.63 m/s, indicating moderate to strong currents influenced by wind and bottom friction. According to Nybakken (2001), current velocity is a primary physical driver in benthic ecology; strong currents prevent the accumulation of fine organic detritus, which might explain the very low abundance of macroinvertebrates. However, despite these seemingly normal physical parameters, coastal areas in Bali heavily utilized for tourism often suffer from invisible anthropogenic stressors, such as nutrient loading from domestic waste and coastal development, which silently degrade benthic habitats (Halpern et al., 2008; Asadi et al., 2018).

FBI Analysis, Ecological Health, and Management Implications

The Family Biotic Index (FBI) was calculated to assess the ecological status of the waters based on the presence and tolerance of macroinvertebrate families. Based on the FBI calculations (Table 3), Station 1 has an FBI value of 6, categorizing it as having rather poor water quality with substantial pollution. Station 2 has an FBI of 8, falling into the very poor water quality category with severe organic pollution. Station 4 shares an FBI value of 6 with Station 1. Station 3 yielded no macroinvertebrate species due to high tide and potentially unfavorable physical habitat conditions.

Table 4. FBI Analysis of Macroinvertebrates at Stations 1-4

ST	Family	Count (xi)	Tolerance (ti)	xi*ti	FBI
I	Toxopneus tidae	1	6	6	6
II	Grapsidae	1	8	8	8
III	-	-	-	-	-
IV	Grapsidae	1	8	8	6
	Holothurii dae	1	4	4	

There is a noticeable discrepancy between the physico-chemical parameters (which suggest good water conditions) and the biological FBI classification (which suggest poor conditions). This occurs because the two methods represent different aspects and time scales. Physico-chemical parameters describe instantaneous water conditions at the time of measurement, whereas the FBI reflects the long-term ecological conditions through the biological response of macroinvertebrates. This fundamental principle of biomonitoring is detailed by Rosenberg and Resh (1993), who state that benthic macroinvertebrates act as continuous monitors of their habitat; they integrate the cumulative effects of intermittent pollution spikes (e.g., nocturnal effluent discharge) that spot-check chemical sampling often misses.

While the FBI was originally designed for freshwater ecosystems, its conceptual application here highlights the dominance of pollution-tolerant taxa in Karang Beach. The poor FBI results strongly correlate with sustained pollutant inputs into the waters. To provide a more robust marine-specific context, future assessments should integrate indices like AZTI'S Marine Biotic Index (AMBI) (Borja et al., 2000; Dauvin et al., 2010), which are specifically tailored to marine benthic succession.

Furthermore, the integration of biological indicators serves as a critical diagnostic tool for broader coastal management. A degraded macrobenthic community not only indicates poor water quality but also a disruption in the marine food web, which directly impacts fisheries resource management. Ensuring a healthy benthic ecosystem is a fundamental prerequisite for sustaining higher trophic populations (Birk et al., 2012; Miloslavich et al., 2018). The findings from Karang Beach underscore the urgent need for integrated coastal zone management that aligns with the global Sustainable Development Goals (SDGs), particularly SDG 14 (Life Below Water), which mandates the reduction of marine pollution and the sustainable management of marine and coastal ecosystems to avoid significant adverse impacts (United Nations, 2015). Without empirical biomonitoring data to guide wastewater mitigation and habitat restoration, the long-term carrying capacity of Karang Beach for both biodiversity and coastal tourism will remain severely threatened

Conclusion

Based on the research at Karang Beach, Bali, it can be concluded that the physical water conditions are relatively stable with an average temperature of 25.5°C, pH of 8.1, and low turbidity ranging from 3.3–4.8 NTU. Although these physico-chemical parameters remain within optimal limits for marine life, the identified macroinvertebrates comprising the families Toxopneustidae, Grapsidae, and Holothuriidae exhibited critically low abundance and diversity. The absence of macroinvertebrate species at Station 3, combined with the low overall density across other stations, indicates that the waters are experiencing moderate to high environmental stress despite the apparently stable physical water quality.

The application of the Family Biotic Index (FBI) analysis confirmed this ecological pressure, with results varying from "rather poor" to "very poor," signaling that sustained organic pollution is significantly impacting the benthic community. This discrepancy between instantaneous physical measurements and the long-term biological response of macroinvertebrates highlights the importance of using biomonitoring as a diagnostic tool for coastal health. Consequently, integrated coastal zone management and strict wastewater mitigation strategies are essential to restore habitat integrity, preserve local biodiversity, and ensure the long-term sustainability of the Karang Beach ecosystem in alignment with the goals of sustainable marine management.

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