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Species distribution modelling of Odonata using Citizen Science Data and Machine Learning Random Forest Algorithm in Sulawesi Island

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Abstract: Odonata are a group of insects that play an important role as natural bioindicators due to their sensitivity to changes in environmental quality, particularly in aquatic ecosystems. These insects are highly dependent on both aquatic and terrestrial habitats throughout their life cycles, making them highly vulnerable to ecological disturbances. Sulawesi Island, located in the Wallacea biogeographic zone, has a high diversity of Odonata species, including many endemic species. However, anthropogenic activities such as deforestation, agricultural expansion, and mining are putting pressure on the sustainability of their natural habitats. This study aims to map the potential distribution of Odonata species on Sulawesi Island using a Species Distribution Modeling (SDM) approach with the Random Forest machine learning algorithm. Species presence data were obtained from the Global Biodiversity Information Facility (GBIF) citizen science platform and combined with 12 bioclimatic variables, including temperature (bio1, bio2, bio4–bio11), seasonal temperature (bio3), and annual precipitation (bio12). The modeling results showed that there were 2,152 Odonata distribution records from 11 families, including endemic species and several species with an "Endangered" conservation status according to the IUCN. The bioclimatic variables that most significantly influence habitat suitability are annual precipitation (bio12) and daily temperature variation (bio2). These findings demonstrate that a citizen science-based SDM approach and algorithms. The modeling results show that there are 2,152 Odonata distribution records from 11 families, including endemic species and several species with an "Endangered" conservation status according to the IUCN. The bioclimatic variables that most influence habitat suitability are annual precipitation (bio12) and daily temperature variation (bio2). These findings suggest that a citizen science-based approach combined with the Random Forest algorithm can be an effective method for supporting biodiversity monitoring and conservation planning. This study also emphasizes the importance of habitat conservation strategies and the development of long-term monitoring systems to ensure the survival of Odonata species in the Wallacea region.

Keyword: Odonata, Random Forest, Sulawesi Island, Species Distribution Modelling (SDM)

INTRODUCTION

Odonata (dragonflies) are an order of insects that are commonly found in various habitats, though most inhabit aquatic environments (Pessacq et al. 2018). This order is divided into two suborders with different body shapes and sizes: Anisoptera and Zygoptera. Common dragonflies (Anisoptera) are larger and fly faster than damselflies (Zygoptera) (Lino *et al.* 2019). Morphologically, dragonflies are characterized by large eyes, unique color patterns on their wings, and nocturnal activity (Futashi 2020). Within ecosystems,

Odonata exhibit various behaviors, including reproduction, territorial behavior, and aggressive responses to environmental changes (Resende *et al.* 2021). The presence of Odonata is crucial because they are often used as indicators of environmental quality and for biomonitoring, and are even more effective than other aquatic macroinvertebrates (Junior *et al.* 2022). Furthermore, Odonata play a role in testing hypotheses regarding environmental changes, owing to their strong association with river ecosystems (Pereira *et al.* 2019). Dragonfly nymphs inhabit calm, shallow waters, while adult insects fly to reproduce and disperse (Porta *et al.* 2023). According to Ferreira *et al.* (2023), dragonflies have a high dispersal capacity and can be found in various types of aquatic environments, particularly rivers. The distribution of dragonflies is also influenced by environmental and spatial factors, depending on the species' sensitivity to habitat conditions and their dispersal capabilities (Mendes 2015).

The island of Sulawesi has a high diversity of Odonata insects, some of which are endemic. This is closely related to the biogeographic habitat niche of Wallacea. According to Ono *et al.* (2020), the oceanic distances separating the Wallacea islands from the Sunda and Sahul landmasses likely contribute to the scarcity of species from Asia and Oceania in Wallacea, as well as the high diversity of endemic species there. The islands within the Wallacea biogeographic region exhibit high biodiversity and a high proportion of endemic species (O'Connell *et al.* 2022). A clear example is the discovery of various endemic dragonfly species on the island of Sulawesi. Findings by Koeneri *et al.* (2020) indicate that the highest abundance of dragonfly species is found in agricultural lands and is strongly influenced by the vegetation along riverbanks, food availability, clean water, and light intensity. Terrestrial habitats play a role just as important as aquatic habitats in supporting the survival of dragonflies. Some species, such as Sympetrum depressiusculum, are even more commonly found in terrestrial habitats with diverse vegetation, indicating that maintaining heterogeneous landscapes is crucial for effective conservation (Hykel *et al.* 2016). However, the high diversity of flora and fauna in the Wallacea region—including Odonata on the island of Sulawesi—faces serious threats due to pressures from human activities. According to Bisjoe and Rizal (2015), the unique and diverse flora and fauna of the Wallacea region must be conserved, as some of these species are already classified as rare and even endangered. Many factors have contributed to the rarity of these species, including the exploitation of natural resources through activities such as mining, forestry, agriculture, hunting, tourism, and fishing, which threaten biodiversity—particularly endemic species (Sturebig *et al.* 2022).

Studying dragonflies (Odonata) is crucial because these insects serve as natural bioindicators for assessing environmental health, particularly in aquatic ecosystems. Changes in dragonfly population size or species composition indicate the significant impact of habitat degradation on other taxa, as dragonflies often serve as indicators of ecosystem health (Luke *et al.* 2017). Adult dragonflies are also frequently used in early monitoring to assess river conditions and as a cost-effective tool for evaluating habitat restoration (Martin and Maynou 2016). Additionally, adult dragonflies are used to assess landscape disturbances, enabling large-scale ecological health assessments by evaluating the species' vulnerability (Sigutova *et al.* 2023). According to Nagy *et al.* (2019), conservation efforts and the management of natural habitats—such as keeping river channels open, preserving natural vegetation landscapes, and maintaining small-scale traditional farming systems along river basins—have been shown to increase the abundance and diversity of dragonfly species. These species serve not only as natural bioindicators reflecting environmental quality but also as keystone species in maintaining aquatic ecosystems. Therefore, preserving natural habitats is crucial for maintaining the diversity and survival of dragonflies (Pereira *et al.* 2019). By studying Odonata, we can gain a more comprehensive understanding of how ecosystems function and develop effective conservation strategies.

METHODOLOGY

Study Area

This study was conducted on the island of Sulawesi, which has a land area of approximately 18,736,843.4096 ha. Administratively, the study area encompasses six provinces: South Sulawesi, with an area of 45,330.55 km^2; Southeast Sulawesi, 36,159.71 km^2; Central Sulawesi, 61,605.718 km^2; West Sulawesi, 16,594.75 km^2; Gorontalo, with an area of 12,025.147, km^2, and North Sulawesi, with an area of 14,500.28 km^2

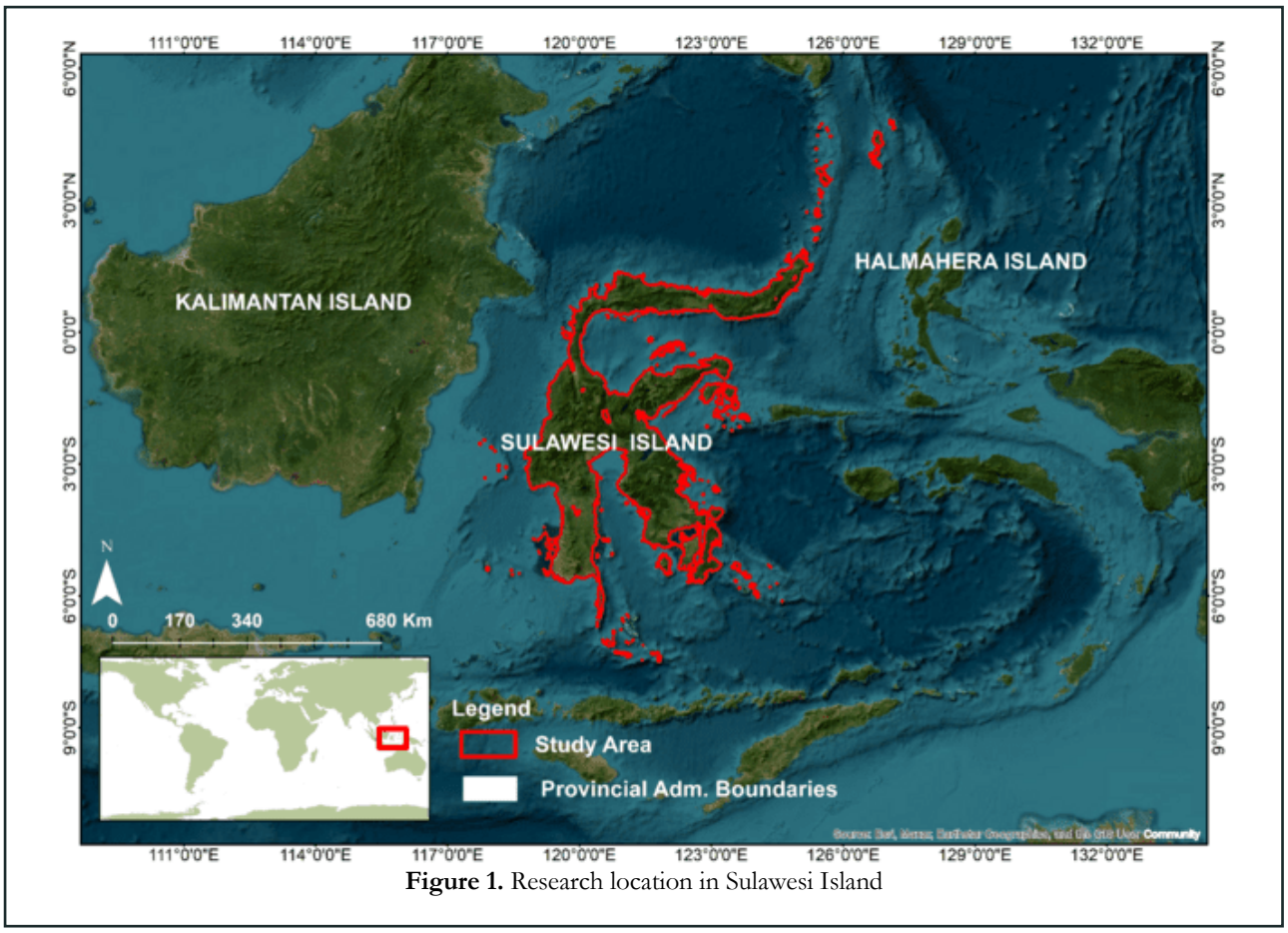


Figure 1. Research location in Sulawesi Island

Data Source

Species Data

Species distribution data were obtained from the Global Biodiversity Information Facility (GBIF) database, which contains observation and free access to global biodiversity data to support scientific research, conservation, and sustainable records based on reports, findings, and previously recorded data. GBIF was developed to facilitate open development (Telenius 2011). Species occurrence data were extracted from GBIF using the `get_gbif` function based on taxon names and specific geographic boundaries via the `rgbif` package in the R software (Chauvier *et al.* 2025). To ensure data quality, the download process was conducted by applying specific filtering criteria, including using only data with geographic coordinates and representing native records. Large-scale data downloads were performed using the `occ_download` function, with download status monitored via `occ_download_wait`, data retrieved using `occ_download_get`, and data imported into R using `occ_download_import` for further analysis (Iglesi *et al.* 2023).

Environmental Data

Environmental data consisted of bioclimatic variables representing temperature conditions obtained from the BIOCLIM dataset. Eleven bioclimatic variables (Bio1-Bio11) were used in this study, including annual mean temperature (Bio1), mean diurnal range (Bio2), isothermality (Bio3), temperature seasonality (Bio4), maximum temperature of the warmest month (Bio5), minimum temperature of the wettest quarter (Bio8), mean temperature of the driest quarter (Bio9), mean temperature of the warmest quarter (Bio10), and mean temperature of the coldest quarter (Bio11). These variables were incorporated into the habitat suitability modeling process to characterize the thermal conditions potentially influencing species distributions.

Habitat Suitability Modeling

Habitat suitability modeling was conducted using a machine learning approach, specifically the RF

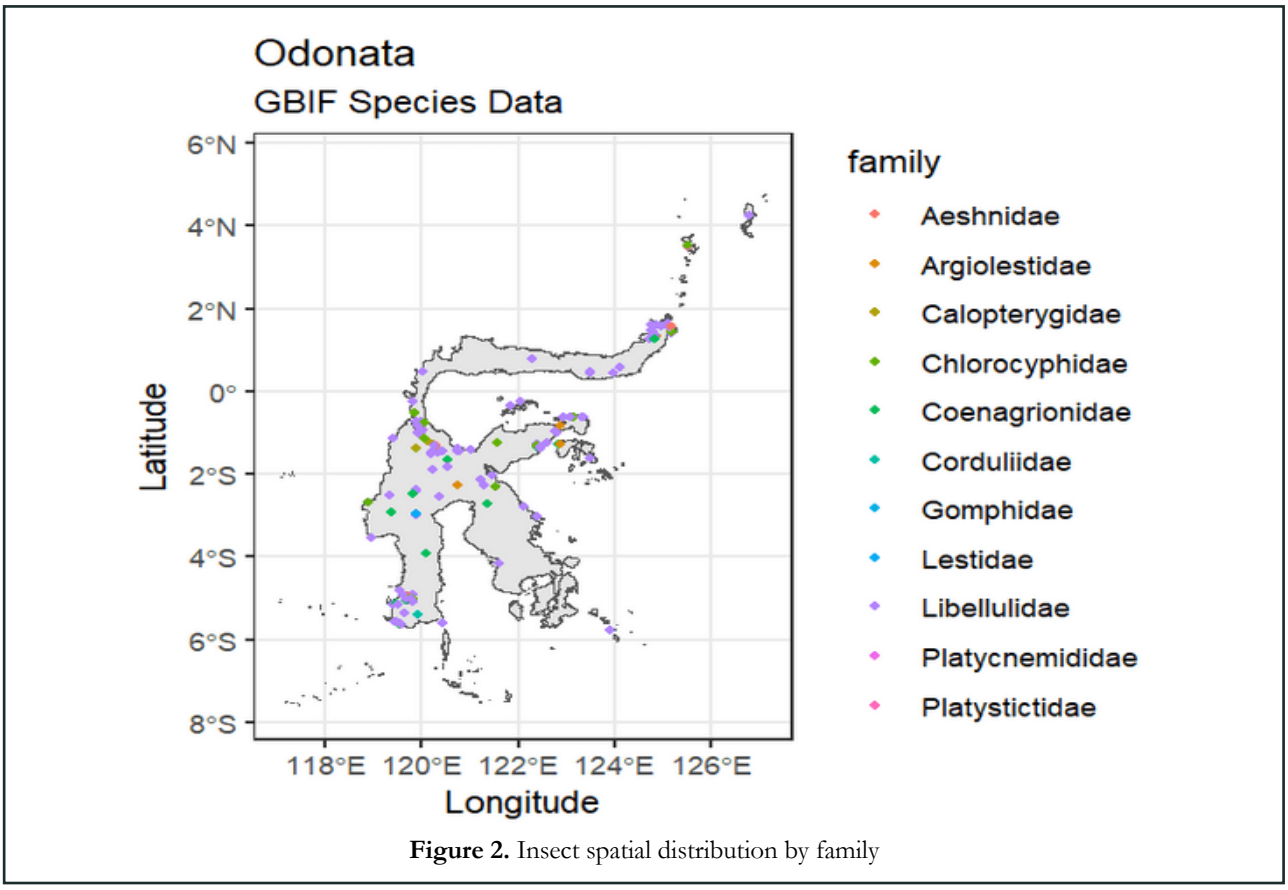


Figure 2. Insect spatial distribution by family

(Random Forest) algorithm. The use of this algorithm was based on the study by Boys *et al.* (2020), which achieved an accuracy rate of 0.85%. Additionally, this analysis employed the SDM (Species Distribution Modeling) approach in R, which generated a habitat consist of temperature (bio1, bio2, bio4–bio11), thermal (bio3), and precipitation (bio12).

Accuracy Assessment

Model performance was evaluated using the Area Under the Receiver Operating Characteristic Curve (AUC) and the Kappa coefficient. The ROC curve illustrates the relationship between the True Positive Rate (TPR) and the False Positive Rate (FPR) across different classification thresholds (Eq.1 and Eq.2). TPR represents the proportion of positive observations correctly predicted by the model and was calculated as follows:

$$TPR = \frac{TP}{TP+FN} \text{.....(Eq.1)}$$

$$TPR = \frac{FP}{FP+TN} \text{.....(Eq.2)}$$

where (TP) and (FN) represent true positive and false negative observations, respectively. AUC represents the area under the ROC curve and measures the model's ability to discriminate between positive and negative observations (Eq.3)(Hanley and McNeil 1982; Jiménez-Valverde 2012). It was expressed as follows:

$$AUC = \int_0^1 T\,PR(FPR)\,d(FPR) \text{.....(Eq.3)}$$

where (FPR) represents the proportion of negative observations incorrectly predicted as positive. AUC values closer to 1 indicate better discriminatory performance, whereas a value of 0.5 indicates discrimination equivalent to random classification (Hanley and McNeil 1982). The Kappa coefficient was also used to evaluate agreement between observed and predicted classifications while accounting for agreement expected by chance. Both metrics were assessed for each Odonata family to compare model performance

Table 3. Species and number of record from GBIF, March 2025 collection

Family	Species (Number of record)
Aeshnidae	*Anaciaeschna jaspidea* (2), *Anax fumosus celebense* (1), *Anax fumosus* (15), *Anax gibbosulus* (1), *Anax guttatus* (9), *Anax panybeus* (9), *Gynacantha arsinoe* (3), *Gynacantha basiguttata* (2), *Gynacantha bayadera* (5), *Gynacantha nausicaa* (20), *Gynacantha penelope* (5), *Gynacantha subinterrupta* (5), *Heliaeschna filostyla* (17, E, LC), *Oligoaeschna venatrix* (5, E, VU)
Argiolestidae	*Argiolestes celebensis* (1, E, DD), *Celebargiolestes askewi* (3, E, DD), *Celebargiolestes cinctus* (62, E, LC), *Celebargiolestes Kennedy* (1), *Celebargiolestes orri* (47, E, LC), *Celebargiolestes toli* (15, E, LC)
Calopterygidae	*Neurobasis kaupi* (132, E, LC), *Vestalis luctuosa* (1)
Chlorocyphidae	*Disparocypha biedermanni* (2, E, LC), *Libellago asclepiades* (33, E, DD), *Libellago aurantiaca* (2), *Libellago celebensis* (99, E, LC), *Libellago daviesi* (52, E, LC), *Libellago lineata* (2), *Libellago manganitu* (11, E, DD), *Libellago rufescens* (78), *Libellago Selys* (4), *Libellago xanthocyana* (69, E, LC), *Rhinocypha flavipoda* (10, E, EN), *Rhinocypha frontalis* (126, E, LC), *Rhinocypha monochroa* (135, E, LC), *Rhinocypha pelengensis (*6, E, EN), *Rhinocypha phantasma* (33), *Rhinocypha sangihensis* (7, E, EN), *Rhinocypha tincta* (1), *Rhinocypha togeanensis* (6, E, EN), *Rhinocypha virgulata* (20, E, EN), *Sclerocypha bisignata* (22, E, LC), *Watuwila vervoorti* (4, E, DD)
Corduliidae	*Hemicordulia assimilis* (11), *Procordulia lompobatang* (11, E, EN), *Procordulia rantemario* (5, E, DD)
Gomphidae	*Ictinogomphus celebensis* (17), *Ictinogomphus Cowley* (1), *Paragomphus capitatus* (7)
Lestidae	*Lestes Leach* (1), *Lestes praemorsus* (18), *Lestes quercifolia* (1)
Libellulidae	*Acisoma panorpoides* (4), *Agrionoptera insignis* (9), *Brachydiplax chalybea* (3), *Brachythemis contaminata* (2), *Celebothemis delecollei* (21), *Crocothemis servilia* (7), *Diplacina militaris* (21, E, LC), *Diplacina torrenticola* (1, E, LC), *Diplacodes trivialis* (47), *Lathrecista asiatica* (13), *Lyriothemis cleis* (1), *Lyriothemis eurydice* (4, E, DD), *Macrodiplax cora* (4), *Nannophlebia aglaia* (4, E, LC), *Nannophya pygmaea* (14), *Neurothemis manadensis* (105), *Neurothemis ramburi* (36), *Orthetrum glaucum* (13), *Orthetrum pruinosum* (24), *Orthetrum pruinosum clelia* (6), *Orthetrum serapia* (45), *Orthetrum testaceum* (2), *Pantala flavescens* (25), *Potamarcha congener* (4), *Protorthemis celebensis* (7, E, DD), *Raphismia bispina* (4), *Rhodothemis nigripes* (1), *Rhyothemis phyllis* (1), *Tetrathemis leptoptera* (3), *Tholymis tillarga* (14), *Trithemis festiva* (13), *Zygonyx ilia* (1), *Zyxomma obtusum* (5), *Zyxomma petiolatum* (5)
Platycnemididae	*Nosoticta flavipennis* (22, E, LC), *Nosoticta Hagen* (22)
Platystictidae	*Drepanosticta bicolor* (1, E, DD), *Drepanosticta ephippiata* (24, E, LC), *Drepanosticta hamulifera* (3, E, VU), *Drepanosticta Laidlaw* (4), *Drepanosticta penicillata* (3, E, DD), *Drepanosticta quadrata* (2), *Drepanosticta watunilensis* (3, E, DD), *Protosticta annulata* (1), *Protosticta bivittata* (7, E, DD), *Protosticta coomansi* (45, E, DD), *Protosticta geijskesi* (50, E, LC), *Protosticta gracilis* (2, E, CR), *Protosticta linduensis* (7, E, DD), *Protosticta marenae* (7, E, DD), *Protosticta maurenbrecheri* (5, E, DD), *Protosticta pariwonoi* (12, E, LC), *Protosticta reslae* (3, E, DD), *Protosticta rozendalorum* (6, E, CR), *Protosticta sp.* (1), *Protosticta simplicinervis* (27), *Protosticta vanderstarrei* (16,E ,LC)

RESULTS

Spatial Distribution of Odonata

Based on records from GBIF data, the family Chlorocyphidae has the highest number of individuals, totaling 722 across 21 species (Figure 2). Geographically, the family Chlorocyphidae is concentrated in Central Sulawesi and South Sulawesi. The family Libellulidae is recorded to have 724 individuals across 34 species and exhibits a wide distribution, found throughout nearly all of Sulawesi. The family Coenagrionidae is distributed fairly evenly but is more concentrated in central and northern Sulawesi, with 268 individuals across 22 species. Furthermore, the Platystictidae family is recorded to have 223 individuals across 21 species. Other families, such as Platycnemididae, Aeshnidae, Argiolestidae, Gomphidae, Calopterygidae, Lestidae, and Corduliidae, have lower numbers of individuals and are restricted to specific regions. Meanwhile, Table 3 illustrates the variation in the number and distribution of individuals within each family, along with the differing conservation statuses among Odonata species in Sulawesi. Based on data from the International Union for Conservation of Nature (IUCN), species conservation statuses range from Least Concern (LC), Vulnerable (VU), Data Deficient (DD), Endangered (EN), to Critically Endangered (CR). In this study, there are also several species that do not yet have a

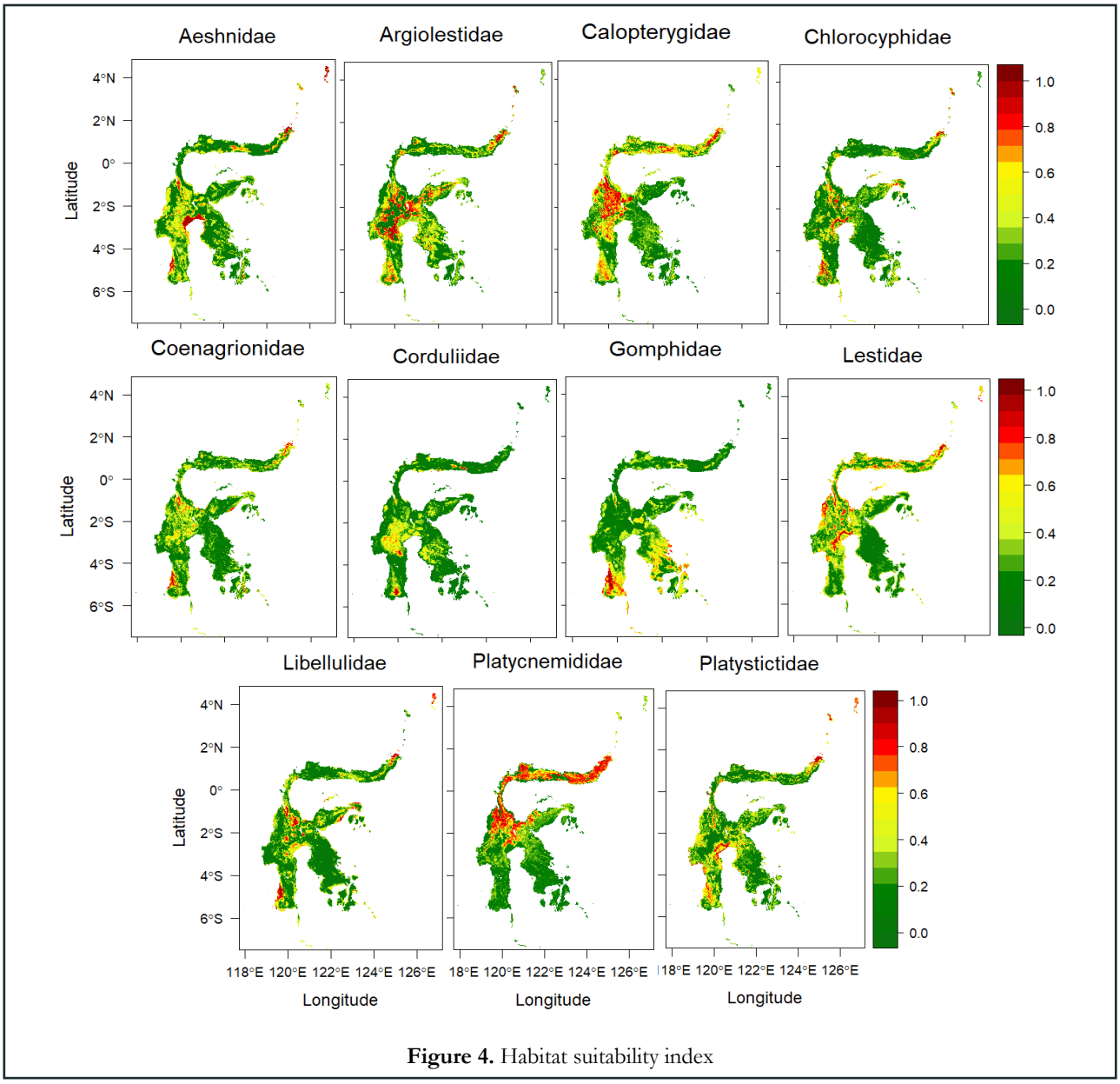


Figure 4. Habitat suitability index

conservation status. Species classified as Least Concern (LC) include Heliaeschna filostyla, Celebargiolestes orri, Disparocypha biedermanni, Neurobasis kaupi, Pseudagrion ustum, Diplacina militaris, Nososticta flavipennis, and Drepanosticta ephippiata. Meanwhile, species classified as Vulnerable (VU) include Oligoaeschna venatrix and Drepanosticta hamulifera. For the Data Deficient (DD) category, some of the recorded species include Argiolestes celebensis, Libellago asclepiades, Teinobasis tenuis, Procordulia rantemario, Protorthemis celebensis, and Drepanosticta bicolor. Species categorized as Endangered (EN) include Rhinocypha pelengensis, Rhinocypha sangihensis, Rhinocypha togeanensis, and Rhinocypha virgulata. Species classified as Critically Endangered (CR) are Protosticta gracilis and Protosticta rozendalorum. Several other species, such as Anaciaeschna jaspidea, Vestalis luctuosa, Libellago aurantiaca, Agriocnemis femina, Hemicordulia assimilis, Ictinogomphus celebensis, Lestes quercifolia, Rhodothemis nigripes, and Protosticta annulata, have not yet been assigned a conservation status by the IUCN.

Habitat Suitability of Odonata

Spatial distribution of habitat suitability of Odonata

Based on habitat suitability modeling (Figure 4), nearly all families have a wide distribution on the

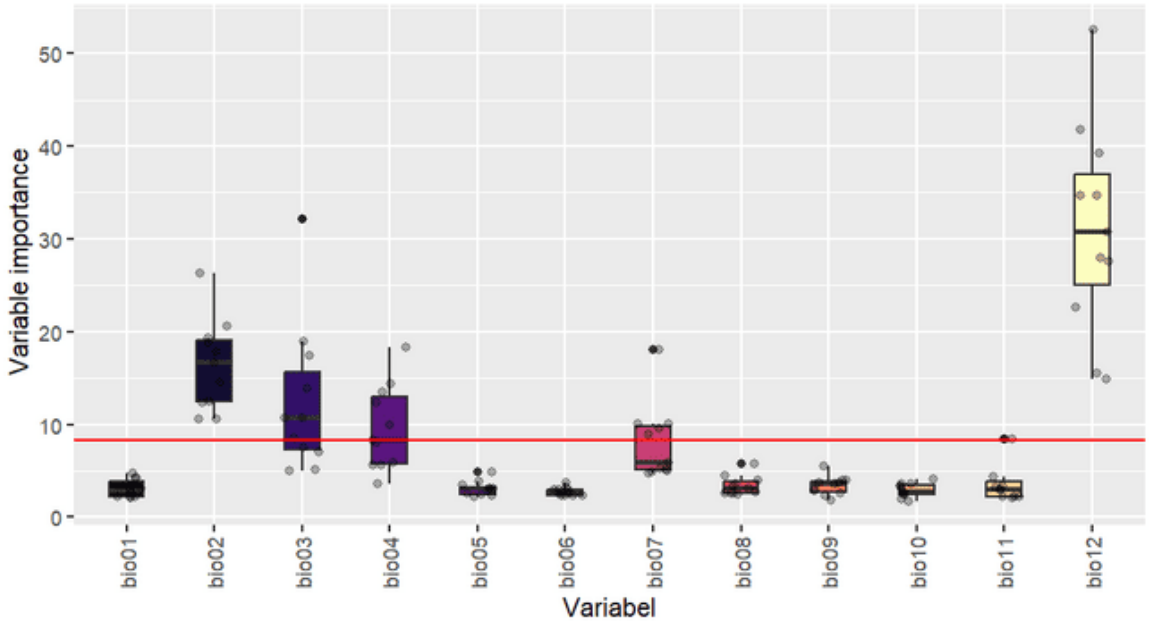


Figure 5. Variable importance of bioclimatic variables, mean of 8,32 (red line)

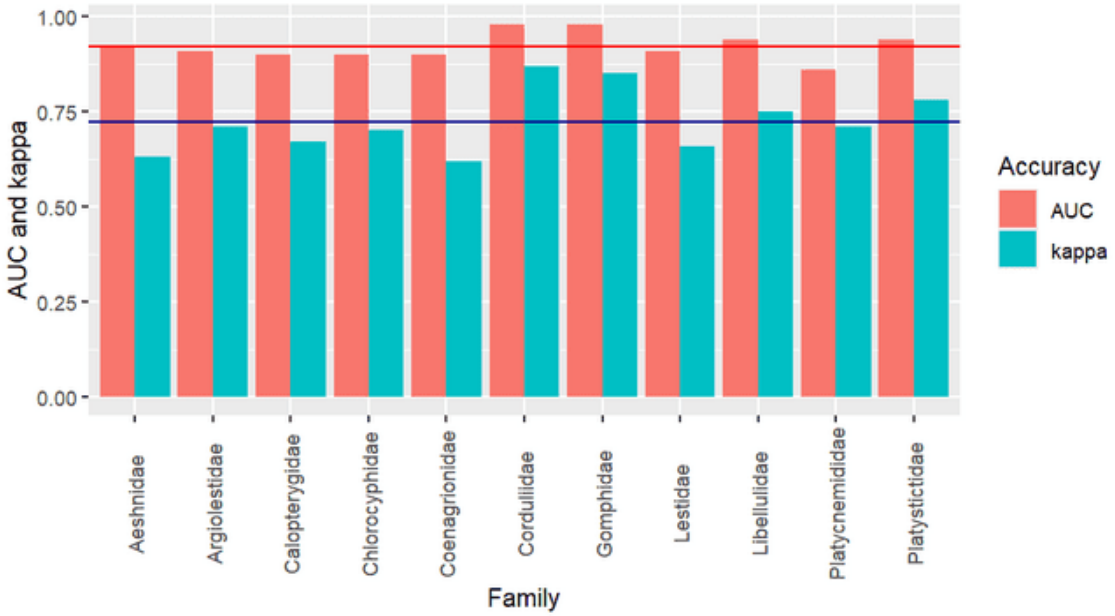


Figure 6. Accuracy of habitat suitability

island of Sulawesi. The family Platycnemididae exhibits high habitat suitability, covering the entire region of North Sulawesi and parts of Central Sulawesi. Meanwhile, the family *Corduliidae* has the lowest habitat suitability, occurring only in a small portion of the island, specifically in the northern and southern regions.

Model Model evaluation and accuracy of habitat suitability

The results of the analysis of the influence of each climatic factor on dragonfly habitats (Figure 5) show that variable bio12 (annual precipitation) has the highest value for dragonfly habitat suitability, followed by bio2 (mean diurnal range), which has an above-average value. Meanwhile, bio6 (minimum temperature

of the coldest month) shows the lowest value among the other variables.

Based on the results of the habitat suitability accuracy evaluation (Figure 6), two indices were used to assess model performance: AUC (Area Under the Curve) and kappa. The accuracy results showed that the average AUC value reached 0.92 and the kappa value was 0.72. The Corduliidae and Gomphidae families showed the highest AUC values, reaching 0.98, while the Platycnemididae family showed the lowest value at 0.86. Meanwhile, the highest kappa value was found in the Corduliidae family, reaching 0.87, and the Coenagrionidae family had the lowest value at 0.62.

DISCUSSION

Odonata Distribution

Mapping insects using data from the Global Biodiversity Information Facility (GBIF) is an effective way to determine habitat suitability and serves as an indicator of environmental quality. Based on the GBIF platform, approximately 2,152 insect species from the order Odonata—encompassing 11 families—were detected across the entire island of Sulawesi. Among these, the Chlorocyphidae family recorded the highest number of sightings at 722 individuals, followed by the Libellulidae family with 472 individuals. In the Sangihe Islands, North Sulawesi, the species Rhinocypha frontalis (family Chlorocyphidae) exhibited the highest abundance percentage at 44.3%, with its dominant habitat located in forested areas (Koneri *et al.* 2022). In contrast, the family Libellulidae, which is dominant in the North Minahasa region, exhibits the highest abundance in agricultural areas, indicating a preference for more open habitats influenced by human activities (Koneri *et al.* 2020; Lino *et al.* 2019). Meanwhile, the two families showing the lowest distribution based on GBIF data are Platycnemididae and Lestidae, with only 24 and 20 individuals recorded, respectively. This aligns with the findings of Khairun *et al.* (2023), who stated that Lestidae has the lowest distribution rate compared to several other families, such as Gomphidae and Libellulidae, which are more adaptable to various environmental conditions.

Based on bioclimatic factors, annual precipitation has the greatest impact on Odonata habitats. This aligns with the findings of Yoon and Kang (2024), which show that high annual rainfall makes freshwater more stable, thereby positively affecting the overall probability of dragonfly presence. Conversely, rainfall can also hinder larval development, thereby limiting dragonfly populations (Amundrud *et al.* 2018). Meanwhile, bio6 indicates the lowest value for dragonfly habitat suitability.

Habitat Suitability of Odonata

Habitat suitability is a major factor influencing the abundance and distribution of Odonata, as this order of insects is highly dependent on environmental conditions in both aquatic and terrestrial habitats. This dependence is evident in the varying responses of Odonata to different environmental characteristics. The diversity of damselflies (Zygoptera) tends to decline in water bodies with dense macrovegetation, likely due to reduced open space and disruption of microhabitat structure, while true dragonflies (Anisoptera) are more sensitive to human-induced land-use changes; however, their populations actually increase in areas with higher water flow (Nagy *et al.* 2019). In addition, some species, such as Boyeria truncata (family Gomphidae), exhibit sensitivity to elevation, with their populations declining in higher-altitude areas (Mahmoud *et al.* 2022). Other factors, such as the presence of aquatic plants, water flow stability, oxygen levels, and riparian (riverbank) vegetation, also play a crucial role in creating suitable habitats for Odonata (Vilenica *et al.* 2020). In fact, well-managed artificial water bodies can provide suitable habitats for various dragonfly species. Findings from Calvão *et al.* (2018) also indicate that dragonfly abundance is higher in rivers surrounded by grazing pastures compared to natural forest areas, suggesting that land cover type influences the structure and composition of dragonfly communities. Nevertheless, the Odonata biotic index is generally higher in lotic (flowing) habitats than in lentic (still) habitats, suggesting ecological specialization toward specific water types (Khelifa *et al.* 2019).

The role of vegetation surrounding water bodies is also a key factor in supporting suitable habitats for Odonata. In particular, well-preserved riparian vegetation plays a significant role in maintaining dragonfly diversity. Dragonflies are known to adapt to the natural resources available in undisturbed habitats, such as aquatic vegetation and organic matter along riverbanks (Borges *et al.* 2021). A decline in aquatic environmental quality can lead to shifts in community composition, where species richness of Zygoptera decreases, while that of Anisoptera tends to increase (Junior *et al.* 2017). Not limited to aquatic habitats, terrestrial habitats also contribute to the survival of adult dragonflies, as adult dragonflies are used in early monitoring to assess river conditions and as a cost-

effective tool for evaluating habitat restoration (Martin and Maynou 2016). Furthermore, adult dragonflies are used to assess landscape disturbances, allowing for large-scale evaluations of ecological health by assessing the vulnerability of these species (Sigutova *et al.* 2023). Some species, such as Sympetrum depressiusculum (Libellulidae), show a preference for open areas with high vegetation cover, such as semi-natural grasslands or open areas within forests (Hykel and Dolný 2016). Meanwhile, species from the family Aeshnidae use tall trees as perching or resting sites, especially when temperatures are low (Minot *et al.* 2021). Therefore, both the quality of aquatic habitats and terrestrial habitat conditions, including vegetation cover and the presence of a tree canopy, are interrelated and crucial aspects in supporting the life cycles of *Odonata* (Sigutová *et al.* 2019). Consequently, conservation efforts and the management of natural habitats, which include keeping river channels open, preserving natural vegetation landscapes, and maintaining small-scale traditional agricultural systems along river basins, have been shown to increase the abundance and diversity of dragonfly species (Nagy *et al.* 2019). In this study, forest cover analysis using the Habitat Suitability Index (HSI) is a key approach, as the loss of riparian vegetation and canopy—which serve as shade, egg-laying sites, or breeding areas—can directly impact the distribution and abundance of Odonata. Overall, *Odonata* serve as effective bioindicators for evaluating the condition of both aquatic and terrestrial ecosystems, and for identifying the impacts of land-cover changes (Junior & Juen 2019).

Methodological Evaluation and Limitation

The Species Distribution Modeling (SDM) approach used in this study successfully mapped the distribution of Odonata on Sulawesi Island, with an AUC value of 0.92, indicating a high level of model accuracy. However, this model still has limitations, such as an AUC accuracy value that is not yet optimal and the possibility of error. For example, the study by D'Ameni *et al.* (2015) modeled insect abundance using a combination of four statistical methods, namely the Generalized Linear Model (GLM), the Generalized Additive Model (GAM), the Generalized Boosted Model (GBM), and Random Forest (RF), yielding very high AUC values of 0.96 for grasshoppers and 0.96 for butterflies. Furthermore, when examined using the Kappa evaluation metric, the Coenagrionidae family had a Kappa value of only 0.62 (Figure 6). This is similar to the study by Grimmett *et al.* (2020), which used only RF-SVM-maxent-GLM in modeling the habitats of New South Wales species and yielded a Kappa value < 0.80. This indicates a need to optimize the machine learning models to achieve an optimal Kappa value, namely > 0.80. For example, the study by Duque-Lazo and Navarro-Cerrillo (2017) used ensemble SDM methods to improve predictive performance, achieving an AUC value of 0.89. Furthermore, the study by Khotimah *et al.* (2025) also yielded a high AUC value of 0.88. In addition, the use of optimal machine learning methods, as in the study by Pereira *et al.* (2025), was also shown to produce a Kappa value above 0.80 using the Random Forest machine learning method. In terms of the variables used, this study utilized only 12 variables from BIOCLIM; it is necessary to test all variables provided by BIOCLIM as well as other variables beyond BIOCLIM. For example, the study by Duan *et al.* (2014), which used 19 variables from BIOCLIM and 7 additional variables, achieved an AUC of 0.97 and a Kappa of 0.90.

CONCLUSIONS

This study demonstrates that a Species Distribution Modeling (SDM) approach combining the Random Forest algorithm and citizen science data can effectively map the potential spatial distribution of Odonata on Sulawesi Island, with average AUC and Kappa values of 0.92 and 0.72, respectively. The modeling results successfully identified areas with varying levels of habitat suitability, with forested areas and watersheds identified as primary habitats with high suitability for the survival of Odonata. A total of 2,152 Odonata presence records were documented across 11 families, including Chlorocyphidae (722), Libellulidae (472), Calopterygidae (132), and Platystictidae (233). Several species were identified as endemic or having high conservation status according to the IUCN, although the conservation status of many species remains poorly documented. These findings highlight the potential of machine learning-based distribution mapping to support long-term biodiversity monitring and conservation strategies for bioindicator groups such as Odonata in the Sulawesi region. To improve the reliability of Odonata distribution modeling, future studies should refine machine learning models using methoods adapted to tropical biodiversity data to improve model performance, particulary the Kappa coefficient. Furthermore, areas identified as highly suitable for Odonata should be prioritized for conservation through the protection and restoration of forest habitats, riparian vegetation, and frshwater ecosystems, alongside long-term monitoring to

maintain habitat quality and suppoort Odonata diversity.

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