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Distribution and Population Abundance of Odonates in Relation to Abiotic Factors in an Urbanized Freshwater Ecosystem: A Case Study from Universiti Sains Malaysia

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ABSTRACT

Odonates, including dragonflies and damselflies, serve as critical bioindicators of freshwater ecosystem health due to their sensitivity to environmental fluctuations. This study examines the distribution and abundance of odonates at Universiti Sains Malaysia, with a particular focus on assessing population abundance and identifying key biotic and abiotic factors influencing their distribution. Over a nine-week sampling period, a total of 1,256 individuals were recorded, comprising four dragonfly species *Brachythemis contaminata*, *Brachydiplax chalybea*, *Orthetrum testaceum*, and *Crocothemis servilia* and one damselfly species, *Ischnura senegalensis.* A hotspot analysis conducted using ArcGIS identified Sampling Station 2 (SS2) as a primary aggregation zone, accounting for 69.82% (877 individuals) of total odonate observations, largely attributed to its proximity to water bodies. The presence of *Hydrilla verticillata* emerged as a crucial factor in determining habitat suitability; however, its degradation due to algal blooms at SS1 and SS2 was associated with a decline in odonate abundance, particularly among species reliant on healthy aquatic vegetation. Statistical analysis revealed a moderate positive correlation between odonate abundance and abiotic parameters such as air temperature (r = 0.544, p < 0.001), relative humidity (r = 0.400, p = 0.008), and wind speed. However, multiple regression analysis indicated that only relative humidity (p = 0.009) and air temperature (p = 0.024) significantly influenced odonate abundance, while wind speed (p = 0.064) did not exhibit a statistically significant effect. Future research is recommended to investigate additional abiotic and biotic factors

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to further refine our understanding of odonate ecology and their role in freshwater ecosystem health assessment.

Keywords: Abiotic, ArcGIS, biotic, damselflies, dragonflies, *Hydrilla verticillate*, odonate

INTRODUCTION

Approximately 6,376 species of odonates, encompassing dragonflies and damselflies, have been identified worldwide. These species are classified into about 965 genera (Sandall et al., 2022). Odonates are categorized into two suborders: Anisoptera, which includes true dragonflies, and Zygoptera, which includes damselflies. Both suborders of the order Odonata undergo an incomplete metamorphosis, where the larval stages encounter 10 to 15 instars (Neog & Rajkhowa, 2016). The Odonata fauna in Malaysia is notably diverse. Dow et al. (2024) reported a total of 743 species in the Sundaland and Wallacea regions, with 549 species recorded in Sundaland, which includes Peninsular Malaysia, Singapore, Borneo, Sumatra, Java, and Bali. Of these, 482 species are endemic to these regions, with 385 being single-region endemics, many confined to specific islands. In Peninsular Malaysia and Singapore, 247 species from 17 families have been documented, comprising 99 damselfly species and 148 dragonfly species. In Sarawak, Malaysian Borneo, 303 species have been recorded.

Dragonflies are a type of insect that have bright colours, large eyes, and exhibit sexual dimorphism, colour transition, and polymorphism (Futahashi, 2016). These insects possess distinctive characteristics that differentiate them from other insects, including their long and thin abdomen, large round eyes positioned atop their heads, short antennae, and two pairs of wings (Neog & Rajkhowa, 2016). Damselflies' forewings and hindwings are almost identical in shape and venation, but dragonflies' forewings and hindwings differ significantly. Damselflies' wings contain similar structural traits, although dragonflies' wings vary significantly in shape and vein pattern (Kuchta & Svensson, 2014). Damselflies have compound eyes on either side of their heads, which provide a wide angle of vision. Their body form is slim and elongated, distinguishing them from dragonflies (Sumanapala, 2017). Damselfly nymphs have extended abdomens with three leaf-shaped tracheal gills. These lamellar gills let the nymphs absorb dissolved oxygen, allowing them to breathe in watery environments (Kriska, 2022).

Odonates demonstrate a higher susceptibility to pollution in comparison to other insects. Jacob et al. (2017) often recommended using odonates as indicators of environmental quality in aquatic habitats because of their well-documented advantages. Only a limited number of odonate species, including those belonging to the Megalagrion genus, have larvae that inhabit upland environments. These larvae are commonly found in damp leaf litter, characterized by a significant level of relative humidity. The remaining insects in this group may exclusively reproduce by depositing their eggs in, or near, freshwater. Dragonfly and damselfly species tend to be most abundant in sites that offer a wide range of micro-habitats. Consequently, an area that harbours many of these insects can be considered a dependable indicator of the quality of its freshwater. Odonates, are highly sensitive to changes in the quality of their habitat. As a result, their diversity and distribution are affected when the structural habitat quality changes. This sensitivity has made them valuable indicators for monitoring and evaluating the condition of the habitat quality (Jacob et al., 2017).

Odonates thrive in a wide range of habitats, with tropical rainforests being recognised as their most abundant and diversified ecosystems (Dow et al., 2015). The insects primarily dwell in riparian forests and places with abundant overhanging vegetation, indicating their inclination towards habitats near water bodies such as ponds, lakes, streams, and canals (Ramli & Manaf, 2021). Due to their susceptibility to environmental changes, they serve as excellent indicators of the overall condition of an ecosystem. Sollai and Solari (2022) emphasized that insects' hormonal regulation, neural function, sensory perception, and other physiological processes play a crucial role in their ability to adapt to environmental changes. Understanding how insects respond to ecological stressors provides valuable insights into habitat quality and overall ecosystem health. Additionally, research on herbivory and insect diversification suggests a complex interaction between dietary intake and evolutionary adaptation, highlighting how specialized feeding strategies have contributed to the vast diversity of insect species worldwide (Sollai & Solari, 2022).

Over the years, Malaysia has faced a notable decline in odonate populations, primarily due to habitat loss from urbanization, deforestation, and pollution (Hezri, 2018). Climate change has further disrupted their ecosystems, exacerbating population declines and threatening their ecological roles as both predators and prey (McCauley et al., 2015). Despite their significance as bioindicators of environmental health, research on odonates in Malaysia remains limited, hindering conservation efforts and a deeper understanding of their population dynamics. This study utilises Geographic Information Systems (GIS) to cartographically represent the spatial distribution of odonates at Universiti Sains Malaysia (USM), Gelugor, Pulau Pinang. GIS is employed due to its ability to analyse and visually display spatial data by integrating geographic information with specialised software (Chang, 2019). The main goals of this research are to determine the population size of odonates (dragonflies and damselflies), examine the factors, both biotic and abiotic, that affect their preference of habitat, and analyse the potential relationship between odonate population size and the biotic and abiotic factors. By employing GIS to determine the population abundance of odonates, researchers and conservationists can pinpoint crucial habitats and track changes in the population dynamics (Dminić et al., 2010). Therefore, GIS aids in the development of well-informed conservation strategies and the implementation of efficient management techniques for odonate species. This helps to reduce the likelihood of severe population loss, especially in Penang, Malaysia.

MATERIAL AND METHOD

Study Area

The study was carried out at the main campus of USM, which is strategically situated at a key entry point to Penang Island. The USM campus has a variety of habitats, such as a designated area for birds that are at risk of extinction, lush tropical forests, lakes, and orchards. The presence of these natural characteristics fosters a garden-like setting that sustains a wide range of plant and animal species, such as dragonflies and damselflies (Lee, 2003). Four sampling stations, namely Aman Damai Student Residence, Tasik Harapan, Jalan Ilmu, and Indah Kembara Student Residence, were selected due to their proximity to water bodies (Figure 1).

Sampling was conducted from mid-January to mid-March 2024, covering the transition from the rainy to the hot season. The study spanned nine weeks, with sampling carried out once per week on a designated day. On each sampling day, all four sampling stations were surveyed consecutively, resulting in a total of nine sampling days over the entire

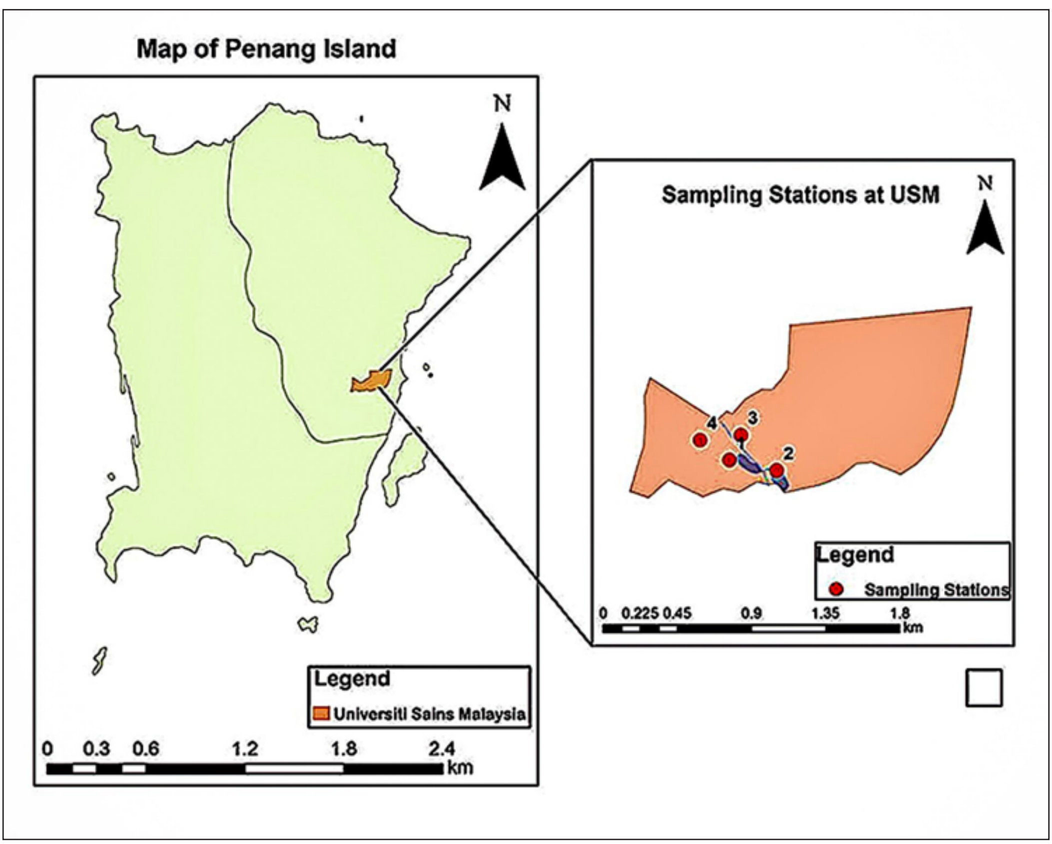

Figure 1. Study area and sampling stations at Universiti Sains Malaysia, Gelugor, Pulau Pinang

study period. The sampling occasion specimen collections were conducted from 2:30 to 4:30 p.m. Over two months of monitoring at the site, it was observed that odonates were most active between 9:00 a.m. and 6:30 p.m. Adult odonates were collected using aerial nets, identified, photographed, and either released or preserved in 70% ethanol for further identification using the Malaysia Biodiversity Information System (MyBIS) handbook "Ancient Creatures: Dragonflies and Damselflies of Malaysia" by Choong et al. (2017). Abiotic parameters, including air temperature, relative humidity, and wind speed, were recorded on every sampling day throughout the nine-week study period. Since sampling was conducted once per week, these parameters were measured a total of nine times, corresponding to each sampling session. Vegetation samples were collected and labeled by station, with photographs taken for species identification. Abiotic parameters, such as the wind speed, air temperature, and humidity, were measured using specialised devices to study their impact on odonate behaviour.

RESULTS AND DISCUSSION

Odonate Population at USM

Over a two-month field survey, 1,256 odonates were recorded at USM. A total of five species of Odonata were recorded. Four of these species are dragonflies from the Libellulidae family: (*B. contaminata*, *B. chalybea*, *O. testaceum*, and *C. servilia*). The fifth species, *I. senegalensis*, is a damselfly that belongs to the Coenagrionidae family (Figure 2). The Libellulidae family dominated the odonate assemblage, consistent with previous findings that highlight their adaptability in diverse freshwater habitats (Ng et al., 2022). Norma-Rashid (2001) highlighted *B. contaminata* as common in Malaysian freshwater habitats, both in urban and rural settings. Similarly, Das et al. (2012) highlighted that this species serves as an indicator of disturbance, frequently occurring in areas impacted by human settlements. On the other hand, the Coenagrionidae family is one of the most widespread and ecologically significant damselfly families, commonly found in various freshwater habitats, including ponds, lakes, and slow-moving streams (Willink et al., 2024). *Ischnura senegalensis*, a member of this family, is widely distributed across Asia, Africa, and parts of Australia, thriving in both natural and disturbed environments (Subramanian & Babu, 2017). Norma-Rashid (2001) noted its frequent occurrence in Malaysian wetlands, including rice fields and urban waterways.

Hotspot analysis using ArcGIS identified Sampling Station 2 (SS2) as the primary hotspot, accounting for 69.82% (877 individuals) of total odonate observations, while SS3 and SS4 had significantly lower abundance (< 250 individuals). Factors influencing this pattern include proximity to water sources, vegetation health, and abiotic conditions (Figure 3). Table 1 summarises odonate distribution across stations and weeks. The study by Barbosa-Santos et al. (2025) highlights that riparian vegetation quality influences the abundance of odonates. Specifically, it states that Zygoptera species were more abundant in streams with higher environmental integrity, emphasising their dependence on riparian vegetation for suitable habitat conditions (Barbosa-Santos et al., 2025). The study by Gajbe (2021) highlights the relationship between proximity to water sources and odonate abundance, where research evaluated the impact of a small artificial water source on odonate diversity in an urban landscape. Results showed that the availability of a water source led to an 80% increase in odonate species, indicating that even small man-made water bodies positively influence odonate populations by providing critical breeding and foraging habitats (Gajbe, 2021). In flowing water sites (lotic environments), the composition of odonate species varied with water temperature and proximity to urban areas. Specifically, different odonate species were found, depending on how warm the water was and how close the site was to urban centres (Prescott & Eason, 2018). Thus, odonate diversity was highest at sites with moderate urbanisation, supporting the intermediate disturbance hypothesis that suggests that moderate disturbance increases species diversity (Jere et al., 2020).

Thus, odonates diversity was highest at sites with moderate urbanization, supporting the intermediate disturbance hypothesis that suggests that moderate disturbance increases species diversity (Jere et al., 2020). The population data (Table 1) shows the following distribution: SS2 has the highest abundance with 877 odonates (69.82%), SS1 has 254 (20.22%), SS3 has 100 (7.96%), and SS4 has 25 (1.99%). Week 3 had the peak number of odonates (192), while week 9 had the lowest (93).

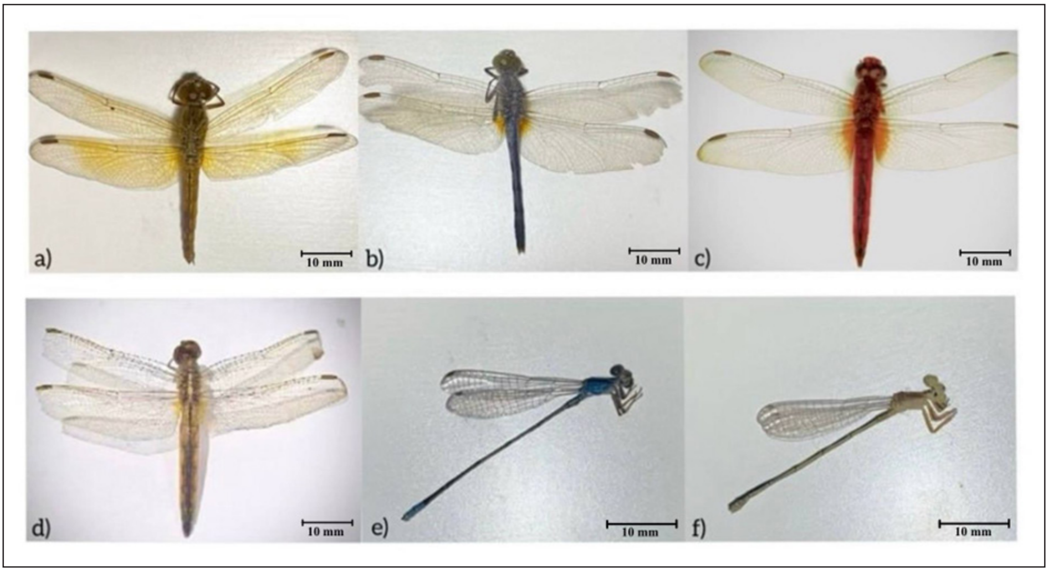

Figure 2. a) *Brachythemis contaminate* (female), b) *Brachydiplax chalybea* (male), c) *Orthetrum testaceum* (male), d) *Crocothemis servilia* (female), e) *Ischnura senegalensis* (male), and f) *Ischnura senegalensis* (female)

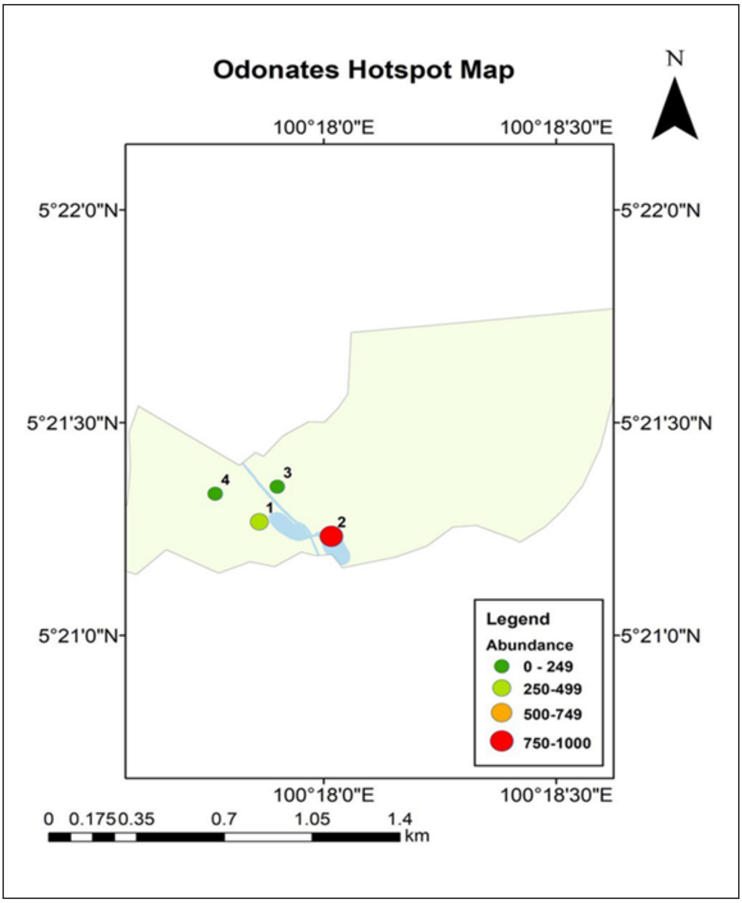

Figure 3. Hotspot mapping of Odonate abundance across sampling stations

Table 1

Odonate abundance by sampling station and week

Sampling station	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Total per station	Total percentage (%)
SS1	42	14	28	36	20	35	28	24	27	254	20.22
SS2	78	62	139	115	108	145	97	75	58	877	69.82
SS3	23	5	17	7	14	5	6	15	8	100	7.96
SS4	12	0	8	0	0	2	0	3	0	25	2.00
Total per week	155	81	192	158	142	187	131	117	93	1256	100
Total percentage (%)	12.34	6.45	15.29	12.58	11.31	14.89	10.43	9.31	7.40		

Influence of Biotic Factors on Odonate Habitat Selection

Table 2 shows the vegetation types at each sampling station and their impact on odonate abundance. Aquatic vegetation, *Hydrilla verticillata* (water thyme), was present at SS1 and SS2, while land vegetation varied across stations, including *Tabernaemontana divaricata* (crepe jasmine, pinwheel flower, or East Indian rosebay), *Cocos nucifera* (coconut palm), *Bambusa vulgaris* (common bamboo or golden bamboo), and *Jacaranda obtusifolia* (*Jacaranda*, green ebony, jambol merah, or jambul merak). Odonates were predominantly found in areas with *Hydrilla verticillata*, while fewer were observed on land vegetation. *Hydrilla verticillata*, an invasive species, showed a significant negative association with several odonate families, whereas other invasive plants did not have any significant impact (Thomas, 2019). Anisopterans such as *B. contaminata*, *B. chalybea*, *O. testaceum*, and *C. servilia* were found in this study; they typically prefer environments with less dense canopy riparian vegetation. As mentioned by de Resende et al. (2021), Odonata are generally found in moderately open canopies that allow sufficient sunlight penetration. Due to their heliothermic nature, dragonflies thrive in sunlit environments and are frequently observed in disturbed or degraded habitats where dense vegetation has been reduced or fragmented.

Bambusa vulgaris may offer an overly dense canopy in SS1 for these species, thereby restricting their abundance in the area. In contrast, all dragonflies and damselflies will thrive in settings containing *J. obtusifolia*, *C. nucifera*, and *T. divaricata*, which have moderate to sparse canopy cover and enable enough sunlight to pass through. *Hydrilla verticillata*, while not contributing to the canopy cover, provides an underwater habitat and breeding ground that can be beneficial, especially when combined with the species' preferred open, sunlit environment. As a result, these dragonflies are more likely to be found in areas where vegetation provides enough sunlight and an aquatic setting appropriate for reproduction in SS2 compared to other sampling stations.

Larval habitat availability also plays a critical role in odonate distribution. Since odonates have aquatic larval stages, the condition of aquatic vegetation is crucial for their breeding success. Figure 4 shows the health deterioration of *H. verticillata* caused by algal blooms, particularly at SS1 and SS2, which appears to have a direct influence on odonate abundance. These algal blooms likely lead to reduced water quality by causing

Table 2
Vegetation types at sampling stations

Sampling station	Aquatic vegetation	Land vegetation
1	*Hydrilla verticillata*	*Bambusa vulgaris*
2	*Hydrilla verticillata*	*Tabernaemontana divaricata*, *Cocos nucifera*
3	-	*Jacaranda obtusifolia*
4	-	*Tabernaemontana divaricata*, *Cocos nucifera*

oxygen depletion, blocking sunlight, and altering nutrient dynamics, which in turn affects the overall ecological balance of the habitat (Wiley & McPherson, 2024). Specifically, species such as *B. contaminata*, *B. chalybea*, *O. testaceum*, and *C. servilia*, which rely on robust aquatic vegetation for breeding and larval development, were less abundant in week 9 when *H. verticillata* was in poor health. This suggests that these species are highly sensitive to environmental degradation and that deterioration in aquatic vegetation directly contributes to odonate population declines. The findings emphasize the close ecological link between aquatic vegetation health and odonate diversity. As *H. verticillata* declines, it likely reduces the availability of shelter, egg-laying sites, and food resources for odonate larvae, ultimately leading to lower adult abundance. This reinforces the role of submerged macrophytes in maintaining odonate populations and highlights the need for conservation efforts to protect aquatic habitats from excessive algal growth and pollution.

In this study, we have examined odonate abundance as it is related to abiotic factors such as the air temperature, relative humidity, and wind speed and found a significant correlation between these variables and odonate counts. Over a nine-week time frame, odonate abundance peaked at 192 individuals in week three and dropped to 81 in week two. According to the research, greater air temperatures (32.18 to 33.20°C), increased humidity (82.50 to 86.25%), and higher wind speeds are associated with higher number of odonates. Odonates have impressive flying capabilities, including hovering and making

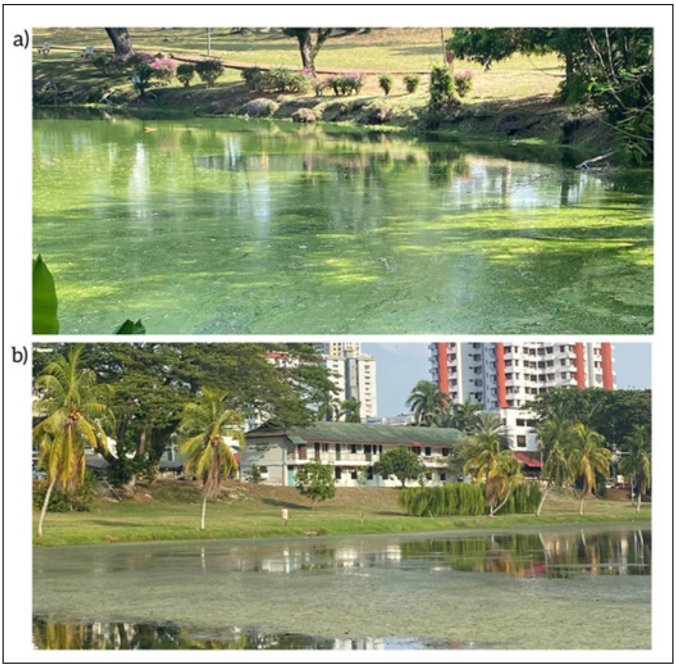

Figure 4. Algae bloom at lakes in (a) Sampling Station 1 and (b) Sampling Station 2 during week 9 of sampling

180° turns. Dragonflies fly faster than damselflies, reaching speeds of up to 25-30 km/h, which has significant effects on their dispersal and geographic distribution (Subramanian & Babu, 2017). The moderate correlation between wind speed and odonate abundance ($r = 0.583$, $p < 0.001$) indicates some impact, but the lack of statistical significance ($p = 0.064$) suggests that wind alone is not the primary limiting factor.

A study by Barzoki et al. (2021) found that wind may have a greater influence on Zygoptera since their bodies are typically smaller than Anisoptera and more susceptible to displacement. To cope with this challenge, damselflies adjust their perching behavior by orienting into the wind (rheotaxis) to maintain stability (Mason, 2017). Additionally, damselflies seek sheltered areas with vegetation to minimize wind exposure (Johansson et al., 2009). In contrast, dragonflies, being larger and having stronger flight muscles, are less affected by these environmental factors and can fly efficiently in open spaces without significant disruption (Barzoki et al., 2021).

Odonates' aerodynamic efficiency differs greatly between dragonflies and damselflies. To take flight, dragonflies must create 221% of the power needed to produce the same lift that would be necessary under perfect aerodynamic conditions, such as those represented by an 'actuator disc' or 'lifting line'. This reduced power would require more efficient flying mechanics. Damselflies, on the other hand, have less aerodynamically effective wing designs and require 275% of the optimal power to obtain the same lift. This greater power need implies that damselflies have less efficient wing structures than dragonflies, which affects their total flying ability (Bomphrey et al., 2016). These findings also show that these abiotic factors play an important role in defining odonate population dynamics, which is consistent with previous studies on the effect of environmental conditions (especially air temperature) on dragonfly dispersal (Flenner et al., 2010; Golfieri et al., 2016). Rachmawati et al. (2023) discovered that dragonflies' poor tolerance to air temperature had a detrimental influence on their survival. This sensitivity can lead to reduced abundance, poor health, lower survival and reproductive success, making it more difficult for these species to thrive or live in high-temperature environments.

Influence of Abiotic Factors on Odonate Abundance

Abiotic factors play a significant role in shaping the abundance and distribution of odonates. The present study revealed significant correlations between air temperature ($r = 0.544$, $p < 0.001$), relative humidity ($r = 0.400$, $p = 0.008$), and wind speed ($r = 0.583$, $p < 0.001$) with odonate abundance (Figure 5). However, multiple regression analysis indicated that only relative humidity ($p = 0.009$) and air temperature ($p = 0.024$) significantly influenced odonate abundance, while wind speed ($p = 0.064$) showed no significant effect. These findings suggest that while temperature and humidity are key determinants of odonate populations, wind speed may have an indirect or context-dependent role.

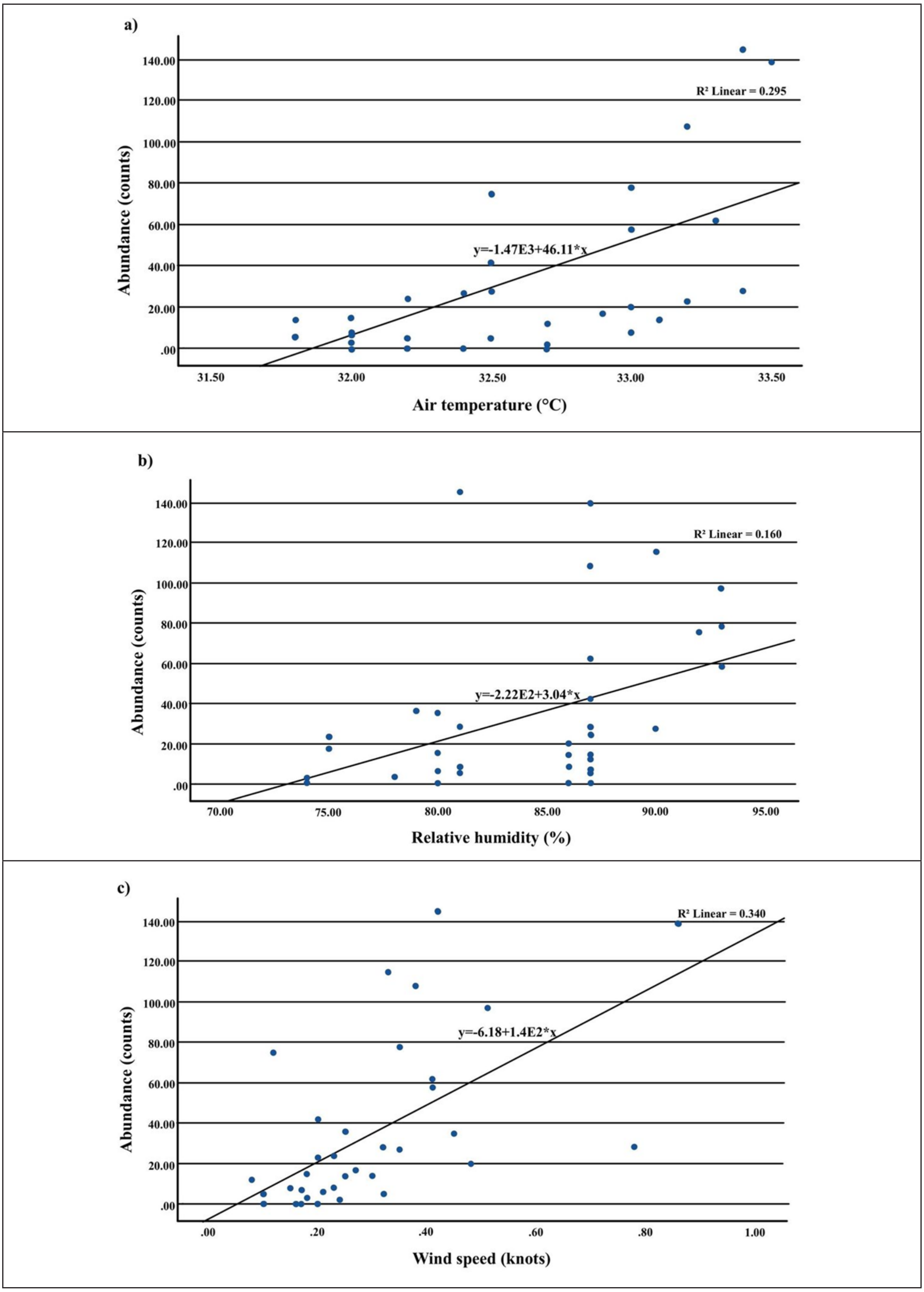

Figure 5. The relationship between odonate abundance and (a) air temperature (°C), (b) relative humidity (%), and (c) wind speed (knots), respectively

Temperature has long been recognized as a critical factor affecting the physiology, behavior, and life cycle of odonates. Rising temperatures have been associated with changes in thermoregulatory behavior, reducing the time available for reproductive activities, as individuals allocate more energy to maintaining optimal body temperature (Marcellino et al., 2024). Temperature playing both a favorable and limiting role depending on specific conditions (Knoblauch et al., 2021). The strong influence of temperature is largely attributed to increased sunlight exposure, which enhances diurnal insect activity, particularly in odonates (Becciu et al., 2019). Our study identified a moderately positive correlation between air temperature and odonate abundance ($r = 0.544$, $p < 0.001$), further supported by regression analysis ($p = 0.024$). Such changes have important implications for mating success and population sustainability under climate change scenarios. Moreover, elevated temperatures negatively affect larval development, as demonstrated by Bílková et al. (2025), who found that temperatures exceeding 24°C significantly reduced larval survival rates and hatchability. This aligns with previous research indicating that warmer temperatures accelerate larval growth and emergence, potentially leading to shifts in phenology (Bobrek, 2021). However, rapid development may not always be advantageous, as it can disrupt predator-prey interactions and alter community dynamics (Sandamini et al., 2019).

Notably, beta diversity in odonate assemblages is strongly linked to temperature fluctuations, with Anisoptera species being particularly sensitive to yearly temperature variations (Barzoki et al., 2021). Climate-induced shifts in minimum temperatures have further intensified changes in odonate life cycles, as evidenced by Villalobos-Jiménez and Hassall (2017), who reported that 50% of odonate species exhibited significant advancements in their phenological events in response to rising minimum temperatures. These shifts underscore the role of climate change in reshaping community structures, favouring climate-resilient species while potentially disadvantaging those with narrow thermal tolerances.

Air temperature and humidity have long been recognized as critical determinants of odonate abundance and diversity (Adu & Oyeniyi, 2019). Relative humidity also plays a crucial role in odonate abundance, as indicated by the moderate positive correlation observed in this study ($r = 0.400$, $p = 0.008$), with regression analysis confirming its significant influence ($p = 0.009$). The optimal humidity range for odonates has been reported to be between 78.11 and 81.67%, which supports their physiological functions and enhances flight activity (Koneri et al., 2022). Higher humidity levels help prevent desiccation and support sustained aerial activity, which is essential for foraging and reproductive behaviors. However, contrasting findings suggest that excessive humidity, particularly during rainy seasons, can negatively impact odonate populations by increasing mortality rates and reducing life expectancy (Palacino-Rodríguez et al., 2020). These fluctuations in odonate abundance over the nine-week sampling period (Figure 6) further illustrate the role of humidity in driving population changes.

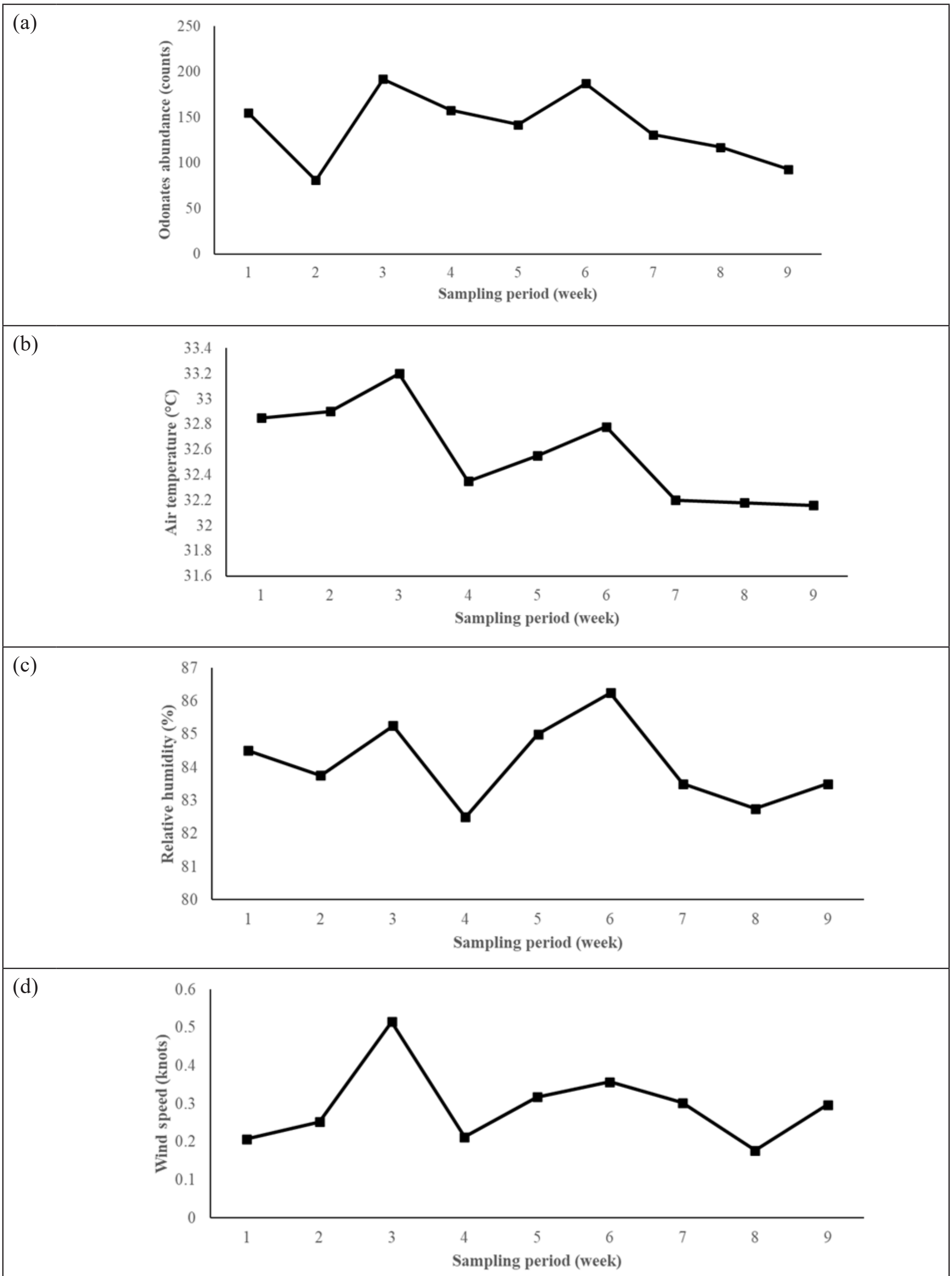

Figure 6. Odonate abundance and associated abiotic factors recorded over a nine-week sampling period at Universiti Sains Malaysia, Pulau Pinang. (a) Odonate abundance (counts), (b) air temperature (°C), (c) relative humidity (%), and (d) wind speed (knots)

The observed relationships between temperature, humidity, and odonate abundance highlight the potential impacts of climate variability on odonate populations. Shifts in temperature and moisture regimes could indirectly affect odonate distribution patterns and community structure, altering the ecological balance in freshwater ecosystems. Future research should further explore the thresholds at which these abiotic factors transition from being beneficial to detrimental, providing a more comprehensive understanding of how odonates respond to environmental changes.

Wind speed, although moderately correlated with odonate abundance ($r = 0.583$, $p < 0.001$), was not a significant predictor in the regression analysis ($p = 0.064$). While previous studies have shown that low wind speeds favour odonate activity (Johansson et al., 2009), strong winds can pose challenges, particularly for damselflies (Zygoptera), which are more susceptible to displacement than dragonflies (Anisoptera) (Barzoki et al., 2021). Consequently, damselflies often compensate by seeking sheltered microhabitats, reducing wind exposure and mitigating displacement risks. Additionally, thermoregulatory behavior may play a compensatory role in heat-stressed damselflies, enabling them to optimize body temperature despite wind-induced flight challenges (Hassall & Thompson, 2008). Given that temperature and humidity significantly influenced odonate abundance in this study, wind speed (Figures 5 and 6) may act as a secondary factor, indirectly shaping habitat selection and species distribution. Odonates exhibit rheotactic behavior, orienting themselves against wind currents to maintain stability during flight (Mason, 2017). However, excessive wind speeds may hinder foraging efficiency and increase energy expenditure, which could indirectly impact population dynamics. The inverse relationship between odonate abundance and wind speed observed in some weeks (Figure 6) highlights the potential impact of wind turbulence on flight efficiency, particularly in open habitats. The contrasting effects of wind speed suggest that its influence on odonates may depend on local environmental conditions and species-specific adaptations.

The broader implications of these findings must be considered in the context of climate change, which is expected to alter species assemblages and ecological interactions. Rising minimum temperatures have already been linked to changes in odonate phenology, with earlier emergence patterns observed in response to warming trends (Villalobos-Jiménez & Hassall, 2017). Additionally, climate-induced shifts in beta diversity suggest that certain species are better adapted to increasing temperatures, leading to changes in community composition (Barzoki et al., 2021). Long-term studies predict that climate-resilient species will gradually dominate odonate populations, while less adaptable species may face local extinction (Assandri, 2021; Bowler et al., 2021; Termaat et al., 2015).

Beyond climatic factors, odonate populations are also threatened by anthropogenic disturbances such as habitat degradation and urbanization. High current speeds, extreme temperatures, and strong winds can disrupt freshwater ecosystems, further exacerbating population declines (Albab et al., 2019). In urban areas such as USM Penang, habitat fragmentation and pollution pose additional threats to odonates, reducing their available breeding and foraging sites (The Habitat Foundation, 2021). Given the complex interplay between abiotic factors and anthropogenic stressors, conservation efforts must consider both climatic and environmental changes to ensure the long-term survival of odonate species.

Odonates rely heavily on clean, stagnant, or slow-moving freshwater sources, such as ponds, streams, and wetlands, particularly during their larval stage. However, rapid urbanization at USM Penang has led to significant habitat degradation, reducing the quality and availability of these aquatic ecosystems. The expansion of roads, buildings, and commercial infrastructure has decreased green spaces, leading to surface runoff, reduced groundwater replenishment, and the drying of small water bodies all of which threaten odonate populations. Similar trends have been observed globally, where water scarcity and land-use changes significantly restrict odonate habitats, particularly in semi-arid regions (Husband & McIntyre, 2021).

Additionally, pollution from agricultural runoff, industrial waste, and untreated sewage has led to increased contaminants, including pesticides, heavy metals, and excessive nutrients, which can be lethal to odonate larvae and reduce prey abundance. Pond size, aquatic vegetation, and freshwater macroinvertebrates also shape odonate diversity, as certain species are limited to agricultural or forest ponds, while others disappear entirely from urban water bodies (Le Gall et al., 2018). Interestingly, the fish-free pond at USM provides a unique habitat where dragonflies can thrive, aligning with McCoy et al. (2009), who found that odonates can persist in fish-free aquatic ecosystems due to reduced predation pressure. Their study highlights how the absence of fish, a major predator of odonate larvae, can create favorable conditions for odonate survival and reproduction. However, the absence of fish may also alter ecosystem dynamics, influencing species interactions and aquatic food webs (May, 2019).

CONCLUSION

This study demonstrates that odonate abundance in the freshwater ecosystems of USM is significantly influenced by abiotic factors, particularly relative humidity and air temperature. While wind speed exhibited a strong correlation with odonate presence, it did not emerge as a significant predictor in the regression analysis. These findings reinforce the ecological sensitivity of odonates to microclimatic conditions, underscoring their potential as bio-indicators of environmental change. The study also highlights the critical role of aquatic vegetation, particularly *H. verticillata*, in shaping odonate distribution. The degradation of this vegetation due to algal blooms was associated with reduced odonate abundance, emphasizing the need for maintaining healthy aquatic habitats. The identification of SS2 as a "hotspot" further suggests that habitat quality and proximity to water sources are key determinants of odonate populations. Thus, conservation efforts should focus on sustaining high-quality freshwater habitats, particularly in urban environments where anthropogenic disturbances threaten biodiversity. Future research should explore additional biotic interactions, such as predator-prey dynamics, and assess the long-term impact of climate variability on odonate populations to enhance conservation strategies.

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