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Dragonfly (Odonata) assemblages in contrasting riparian land uses of Central Halmahera: An exploratory baseline survey and its prospects for biology learning

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ABSTRACT

Wallacean odonates remain poorly documented, and biology courses at Universitas Khairun lack curated local data on freshwater insects for research-based learning. This exploratory study documented adult dragonflies and damselflies (Odonata) under three contrasting riparian land uses in Central Halmahera, North Maluku, and outlined how the data could support biology learning. Six sites (two each near forest, agriculture/plantation, and settlement/industry) were surveyed once in August–September 2026 along ±300 m bank transects. Richness was compared using rarefaction of Hill numbers standardised to six individuals, with 95% bootstrap confidence intervals. In total, 38 individuals of seven taxa from five families were recorded. No taxon was shared among land-use categories, but replicate sites within categories also shared no taxa. Rarefied richness was 2.00 (95% CI 1.66–2.34) for forest, 2.80 (2.23–3.37) for agriculture/plantation, and 1.29 (1.00–1.71) for settlement/industry, where *Ischnura senegalensis* from one drainage ditch dominated. *Drepanosticta* sp. and *Rhinocypha* sp. occurred only in shaded forest streams. Because land use was confounded with elevation, stream type, location, and date, these differences are descriptive. The data provide a baseline and testable hypotheses for replicated sampling, and we propose, but have not yet evaluated, integrating them into biology courses through course-based field research.

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INTRODUCTION

Freshwater ecosystems are among the most biodiverse ecosystems per unit area and, at the same time, among the most threatened by human activities. Aquatic insects form a major component of this diversity and depend strongly on the condition of aquatic habitats and the surrounding vegetation (Dijkstra et al., 2014). The riparian zone shades the stream, stabilises banks, filters sediments, and provides microhabitats for semi-aquatic organisms. Land-use change along rivers, such as conversion to agriculture, settlement expansion, and industrial activities, tends to reduce riparian vegetation cover and alter the physical character of streams.

Dragonflies and damselflies (Odonata) are widely used as bioindicators of freshwater condition because their life cycle comprises an aquatic larval stage and an adult stage closely associated with bankside vegetation (Bried & Samways, 2015; Miguel et al., 2017), and dragonfly assemblages have been used to build continental-scale freshwater assessment indices (Vorster et al., 2020). Nevertheless, the efficiency of odonates as indicators depends on species bionomics, taxonomic resolution, and the life stage sampled (Dutra & De Marco, 2015; Valente-Neto et al., 2016), so local baseline data are required before odonates can be used for monitoring in a new region.

Studies in Neotropical streams show that the loss of riparian vegetation often alters odonate community structure: Zygoptera, which are generally small-bodied and associated with shaded habitats, tend to decline in disturbed streams, whereas heliophilic and highly mobile Anisoptera tend to increase (Monteiro-Júnior et al., 2014; Calvão et al., 2018; Oliveira-Junior & Juen, 2019). Responses to habitat loss may also be nonlinear, with abrupt changes beyond certain thresholds (Rodrigues et al., 2016). Outside streams, vegetation, water quality, and land cover also drive odonate assemblages in urban ponds (Perron et al., 2021). In Indonesia, rainforest degradation in East Kalimantan has been shown to change the taxonomic structure and functional diversity of dragonflies (Dolný et al., 2012). Because these responses vary among regions and systems, they cannot simply be assumed for Wallacea.

Wallacea, including the Moluccas, harbours a distinctive but poorly studied odonate fauna. The most recent checklist of the Odonata of Sundaland and Wallacea reports 166 primary records for Halmahera, which the authors equate to approximately 0.9 records per 100 km² (Dow et al., 2024). Several species endemic to North Maluku are known only from their type material; for example, *Drepanosticta halmahera* is listed as Data Deficient on the IUCN Red List (Dow, 2019), and recent records from Obi Island suggest that endemic Moluccan damselflies are associated with rocky, densely vegetated forest streams (Harahap & Shahroni, 2024). Meanwhile, Central Halmahera Regency is undergoing rapid landscape change around Weda Bay due to the expansion of agriculture, settlements, and industrial areas. To our knowledge, apart from the records compiled by Dow et al. (2024), no published study has compared odonate assemblages among rivers under different land-use categories in Central Halmahera.

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This knowledge gap also has an educational dimension. Field-based teaching is recognised as essential for developing biological understanding, yet it faces declining opportunities and logistical constraints (Fleischner et al., 2017), and field courses have been shown to improve undergraduate biology students' cognitive learning (Easton & Gilburn, 2012). Course-based undergraduate research experiences (CUREs), in which students contribute to authentic research questions, are associated with gains in scientific skills and persistence in science (Auchincloss et al., 2014; Corwin et al., 2015; Linn et al., 2015), and participation in biodiversity data collection can strengthen environmental science learning and agency for conservation (Ballard et al., 2017). At the Biology Education Study Program of Universitas Khairun (FKIP Unkhair), however, courses such as Entomology, Invertebrate Zoology, and Animal Ecology have no curated local dataset on Wallacean freshwater insects that students can analyse, which limits opportunities for research-based learning grounded in the North Maluku context. A small, well-documented baseline dataset, including its limitations, can serve both as a starting point for ecological monitoring and as a resource for designing such learning.

This exploratory survey therefore aimed to: (1) document the composition of adult odonates at six river sites in Central Halmahera; (2) describe differences in assemblage composition and sample-size-standardised richness among three riparian land-use categories (forest, agriculture/plantation, and settlement/industry), treating the comparisons as preliminary; (3) generate testable hypotheses on candidate indicator taxa for future replicated sampling; and (4) outline how the dataset could be integrated into biology courses at FKIP Unkhair. We expected, as hypotheses to be tested later rather than in this survey, that shade-associated Zygoptera would be restricted to forest streams and that assemblages in open, disturbed streams would be dominated by widespread tolerant species.

METHODS

Study Area and Design

The study was conducted in Central Halmahera Regency, North Maluku Province, Indonesia, at six sites in the districts of North Weda, Central Weda, and Weda (Figure 1; Table 1). Sites were selected through a preliminary survey on the basis of accessibility, safety, and adjacent land use, and were assigned a priori to three land-use categories with two sites each: forest (LOC-01, LOC-02), agriculture/plantation (LOC-03, LOC-04), and settlement/industry (LOC-05, LOC-06). LOC-05 is a village drainage ditch rather than a river and is therefore a different habitat type. Land-use category was confounded with elevation (forest 115–120 m, agriculture/plantation 40–45 m, settlement/industry 10–12 m), stream type, geographic cluster, and survey date; land cover around each site was not quantified. Consequently, the design does not allow differences among categories to be attributed to habitat disturbance, and all comparisons are treated as descriptive.

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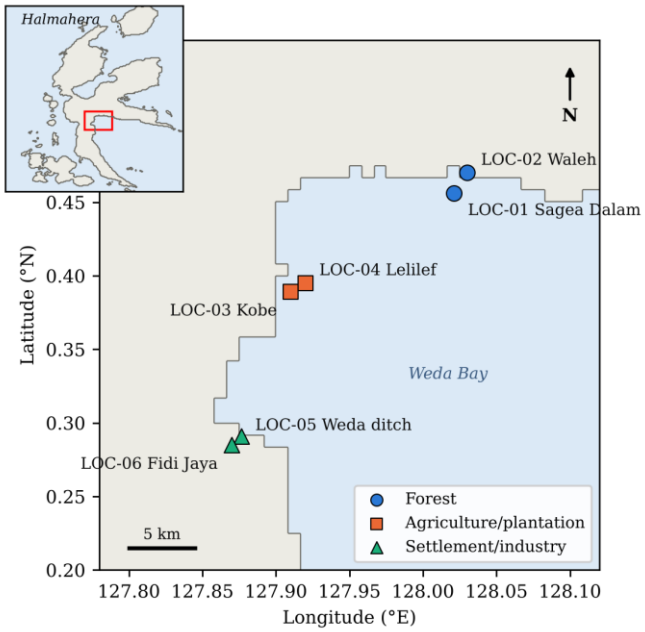


Figure 1. Location of the six survey sites near Weda Bay, Central Halmahera; marker shape and colour indicate land-use category, and the inset shows the position of the study area on Halmahera. Coastline from the GLOBE 1-km land mask.

Field Survey and Effort

Each site was surveyed once: LOC-01 on 20 August 2026, LOC-02 on 25 August 2026, and LOC-03 to LOC-06 on 12 September 2026. At each site, a two-person team (one lecturer and one student) walked a bank transect of approximately 300 m and recorded every adult odonate encountered, with its taxon, sex, number of individuals, microhabitat, and behaviour; individuals were photographed where possible. The protocol specified a morning (08:00–11:00 Eastern Indonesia Time, WIT) and an afternoon (14:00–18:00 WIT) session. All records in the dataset, however, were made between 08:30 and 13:00 WIT, and on 12 September two teams each surveyed two sites. Survey effort (person-hours), walking pace, scanning width, and weather conditions were not recorded, and no explicit rule for avoiding repeated counts of territorial individuals was applied; counts are therefore treated as relative abundance within a single visit.

Habitat Variables

At each site, riparian canopy cover (%), river width (m), current velocity (m/s), dominant bottom substrate (stone, sand, mud), water clarity (clear, slightly turbid, turbid), elevation (m), and a human-activity score (1–5; 1–2 = low, 3 = moderate, 4–5 = high, based on the intensity of agriculture, settlement, and industrial activity adjacent to the transect) were recorded once. Riparian canopy cover was estimated visually, to the nearest 5%, as the proportion of the stream surface shaded by overhanging vegetation along the transect. Current velocity was measured with the float method, by timing a floating object over a measured reach of the main channel and expressing surface velocity in m/s. River width was measured with a measuring tape at the water surface. Water clarity was classified visually into three categories according

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to the visibility of the stream bed (clear: bed fully visible; slightly turbid: bed partly visible; turbid: bed not visible). Elevation and site coordinates were recorded with a handheld GPS receiver. Water-quality parameters (temperature, dissolved oxygen, pH, conductivity) were not measured.

Identification

No specimens were collected. Individuals were identified from field observation and photographs by the research team at the Biology Laboratory, FKIP Unkhair. Zygoptera were identified with reference to Kalkman and Orr (2013), Anisoptera with reference to Theischinger et al. (2021), and nomenclature and known distributions were checked against Dow et al. (2024). Sex was assigned from external colouration and body form. Two taxa were retained at genus level (*Drepanosticta* sp. and *Rhinocypha* sp.) because the diagnostic characters, particularly male terminal appendages, could not be resolved from the photographs. Six records are supported by photographs (P-001 to P-006), which are archived by the research team; three records (a female *Drepanosticta* sp., *Rhyothemis regia*, and female *Ischnura senegalensis*) lack photographs.

Data Analysis

The site × taxon abundance matrix (Table 2) is the primary result. Compositional overlap was summarised with the Jaccard index for each pair of sites, separating pairs within the same category from pairs in different categories. Because the number of individuals differed among categories (6–21), taxon richness and diversity were compared using individual-based rarefaction of Hill numbers of order q = 0 (taxon richness), q = 1 (exponential of Shannon entropy), and q = 2 (inverse Simpson concentration), standardised to the smallest category sample (m = 6), with 95% confidence intervals from 1,000 bootstrap replicates (Chao et al., 2014; Gotelli & Colwell, 2001); sample coverage was estimated following Chao and Jost (2012). Inferential tests were not applied: with two sites per category, a Kruskal–Wallis test cannot reach significance at $\alpha = 0.05$ regardless of effect size, and five of the six sites recorded a single taxon. Analyses were performed in R-Studio and SPSS ver 25.0; the dataset and code are available from the corresponding author on reasonable request.

Ethics and Permits

The survey was non-invasive and involved no collection of specimens. Student co-authors participated as members of the research team; no data on student learning were collected in this study.

RESULTS AND DISCUSSION

Habitat Characteristics

Riparian canopy cover ranged from 85–90% at forest sites to 25–30% at agriculture/plantation sites and 0–5% at settlement/industry sites (Table 1). Across the same sequence, current velocity ranged from 0.45–0.60 to 0.25–0.35 and 0.10–0.15 m/s, the substrate shifted from stone to sand and mud, water became more turbid, and the human-activity score

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increased from 1 to 5. These differences confirm the contrast among the a priori categories but do not constitute an independently quantified disturbance gradient.

Table 1. Location and habitat characteristics of the six survey sites (single visit)

Site	Land-use category	Latitude (°N)	Longitude (°E)	Elevation (m)	Canopy (%)	Width (m)	Current (m/s)	Substrate	Human activity	Water clarity
LOC-01 Sagea Dalam River	Forest	0.4561	128.0211	120	85	3.5	0.45	Stone	1	Clear
LOC-02 Waleh River	Forest	0.4700	128.0300	115	90	4.0	0.60	Stone	1	Clear
LOC-03 Kobe River	Agriculture/ plantation	0.3892	127.9102	45	30	5.0	0.25	Sand	3	Slightly turbid
LOC-04 Lelilef River	Agriculture/ plantation	0.3950	127.9200	40	25	4.5	0.35	Sand	3	Slightly turbid
LOC-05 Weda drainage ditch	Settlement/ industry	0.2910	127.8765	12	5	2.0	0.10	Mud	5	Turbid
LOC-06 Fidi Jaya River	Settlement/ industry	0.2850	127.8700	10	0	2.5	0.15	Mud	5	Turbid

Human-activity score: 1–2 = low, 3 = moderate, 4–5 = high. LOC-05 is a drainage ditch, not a river.

Assemblage Composition

In total, 38 adult odonates of seven taxa from five families were recorded (Table 2): 28 Zygoptera (73.7%) and 10 Anisoptera (26.3%), comprising 27 males and 11 females. Five of the six sites recorded a single taxon; only LOC-03 recorded two (*Orthetrum sabina* and *Rhyothemis regia*). No taxon occurred at more than one site, so the Jaccard index was 0 for all 15 site pairs, both the three pairs within the same land-use category and the 12 pairs between categories. The absence of shared taxa among categories is therefore matched by an equal absence within categories and cannot be attributed to land use with the present data. The proportion of Zygoptera was 100% (6 of 6 individuals) in forest, 18.2% (2 of 11) in agriculture/plantation, and 95.2% (20 of 21) in settlement/industry sites. Of the 21 settlement/industry individuals, 20 were *I. senegalensis* recorded at the LOC-05 drainage ditch, where mating and oviposition on aquatic weeds were observed.

Table 2. Site × taxon abundance of adult odonates (single visit); values are numbers of individuals (males/females)

Taxon	Family (suborder)	LOC-01	LOC-02	LOC-03	LOC-04	LOC-05	LOC-06	Total (M/F)
Drepanosticta sp.	Platystictidae (Z)	3 (2/1)	–	–	–	–	–	3 (2/1)
Rhinocypha sp.	Chlorocyphidae (Z)	–	3 (3/0)	–	–	–	–	3 (3/0)
Orthetrum sabina (Drury, 1773)	Libellulidae (A)	–	–	5 (5/0)	–	–	–	5 (5/0)
Rhyothemis regia (Brauer, 1867)	Libellulidae (A)	–	–	4 (4/0)	–	–	–	4 (4/0)
Ceriagrion batjanum Asahina, 1967	Coenagrionidae (Z)	–	–	–	2 (0/2)	–	–	2 (0/2)
Ischnura senegalensis (Rambur, 1842)	Coenagrionidae (Z)	–	–	–	–	20 (12/8)	–	20 (12/8)

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Anax guttatus (Burmeister, 1839)	Aeshnidae (A)	–	–	–	–	–	1 (1/0)	1 (1/0)
Individuals (N)		**3**	**3**	**9**	**2**	**20**	**1**	**38 (27/11)**
Taxa (S)		**1**	**1**	**2**	**1**	**1**	**1**	**7**

Z = Zygoptera; A = Anisoptera. Land-use category: LOC-01–02 forest; LOC-03–04 agriculture/plantation; LOC-05–06 settlement/industry.

Sample-Size-Standardised Richness and Diversity

Estimated sample coverage was 1.00 for forest and agriculture/plantation and 0.95 for settlement/industry samples (Table 3), but these values describe completeness relative to the few individuals observed during one visit, not completeness of the site assemblages. Standardised to six individuals, rarefied taxon richness (q = 0) was 2.00 for forest, 2.80 for agriculture/plantation, and 1.29 for settlement/industry samples (Table 3; Figure 2). Confidence intervals overlapped between forest and both other categories; the interval for agriculture/plantation did not overlap that for settlement/industry, but this contrast rests on 11 and 21 individuals from two sites each, the latter dominated by a single site. The same ordering was observed for q = 1 and q = 2.

Table 3. Observed and rarefied Hill numbers (standardised to m = 6 individuals) by land-use category, with 95% bootstrap confidence intervals

Land-use category	Sites	N	S_{obs}	Coverage	q = 0 (m = 6)	q = 1 (m = 6)	q = 2 (m = 6)
Forest	2	6	2	1.00	2.00 (1.66–2.34)	2.00 (1.58–2.42)	2.00 (1.50–2.50)
Agriculture/plantation	2	11	3	1.00	2.80 (2.23–3.37)	2.55 (1.99–3.11)	2.36 (1.81–2.91)
Settlement/industry	2	21	2	0.95	1.29 (1.00–1.71)	1.14 (1.00–1.38)	1.09 (1.00–1.25)

Lower confidence limits are truncated at 1.00, the minimum possible value. Coverage refers to the individuals observed in one visit.

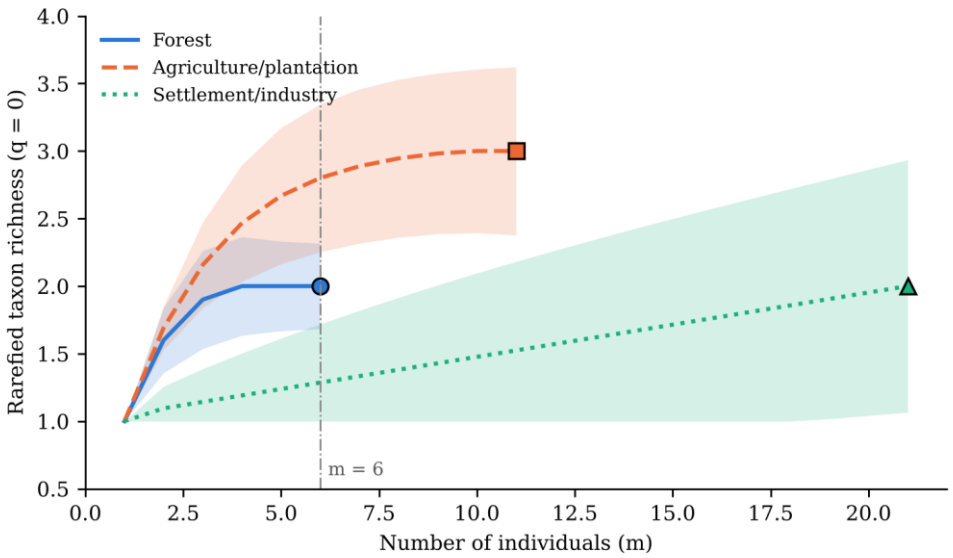


Figure 2. Individual-based rarefaction curves of taxon richness (q = 0) with 95% bootstrap confidence bands; end-point markers show observed samples, and the dashed vertical line marks the common sample size (m = 6)

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Discussion

The survey recorded seven taxa, each confined to a single site. Taxa differed among land-use categories, but replicate sites within each category differed to the same extent, so the observed pattern is better described as high site-to-site turnover in a very small sample than as a land-use effect. Odonate detectability also differs between densely shaded forest banks and open banks, and only six individuals were recorded at forest sites; differences in detection and survey effort may therefore contribute to the observed counts. Studies that linked riparian vegetation loss to odonate assemblage change used many more sites and individuals (Monteiro-Júnior et al., 2014; Calvão et al., 2018; Oliveira-Junior & Juen, 2019), and their conclusions cannot be tested with the present data.

The proportion of Zygoptera did not decline monotonically across the categories (100%, 18%, and 95%). This departs from the shift from Zygoptera to heliophilic Anisoptera reported in Neotropical streams (Monteiro-Júnior et al., 2014; Calvão et al., 2018), because the settlement/industry sample was dominated by *I. senegalensis*, a damselfly recorded across much of Sundaland and Wallacea (Dow et al., 2024). Suborder-level patterns may thus be misleading where tolerant Coenagrionidae dominate disturbed sites, which supports using species traits rather than suborder alone when interpreting odonate responses (Dutra & De Marco, 2015). The mating and oviposition of *I. senegalensis* at the LOC-05 ditch indicate reproductive activity; larvae or exuviae were not sampled, so successful development there was not confirmed. The higher richness recorded at agriculture/plantation sites (three taxa versus two) rests on 11 individuals and is reported as a descriptive observation, not as evidence of an intermediate-disturbance peak, particularly because odonate responses to habitat loss can be nonlinear (Rodrigues et al., 2016).

Drepanosticta sp. was recorded at LOC-01 and *Rhinocypha* sp. at LOC-02, both in clear, stony, densely shaded forest streams. Species identity could not be confirmed from the available photographs. These genera are of interest because endemic Moluccan congeners are poorly known (Dow, 2019; Dow et al., 2024) and because endemic damselflies on nearby Obi Island have been recorded in similar habitats (Harahap & Shahroni, 2024). Collecting diagnostic evidence, such as photographs of terminal appendages or voucher specimens with appropriate permits, is a priority for subsequent visits.

Rather than indicator taxa, the data generate three hypotheses for replicated sampling: (H1) *Drepanosticta* and *Rhinocypha* occur predominantly at sites with high riparian canopy cover; (H2) *I. senegalensis* and *O. sabina* dominate open, low-canopy sites; and (H3) taxon richness standardised by sample coverage differs among land-use categories after accounting for elevation and stream type. Testing these hypotheses requires at least three to five sites per category with comparable elevation and stream order, repeated visits, quantified land cover around each site, standardised effort, and indicator species analysis (Dufrêne & Legendre, 1997), with larval sampling added where possible (Valente-Neto et al., 2016). Such a design would allow dragonfly-based assessment approaches (Vorster et al., 2020) to be evaluated for rivers in North Maluku.

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Limitations

The main limitations are: (1) a single visit per site, with dates differing among categories; (2) two sites per category and confounding of land use with elevation, stream type, location, and date; (3) unrecorded survey effort, weather, and counting rules; (4) differences in detectability between shaded and open banks; (5) identification from photographs, with two taxa retained at genus level and three records without photographs; and (6) the use of visual estimates for canopy cover and water clarity and the absence of water-quality and quantified land-cover data. The results should therefore be read as a documented baseline rather than as evidence of disturbance effects.

Prospects for Biology Learning at FKIP Universitas Khairun

The dataset produced here, a georeferenced site × taxon matrix with habitat variables and photographic records, is small but complete and transparent about its limitations, which makes it suitable as a teaching case. Table 4 outlines how it could be integrated into courses of the Biology Education and Master of Biology Education study programs at FKIP Unkhair. The proposal follows the CURE model, in which students work on an authentic question with an uncertain answer, collect and analyse real data, and communicate results (Auchincloss et al., 2014; Corwin et al., 2015). It also draws on field-based teaching (Easton & Gilburn, 2012; Fleischner et al., 2017) and on biodiversity data collection as a route to environmental learning and conservation agency (Ballard et al., 2017).

Table 4. Proposed integration of the Odonata baseline dataset into biology courses at FKIP Universitas Khairun (not yet implemented or evaluated)

Course / program	Learning focus	Proposed activity using this study	Evidence to collect in future evaluation
Entomology; Invertebrate Zoology (S1)	Odonate morphology, identification, and the limits of photo-based identification	Students identify taxa from the archived photographs, compile diagnostic characters, and contribute to a photo-based identification guide for Halmahera Odonata	Identification accuracy; rubric-scored diagnostic descriptions
Animal Ecology (S1)	Sampling design, replication, confounding, and sample-size-standardised diversity	Students analyse the site × taxon matrix, compute rarefied Hill numbers, and redesign the survey to remove the confounding identified here	Pre–post scientific reasoning tasks on experimental design; quality of revised sampling plans
Field practicum / CURE (S1)	Authentic data collection and data management	Students join the next replicated visits as observers using a standardised protocol (effort, weather, counting rules) and add records to the shared dataset	Rubric of scientific inquiry skills; data-quality audit of student records; reflective journals
Learning media and technology (S1)	Developing contextual learning resources	Students convert the photographs and site data into digital learning media for school biology topics on biodiversity and environmental change	Expert validation and student/teacher practicality ratings of the media
Research methodology (S2)	Research design and supervision of undergraduate research	Master's students co-supervise S1 teams and design the evaluation of the CURE	Research proposals; mentoring logs

S1 = undergraduate (Bachelor) program; S2 = Master's program.

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These activities are proposals: their effects on learning have not been evaluated in this study. A subsequent study will therefore implement the field practicum as a CURE in the Animal Ecology and Entomology courses and evaluate it with pre–post measures of scientific inquiry skills and conceptual understanding, following assessment recommendations for CUREs (Auchincloss et al., 2014). The same replicated field visits needed to test H1–H3 can thus serve as the learning context, linking the ecological and educational aims of the research program.

CONCLUSION

Seven odonate taxa from five families (38 individuals) were recorded at six river sites in Central Halmahera during a single visit (aim 1). No taxon was shared among land-use categories, but replicate sites within categories also shared no taxa, and land use was confounded with elevation, stream type, location, and date; differences in composition and in rarefied richness among categories are therefore descriptive and cannot be attributed to disturbance (aim 2). *Drepanosticta* sp. and *Rhinocypha* sp. were recorded only in shaded forest streams, and *I. senegalensis* dominated a settlement drainage ditch; these patterns are stated as hypotheses for replicated, multi-visit sampling with quantified land cover, standardised effort, and verified identifications, rather than as indicator taxa (aim 3). The dataset offers a transparent local baseline that can be integrated into entomology, animal ecology, field practicum, learning-media, and research-methods courses at FKIP Universitas Khairun through a course-based research model, whose effects on learning remain to be evaluated (aim 4).

Author Contributions

ZA: conceptualisation, methodology, field supervision, data analysis, and writing of the original draft. AM & S: methodology, field supervision, identification, and review and editing. RR, SY, WGT, MMLB, and MB: field data collection, photographic documentation, and data curation. All authors read and approved the final manuscript.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

The site × taxon dataset, habitat variables, photographs, and analysis code are available from the corresponding author on reasonable request.

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