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ANURAN DIVERSITY AND COMMUNITY STRUCTURE IN LESTI UPRIVER ACROSS BUFFER ZONE HABITAT IN BROMO TENGGER SEMERU NATIONAL PARK

DIVERSITAS DAN STRUKTUR KOMUNITAS ANURA DI HULU SUNGAI LESTI DI HABITAT KAWASAN PENYANGGA TAMAN NASIONAL BROMO TENGGER SEMERU

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ABSTRACT

In Bromo Tengger Semeru National Park (BTSNP), buffer zone areas, one of which is the Lesti upstream rivers, play a critical role in sustaining biodiversity and community life. Frogs serve as a bioindicator of environmental change, particularly in the upstream rivers of the Lesti. The present study examines Anura's diversity and community structure in the upstream rivers of Lesti, which are included in the BTSNP buffer zones. Throughout the surveys, up to 14 anuran species were encountered in four sites adjacent to the BTSNP border and crossed by the Lesti rivers. This study suggests that buffer zones may support herpetofaunal diversity by allowing humans to interact with them and sustainably utilize the resources in the areas. Urban development and conservation in these areas must be kept current to minimize environmental disruption caused by humans.

Keywords: *Amphibians, buffer zone habitat, BTSNP, Lesti River*

ABSTRAK

Daerah zona penyangga di Taman Nasional Bromo Tengger Semeru (TNBTS), salah satunya adalah sungai hulu Lesti, memainkan peran penting dalam mempertahankan keanekaragaman hayati dan kehidupan masyarakat. Katak berfungsi sebagai bioindikator perubahan lingkungan, terutama di hulu sungai Lesti. Studi ini meneliti keragaman dan struktur komunitas Anura di hulu sungai Lesti, yang termasuk dalam zona penyangga TNBTS. Sepanjang survei, ditemui hingga 14 spesies anuran di empat lokasi yang berdekatan dengan perbatasan TNBTS dan dilintasi oleh sungai Lesti. Studi ini menunjukkan bahwa zona penyangga dapat mendukung keragaman herpetofaunal dengan memungkinkan manusia untuk berinteraksi dengan mereka dan secara berkelanjutan memanfaatkan sumber daya di daerah tersebut. Pembangunan dan konservasi di daerah-daerah ini harus tetap berjalan untuk meminimalkan gangguan lingkungan yang disebabkan oleh manusia.

Kata kunci: *Amfibi, habitat zona penyangga, TNBTS, Sungai Lesti*

INTRODUCTION

The tropical montane forest has become a key factor in conserving and providing suitable habitats for various flora and fauna [1]. Java island, as it was largely formed by a volcanic mountain complex, was dominated by the highland area and tropical rainforest harbouring rich resources essential for rural communities living nearby and, most importantly, water sources [2]. Consequently, most of the rural communities in the highland area were found near the upriver. These close proximities could threaten the organism and environment in the area if the natural resources were exploited unsustainably.

Bromo Tengger Semeru National Park (BTSNP) is one of the important national parks with the highest mountain peak in Java (Semeru mountain; alt: 3,676 m asl), providing an essential ecosystem for flora and fauna in Java. The higher area in BTSNP is categorized as a conservation area. In contrast, the lower area is categorized as a buffer zone (transition area between the conservation area and urban/rural area). BTSNP encompasses a 50,276.20 ha area, with the buffer zone covering 96.349,56 ha of area. This area (i.e., buffer zone) is mostly organized by PERHUTANI, utilized for protected forest or production forest (e.g., monoculture, settlements, agroforestry) [3]. Lesti River is one of the upriver in BTSNP essentials for the rural communities living nearby by providing the water for their agricultural needs, volcanic sand for construction, tourism site, and drinking water. Nevertheless, these activities could threaten the environment and organisms in the river due to various factors, e.g., agrochemicals contamination, household waste, and volcanic sand mining. These factors seriously threaten animals sensitive to environmental stressors/change, including frogs (Amphibian, Anura) [4, 5].

As previously reported, environmental degradation was considered the major cause of the global decline of the amphibian population, more likely occurring for the amphibians distributed in the highland area of rainforest habitat [8]. Amphibians are considered bioindicators of environmental change in a freshwater ecosystem [6]. Due to their complex life cycle living in both terrestrial and aquatic habitats, they are susceptible to various environmental stressors [7]. Besides, human disturbance could introduce a fungal disease (i.e., Chytridiomycosis [9]) and invasive species (i.e., Bullfrog [10]). The previous study on the diversity and community structure of frog (Anura) has been carried out in BTSNP rivers or streams, e.g., Ledok Amprong river [11]; Coban Jahe [12], and Coban Pelangi [13], showing diversity pattern due to environmental change. Still, comparing the diversity and community structure of frogs across different degrees of disturbance within the same river may provide a clear picture of the significant impact of environmental change and provide a key reference for future resource management.

Records and surveys of frogs provide the preliminary and baseline data toward sustainable management, particularly for the buffer zone habitat (intersection between natural habitat and rural area), to protect and conserve the environmental quality essential for the nearby rural community. In this study, we investigate the diversity and community structure of Anura (frogs) located in Lesti upriver, which are included in the buffer zone habitat of BTSNP.

METHODS

Study area. Lesti upriver springs from Semeru mountain and flows across many villages in Malang Regency. This river flows across four villages, i.e., Site 1: Ngadas (8°04’59.89” S; 112°50’12.88” E), Site 2: Sumberejo (8°05’26.99” S; 112°49’27.80” E), Site 3: Patokpicis (8°07’02.36” S; 112°47’05.43” E) dan Site 4: Blayu (8°07’21.09” S; 112°44’44.23” E) (Figure 1, Figure 2). The land use of the area for the study can be categorized as submontane forest, plantation, and agricultural area, with an altitude ranging from 499–1097 m asl.

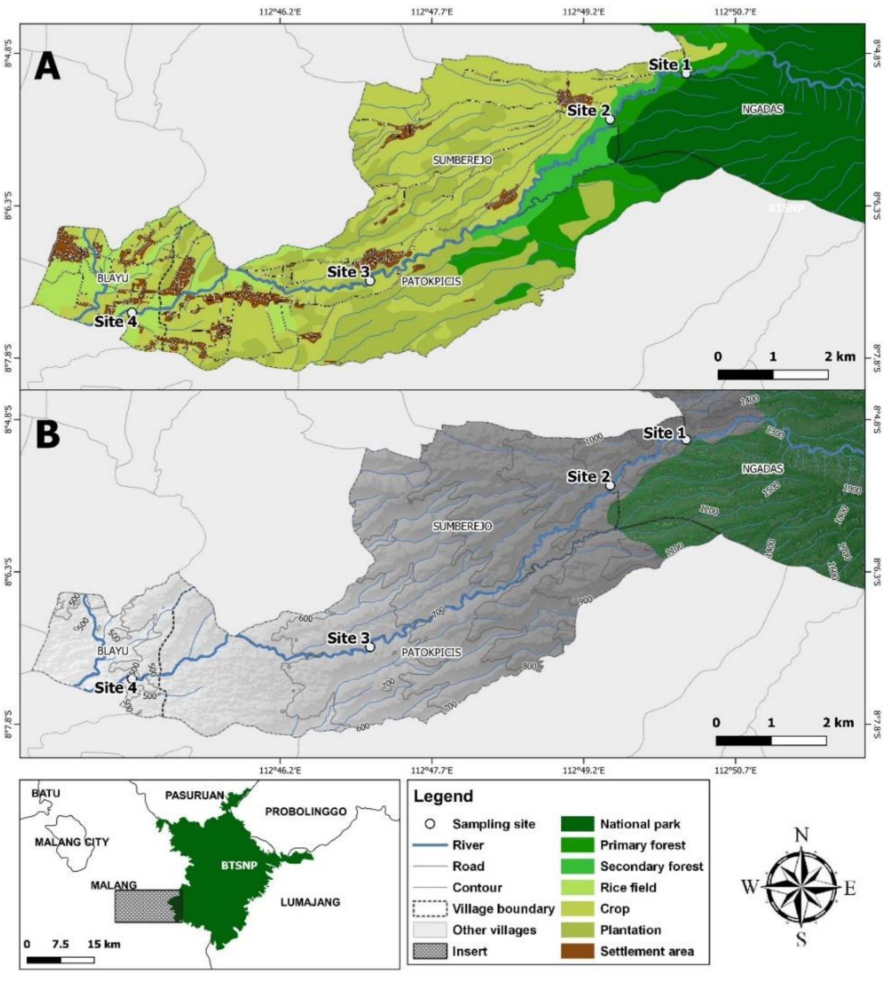

Figure 1. Geographical maps showing the sampling site, A) land use, and B) elevation

Figure 2. Habitats for each site: A) site 1, B) site 2, C) site 3 dan D) site 4

Anuran observation. The observation was carried out using a visual encounter survey using purposive sampling methods [14, 15], during March 2021 (rainy season), across the designated four sites. The observation was conducted for 4 hours at night (18.00-22.00) by 4–5 surveyors guided by a local expert. We recorded the information on individuals, elevation, location, habitat, and natural history, along with documentation of the species *(in situ)*. We identified the species by examining the external morphological characters from previous references [16, 17, 18, 19, 20]. Microclimatic data (i.e., temperature and humidity) and water parameters (i.e., water temperature, pH, conductivity, and dissolved oxygen) were taken during the surveys.

Data analysis. We grouped amphibian species by family and reported the conservation status based on the IUCN Red List of the Threatened Species [21], preferred microhabitat, and reproduction mode. The data were analyzed for relative abundance index (RAI), species richness, diversity index (H', Shannon-Wiener), dominance index (D, Simpson index), and evenness index (J', Pielou) [22, 23, 24, 25]. To examine the significance of differences in species diversity between locations, we utilized Zar's modified *t*-tests, also known as Hutcheson *t*-tests [26, 27]. We used Microsoft Excel software to calculate their respective categorization. We carried out Canonical Correspondence Analysis (CCA) where the response variables were species richness and abundance, as well as the functional groupings of amphibians. In addition, abiotic factors such as air temperature, humidity, water temperature, pH, conductivity, and dissolved oxygen (DO) were included as explanatory variables in CCA. Past4 was used to perform these analyses [28].

RESULTS AND DISCUSSION

Species diversity of Anura in Lesti upstream river. Field observations from four sites revealed the presence of 5 families containing 14 anurans species (Figure 3; Table 1). Diversity of anuran in Lesti upstream River accounted for 32% of Java island's amphibian species (40 anurans and three caecilians), where 13 species were classified as least concern by the IUCN, while one species was classified as near threatened (i.e., *Rhacophorus reinwardtii*). According to their microhabitat types, the majority of terrestrial frogs are Bufonidae (except *Phrynoidis asper*, which occurs in semi-aquatic habitats), the majority of aquatic frogs are Ranidae and Dicroglossidae (e.g., *Limnonectes microdiscus*, *Occidozyga sumatrana*), the majority of arboreal frogs are Rhacophoridae, and Microhylidae and some dicroglossid frogs can be found on shrubs or the ground (i.e., *Fejervarya cancrivora* and *Fejervarya limnocharis*). According to their reproduction modes, the majority of anuran species laid their eggs directly on water bodies, while two species (Rhacophoridae) laid their eggs in vegetation above the water bodies (in a foam nest) (Table 1; Figure 4). Most anuran species were found on rocks near rivers, riverbanks, sedimentation along the river banks, riparian vegetation along the river banks, and walkways along the river sides. Most anurans encountered in this study are found in the upstream river regions of Java's highlands. Numerous tadpoles of various species were discovered along rivers' banks and in artificial ponds (made by farmers).

Figure 3. Documentation of anuran species found in Lesti upstream river: Bufonidae, A) *Duttaphrynus melanostictus*, B) *Ingerophrynus biporcatus*, C) *Phrynoidis asper*; Dicroglossidae, D) *Fejervarya cancrivora*, E) *Fejervarya limnocharis*, F) *Occidozyga sumatrana*, G) *Limnonectes microdiscus*; Microhylidae, H) *Microhyla achatina*, I) *Microhyla palmipes*; Ranidae, J) *Chalcorana chalconota*, K) *Wijayarana masonii*, L) *Odorrana hosii*; Rhacophoridae. M) *Polypedates leucomystax*, N) *Rhacophorus reinwardtii*.

Figure 4. Breeding site of anuran showing its eggs around Lesti upstream river, A) *Wijayarana masonii* in shallow water parts of the riverbank, B) *Polypedates leucomystax* in an artificial pond of agriculture near the river

Anura has a complex life cycle, with the tadpole stage occurring primarily in aquatic habitats and the frog stage occurring primarily in terrestrial habitats, which allows for the identification of several species of frogs. The population will inevitably decline if there is significant disturbance during either (or even both) of these phases [29]. Numerous species of frogs, such as *O. hosii* and *W. masonii*, are still abundant, but their habitat is restricted to highlands and unpolluted water conditions [30]. In contrast to *P. leucomystax*, which has the same reproductive mode and strategy but is tolerant of damaged environments, *R. reinwardtii* is the only amphibian in this study classed as NT (near threatened) based on the IUCN Red list, and it is comparatively infrequently found. Frog species recorded in this study are not listed in the protected category under CITES and PERMEN LHK No. 20 2018. Overharvesting of *F. cancrivora* can have a detrimental effect on the population; additionally, the abundance of *F. cancrivora* is significantly different than that of *F. limnocharis*. At site 4, which is not far from human settlements and activities, we discovered *F. cancrivora* being hunted by local communities and several species being crushed to death by vehicles (e.g., *D. melanostictus*, *F. limnocharis*).

Community structure of Anura in Lesti upriver. The percentage of relative abundance of each amphibian species with a high value is typically assigned by tolerant amphibians (e.g., *C.*

chalconota, *P. leucomystax*) and dominant in their discovery location (e.g., *O. hosii*, *P. asper*, & *F. limnocharis*) (Table 1). Site 4 had the greatest species richness, followed by Site 3, Site 2, and Site 1 (Figure 5A). The diversity index (H') for Site 1 was low, whereas it was moderate for Sites 2, 3, and 4 (Figure 5B). When using Zar's modified *t*-tests or Hutcheson *t*-tests, most of diversity index showed significant differences between sites, except for site (2-3) and site (3-4) (Table 2). The lowest species richness and diversity index (i.e., Site 1) was most likely caused by the presence of species that are particularly adapted to torrent streams (e.g., *C. chalconota*, *O. hosii*, *W. masonii*, *and L. microdiscus*), as well as species that are particularly adapted to riparian vegetation (e.g., *Polypedates leucomystax*). According to the evenness index, Site 1 had the lowest value, indicating that the community was environmentally depressed, whereas the other sites can be considered unstable (Figure 5C-5D). Site 1 had the highest dominancy index, followed by Site 2, owing to the presence of *Odorrana hosii*, particularly adapted to torrent streams. Site 3 was dominated by *P. asper*, which is commonly found in torrent streams that have been disturbed by humans (e.g., sand mining, artificial pond). Due to agricultural activity, *F. limnocharis* dominated Site 4, as these habitats are suitable for this species and other dicroglossid frogs. As a result, the dominancy index followed the opposite trend as the evenness index (Figure 6).

Environmental condition in Lesti upriver. The overall study sites had an air temperature of 22.5–26°C, relative humidity of 80–94%, and a water temperature of 20.8–25.1°C. These could be due to the effect of altitude, with the highest altitude exhibiting a cooler air temperature and thus affecting the humidity. The water temperature was 1–2°C lower than the ambient air temperature, which is normal. The water pH was neutral, ranging between 6.9–7.13, and the water conductivity was approximately 8 mS/m, except for Site 4, which had a conductivity of approximately 12.27 mS/m. Dissolved oxygen levels were found to be highest in Site 1 and lowest in Site 4. This could be due to the rivers' contours and characteristics in Site 1, which include a torrent stream, whereas they were slower in Site 4. Changes in water characteristics may also be influenced by land conversion and human settlements that drew their resources from rivers, as seen in Sites 3 and 4, where household waste and agricultural contamination were more pronounced (Table 3).

Table 1. Checklist of Anurans in Lesti upriver. **Notes:** Anurans occurrence at each site = present: (✓), absent: ( ); RAI (relative abundance index) in percentage value (%); CS = conservation status based on IUCN red list (LC: least concern, NT: Near Threatened); PM = most preferred microhabitat (A: arboreal, H: herbaceous-shrub, S: semiaquatic, T: terrestrial); RM = reproductive mode (A: eggs laid in water and larvae develop in water, B: eggs laid in vegetation and larvae develop in water).

Species	**Site**				**RAI**	**CS**	**PM**	**RM**
	1	**2**	**3**	**4**				
Bufonidae								
Duttaphrynus melanostictus (Schneider, 1799)			✓	✓	3.19	LC	T	A
Ingerophrynus biporcatus (Gravenhorst, 1829)				✓	0.88	LC	T	A
Phrynoidis asper (Gravenhorst, 1829)			✓	✓	11.84	LC	S/T	A
Dicroglossidae								
Fejervarya cancrivora (Gravenhorst, 1829)				✓	1.18	LC	H	A
Fejervarya limnocharis (Gravenhorst, 1829)				✓	7.65	LC	H	A
Limnonectes microdiscus (Boettger, 1892)	✓	✓			4.63	LC	S	A
Occidozyga sumatrana (Peters, 1877)				✓	1.18	LC	S	A
Microhylidae								
Microhyla achatina Tschudi, 1838		✓	✓	✓	5.17	LC	H	A
Microhyla palmipes Boulenger, 1897				✓	3.82	LC	H	A
Ranidae								
Chalcorana chalconota (Schlegel, 1837)	✓	✓	✓	✓	13.68	LC	S	A
Odorrana hosii (Boulenger, 1891)	✓	✓			29.96	LC	S	A
Wijayarana masonii (Boulenger, 1884)	✓	✓			6.04	LC	S	A
Rhacophoridae								
Polypedates leucomystax (Gravenhorst, 1829)	✓	✓	✓	✓	9.06	LC	A	B
Rhacophorus reinwardtii (Schlegel, 1840)			✓		1.72	NT	A	B

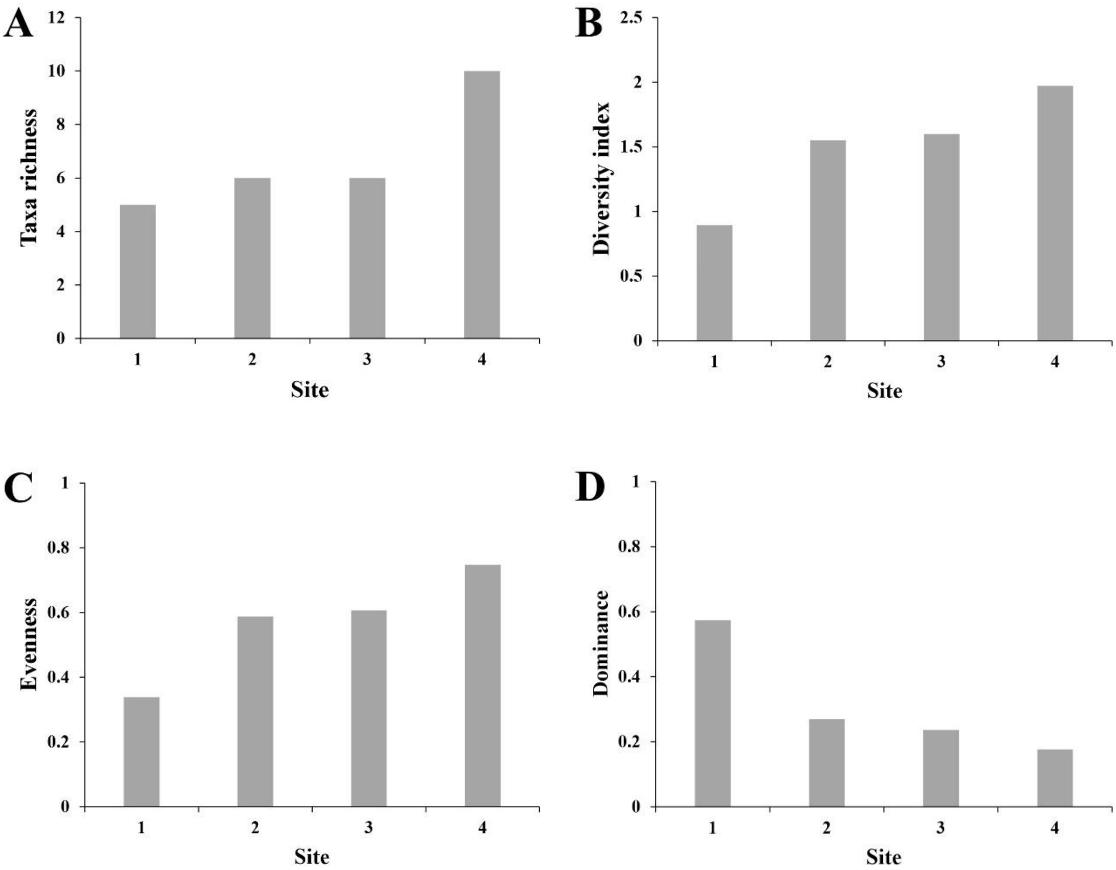

Figure 5. Diversity index and community structure of Anuran in Lesti upstream river A) taxa richness, B) diversity index, C) evenness, and D) dominance

Table 2. Summary of results of Zar's modified *t*-tests or Hutcheson *t*-tests, comparing species diversity between surveyed sites on buffer zones of Bromo Tengger Semeru National Park, East Java, Indonesia.

Site		**H_x**	**H_y**	**$t_{cal.}$**	**$t_{crit.}$**	**Statistical value**
Site 1 vs	Site 2	0.893	1.551	4.816	1.973	df = 172, $p \leq 0.05$
	Site 3	0.893	1.600	4.322	1.992	df = 75, $p \leq 0.05$
	Site 4	0.893	1.972	7.842	1.973	df = 180, $p \leq 0.05$
Site 2 vs	Site 3	1.551	1.600	0.327	2.001	df = 58, $p \geq 0.05$
	Site 4	1.551	1.972	3.450	1.975	df = 160, $p \leq 0.05$
Site 3 vs	Site 4	1.600	1.972	2.453	2.001	df = 60, $p \geq 0.05$

Note: Significant difference between sites, $p \leq 0.05$; No significant difference between sites, $p \geq 0.05$

Table 3. Abiotic factors in each site recorded

Abiotic Factors		**Site**			
		1	**2**	**3**	**4**
Microclimate	Air Temperature (°C)	22.5	23	25	26
	Relative humidity (%)	80	80	86	94
Water parameter	Temperature (°C)	20.8	22.5	24.8	25.1
	pH	7.13	6.9	7.02	7.11
	Conductivity (mS/m)	8.01	8.36	8.53	12.27
	DO (mg/L)	5.94	5.06	4.68	3.99

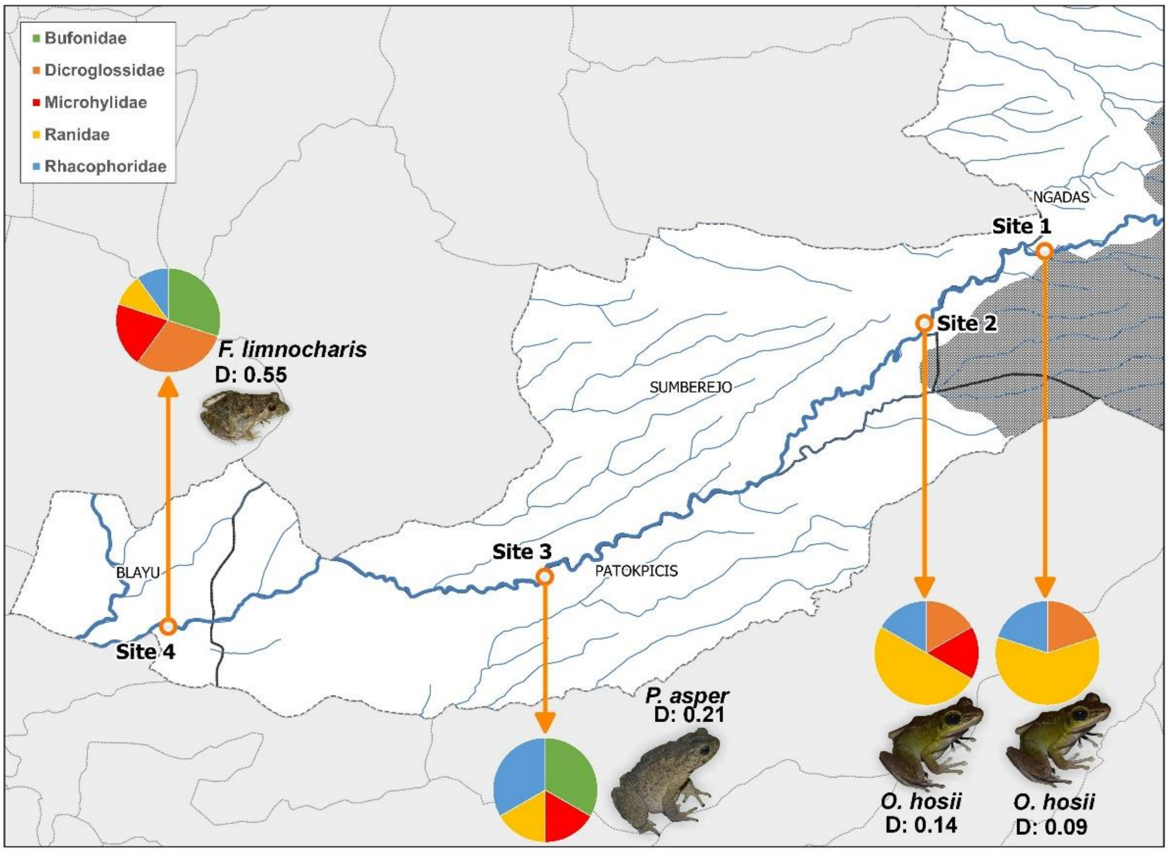

Figure 6. Composition of anuran on each site with additional information about dominating species in Lesti upstream river

Relationship of amphibians diversity and environmental conditions. According to the CCA study of the graph's inertia, axis 1 represents 67.89 percent, whereas axis 2 represents 26.19 percent. Group 1 is a paddy field habitat group that has adapted to its environment: The habitats of *I. biporcatus*, *F. cancrivora*, *F. limnocharis*, *O. sumatrana*, and *M. palmipes* are supported by high water conductivity and pH conditions. Group 2 frogs are adapted to highland rivers with a torrential stream: Altitude factors and high dissolved oxygen waters affect *L. microdiscus*, *W. masonii*, and *O. hosii*. *Microhyla achatina* and *P. asper* are tolerant species in disturbance areas. Cosmopolitan species include *D. melanostictus*, *C. chalconota*, and *P. leucomystax*. Given that *R. reinwardtii* belongs to the group of tree frogs, which is less impacted by environmental factors like microclimate and water parameters due to the adaptation of its reproductive strategy that uses puddles or ponds to spawn, it is separated from other groups projected in CCA analysis due to a lack of environmental data that does not include the land cover and vegetation type (Figure 7).

Changes in land cover and elevation may affect the herpetofauna community, as each species has its distribution range and preferred habitat [31, 32]. Amphibian habitats are affected indirectly by these changes in abiotic factors (water parameters and microclimate) [33, 34]. Disturbances to buffer zone habitats can adversely impact amphibian communities as a result of a variety of ecological problems identified as causes of amphibian population declines, including pollution, habitat loss, habitat modification, fragmented habitat, roadkill, and amphibian exploitation for food by humans [35, 36, 37, 38, 39, 40]. It is worth noting that frogs are critical components of their ecosystem, serving as predators that control arthropod populations and as prey for reptiles and birds. If the amphibian population declines, it will affect the food web and the ecosystem as a whole [41, 42, 43].

Frogs in habitats near the Lesti river exhibit various microhabitat characteristics. The majority of the food that frogs consume is arthropods of various types. Frogs' diverse sizes and habitats make them effective predators of various arthropods [44], recognizing them as biological control agents for various insects, including agricultural pests. Frogs can be used as environmental-friendly biological control agents because they are indigenous to their habitat and do not contribute to other environmental problems due to their natural role in ecosystems [45, 46], such as those in the Lesti upstream rivers. However, the effects of agrochemicals, such as pesticides, are dangerous because the Anura becomes indirectly affected as a non-target organism [47, 48, 49].

Planning and promoting sustainable agricultural production systems (agroforestry and organic agriculture) in buffer zones and habitat restoration on degraded lands can contribute to reducing anthropogenic stress in the buffer zones surrounding BTSNP, particularly along the Lesti River rivers. Due to easy access to clean water, sand mining, agriculture, and aquaculture, the river flowing from Mount Semeru is critical to the community living in the area [50]. Suppose water quality deteriorates due to land use changes and agrochemical pollution. In that case, difficulties will arise, particularly for people whose livelihoods are dependent on the Lesti river and the wildlife communities that inhabit it, one of which is amphibians. Erosion, flooding, and landslides are frequently overlooked indicators of the ecological health of riverine habitats. Apart from having a detrimental effect on society, the effect indirectly affects river biodiversity [51]. The anuran community is one of the wildlife species directly dependent on river conditions. Most of its life stages are linked to the aquatic and terrestrial environments surrounding the river, and any environmental changes will reflect changes in diversity and the anuran community [52]. Buffer zones are critical for conserving biodiversity and sustaining rural communities located within conservation areas. Indonesia is still grappling with a slew of intricate and interconnected ecological issues. It can begin by examining the watershed problem, which affects the carrying capacity of the environment and its constituent components in an area with economic activity [53, 54], with a particular emphasis on sand mining issues, land conversion along natural rivers, household waste, and animal hunting.

To our knowledge, the conservation of frogs as environmental change bioindicators has received less attention [55], particularly in Indonesia. Additionally, amphibian research focuses on the inventory and discovery of new species rather than applied ecology [56, 57, 58]. Our survey is constrained by seasonal factors (it was conducted only during the rainy season), a small survey coverage area, and ecological data records, all of which pose future research challenges, including studies on frogs as non-target organisms exposed to agrochemicals as well as frogs' ability to predate as biological control agents in agricultural habitats. Comparing diversity and community structure patterns to previous research is difficult given the inherent differences in habitat disturbance and ecological factors [59]. Nevertheless, our effort can be used to generate appropriate recommendations for resolving environmental issues, revitalizing the food supply, and promoting agricultural development on a sustainable basis. Thus, community and government collaboration are critical for developing and implementing a comprehensive conservation strategy, particularly in the buffer zone.

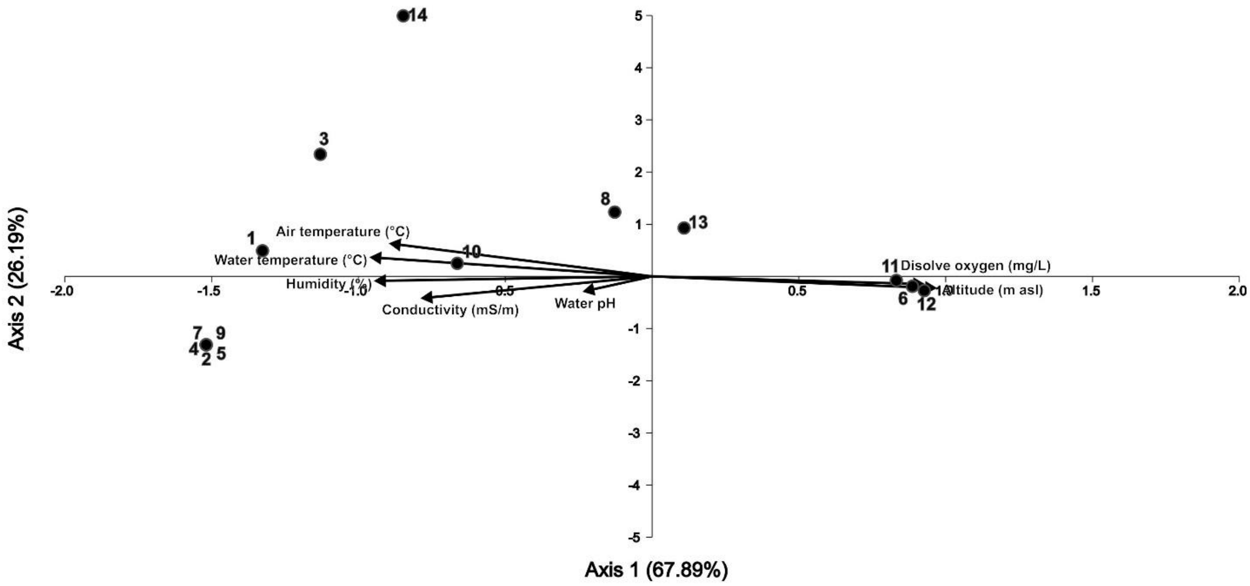

Figure 7. Canonical correspondence analysis (CCA) shows the relationship between the abiotic factor and amphibian species. Noted amphibians species: 1) *Duttaphrynus melanostictus*, 2) *Ingerophrynus biporcatus*, 3) *Phrynoidis asper*, 4) *Fejervarya cancrivora*, 5) *Fejervarya limnocharis*, 6) *Limnonectes microdiscus*, 7) *Occidozyga sumatrana*, 8) *Microhyla achatina*, 9) *Microhyla palmipes*, 10) *Chalcorana chalconota*, 11) *Wijayarana masonii*, 12) *Odorrana hosii*, 13) *Polypedates leucomystax*, 14) *Rhacophorus reinwardtii*

CONCLUSION

The Lesti upstream river had 14 species (5 families) of Anura. There was a change in anuran diversity and community structure along the river gradient. Each anura type and community has distinct characteristics, requiring unique environments and habitats. Adding data and investigating ecological factors could be done in future research and applied research like ecotoxicology.

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