Odonata diversity in the Laine Waterfall Area, Sangihe Islands, North Sulawesi, Indonesia

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Abstract. In the ecosystem, Odonata functions as a biological control agent and an indicator of the freshwater environment. Therefore, this research aims to analyze Odonata diversity in the Laine Waterfall Area, Sangihe Islands, North Sulawesi, Indonesia. The sampling was carried out in 3 types of aquatic habitats, namely waterfalls, secondary forests, and agricultural land. In each habitat, 3 line transects with a length of 100 m were constructed around the river flow and the sampling was conducted along the transect using a sweep net. The results obtained a total of 5 families, which consists of 25 species and 928 individuals of dragonflies. Among the families, Libellulide was dominant, while the species with the highest abundance was *Nososticta flavipennis*. Furthermore, the highest abundance, richness, and species diversity index were discovered in waterfall habitats. This showed that the research location is suitable for dragonfly activity due to several factors, namely temperature, humidity, and light intensity, which were normal for the species' activity.

Key Words: dragonflies, freshwater, indicators, Libellulidae, waterfall.

Introduction. Laine Waterfall is an ecotourism spot located in South Mangangitu Sub-district, Sangihe Islands Regency, North Sulawesi, Indonesia. In this area, there are rivers and various types of ecosystems such as secondary forests, plantations, and community settlements, with many flora and fauna living in the ecosystems, including dragonflies of the Odonata order. Previous research showed that there are 6000 species of dragonflies in the world, 630 genera, and 28 families (Kannagi et al 2016; Varshini & Kanagappan 2016). The dragonflies are grouped into two sub-orders, namely *Zygoptera* with 2739 species and 19 families, and *Anisoptera* with 2941 species and 12 families, where approximately 1000 to 1500 species have not been described (Mapi-ot et al 2013).

Odonata (dragonflies and damselflies) is an order with some of the earliest winged insects that evolved in the Permian period and spread throughout the world except in Antarctica (Tuhin & Khan 2018). Meanwhile, both freshwater insects and female dragonflies lay eggs in water or submerged plants and larval development occurs in the water. Since adult insects live in the air, the success of foraging and reproduction is highly dependent on the availability of freshwater resources (Harisha 2016). Dragonflies are familiar to freshwater areas because they spend most time as nymphs that are very dependent on freshwater habitats (Susanti 1998).

Adult dragonflies play an important role in the ecosystem. They can be used as biological control agents to suppress the growth of insect pests on food crops (Ávila Júnior et al 2020). At all stages in their life cycle, dragonflies are predators that consume a variety of insects and other organisms. The nymphs also function as predators in aquatic ecosystems. They also serve as a good indicator of the quality of an aquatic environment due to the ecophysiological adaptations that enable them to inhabit different aquatic ecosystems (Dolny et al 2011; Das et al 2012; Daso et al 2021).

In the waterfall area, the condition of the aquatic ecosystems affects the diversity and survival of dragonflies. Previous research on the diversity of dragonflies such as their inventory in the Curug Panjang waterfall area and their relationship to the surrounding habitat conditions have been carried out (Noviyana et al 2021). Furthermore, there is research on dragonfly communities in stagnant and flowing water in the Cibodas Botanical Gardens area by Febrianti et al (2021), community structure and diversity of dragonfly and damselfly (Odonata) in the Selorejo waterfall area by Susanto & Zulaikha (2021), and the diversity of dragonflies (odonatan) in Menoreh Karst, Kedung Pedut Waterfall (Rachman & Rohman 2016).

Meanwhile, research on dragonfly diversity in the Laine waterfall area, North Sulawesi has not been carried out. The area is one of the hot spots for biodiversity that can be developed for ecotourism in the Sangihe Islands. The area is also prone to environmental degradation due to the conversion of the waterfall surroundings, which are supposed to be a buffer zone into agricultural land. North Sulawesi has a fairly high rate of forest destruction, which has risen by 67% on wet forest habitat over the last two decades for timber and agricultural purposes (Lee et al 2001). This forest damage affects the flora and fauna of forest ecosystems. Therefore, this research aims to analyze the diversity of Odonata in the Laine Waterfall Area, Sangihe Islands, North Sulawesi, Indonesia.

Material and Method

Research area and land-use types. This research was conducted from May to August 2021 in the Laine Waterfall Area, Sangihe Islands, North Sulawesi Province, Indonesia (Figure 1). Sampling was carried out along the river in 3 types of habitats, namely waterfalls, secondary forest, and agricultural land.

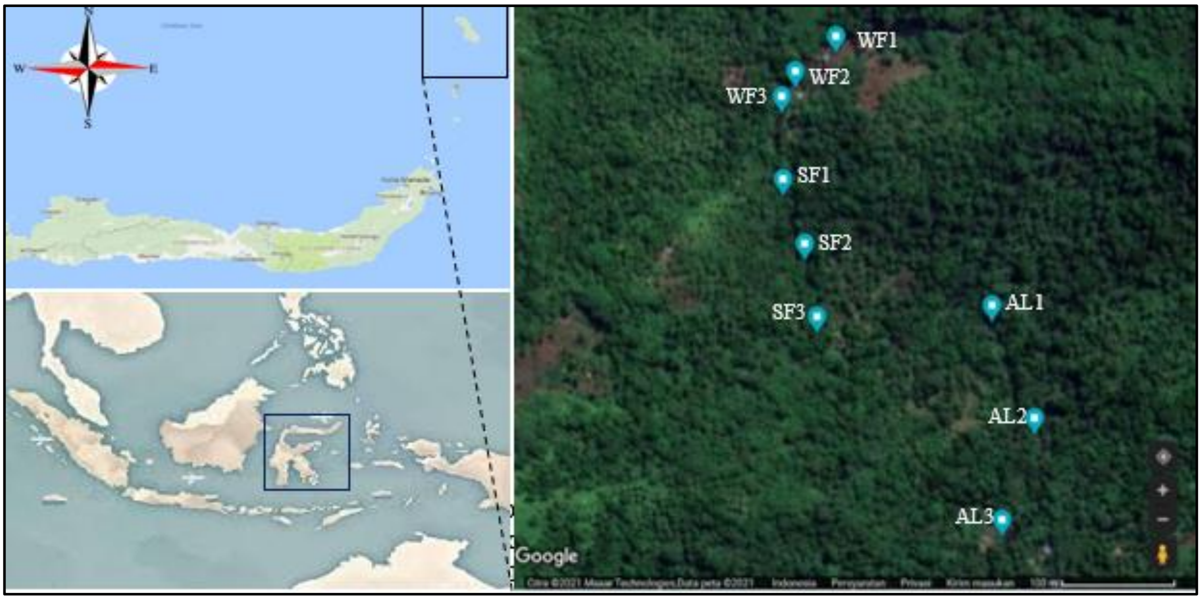

Figure 1. Map of the study area in Sangihe Islands, North Sulawesi; WF - waterfall; SF - secondary forest; Al - agriculture land.

Waterfall. The waterfall habitat presented vegetation such as *Ficus* sp. (Moraceae), *Litsea* (Lauraceae), ferns (Pteridophyta), shrubs (Asteraceae), grasses (Poaceae), and teki (Cyperaceae). The width of the river was approximately 12 m. The temperature was between 29.83-30°C, humidity between 82-83%, the percentage of canopy cover was 65-70%, and the altitude was 83-89 m asl. The coordinates were 03°26'40.89"S and 125°35'56.63"E (transect 1), 03°26'39.9"S and 125°35'55.50"E (transect 2), 03°26'39.20" and 3°26'39.20"E (transect 3) (Figure 1).

Secondary forest. The secondary forest was overgrown by various types of trees such as *Ficus* sp. (Moraceae), *Alstonia macrophylla* (Rubiaceae), *Litsea* (Lauraceae), *Garcinia* sp. (Fagaceae), and bamboo (*Bambusa* sp.). In this habitat, there were streams with river widths ranging between 6-7 m. The environmental conditions include a temperature of 28.8-29.7°C, humidity between 82.1-83%, the percentage of canopy cover was 70- 80%, and the altitude was 72-76 m asl. The secondary forest was located at 03°26'36.93"S and 125°35'55.13"E (transect 1), 03°26'35.20"S and 125°35'55.70"E (transect 2), 03°26'33.12" and 125°35'56.17"E (transect 3) (Figure 1).

Agricultural land. The agricultural land is managed by farmers intensively by cultivating various plants. The dominant plants are coconut (*Cocos nucifera*), banana (*Musa* sp.), clove (*Eugenia aromatica*), bamboo (*Bambusa* sp.), and nutmeg (*Myristica fragrans*), with a river width between 6-7 m. The agricultural land had temperatures ranging from 30.7-32.1°C, humidity between 78-80.5%, the percentage of canopy cover was between 60-70%, and the altitude was between 66-70 m asl. The land was located at the coordinates 03°26'33.44"S and 125°36'01.10"E (transect 1), 03°26'30.31"S and 125°36'02.34" (transect 2), 03°26' 27.50" and 125°36'01.40'"E (transect 3) (Figure 1).

Sampling. This research used the purposive random sampling method, where 3 transects were made with a length of 100 m along the river bodies in each habitat. The width of the transect was 2 m: 1 m on the edge and 1 m on the water body from the edge (Sugiman et al 2020).

The dragonflies were observed in sunny weather from 08.00 am to 04.00 pm and most of them were active during the period (Renner et al 2015; Khan 2018). Meanwhile, the sampling was carried out along the transect line using an attack net (40 cm Ø, 65 cm depth, with an aluminum handle of 90 cm (Mapi-ot et al 2013). The observation was carried out directly or using binoculars and a camera. The samples were identified using a field guide in one hour at a walking speed of 1.8 m min^{-1} to avoid double counting. Dragonflies that were not directly identified were caught using insect nets, put into euthanasia container with tissue paper, and filled with ether for euthanasia and preservation until further identification. After death, the sample was immediately removed from the euthanasia container, dried in the sun, and stored in triangular paper envelopes measuring 30x20 cm with the wings folded over the body (Koneri et al 2020).

The process of identifying adult dragonflies was carried out based on external morphological characteristics and the samples were identified using dragonfly identification books (Watson & O'Farrell 1991; Miller 1995; Wilson 1995; Orr & Hämäläinen 2003; Kalkman & Orr 2013; Orr & Kalkman 2015). During sampling, the environmental parameters observed included air temperature, humidity, wind speed and light intensity. A thermohygrometer was used to measure air temperature and humidity, the wind speed was measured using an anemometer, and light intensity was measured using a lux meter. Similarly, the coordinates and elevation of the research location were recorded using the Global Positional System (GPS).

Statistical analysis. In this research, the data analysis discussed included species abundance (n), taxa (S), species diversity index (H), and species evenness index (E). The species abundance is the number of individuals from species in each habitat, while taxa are the number of species in each habitat. Furthermore, the dragonfly species diversity in the three habitat types was determined using the Shannon index (H) and Pielou evenness index (J) (Magurran 1988). All indices were calculated with the PAST 2.17 program (Hammer et al 2001). The differences in species abundance, number of species, species diversity index, and species evenness index among habitat types were analyzed using Statistica version 6 program, one-way ANOVA, and Duncan's test at 95% confidence level (Stat Soft 2001; Ohsawa 2005).

The dragonfly communities' similarities among habitat types were also analyzed using analysis of similarity (ANOSIM), where the abundance of dragonfly species was used as the data (Magurran 1988). Based on the abundance data, an analysis (cluster analysis) was made and visualized using non-metric dimensional scaling (NMDS), and group analysis of each habitat was arranged hierarchically in form of a dendrogram. Furthermore, ANOSIM and NMDS were analyzed based on the Bray-Curtis dendrogram inequality index. The relationship between the sampling habitat types and the environmental factors was measured by principal component analysis (PCA), while ANOSIM, NMDS, and PCA were analyzed using Paleontological Statistics (PAST software 3.10) (Cuartas-Hernández & Gómez-Murillo 2015; Wakhid et al 2021).

Results

Odonata community structure. The results obtained a total of 2 suborders from Odonata, namely Anisoptera and Zygoptera, with 5 dragonfly families, which consist of 25 species and 928 individuals. The sub-order Anisoptera consisted of one family, namely Libellulidae, while Zygoptera consisted of 4 families, namely Chlorocyphidae, Coenagrionidae, Platycnemididae, and Platystictidae. The highest abundance of the sub-order was discovered in Zygoptera, with a total of 662 individuals (71.3%), while Anisoptera had only 266 individuals (28.7%) (Table 1).

Table 1

Number of sub ordo, family, species and individuals Odonata

Suborder/family/species	*Habitat types /number of individuals*			Σ	%
	Agricultural land	*Secondary forest*	*Waterfall*		
Anisoptera					
Libellulidae					
Diplacina militaris	1	0	1	2	0.22
Diplacina sanguinolenta	4	15	11	30	3.23
Diplacodes trivialis	0	2	8	10	1.08
Orthetrum glaucum	0	0	4	4	0.43
Orthetrum pruinosum	85	14	21	120	12.93
Orthetrum sabina	0	1	0	1	0.11
Pantala flavescens	5	0	0	5	0.54
Nannophya pygmaea	0	0	17	17	1.83
Neurothemis manadensi	0	1	11	12	1.29
Neurothemis ramburii	10	3	12	25	2.69
Neurothemis stigmatizans	0	0	13	13	1.40
Neurothemis terminata	0	2	16	18	1.94
Tetrathemis leptoptera	0	3	2	5	0.54
Tetrathemis platyptera	1	3	0	4	0.43
Zygoptera					0.00
Chlorocyphidae					0.00
Libellago daviesi	20	66	31	117	12.61
Rhinocypha frontalis	52	89	76	217	23.38
Coenagrionidae					0.00
Agriocnemis femina	0	0	4	4	0.43
Pseudagrion pilidorsum	9	10	28	47	5.06
Pseudagrion ustum	0	1	0	1	0.11
Platycnemididae					0.00
Nososticta emphyla	0	16	0	16	1.72
Nososticta flavipennis	64	68	87	219	23.60
Teinobasis laidlawi	0	0	6	6	0.65
Teinobasis rufithorax	0	0	1	1	0.11
Teinobasis sp	12	9	11	32	3.45
Platystictidae					0.00
Protosticta simplicinervis	0	0	2	2	0.22
Grand total	263	303	362	928	100

Libellulidae family had the highest number of species, 14 (51.9%), followed by Platycnemididae with 5 species (22.2%). The family with the least number of species is Platystictidae, with only one species (3.7%) (Figure 2a). The highest abundance of dragonfly families was discovered in Chlorocyphidae, with 334 individuals (36.7%), followed by Platycnemididae, with 274 individuals (28.8%) (Figure 2b). The dragonfly species that had the highest abundance was *Nososticta flavipennis* with 219 individuals (23.60%), while *Rhinocypha frontalis* had 217 individuals (23.38%). The *Orthetrum sabina, Pseudagrion ustum, and Teinobasis rufithorax* were species with a small number of individuals, namely one individual each (0.11%) (Table 1).

The distribution of species in each habitat is different, there are species discovered in all, two, or only one type of habitat. A total of 8 species of dragonflies were discovered in all types of habitats. Furthermore, *Tetrathemis platyptera* and *Diplacina militaris* were discovered in the agricultural land and waterfall habitats, respectively, while 4 species were also discovered in the secondary forest and waterfall. During this research, some species were only found in one habitat and were missing from other habitats. A total of 7 species of dragonflies were found only in the waterfall, while the secondary forest had 3 species and only one species was discovered in agricultural land, namely *Pantala flavescens* (Table 1).

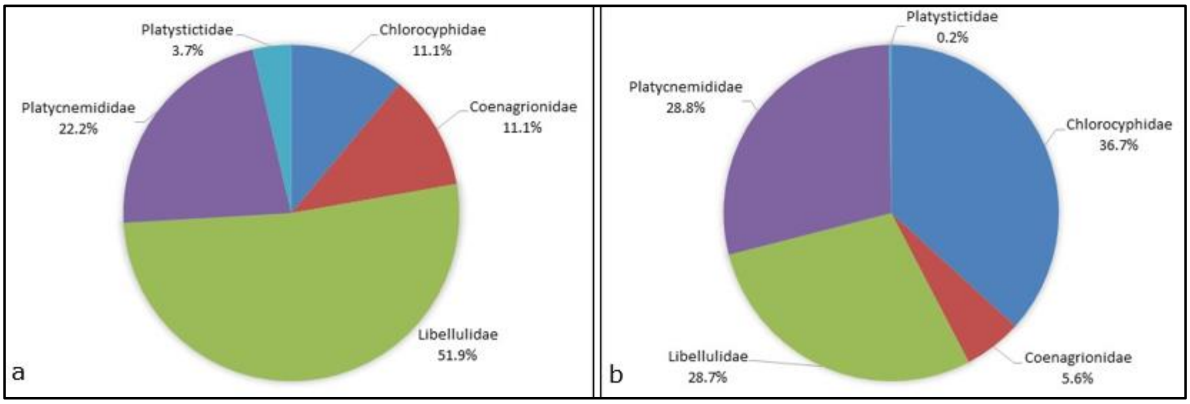

Figure 2. Composition of dragonfly families according to species (a) and abundance (b).

Diversity of dragonfly species. The highest average abundance of dragonflies was observed in the waterfall habitat (120.67 ind), followed by the forest with 101 individuals and agricultural land with 87.67 individuals (Figure 3a). The highest species richness and diversity index value of dragonflies were also discovered in the waterfall habitat, with 10.67 species and H=1.94, while the lowest was observed in the agricultural land, with 6 species and H=1.5 (Figure 3b-c). The species evenness index value of 0.75 in the agricultural land habitat was higher than the 0.68 value in the waterfall area and 0.58 in the secondary forest (Figure 3d).

The analysis of the results showed that the average species richness of dragonflies was different between the three habitats ($p<0.05$). In the agricultural land, species richness was not significantly different from the secondary forest, however, agricultural land was different from the waterfall. The mean individual abundance (ANOVA: F2.8=0.641, p=0.559), Shannon diversity index (ANOVA: F2.8=3.781, p=0.087), and Pielou evenness index (ANOVA: F2.8=1.140, p=0.38) was not different among the three habitats (Figure 3).

The similarity of dragonfly communities among habitats. The analysis of the similarity of dragonfly communities between habitats showed that the highest similarity index occurred in secondary forests with waterfalls (69%), while the lowest was in agricultural land with waterfalls (61%). The dendrogram results from the Bray-Curtis similarity matrix showed that the secondary forest habitat had one group in common with the waterfall, while the agricultural land was separated (Figure 4a). Furthermore, analysis of similarity (ANOSIM) showed that there was no significant difference in the composition of dragonflies in the three habitats, where R=-1.777 and p=0.819. The insignificant difference in dragonfly composition among the three habitats also occurred in NMDS ordinance, which showed that the ordinance points in each habitat were closely related (Figure 4b).

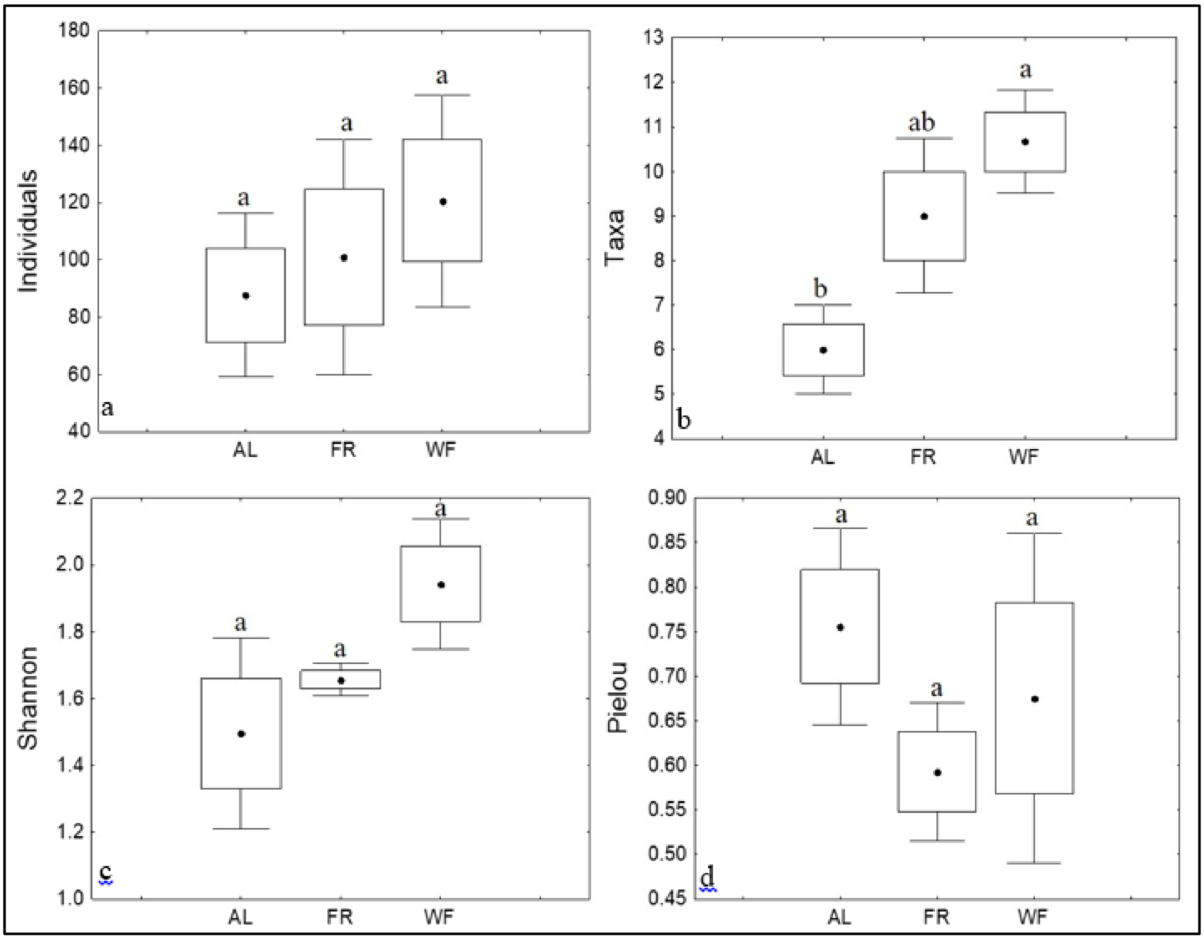

Figure 3. The community structure of dragonflies in three habitats; AL - agricultural land; FR - secondary forest; WF - waterfall); a - abundance; b - taxa; c - diversity; d - evenness species indexes; • - mean, □ - ±SE; 工 - ± SD. The same letter in the same picture shows no significant differences.

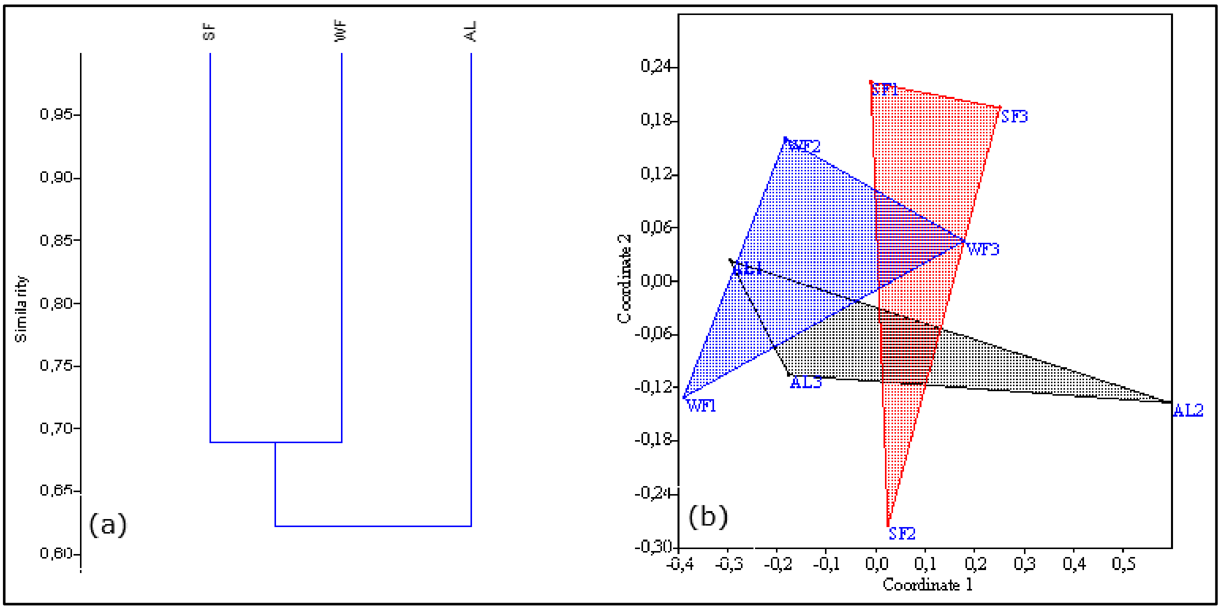

Figure 4. Dendrogram cluster analysis (a) and non-metric dimensional scaling (NMDS) (b) of dragonflies composition in three habitats (stress value: 0.1262); AL - agricultural land; FR - secondary forest; WF - waterfall.

Influence of environmental factors. The ambient temperature measured during the sampling varied within habitats. The average temperature showed a small variation, where the highest temperature (31.85±0.26°C) occurred in agricultural land and the lowest was in the waterfall (29.54±0.17°C). Furthermore, the highest light intensity was in the agricultural land with 13218.67±627.58 lux and the lowest was in the secondary forest with a value of 6695.92±7103.92 lux. The average relative humidity showed little variation between the three habitats, with the lowest being in agricultural land (78.11±1.3%), while the highest was in the waterfall (81.67±0.67%). During the research, the wind speed was very low, specifically in secondary forests and waterfall with zero wind speed. Therefore, the habitat with some wind speed was the agricultural land, with a value of 0.06±0.06 m s^{-1} (Table 2).

Table 2

Environmental factors of the three habitats

	Agricultural land		*Secondary forest*		*Waterfall*	
Environmental factor	*mean*	*SE*	*mean*	*SE*	*mean*	*SE*
Temperature (°C)	31.85	0.26	29.62	0.50	29.54	0.17
Light intensity (lux)	13218.67	627.58	7103.92	1424.14	12325.00	843.36
Humidity (%)	78.11	1.30	81.49	0.49	81.67	0.67
Wind velocity (m s^{-1})	0.06	0.06	0.00	0.00	0.00	0.00

PCA ordinances showed a clear variation in the spatial pattern of environmental factors from the three observed habitats. The ordinance plot also indicated that there are two separate habitat groups, where the first one consists of secondary forest and waterfall habitats, which are adjacent and overlapping, while agricultural land is separate. Furthermore, the adjacent and overlapping ordinances between habitats are influenced by the high similarity of environmental characteristics. PCA results showed that the secondary forest and waterfall habitats are characterized by low air temperature and light intensity, together with high relative humidity. Meanwhile, the agricultural forest habitat is characterized by high light intensity, temperature and wind speed, and low humidity (Figure 5).

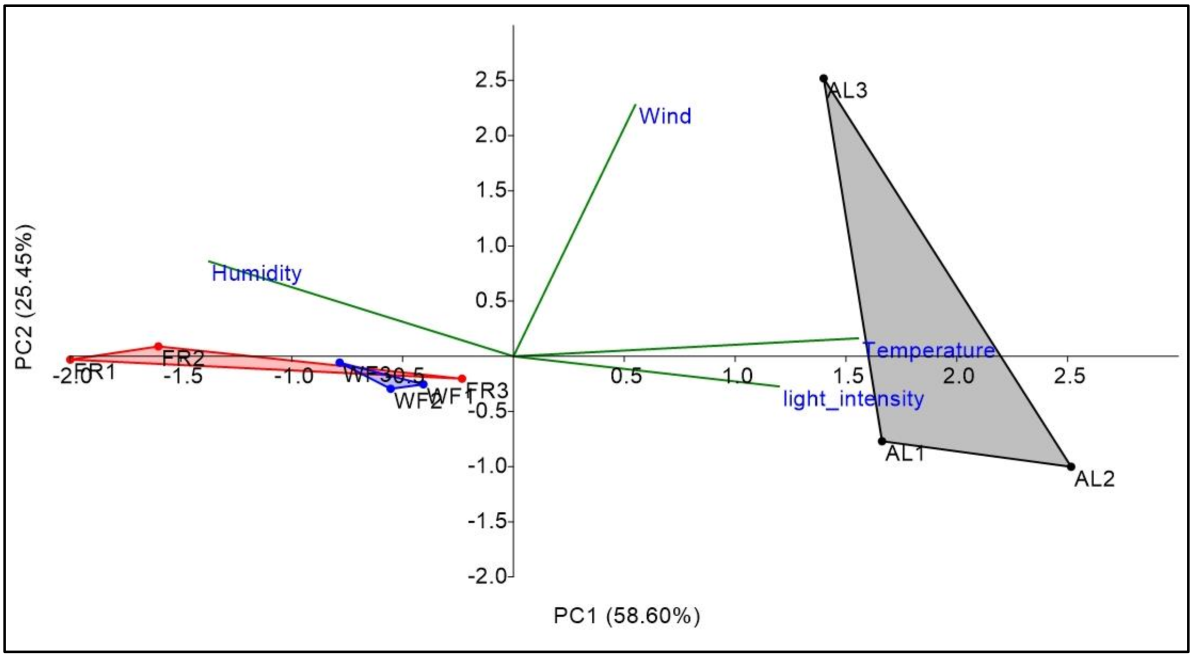

Figure 5. PCA ordinations of three habitats; AL - agricultural land; FR - secondary forest; WF - waterfall.

Discussion. A total of 25 species were obtained during the research. Meanwhile, compared to the results obtained on Sulawesi and other islands in Indonesia, the value was higher than in some other studies. 15 species were previously reported by Koneri et al (2017), 19 species by Nangoy & Koneri (2017), 20 species by Koneri et al (2020), 23 species by Rohman et al (2020), and 12 species by Noviyana et al (2021). Several previous research results discovered more species as reported by Suriana et al (2014) with 28 species, Kaize & Kalkman (2011) found 43, and Leksono et al (2017) reported 30 species of dragonflies. The difference in the number of dragonfly species caught at each research location depends on the area of observation, habitat type, length of time for sampling, and the sampling technique. According to Dolny et al (2011) and Siregar & Bakti (2016), the distribution and composition of dragonfly species varied between research locations due to habitat suitability, heterogeneous vegetation, weather conditions during sampling, and biotic, physical, and chemical factors.

The abundance of the sub-order Zygoptera is higher than that of Anisoptera because the research location was on a river with flowing water. Generally, the sub-order Zygoptera is smaller in size, has a finer structure and has a slimmer abdomen than the common dragonfly (Anisoptera). Meanwhile, both the adults and nymphs are predators that consume small invertebrates, fish, and tadpoles. According to Orr & Kalkman (2015), Zygoptera is generally near aquatic habitats and adapt to flowing water, while Rahadi et al (2013) stated that it can be found around clean and flowing river waters with moderate intensity of sunlight or under shade. This is also supported by the higher percentage of canopy vegetation cover in secondary forests, waterfalls, and lower temperatures than in agricultural land. Previous research by Narender et al (2016) showed that the percentage of shade from trees and aquatic vegetation in rivers is more favored by Zygoptera than Anisoptera.

Moreover, Libellulidae is a family of dragonflies with many species and belongs to the largest group of Anisoptera. It is also one of the common dragonflies often present in stagnant waters, all types of fresh, or slightly brackish water. Although most genera prefer flowing or stagnant waters, most species in stagnant waters are occasionally present in flowing waters. Several previous research reports Libellulidae as a dominant family (Mapi-ot et al 2013; Dayakrishna & Arya 2015; Siregar & Bakti 2016; Seidu et al 2017; Tuhin & Khan 2018; Rohman et al 2020; Yen & Dawood 2021; Noviyana et al 2021).

Akbar & Basukriadi (2021) showed that Libellulidae is the largest group of dragonflies with more than 1000 species and approximately 140 genera. They are mostly heliothermic, therefore, depend on direct sunlight for thermoregulation and flight behavior. The heliothermic species are directly affected by the loss of forest cover and interspecific competition, where they excel in degraded habitats. According to Ilhamdi et al (2020), Libellulidae acts as a predator and consumes all species of aquatic organisms, pests in plantations, and all insects according to their size such as Anopheles mosquito larvae.

The highest family abundance is in Chlorocyphidae of the sub-order *Zygoptera*, with the morphology of a small and fat body, an abdomen that is shorter than the wings, and an upturned snout head. This family is observed when perched on tree branches and rocks in the river. In this research, the Chlorocyphidae family consists of two species, namely *Libellago daviesi* and *R. frontalis*. According to Rahadi et al (2013), Chlorocyphidae has a shorter abdomen length than its wings together with a large and prominent head that seems like a snout, while Setiyono et al (2017) stated that Chlorocyphidae has shiny wings.

The two dominant species, namely *N. flavipennis* (Platycnemididae) and *R. frontalis* (Chlorocyphidae) that were discovered belong to the sub-order Zygoptera and are in many secondary forest habitats and waterfalls. They are dominant because they are supported by the habitat environmental conditions in the presence of plants and rocks in the river. These species usually hide in the grass and small plants near waters for avoiding predators. Furthermore, they actively fly in the morning and during the day with the ability to fly slowly. According to Hartika et al (2017), dragonflies use the vegetation around the waters to search for food and shelter from predators.

N. flavipennis flies low and often perches on leaves as well as twigs of plants and rocks around rivers. This species is common in Eastern Indonesia, Papua New Guinea, the Solomon Islands, and Australia. Moreover, its main habitat is river flow in forests and some inhabit lakes and ponds. Thile the body size is between 16.5-21 mm, with slight variations in size. The female dragonflies are usually black with yellow, green, or blue markings and males usually have a transparent yellow coloration on the wings (Kalkman & Orr 2013).

R. frontalis is a fairly variable species, specifically in body size and in the size of the blue spots at the front. It is usually found in the northern part of Sulawesi Island. This dragonfly is a lowland species that prefers streams in forested habitats, shady rivers within plantations, or steep gorges. The males stay near the water most of the day, while the female appears in the river only on sunny days. Furthermore, the female dragonflies usually lay their eggs on dead wood, rotting wood, or other plant substrates in water (van Tol & Günther 2018).

The diversity of dragonfly species in a habitat is strongly influenced by biotic and abiotic factors. In this research, the highest abundance, richness, and diversity index values of dragonflies occurred in waterfall and secondary forest habitats, while the lowest were observed in agricultural land. The habitat conditions at the waterfall supported the presence of dragonflies, as shown by the diversity of vegetation, trees, shrubs, aquatic plants. Some research reported that Odonata numbers increase in forested areas, less disturbed habitats, shady areas along rivers and aquatic vegetation, and pristine waters (Mapi-ot & Enguito 2014; Harisha & Hosetti 2017; Luke et al 2017; Seidu et al 2017).

Generally, dragonflies prefer habitats close to the water, with surrounding vegetation. Fallen plant stems and rotting logs in the water are used by some species for laying eggs (de Resende et al 2021). In the waterfall habitat and secondary forest, there were many plants around the river, both low-level plants, and trees. This showed that many species of dragonflies are near vegetation to search for prey or avoid predators. Vegetation on the river banks influences the behavior of adult dragonflies, which use it for sunbathing, searching for food, resting, and sheltering. According to Perron et al (2021), dragonflies also use aquatic vegetation for laying and inserting eggs into submerged plants or trees. Dragonflies in various life stages use aquatic vegetation to perch, hide from predators, and search for prey. Ball-Damerow et al (2014) stated that habitats with canopy cover had higher Odonata species richness and diversity.

Forest modification caused by subsistence gardening can lead to the loss of approximately 25% of the species within closed-canopy forest habitats. Previous research showed that the undisturbed and disturbed habitats had different Odonata diversity (Aspacio et al 2013). Similarly, Dolny et al (2011) stated that habitat type is an important factor for dragonfly species composition because the distribution of Odonata species changes significantly based on habitat degradation.

The analysis of the similarity of dragonfly communities among habitat types gave the highest value between waterfalls and secondary forests, with a Bray-Curtis similarity index of 69%. This value indicates that 69% of species in waterfalls are also present in secondary forests. Therefore, the community similarity in the two research locations is categorized as low, since it can only be high when the community similarity index reaches 100% (Krebs 1999). According to Murti et al (2017), a community similarity index higher than 50% shows highly similar species in the habitat and lower than 50% shows low similarity among species in the habitat. Similarity analysis with NMDS also showed that there are still overlapping points between the observed habitats, which indicated that the three types of habitat do not have different species compositions.

Based on the measured environmental factors, waterfall and secondary forest habitats have approximately the same factor values, such as high humidity, air temperature of 29.54-31.85°C, and high sunlight intensity. Putri et al (2019) stated that the effective air temperature when dragonflies are active is 15°C-45°C. This showed that the air temperature at the research location is still relatively normal for dragonflies. Furthermore, Wulandari et al (2019) stated that the minimum humidity for dragonfly activity is 70%, while the optimal humidity that supports dragonfly life is between 85-90%. In this research, the average air humidity ranges from 78.11 to 81.67%, therefore, it is considered normal for dragonfly activity. The light intensity measured on average was from 7103.92 to 13218.67 lux. This showed that dragonflies will actively search for prey and breed during the day when the sun is shining and become more active and difficult to approach (Putri et al 2019).

Air temperature, humidity, and light intensity significantly affect the life of dragonfly species from the metamorphosis phase, including wing pigmentation, flight, search for prey, mating behavior, and egg-laying behavior. This is because the temperature is an important environmental factor for odonates that plays a direct role in regulating the activities for emergence by affecting the rate of chemical reactions in the body and controlling metabolic activities. Furthermore, light intensity and humidity are important factors for the flight of odonates. The openness of a place is closely related to the intensity of light that enters and is needed by the dragonfly. Dragonflies are insects with a positive response to light, which makes them active during the day (Noviyana et al 2021). According to Svensson & Waller (2013), sufficient light intensity is necessary to move or pump the chest and wing muscles of the dragonfly for flying.

Conclusions. The diversity of odonata in the Laine Waterfall Area varies among habitats. Based on the results, the habitats with the highest and lowest dragonfly diversity are waterfalls and agricultural land, respectively. Several factors that cause differences in diversity include variation in canopy cover, air temperature, humidity, light intensity, and the presence of vegetation. Therefore, this research recommends that the local government maintain the sustainability of the river and prevent the conversion of forest into agricultural land and settlements for dragonfly conservation.

Acknowledgements. The authors are grateful to the Directorate General of Higher Education, Ministry of Education, Culture, Research, and Technology for funding this research through the Basic Research scheme with the contact number: 1994/UN12.13/LT/2021, July 12, 2021.

Conflict of Interest. The authors declare that there is no conflict of interest.

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Received: 21 December 2021. Accepted: 30 January 2022. Published online: 01 May 2022.
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How to cite this article:
Koneri R., Nangoy M. J., Elfidasari D., 2022 Odonata diversity in the Laine Waterfall Area, Sangihe Islands, North Sulawesi, Indonesia. AACL Bioflux 15(3):1083-1095.