SPECIES DIVERSITY OF DRAGONFLIES ON THE SANGIHE ISLANDS, NORTH SULAWESI, INDONESIA

KONERI, R.[1*] – NANGOY, M. J.[2] – SIAHAAN, P.[1]

[1]*Department of Biology, Faculty of Mathematics and Natural Sciences, Sam Ratulangi University, Kampus Bahu Street, Manado 95115, North Sulawesi, Indonesia*

[2]*Department of Animal Production, Faculty of Animal Science, Sam Ratulangi University, Kampus Bahu Street, Manado 95115, North Sulawesi, Indonesia*

**Corresponding author*
e-mail: ronicaniago@unsrat.ac.id; phone: +62-813-4027-5276

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Abstract. The diversity of dragonflies on an island is strongly influenced by habitat degradation, as well as the size and distance from the mainland. Therefore, this study aims to analyze the species diversity of dragonflies in the Sangihe Islands, North Sulawesi, Indonesia. It was carried out in five types of habitats namely forests, waterfalls, dams, agricultural land, and settlements. In each habitat, four-line transects with a length of 100 m each were made and placed around the river. The results showed 6 families which included 32 species and 3020 individuals. Libellulidae is the family with the highest number of species. Furthermore, the dominant species in the suborders Anisoptera and Zygoptera were *Orthetrum pruinosum* and *Rhinocypha frontalis*, respectively. Forests, waterfalls, and dams tend to have the highest species richness and diversity index compared to other habitats. Based on the results, the diversity of dragonflies at the observation site is strongly influenced by the complexity of the vegetation and environmental factors, including temperature and humidity. The presence of the families Chlorocyphidae, Calopterygidae, and Platycnemididae in each of the studied habitats indicates that the water quality is still very good and supports the life of dragonflies.
Keywords: *dams, forests, Libellulidae, waterfalls, Rhinocypha frontalis*

Introduction

Sangihe is the outermost island in North Sulawesi with an area of approximately 11,863.58 km^2 consisting of 736.98 km^2 landmass (6.2%) and 11,126.61 km^2 ocean (93.8%). Geographically, the Sangihe Islands regency is located at 4° 4’ 13” and 4° 44’ 22” north latitude - 125° 9’ 28” and 125° 56’ 57” east longitude between the Sulawesi and Mindanau (Philippines) islands. It consists of 105 large and small islands of which 26 are inhabited and 79 are uninhabited (Setiawan et al., 2016). These Islands have several types of ecosystems including forests, plantations, rivers, beaches, seas, and others, each ecosystem is inhabited by various flora and fauna such as dragonflies.

Dragonflies, an Odonata species, occupy forests, agricultural land, lakes, rivers, and other aquatic habitats (Kanaujia et al., 2015). The number of Odonata species including damselflies and dragonflies found in the world is approximately 5900 (Van Tol, 2000; Potapov et al., 2020). In Indonesia, approximately 700 species of dragonflies have been discovered and some are endemic to North Sulawesi (Murwitaningsih et al., 2019), which reportedly has over 143 (Van Tol, 2000). These insects tend to colonize a wide array of extreme environments such as hot springs, sulfidic, acidic, alkaline, and hypoxic water bodies, as well size ephemeral wetlands, pools, salt-water wetlands, and mangroves (Potapov et al., 2020).

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Furthermore, dragonflies are an important component in maintaining the balance of ecosystems and biodiversity (Monteiro-Júnior et al., 2014; Saha and Gaikwad, 2014; Das et al., 2012; Harabiš and Dolný, 2012; Willigalla and Fartmann, 2012; Siregar and Bakti, 2016). The nymphs produced by these insects function as predators in aquatic ecosystems, while the adult prey on pests of agricultural crops, hence, they are used as biological control agents (Willigalla and Fartmann, 2012; Agus et al., 2017). Adult dragonflies often lay eggs in clean water, hence, they need a natural habitat to support daily living. These insects are also used as bioindicators of forest and aquatic environmental quality (Dolný et al., 2011; Ilhamdi et al., 2020; Das et al., 2012).

Information on the distribution and diversity of flora and fauna in different habitat types at the local and regional levels is key to biodiversity conservation. Several studies on the diversity of dragonflies have been carried out, particularly in relation to ecosystems and as environmental indicators (Dolný et al., 2011; Mapi-ot et al., 2013; Kannagi et al., 2016).

In Indonesia, studies on dragonfly diversity have been conducted in various areas such as in Central Kalimantan Province (Hendriks, 2020), Genus Orthetrum in the Mount Prau Nature Reserve, Central Java Province (Setyawati et al., 2017), Asmat and Mappi Papua Regencies (Kaize and Kalkman, 2011), as well as in the Cibodas Botanical Gardens, West Java Province (Murwitaningsih et al., 2019). Moreover, the community structure and diversity of Odonata were investigated at the West Lombok Nature Tourism Park, West Nusa Tenggara Province (Ilhamdi et al., 2020), while the variety and composition of the dragonflies community were analyzed in the Tangkoko Nature Reserve, North Sulawesi Province (Koneri et al., 2017). A similar study was also conducted in Bogani Nani Wartabone National Park North Sulawesi (Nangoy and Koneri, 2017), as well as in the Tunan waterfall area, North Minahasa, North Sulawesi Province (Koneri et al., 2020), and in Bawean Islands Nature Reserve, East Java Province (Rohman et al., 2020).

Meanwhile, studies on dragonfly diversity in North Sulawesi Province were mostly carried out on the mainland and only a few were conducted on the islands. Furthermore, there are no studies on Odonata diversity in the outer islands of this province including Sangihe. The islands are experiencing problems due to forest destruction, conversion of forest habitats into agricultural areas, as well as a decrease in water quantity and quality (Lee et al., 2001). These conditions tend to reduce dragonflies diversity, therefore, this study aims to analyze the diversity of dragonflies species in the Sangihe Islands, North Sulawesi, Indonesia. The results are expected to become basic data for the conservation of dragonflies diversity and species in the Sangihe Islands.

Material and methods

Study area and land-use types

Sampling was carried out on adult dragonflies from May to August 2021 in the Sangihe Islands, North Sulawesi Province, Indonesia (*Table 1; Fig. 1*). It was conducted along the river in 5 types of habitats, consisting of forests, waterfalls, dams, plantations, and settlements. Forest is a natural habitat with a complex vegetation structure dominated by various types of trees such as *Ficus sp* (Moraceae), *Alstonia macrophylla* (Rubiaceae), *Litsea* sp. (Lauraceae), and *Garcinia* sp. (Fagaceae). Furthermore, waterfalls are habitats with vegetation dominated by *Ficus* sp. (Moraceae), ferns, and grasses *(Poaceae)*, while dam is a river flow for hydroelectric power generation and is

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dominated by *Ficus* sp. (Moraceae), *Litsea* (Lauraceae), bush vegetation (Astreaceae), and grasses *(Poaceae)*, as well as teki (*Cyperaceae* sp.). Plantations is managed by the community and are planted with various crops such as clove (*Eugenia aromatica*), coconut (*Cocos nucifera*), banana (*Musa* sp.), and nutmeg (*Myristica fragrans*). Meanwhile, settlement habitats are rivers flowing around residential areas and vegetated with grass (*Poaceae*) (*Fig. 2*).

Table 1*. The sampling habitats and coordinates on the Sangihe Island*

Habitats	Transect	Latitude (N)	Longitude E	Habitats	Transect	Latitude (N)	Longitude E
Dam	DM1	03°30’09.14”	125°31’45.87”	Plantation	PT3	03°26’30.31”	125°36’02.34”
Dam	DM2	03°30’06.30”	125°31’ 44.10”	Plantation	PT4	03°26’ 27.50’	125°36’01.40”
Dam	DM3	03°30’03.45”	125°31’42.44”	Settlement	ST1	03°27’33.20”	125°30’ 35.20”
Dam	DM4	03°30’01.41”	125°31’41.87”	Settlement	ST2	03°27’ 37.50”	125°30’33.90”
Forest	FR1	03°30’11.21”	125°31’45.64”	Settlement	ST3	03°26’09.62”	125°36’00.85”
Forest	FR2	03°27’08.96”	125°34’47.17”	Settlement	ST4	03°26’05.20”	125°36’05.20”
Forest	FR3	03°27’05.33”	125°34’48.92”	Waterfall	WF1	03°26’59.52”	125°34’53.74”
Forest	FR4	03°26’33.12”	125°35’56.10”	Waterfall	WF2	03°27’01.55”	125°34’49.66”
Plantation	PT1	03°29’51.22”	125°31’44.42”	Waterfall	WF3	03°26’40.89”	125°35’55.47”
Plantation	PT2	03°27’13.38”	125°34’48.50”	Waterfall	WF4	03°26’36.93”	125°35’55.13”

Sampling

The purposive random sampling method was used on forest habitats, dams, waterfalls, plantations, and settlements of the Sangihe Islands. For each of these habitat types, four line transects with a length of 100 m each were made along the river body. The width of the transect was 2 m: 1 m on the edge and 1 m on the water body from the edge in line (Sugiman et al., 2020).

Dragonflies collection was carried out in sunny weather from 8:00 am to 4:00 pm when most of the insects were still active (Renner et al., 2015; Khan, 2017). The sampling of dragonflies was conducted monthly for four months. This was performed along the transect line using insect nets (40 cm, 65 cm deep) with an aluminum handle 90 cm long (Mapi-ot et al., 2013). The observation was carried out directly or using binoculars and cameras while the samples were identified through field guidance. Samples that were not directly identified were caught using insect nets for further identification. The captured dragonflies were placed into kill bottles containing some tissue paper and filled with ether. After death, they were immediately removed from the bottle, dried in the sun, and then stored in triangular paper envelopes measuring 30 x 20 cm with the wings folded above the body (Koneri et al., 2020).

The identification process was carried out based on external morphological characteristics using dragonflies identification books (Watson and O’farrell, 1991; Miller, 1995; Wilson, 1995; Orr and Hämäläinen, 2003; Kalkman and Orr, 2013; Orr and Kalkman, 2015). Subsequently during sampling, environmental parameters such as air temperature, humidity, wind speed, and light intensity were observed. The air temperature and humidity were measured using a thermo-hygrometer (Deko 637 Thermo-hygrometer), while wind speed and light intensity were calculated with the Anemometer and Lux meter, respectively (Lutron LM8010 Type K). Additionally, the coordinates and elevation of the study location were simultaneously recorded using the Global Positional System (Garmin GPSMAP 78s).

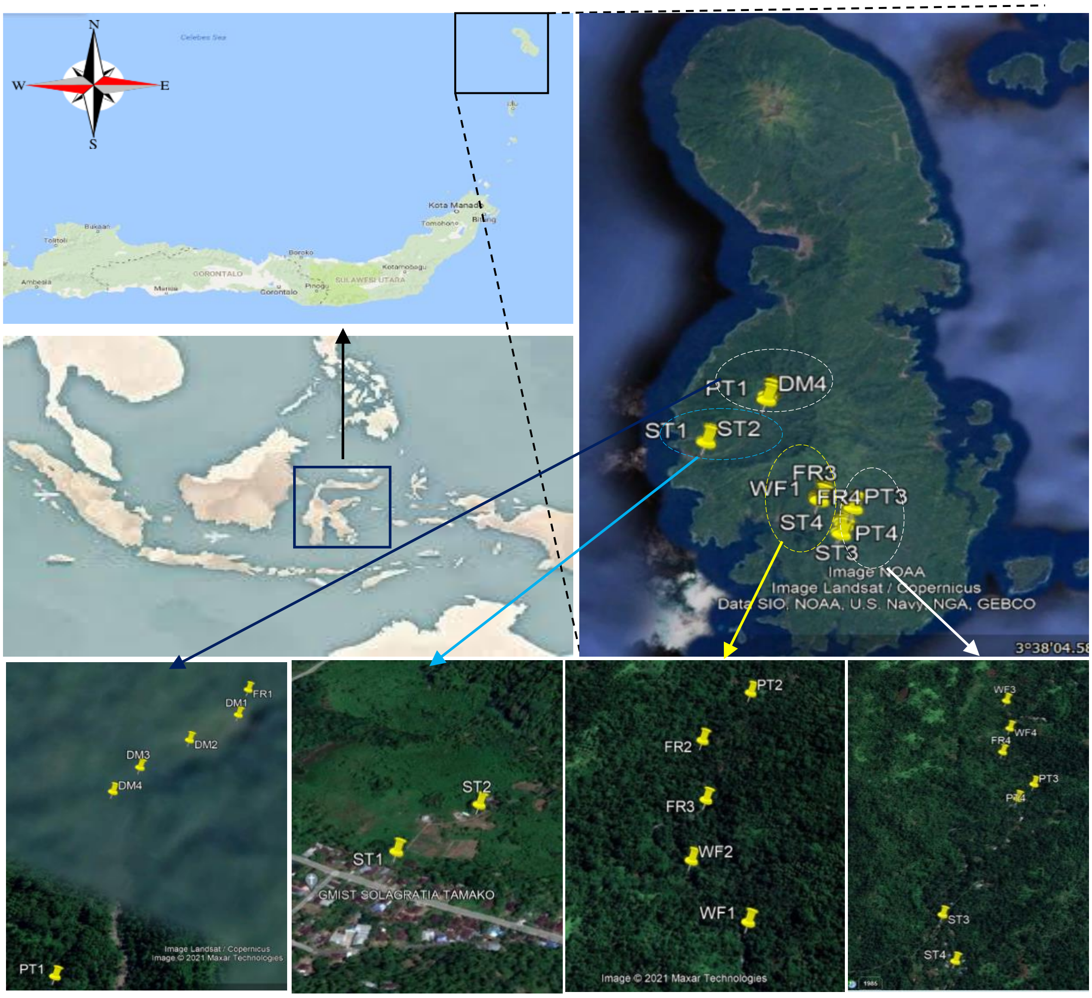

Figure 1. *Map of the study area in Sangihe Islands, North Sulawesi. (FR: forest; DM; dam; WF: waterfall; PT: plantation; ST: settlement)*

Figure 2. *Some photos of sampling site: forest (1); dam (2); waterfall (3); plantation (4); settlement (5)*

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Data analysis

The dragonflies abundance and richness data were tabulated for each habitat. The Rank-abundance curve was analyzed by an Excel program based on the percentage of total individuals, while species richness (Chao1) was used to estimate the number of species in each habitat. Meanwhile, interpolation-extrapolation rarefaction curves of species were created using the software an R package iNEXT (iNterpolation/EXTrapolation) (Hsieh et al., 2016).

Species diversity was calculated using the richness, diversity, and evenness indices. The species richness index was calculated using the formula from Margalef (R1) as follows:

$$RI = \frac{S-1}{LogN} \quad \text{(Eq.1)}$$

Description: R: Richness Index; S: Number of species (n1, n2, n3, ….) and N: total individuals in sampling (Magurran, 1988). Furthermore, the species diversity index was calculated using the Shannon-Wiener index (Omayio et al., 2019) as follows:

$$H' = -\sum_{i=1}^{s}(P_i \ln P_i) \quad \text{(Eq.2)}$$

Description: Pi = ni/N; H': Shannon-Wiener diversity index, ni: number of individuals for each species, N: number of individuals for all species (Magurran, 1988). Meanwhile, the species evenness index was calculated using the Shannon (E) evenness index (Magurran, 2004) as follows:

$$E = \frac{H'}{\ln S} \quad \text{(Eq.3)}$$

Description: E: Evenness index, H': Shannon-Wiener diversity index, S: number of species (n1, n2, n3, ….).

To test the significant differences in individual abundance, species richness, Shannon diversity, and evenness indices of dragonflies between the five habitats, the one-way ANOVA statistical analysis and Tukey's test at 95% confidence level with Statistica version 6 software were used (Bashir et al., 2019; Ajerrar et al., 2020).

The differences in the sample composition for each habitat were analyzed using analysis of similarity (ANOSIM), while differences between the habitat types were assessed with non-metric dimensional scaling (NMDS). ANOSIM and NMDS were analyzed based on the Bray-Curtis inequality index, while the principal component analysis (PCA) was conducted to determine the relationship between the sampling location and the measured environmental factors. ANOSIM, NMDS and PCA were analyzed using Paleontological Statistics software (PAST software 3.10) (Cuartas-Hernández and Gómez-Murillo, 2015; Wakhid et al., 2021).

Results

Dragonflies composition

Dragonflies found in five habitats on the Sangihe Islands were 2 suborders namely Anisoptera and Zygoptera consisting of 6 families, 32 species, and 3020 individuals. 2

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families were found for Anisoptera including Libellulidae with 16 species and Macromiidae with 1 species, while Zygoptera consisted of 4 families including Platycnemididae with 6, Chlorocyphidae with 4, Coenagrionidae with 4, and Platystictidae with 1 species (*Table 2*).

Table 2. *The list of species of dragonflies in all habitats*

Sub Ordo/Family/Species	Dam	Forest	Plantation	Settlement	Waterfall	Total	%
Anisoptera							
Libellulidae							
Diplacina militaris	1	0	2	1	9	13	0.43
Diplacina sanguinolenta	65	36	52	4	19	176	5.83
Diplacodes trivialis	3	4	0	0	10	17	0.56
Lathrecista asiatica	0	0	0	3	0	3	0.10
Nannophya pygmaea	13	0	1	9	59	82	2.72
Neurothemis manadensi	12	0	2	14	11	39	1.29
Neurothemis ramburii	39	4	13	33	22	111	3.68
Neurothemis stigmatizans	11	0	2	12	24	49	1.62
Neurothemis terminata	2	0	2	4	16	24	0.79
Orthetrum glaucum	17	0	5	0	7	29	0.96
Orthetrum pruinosum	77	9	42	154	47	329	10.89
Orthetrum sabina	1	3	2	21	0	27	0.89
Pantala flavescens	5	0	0	6	5	16	0.53
Tetrathemis irregularis	0	1	0	0	4	5	0.17
Tetrathemis leptoptera	0	3	0	0	2	5	0.17
Tetrathemis platyptera	0	0	0	6	1	7	0.23
Macromiidae							
Macromia melpomene	0	0	0	0	2	2	0.07
Zygoptera							
Chlorocyphidae							
Celebargiolestes cinctus	2	7	0	0	3	12	0.40
Celebargiolestes orri	0	2	0	0	0	2	0.07
Libellago daviesi	59	124	132	59	112	486	16.09
Rhinocypha frontalis	72	124	156	78	151	581	19.24
Coenagrionidae							
Agriocnemis femina	22	1	7	53	4	87	2.88
Pseudagrion crocops	1	11	0	0	0	12	0.40
Pseudagrion pilidorsum	53	51	26	0	62	192	6.36
Pseudagrion ustum	7	1	0	0	0	8	0.26
Platycnemididae							
Nososticta emphyla	3	16	9	0	3	31	1.03
Nososticta flavipennis	37	85	85	54	131	392	12.98
Prodasineura autumnalis	0	7	0	0	0	7	0.23
Teinobasis laidlawi	5	41	0	0	6	52	1.72
Teinobasis rufithorax	3	1	0	0	21	25	0.83
Teinobasis sp	25	40	86	3	28	182	6.03
Platystictidae							
Proposticta simplicinervis	0	9	2	0	6	17	0.56
Total	**535**	**580**	**626**	**514**	**765**	**3020**	**100**

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Zygoptera had the highest abundance in all habitat types namely 60.07%, especially in waterfalls with 25.30%, while Anisoptera only consisted of 1 family of Libellulidae with 11 species. Furthermore, Zygoptera consisted of 6 families including Coenagrionidae with 5 species, Argiolestidae, Calopterygidae, Chlorocypidae, Platycnemididae, and Lestidae with 1 species, respectively.

The percentage composition of the dragonflies family based on the abundance of individuals in each habitat was different. Chlorocyphidae of the sub-order Zygoptera had the highest abundance in forests with 44.3%, followed by plantations 46.0%, and waterfalls 34.8%. Meanwhile, Libellulidae of the suborder Anisoptera was mostly found in dams with 46.0% and settlements 51.9%. Similarly, Macromiidae were the family with the least abundance of individuals namely 0.3% and were only found in waterfalls (*Fig. 3*).

Species from the suborder Zygoptera with the highest abundance were *Rhinocypha frontalis* with 19.24% and *Libellago daviesi* 16.09%. Both species belong to the family Chlorocyphidae, while the species from Zygoptera with the lowest abundance was *Prodasineura autumnalis* (0.23%) (*Fig. 4*).

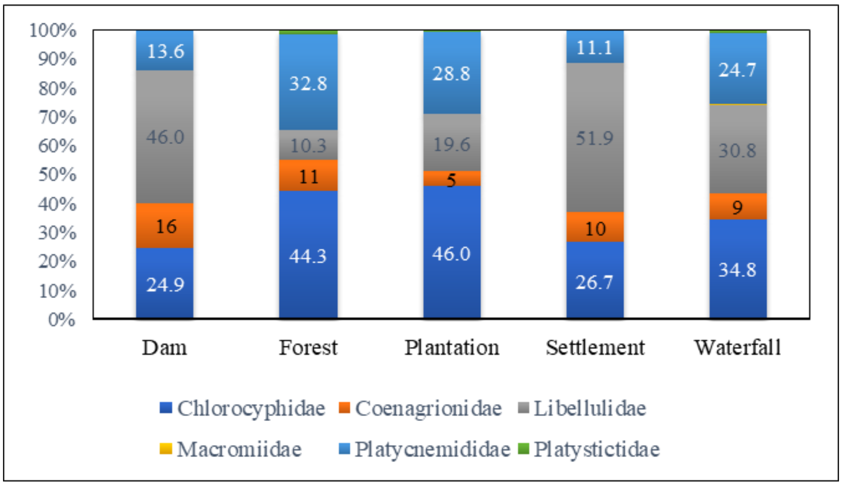

Figure 3. *The relative abundance of dragonflies based on the family in five habitats*

Figure 4. *Several species of dragonflies suborder Zygoptera in five habitat types in the Sangihe Islands. (1-2: Chlorocyphidae: Libellago daviesi (1); Rhinocypha frontalis (2); 3-4: Coenagrionidae: Pseudagrion pilidorsum (3); Agriocnemis femina (4); 5-7: Platycnemididae: Nososticta flavipennis (5); Teinobasis sp (6); Nososticta emphyla (7); Platystictidae; Proposticta simplicinervis (8)*

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Furthermore, the species with the highest abundance from the sub-order Anisoptera was *Orthetrum pruinosum* with 10.89%, followed by *Diplacina sanguinolenta* with 5.83%, both species belong to the family Libellulidae (*Fig. 5*). Meanwhile, *Macromia melpomene* was the species with the lowest abundance of 0.07% (*Table 2*).

Based on the results, 8 species were widely distributed in all habitat types, 8 were also found in 4 habitats, while 7 and 5 species were found in 3 and 2 respectively. Moreover, 4 species were only found in one habitat, namely *Lathrecista asiatica* (Anisoptera: Libellulidae) in settlements, *Celebargiolestes orri* (Zygoptera: Chlorocyphidae) and *Prodasineura autumnalis* (Zygoptera: Platycnemididae) in forests, as well as *Macromia melpomene* (Anisoptera: Macromiidae) in waterfalls (*Table 2*).

Figure 5. *Several species of dragonflies sub order Anisoptera in five habitat types in the Sangihe Islands (Libellulidae: Orthetrum pruinosum (1); Diplacina sanguinolenta (2); Neurothemis stigmatizans (3); Nannophya pygmaea (4); Neurothemis ramburii (5); Orthetrum glaucum (6); Orthetrum sabina (7); Diplacodes trivialis (8).*

Species ranking

Among the 32 species of dragonflies found, *Rhinocypha frontalis*, *Libellago davesi*, *Nososticta flavipennis*, and *Orthetrum pruinosum* were ranked 1, 2, 3, and 4 with relative abundances of 19.24%, 16.09%, 12.98%, and 10.89, respectively. The next three species between ranks 5-7 had a relative abundance range of 6.36%-5.83%. The low steepness of the curve indicates a high evenness of species (*Fig. 6*).

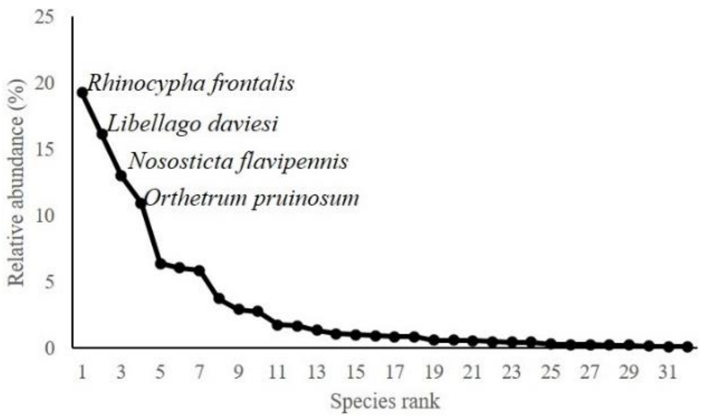

Figure 6. *The rank-abundance curve of dragonflies in all habitats*

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Dragonflies species richness and diversity

The interpolation-extrapolation rarefaction curve for each habitat showed a rapid increase at the beginning of the sampling and then approached the asymptote point (*Fig. 7*). The rarefaction curve interval of dragonflies species in agricultural land and settlements was separated compared to the other three habitats indicating that species richness in agricultural land and settlements is lower. Based on the extrapolated rarefaction curve, it is assumed that the number of dragonflies species found in the five habitats is raised by increasing the number of samples.

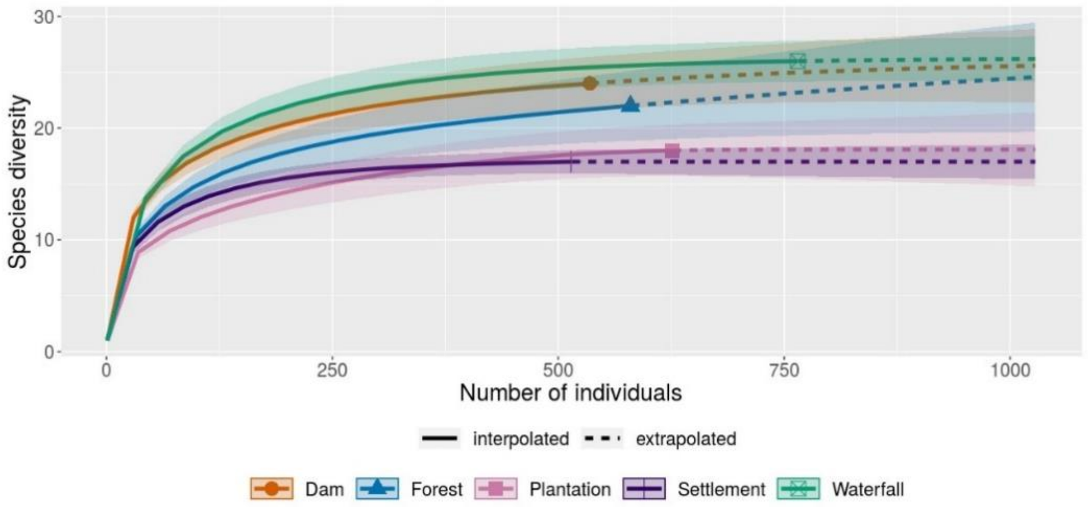

Figure 7. *The individual rarefaction curve of dragonflies for five habitats*

Among the five observed habitats, the highest average abundance and species diversity index were found in waterfalls with abundance = 191.3 individuals; H = 2.12, while the lowest was found in settlements with an abundance of 128.5, as well as individual and a diversity index of 1.60. Furthermore, dams and settlements were the habitats with the highest (2.48) and lowest (1.60) species richness indices, respectively. Meanwhile, the highest and lowest species evenness indices were found in dams (0.64) and forests (0.58), respectively (*Fig. 8a-d*). The statistical analysis showed that the average individual abundance with ANOVA: F4, 19 = 0.478; P = 0.752, Margalef species richness index ANOVA: F4, 19 = 1.743; P = 0.193, Shannon diversity index ANOVA: F4, 19 = 2.732; P = 0.069, and Pielou evenness index with ANOVA: F4, 19 = 0.471; P = 0.756 did not differ between the habitats (*Fig. 8a-d*).

Composition of dragonflies species between habitats

Based on the Analysis of Similarity (ANOSIM) results, the composition of dragonflies in five habitats did not show a significant difference with R = 0.00083; P = 0.4597. This was also observed in the NMDS ordinance results which show that the ordinance points in each habitat were close together and overlap (*Fig. 9*).

Effect of environmental factors

The average temperature showed a small variation between the three habitats with the lowest in forests namely 28.92 °C and the highest in settlements with 31.61 °C.

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The highest and lowest light intensities were found in settlements with 9215.0 Lux and forests 6695.9 Lux. Furthermore, settlements were the habitats with the highest wind speed namely 0.62 m/s, while the lowest was found in forests and waterfalls with 0.00 m/s. The mean relative humidity showed little variation between the five habitats with the lowest in settlements of 72.47% and the highest in waterfalls 84.31% (*Table 3*).

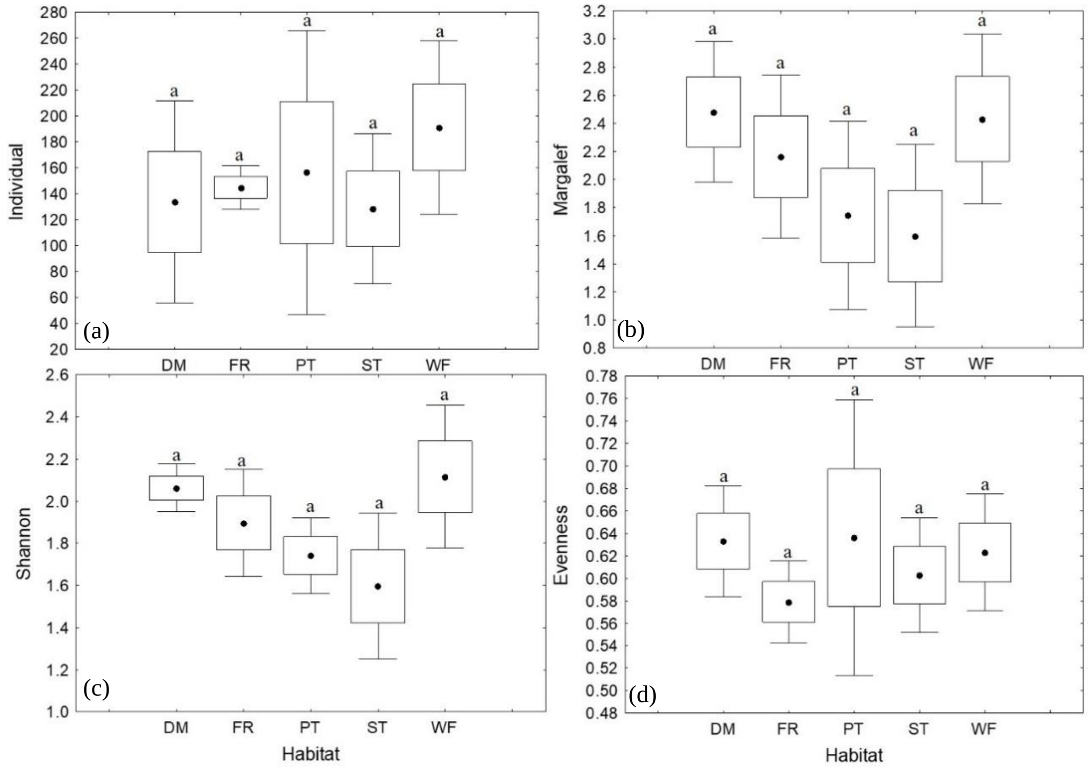

Figure 8. *The community structure of dragonflies in five habitats ((a): abundance, (b) richness, (c) diversity and (d) evenness species indexes; DM: Dam; FR: Forest; PT: Plantation; ST: Settlement; WF: Waterfall; (●): Mean, (□): ± SE, (⌶): ± SD. The same letter in the same picture does not differ significantly according to Tukey's test 95% confidence level*

Table 3. *Environmental factor of five habitats*

Environmental factors	Dam		Forest		Plantation		Settlement		Waterfall	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Temperature (°C)	28.93	0.29	28.92	0.33	31.20	0.27	31.61	0.21	29.09	0.19
Light (Lux)	8784.2	1122.5	6695.9	3306.6	8602.5	1403.8	9215.0	1425.8	6750.3	2125.5
Wind (m/s)	0.48	0.14	0.00	0.00	0.08	0.06	0.62	0.21	0.00	0.00
Humidity (%)	81.42	0.81	82.23	0.36	79.05	1.42	72.47	1.48	84.31	0.90

The PCA ordinances show a clear variation in the spatial pattern of environmental factors from the five observed habitats (*Table 4*). The plot obtained shows two distinct habitat groups, the first consists of adjacent and overlapping forests, waterfalls, and dams, while the second consists of settlements and plantations. The adjacent and

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overlapping ordinances between habitats are influenced by the high similarity of environmental characteristics between habitats. Furthermore, the PCA results showed that waterfalls and forests are characterized by high relative humidity and low air temperature, while settlements have high air temperature with low relative humidity (*Fig. 10*).

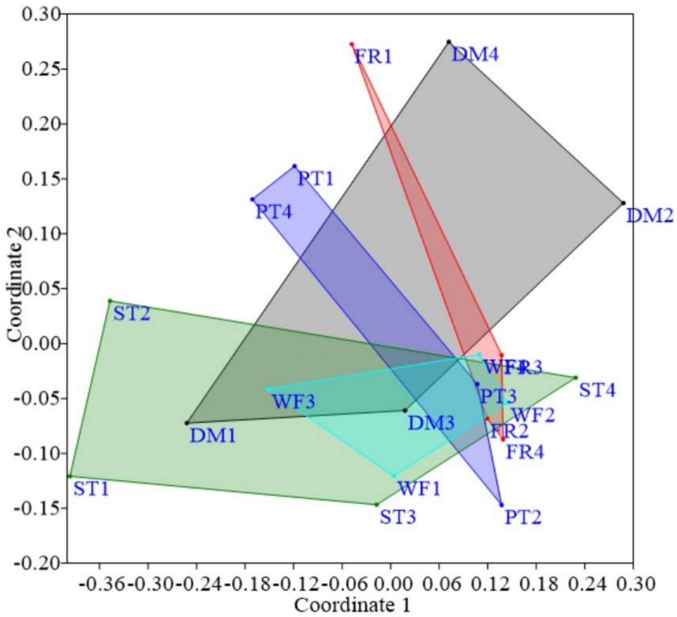

Figure 9. *Non-metric dimensional scaling (NMDS) of dragonflies composition in five habitats (stress value: 0.15); ANOSIM (R = 0.00083; P = 0.4597). (DM: dam; FR: forest; PT: plantation; ST: settlement; WF: waterfall)*

Table 4. *Environmental factor and PCA scores of five habitats*

Habitats	Environmental factors					PCA scores			
	Transect	**Temperature (°C)**	**Light (Lux)**	**Wind (m/s)**	**Humidity (%)**	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Dam	DM1	28.70	11495.00	0.77	83.87	-0.17707	15.334	-12.181	0.3609
Dam	DM2	28.03	7325.33	0.77	79.67	-0.15989	0.63368	-18.433	-0.3776
Dam	DM3	79.67	10891.67	0.00	79.67	-0.17173	0.35597	0.6501	-0.4288
Dam	DM4	29.20	5425.00	0.40	82.47	-0.59201	-0.02225	-0.7923	0.29446
Forest	FR1	27.97	400.33	0.00	83.57	-20.228	-0.89074	-0.8187	-0.2274
Forest	FR2	28.70	3858.33	0.00	81.97	-13.156	-0.5291	-0.2884	-0.2802
Forest	FR3	28.97	3858.33	0.00	81.97	-12.032	-0.58375	-0.1910	-0.1627
Forest	FR4	30.03	19466.67	0.00	81.43	0.20544	1.96	14.635	-0.3989
Plantation	PT1	32.23	3390.67	0.00	73.77	11.737	-18.907	0.8644	0.07843
Plantation	PT2	30.80	11233.33	0.00	79.77	0.26396	0.21555	10.507	0.02026
Plantation	PT3	31.00	10893.00	0.00	82.17	0.02128	0.279	11.191	0.47066
Plantation	PT4	30.77	8893.00	0.33	80.50	0.42707	0.09444	0.1811	0.49217
Settlement	ST1	32.00	12391.67	1.07	68.37	35.936	0.18105	-0.723	-0.23902
Settlement	ST2	31.87	12391.67	1.07	72.00	30.762	0.45673	-0.7334	0.23364
Settlement	ST3	30.80	6420.67	0.00	77.60	0.26392	-0.79545	0.63505	-0.1053
Settlement	ST4	31.77	5656.00	0.33	71.90	17.548	-12.785	0.19067	-0.1983
Waterfall	WF1	29.33	3582.67	0.00	83.07	-12.096	-0.63042	-0.0726	0.16511
Waterfall	WF2	29.67	2863.33	0.00	81.67	-0.93076	-0.92424	-0.0229	0.13742
Waterfall	WF3	28.80	14768.00	0.00	86.37	-12.076	17.068	0.6847	-0.0270
Waterfall	WF4	28.57	5787.33	0.00	86.13	-17.897	0.12848	0.13568	0.19324

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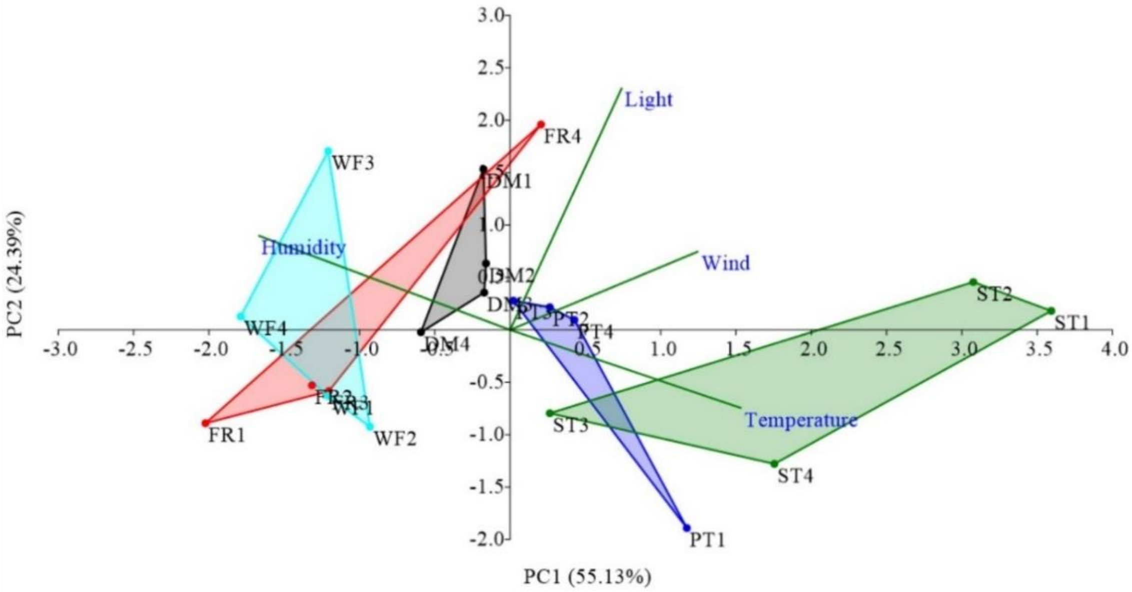

Figure 10. *PCA ordinations of five habitats. (DM: dam; FR: forest; PT: plantation; ST: settlement; WF: waterfall)*

Discussion

Dragonflies species found in the Sangihe Islands was only 0.54% of the 5,900 species in the world (Van Tol, 2000; Potapov et al., 2020), 3.56% of the 900 in Indonesia, and 21.92% of the 146 in Sulawesi (Lupiyaningdyah, 2020). The number of species found is smaller than that of the mainlands with a total of 146, this difference is due to the variation in the area of the islands. The Sangihe Islands have a land area of about 736.98 km^2 (Mokodompis, 2020), while the mainland of Sulawesi is approximately 174,600 km^2 (Decentralization Support Facility, 2011).

The number of species on an island reportedly depends on the total area. Previous studies showed that the island area has a positive correlation with the number and diversity of species. It directly affects the species diversity in two ways, first, large islands allow the species to spread widely, second, it supports more flora and fauna as the habitats and ecosystems are more diverse than small islands (Farizawati et al., 2014).

The sub-order Anisoptera has more species than Zygoptera due to its wide distribution and adaptability to various types of habitats. Meanwhile, Zygoptera are very sensitive to environmental conditions, have limited ability to spread, and prefer to live in vegetated and slightly shaded habitats (Pujiastuti et al., 2017). Several studies reported that Anisoptera are more common than Zygoptera (Dolný et al., 2011; Kaize and Kalkman, 2011; Narender et al., 2016; Seidu et al., 2017; Nilamsari et al., 2021).

Zygoptera are dragonflies with the highest abundance in waterfall and forest as these habitats have vegetation and shade with undisturbed environmental conditions. In tropical rain forests, they have limited distribution and competition outside the preferred habitats and are highly sensitive to changes in riparian vegetation. According to (Rahadi et al., 2013), Zygoptera are found around clean and flowing river waters with moderate intensity of sunlight or under tree shades. Moreover, (Narender et al., 2016) stated that the canopy cover and water vegetation in rivers were favored by Zygoptera compared to Anisoptera.

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Libellulidae has the highest number of species compared to other dragonflies families. This is because it is the largest family in the sub-order Anisoptera with a distribution pattern and high adaptability. This family is one of the common dragonflies and is often found in stagnant and flowing as well as fresh or slightly brackish water. Previous studies stated that Libellulidae are more common than other dragonflies families (Das et al., 2012; Narender et al., 2016; Acharjee and Karzee, 2016; Siregar and Bakti, 2016).

The most common habitat for Libellulidae is settlements characterized by little vegetation and less tree canopy cover. (Kalkman and Orr, 2013) reported that Libellulidae were found in almost all habitat types and were dominant in stagnant as well as flowing water. This family has the greatest migratory ability, including a distribution that spans more than one area and is also found on isolated islands (Van Tol, 2008). Another factor that causes this family to have the highest number of species is due to a shorter life cycle and tolerance to various habitats (Arulprakash and Gunathilagaraj, 2010). Libellulidae prey on all types of aquatic organisms as well as pests found in food crops and plantations, hence, they are used as biological control agents. Additionally, Rohman and Faradisa (2020) reported that Libellulidae are aggressive predators that feed on almost all insects.

Rhinocypha frontalis (Chlorocyphidae) and *Orthetrum pruinosum* (Libellulidae) are the dominant dragonflies found from the Suborders Zygoptera, and Anisoptera, respectively. *R. frontalis* was found mostly in waterfalls, forests, and agricultural land, while the lowest abundance was in settlements. During the observation, many of these species were found perched on the leaves and twigs of trees on the riverbank and rocks in the river. According to (Rahadi et al., 2013) *R. frontalis* is generally found in clean waters with moderate intensity of sunlight. This type perches on branches under the tree canopy and are commonly found in various clean springs (Pamungkas and Ridwan, 2015).

O. pruinosum species were dominantly found in settlements and rarely found in forest habitats. These species are generally found flying around rivers and occasionally perching on plants found in settlements. In sunny weather, these dragonflies fly low around the water, before finally landing on aquatic plants to reduce the body temperature. The adult dragonflies of *O. pruinosum* are flying insects, hence, they move from one place to another. Corbet (1999), stated that several species from the sub-order *Anisoptera* are flying insects which migrate long distances thereby affecting the distribution. These dragonflies travel at a maximum speed of 36 km/h (Amir and Kahano, 2003).

Based on the results, the abundance, as well as richness, diversity, and evenness indices were not significantly different between the habitats. This is caused by the microhabitats were not segregated from the surrounding habitats. This could be the reason for the detected similarities. However, waterfalls, dams, and forests tend to have higher species richness and diversity indices compared to other habitats. The three habitats have the same type of vegetation characteristics and do not receive significant human disturbance. Waterfalls and forest habitats have varied types such as rocky rapids and complex vegetation structures. Meanwhile, the habitat type is a factor that supports the diversity of dragonflies species. Herlambang et al. (2016) stated that the main factors that cause diversity differences in a habitat include food resources, habitat type, light intensity, temperature, humidity, and vegetation structure. Habitat variation also leads to the availability of various food types for dragonflies prey, hence, species

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diversity becomes high. Moreover, Hendriks (2020) stated that habitat is directly proportional to the physical condition of the environment, meaning that each type of habitat has its physical condition, which is also influenced by several factors such as vegetation density, canopy cover, and altitude. Therefore, these limits affect the presence and distribution of dragonflies species.

The vegetation in a habitat influences the diversity of dragonflies, forests with very dense vegetation as well as no disturbance and conversion of functions tend to have a high diversity (Dolný et al., 2011). Several previous studies reported that an increase in vegetation cover and plant biodiversity elevates the species richness and diversity. The presence of vegetation around rivers greatly influences the behavior of adult dragonflies such as sunbathing, foraging, roosting, and sheltering (Buchwald, 1992; da Silva Monteiro Júnior et al., 2013; Kolozsvári et al., 2015; Hendriks, 2020).

Based on the environmental factors measured, forest habitats, waterfalls, and dams form one group, indicating that there were high similarities between these habitats. Meanwhile, agricultural land and settlements form another group. Furthermore, the PCA results showed that waterfalls, dams, and forests are characterized by high relative humidity and low air temperature, while settlements habitats are characterized by high air temperatures and low relative humidity. The low temperature and high humidity in the forest and waterfalls due to the slightly denser canopy conditions and the presence of many trees on the riverbanks caused the inhibition of the air temperature rate and the intensity of sunlight. Differences in environmental factors between habitats affect the diversity of dragonflies species. Feriwibisono et al. (2016), reported that the diversity in a habitat is strongly influenced by environmental quality factors, such as pH, temperature, humidity, chemical conditions, and food availability.

Humidity and temperature affect plants and animals, especially small insects which are the main food of dragonflies. Also, temperature determines the various activities in finding a place to rest, as well as flight and breeding time. Furthermore, light intensity is an abiotic factor that affects several activities including sunbathing and foraging for food. At the optimal level, dragonflies bask and forage for food, but when it is extremely low or high, they spend more time resting in the habitat (Susanto dan Zulaikha, 2021).

Celebargiolestes orri (Zygoptera: Chlorocyphidae) and *Prodasineura autumnalis* (Zygoptera: Platycnemididae) are dragonflies species used as bioindicators of environmental health. Both species are only found in forest habitats where the water environment is not polluted. Female adult dragonflies in oviposition choose clear and clean water habitats, as the nymphs are sensitive to polluted water quality (John, 2001; Villalobos-Jimenez et al., 2016). In general, the water condition at the study site namely Sangihe Islands is categorized as clean and unpolluted. This is due to the presence of three families namely Chlorocyphidae, Calopterygidae, and Platycnemididae in each of the studied habitats. According to Hasanah et al. (2021) the presence of dragonflies from these families describes the condition of clean waters.

Conclusions

This study describes the diversity of dragonflies species in different habitats of the Sangihe Islands. Based on the results, there are 6 families which include 32 species and 3020 individuals. The diversity in the five habitat types showed no significant differences, but the richness and species diversity indices tend to be higher in the forest,

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dam, and waterfall habitats. Based on the environmental factors, forests and waterfalls have the same characteristics. Furthermore, the presence of the families *Chlorocyphidae, Calopterygidae,* and *Platycnemididae* in each studied habitat indicate that the water quality is generally good and supports the life of dragonflies. Therefore, the local government is recommended to preserve the river and not changing the forest function into agricultural land and housing to support dragonfly conservation as most part of the life cycle is highly dependent on water quality. Recommendations for further research are the identification of dragonflies in the Sangihe Islands through molecular phylogenetic analysis. The results of this follow-up study are expected to produce molecular-based basic data on dragonfly diversity and storage of dragonfly molecular data on GenBank and BOLD.

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