BIODIVERSITAS
Volume 25, Number 7, July 2024
Pages: 2907-2920

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d250712

Habitat characteristics and threats of little-known endemic dragonfly, *Neurothemis feralis* (Burmeister, 1839) (Odonata: Libellulidae) in East Java, Indonesia

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Manuscript received: 17 May 2024. Revision accepted: 6 July 2024.

Abstract. *Susanto MAD, Gama ZP, Leksono AS. 2024. Habitat characteristics and threats of little-known endemic dragonfly,* Neurothemis feralis *(Burmeister, 1839) (Odonata: Libellulidae) in East Java, Indonesia. Biodiversitas 25: 2907-2920. Neurothemis feralis* is a dragonfly with limited distribution and is found only in the lowlands of Java, Sumatra, Krakatau, and Bangka. Its habitats that traverse anthropogenic area face various threats from human activities. Despite the imminent depopulation, much essential information regarding the biology of *N. feralis* remains scarce, deeming it with data deficient conservation status according to the International Union for Conservation of Nature (IUCN) Red List. This study aims to study habitat characteristics of *N. feralis* for future conservation purposes. This study was conducted in Surabaya, Sidoarjo, and Gresik, East Java Province, Indonesia, and had a five-month study period from July to November 2023. The results showed that *N. feralis* prefers locations with 36-64% air humidity, 29.2-35.8°C air temperature, and 16970-36400 lux light intensity. Air humidity positively correlated with the abundance of *N. feralis*, while high temperatures and light intensity tend to have negative impact. The coverage of vegetation with 20-100 cm height was found as another habitat component that positively affects its abundance, while the loss of this coverage understandably negates the dragonfly abundance. Vegetation provides habitat for *N. feralis*, as well as its prey, competitors and even predators. Despite *N. feralis* population can still be observed from urban areas with up to 82.40% residential allotment (within 500 m radius of the study site), the disappearance of its population is likely if believably impending if anthropogenic activities (e.g., land conversion and vegetation burning) continue to occur.

Keywords: Anthropogenic, dragonfly, habitat preference, urban, vegetation

INTRODUCTION

Dragonflies taxonomically belong to the order Odonata (Orr and Kalkman 2015). They experience three life stages, live as eggs and nymphs in aquatic bodies (Aziz and Mohamed 2018; Choong et al. 2020) before emerging as terrestrial adults (Deacon et al. 2019; Kietzka et al. 2021). Dragonflies are highly dependent on freshwater ecosystems as their primary habitats to ensure their life cycle continues (Paulson 2009; Thongprem et al. 2021). Freshwater ecosystems that intersect with anthropogenic areas, such as urbanized sites, face depopulation threats from land use change and environmental pollution. The freshwater ecosystems that intersect with anthropogenic areas, such as in urbanized sites, have experienced many land use changes and environmental pollution, potentially threatening dragonfly populations. This problem is similarly faced by at least 16% of 6,322 (Sandall et al. 2022) global dragonfly species, in addition to the ecological threats caused by environmental pollution, pesticide use, and climate change (IUCN 2021). Generally, dragonfly species have different tolerance levels in response to environmental damage and have habitats with different characteristics. Data on the habitat characteristics of a dragonfly species can be used to analyze its threat from changes in environmental quality. In addition, it can also be used as a guideline in developing conservation measures for endangered species.

Indonesia is estimated to harbor around 919 dragonfly species (Kalkman and Orr 2013; Orr and Kalkman 2015; Dow et al. 2024). There have been 356 studies on Indonesian dragonflies spanning between 1773-2019, mostly (282 studies) focusing on biodiversity (diversity, inventory, collection) and taxonomy (new species, phylogeny, morphology) (Lupiyaningdyah 2020). Research on ecological aspects such as population and habitat, especially for Indonesian endemics, still needs to be completed. It included the studies on life history and microhabitat of *Pericnemis stictica* (Coenagrionidae) in Central Java (Faradilla et al. 2020) and on the movement and dispersal of Javan endemic *Drepanosticta spatulifera* (Platystictidae) (Nugrahaningrum and Soesilohadi 2021). An endemic Indonesian dragonfly that lacks information regarding its habitat characteristics is *Neurothemis feralis*.

Neurothemis feralis (Libellulidae) was first described by Burmeister (1839) as *Libellula equestris* var. *feralis* from Chennai, India, where *Libellula equestris* is a synonym of *Neurothemis tullia*. However, Burmeister's

(1839) description of the species as *L. equestris* var. *feralis* could have been better. It did not detail the number of specimens and sex, which hamper the confirmation of whether it is a subspecies of *N. tullia* in India or a separate taxon from Java (Seehausen 2017). The holotype of *N. feralis* has a different coloration and wing pattern from the specimens of *N. tullia* in India and corresponds to those found on Java Island, so *N. feralis* is not a subspecies of *N. tullia*, but a valid species (Seehausen 2017).

Neurothemis feralis is a little-known dragonfly species that can only be found in Java, Krakatau Island, Sumatra, and Bangka Island (Lieftinck 1934; Tol 1990; Baskoro et al. 2018; Dow et al. 2024; iNaturalist 2024). It is relatively rare and has a very limited distribution (Lieftinck 1934). Its distribution in Java is known from Bekasi, Jakarta, Bogor, Banyumas, Semarang, Rembang, Gresik, and Sidoarjo (Lieftinck 1934). Recent studies reported the existence of *N. feralis* in Semarang (Baskoro et al. 2018), Sidoarjo (Abdillah 2020), and Surabaya (Susanto 2022; Susanto et al. 2023). These studies, however, were more about population rather than habitat characterization. *N. feralis* is found in the habitat types of rice fields, fish ponds, and swamps (Abdillah 2020; Baskoro et al. 2018) and can be found in urban areas, namely in the habitat type of ponds (Susanto 2022). In East Java, *N. feralis* live in lowland habitats, mostly in urban areas in Surabaya, Sidoarjo, and Gresik, Indonesia.

With current minimum information regarding the habitat of *N. feralis*, in addition to the threat of local extinction and challenging situation in conserving it, it is urgent to have a complete account of the habitat characteristics of this species. The International Union for Conservation of Nature (IUCN) reports that further data on *N. feralis* is urgently needed for formulating conservation actions, especially regarding its population, distribution, and ecology (Dow 2013). Therefore, this study aims to report and provide information on the habitat characteristics and threats of *N. feralis* dragonflies in East Java that can be used as recommendations for future *N. feralis* conservation efforts.

MATERIALS AND METHODS

Study area

This study was conducted on five habitat types spread in three cities in East Java Province, namely Surabaya, Sidoarjo, and Gresik, Indonesia. The selection of study sites was based on the presence of *N. feralis*, which was previously confirmed through preliminary studies (Figure 1). The preliminary studies to determine the distribution location of *N. feralis* species in East Java had been carried out for four years, from 2020 to 2023. More distributional information was gained through literature studies in scientific journals and citizen science databases (GBIF Secretariat 2023; iNaturalist 2024). Upon these preliminary data, five habitat types were established: urban forests, rice fields, reservoirs, fish ponds, and natural ponds (Table 1). Each habitat type was selected according to the environmental characteristics and conditions of *N. feralis*. A total of 10 study sites were chosen (Figure 2), in which two sites represented a habitat type. The two sites on each habitat type helped to broaden the perspective on characterizing the habitat type, since more differences in environmental conditions.

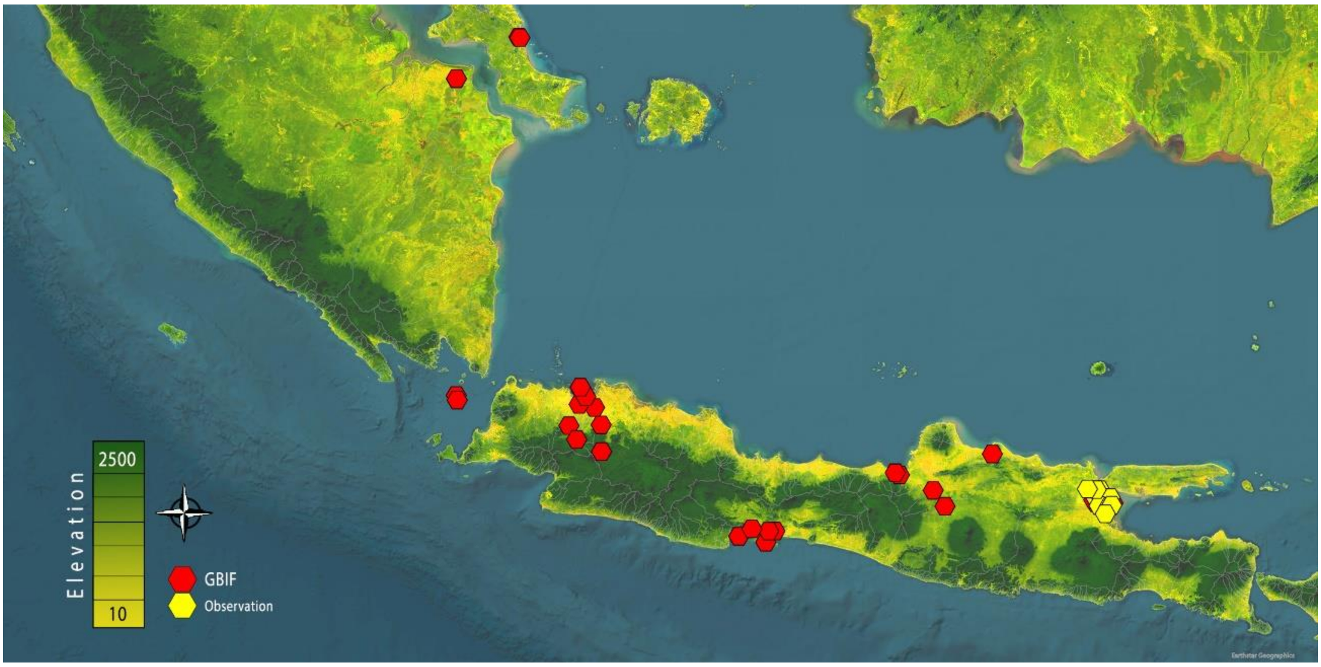

Figure 1. Distribution of *Neurothemis feralis* in Java and Sumatra (according to GBIF Secretariat 2023)

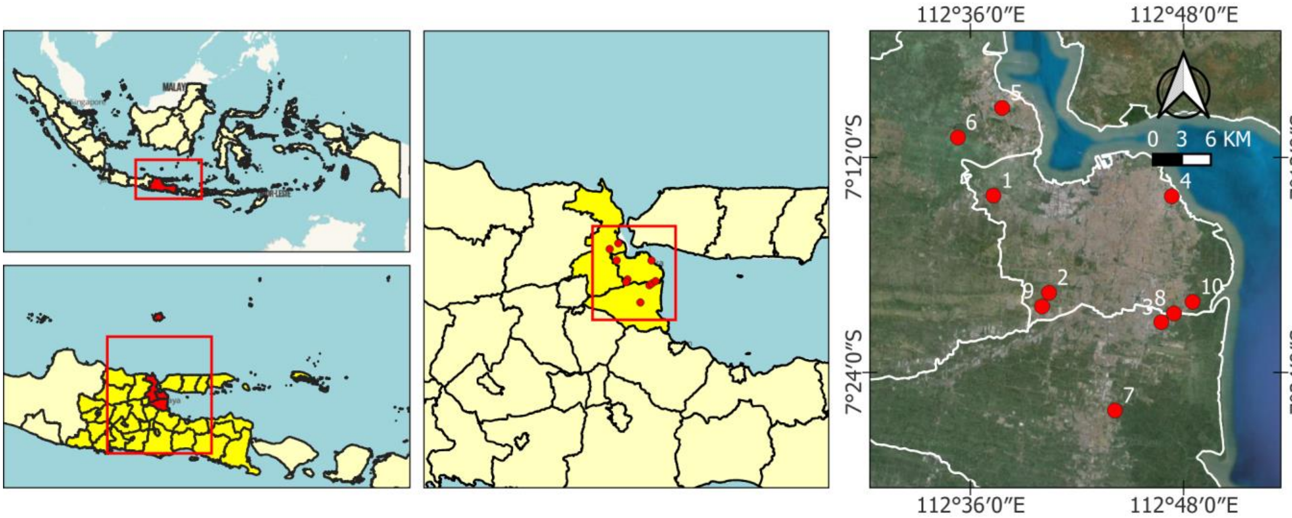

Figure 2. This study's survey sites are in Surabaya, Sidoarjo, and Gresik, East Java, Indonesia. Note: Site numbers refer to Table 1.

Table 1. Information on study sites

No.	Site	Site code	GPS coordinates		Elevation (m asl.)
			Latitude	Longitude	
1	Urban Forest	UF	-7.235444°	112.621639°	04
2	Cultural Reserve Urban Forest	CR	-7.325861°	112.673861°	08
3	Tambakrejo Rice Field	TRF	-7.353333°	112.779194°	03
4	Kenjeran Rice Field	KRF	-7.236028°	112.789111°	02
5	Ngipik Reservoir	NR	-7.153861°	112.629861°	13
6	Betiring Reservoir	BR	-7.181306°	112.588361°	05
7	Buduran Fish Pond	BPF	-7.435500°	112.735722°	02
8	Gununganyar Fish Pond	GPF	-7.345083°	112.791111°	02
9	Warugunung Pond	WP	-7.338722°	112.667361°	18
10	Gununganyar Pond	GP	-7.334333°	112.808611°	01

Identification

Adult *N. feralis* has a relatively small body size for Anisoptera dragonflies, which is 26-30 mm. The male is characterized by a dark color from the base of the wings to the nodes and curves downward (Seehausen 2017). The thorax and abdomen are black, with a yellowish-brown color on the upper abdomen of immature individuals (Figure 3.A). Appendages are yellow at the base (become darker when older) and black at the tip (Figure 3.C). The female has yellow extending from the base of the wings to around the nodes, with brown pattern at the tip of the wings (Seehausen 2017). The thorax and abdomen are brown, with sides with a yellowish-brown color extending on the top (Figure 3.E).

Data collection

Fieldwork was conducted from July to November 2023. Field data collection was carried out by making monthly visits to each and all study sites subsequently; therefore, each site received five visitations or fifty field surveys for the overall study. Data collection was performed during sunny daylight, starting from 07.00 until 16.00. It was carried out using transect method, divided into terrestrial plots with a total of 50x5 m, detailed into 10 subplots of 5x5 m, and 20x2 m aquatic plots, divided into 10 subplots of 2x2 m. The data collected in each subplot included the counting of adult *N. feralis* individuals, its potential prey, and its prominent competitors; all were observed using the sweeping net technique. In this study, potential prey was determined as any aerial insect measuring between 4.5-30 mm, potential competitors were defined as other dragonfly species, and potential predators as vertebrates and other arthropods. Population counting of *N. feralis* involved capturing all individuals to avoid double counting, which then released upon the site perceived to contain no more individuals of the targeted species. Some representative males and females were sampled and preserved for further identification and documentation purposes. Potential prey were assessed using the sweep net technique, with 10 sweeps conducted on each plot (Hykel et al. 2016). Potential predators and competitors were assessed using Visual Encounter Survey (VES) assisted with direct observation using photography technique. Potential prey are identified at the family level, while potential competitors and predators are identified at the species level. The entire identification process is carried out using identification books (MacKinnon et al. 2010; Setiyono et al. 2017; Baskoro et al. 2018; Boyle et al. 2021; Taufiqurrahman et al. 2022) and websites (iNaturalis 2024). The specimens produced from this study were stored in the KUTRIK Entomology Study Group repository.

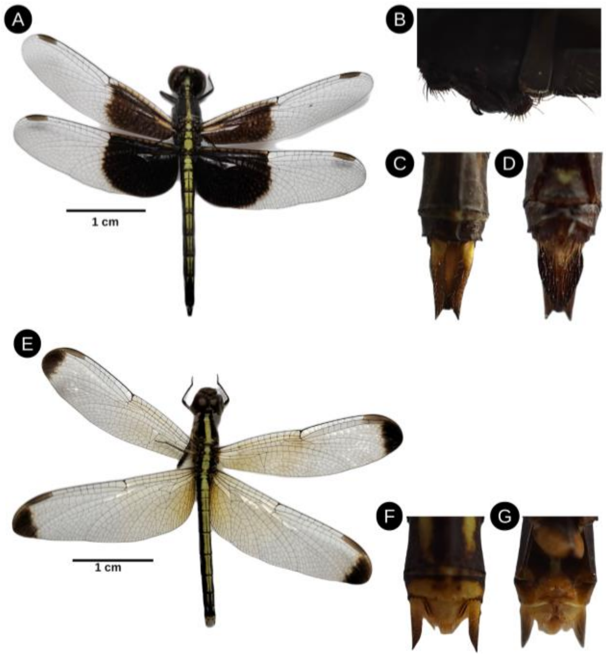

Figure 3. *Neurothemis feralis* A. Male, B. Secondary genitalia ♂ (lateral), C. Cerci (upper appendages) ♂ (dorsal), D. Epiproct (lower appendages) ♂ (ventral), E. Female, F. Cerci ♀ (dorsal), G. Cerci ♀ (ventral)

Measurements of microclimates, including air temperature and air humidity (using a thermohygrometer) and light intensity (using a light meter), were taken from each subplot, along with the data on terrestrial vegetation cover composition (following Worthen et al. 2021), which included plants with height categories of >20 cm, 20-100 cm, 100-200 cm, and <200 cm. Meanwhile, aquatic vegetation was divided into emergent and floating vegetation. Land use cover composition in each site was calculated within 500-meter radius (with a circle shape) with a total area of 785,000 m^2 using QGIS 3.22 software. The land use analysis includes seven types of land, namely settlement, rice fields and agriculture, barren land, road, waters, industry, and plantation.

Data analysis

Data on the abundance of *N. feralis* and the potential food chains it is involved in, which include prey, predators, and competitors, were analyzed using descriptive analysis with tables and graphs processed using Microsoft Excel 2020 and Paleontological Statistics (PAST) 4.10 (Hammer et al. 2001). Microclimate data at each study site were analyzed using Boxplot with PAST 4.10 software. Potential food chain data were analyzed using the Important Value Index (IVI), with the formula IVI = relative abundance (%) + relative frequency (%). Data on the quality of various *N. feralis* habitats, including potential food webs, vegetation, microclimate, vegetation cover, and adult *N. feralis* abundance data, were analyzed using Spearman's correlation analysis using PAST 4.10. In addition, to analyze the correlation between Odonata abundance, sampling location, and environmental factors, a Canonical Correspondence Analysis (CCA) test was conducted using PAST 4.10.

RESULTS AND DISCUSSION

The abundance of population and general conditions of *Neurothemis feralis* habitat

The five-month survey conducted at ten study sites in East Java recorded a total of 486 individuals of *N. feralis*, with tendency to decline its abundance. Initially, 248 individuals were recorded in July, while during the last survey in November, only 12 individuals were observed. The population at all sites showed that males were dominant over females (306 males versus 180 females). Cultural Reserve, an urban forest habitat type, became the most populated site where a total of 101 individuals were recorded. On the other hand, Warugunung, a pond habitat type, was recorded as the least populated site, with a total of 25 individuals.

The population of *N. feralis* showed temporal fluctuation during the monthly observation (Figure 4). Furthermore, the observation in October and November at six sites, Cultural Reserve, Ngipik Reservoir, Gununganyar Fish Pond, Gununganyar Pond, Urban Fores, and Warugunung Pond, demonstrated no presence of any *N. feralis*.

The results of this study show that the population of *N. feralis* has decreased seriously due to damage to environmental conditions and the loss of water bodies. Damage and loss of most of the important components that make up the habitat can disrupt *N. feralis* activities, so the population will continue to decline until it disappears. At the Cultural Reserve site, which is the site with the highest abundance, in September and October, some trees and herbaceous vegetation have been cut, as well as landscaping that resulted in the loss of swamp water bodies and the loss of herbaceous vegetation on the edge of the ponds (Figure 5). This reduced the abundance of *N. feralis*, which previously had 38 individuals in August, to only nine individuals in September and was no longer found in October and November. Damage or loss of vegetation can have a huge impact on insect populations (Bell et al. 1991). Damage to vegetation at the edge of water bodies caused by anthropogenic activities can have a negative impact on dragonflies (De Oliveira-Junior et al. 2017).

The decline of habitat quality and loss of water bodies also occurred at the Gununganyar Fishpond and Ngipik Reservoir sites. Construction on Gununganyar Fish Pond occurred from September to October, which resulted in the loss of all water bodies and vegetation. This reduced the abundance of *N. feralis*, which previously had 25 individuals in August, to only two individuals in September and was not found again in October and November. Dragonflies are sensitive to environmental changes due to anthropogenic activities such as land use change, and damage and loss of water bodies will also affect dragonfly abundance (Goertzen and Suhling 2019). Meanwhile, in most areas of Ngipik Reservoir, herbaceous vegetation was burning in September and October. Hence, *N. feralis*, which previously had 19 individuals in August, had only three individuals in September and none in October and November.

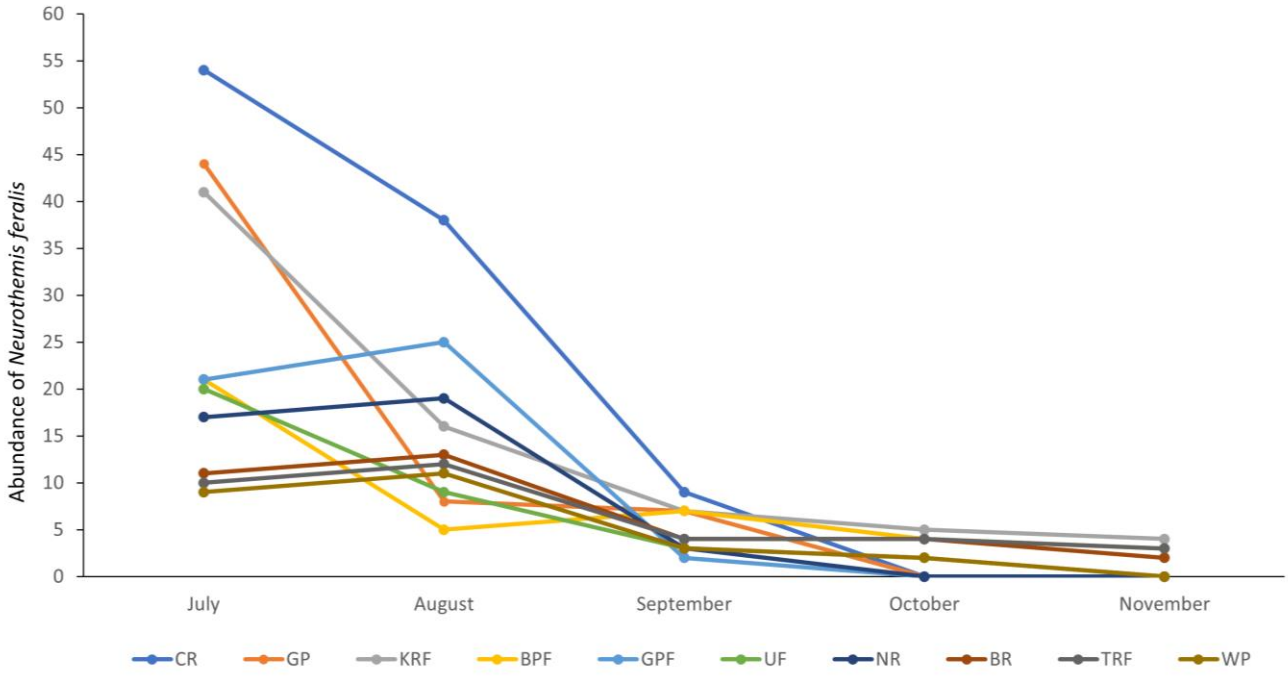

Figure 4. Abundance (individuals per sampling attempt) of *Neurothemis feralis* at study sites

Figure 5. Habitat shifting and vegetation burning at study sites between July-October: A-B. Cultural reserve; C-D. Gununganyar fish pond; E-F. Ngipik reservoir

Figure 6. Habitat shifting due to drought observed at sites during period July-September. A-B. Warugunung Pond, C-D. Urban Forest

In November, two more sites were observed the absence of *N. feralis*: Tahura and Warugunung Pond. The drought that has occurred since September has diminished aquatic bodies in both sites (Figure 6). This absence was unexpected, as the observation during the previous two months had recorded only five individuals at each site. In addition, the last individuals observed at these sites were males, which likely related to their independence toward aquatic bodies, in contrast to females, that require it for laying eggs. Warugunung also experienced land-burning during November, which severed the coverage of grass and herbaceous, adding the causative factor for the absence of *N. feralis*.

Neurothemis feralis was always observed at four sites: Tambakrejo Rice Field, Kenjeran Rice Field, Betiring Reservoir, and Buduran Pond. During the study, these four sites retained their aquatic habitats despite having their water volume decreased. The rice fields in Tambakrejo and Kenjeran were harvested in September, yet aquatic habitats in the forms of puddles or small ponds remained. The presence of limited water sources at these two sites helped the existence of *N. feralis* throughout the observation period. It possibly still uses these water sources for breeding and laying eggs (Tang et al. 2010).

Microclimate condition

Microclimate is an abiotic environmental component that plays a vital role in the survival of dragonflies. Most species require ideal microclimate to optimize their activities, such as foraging, sunbathing, mating, and resting. This study observed that *N. feralis* inhibits sites with 29.2-35.8°C air temperatures, 36-64% air humidity, and 16970-36400 lux light intensity (Figure 7).

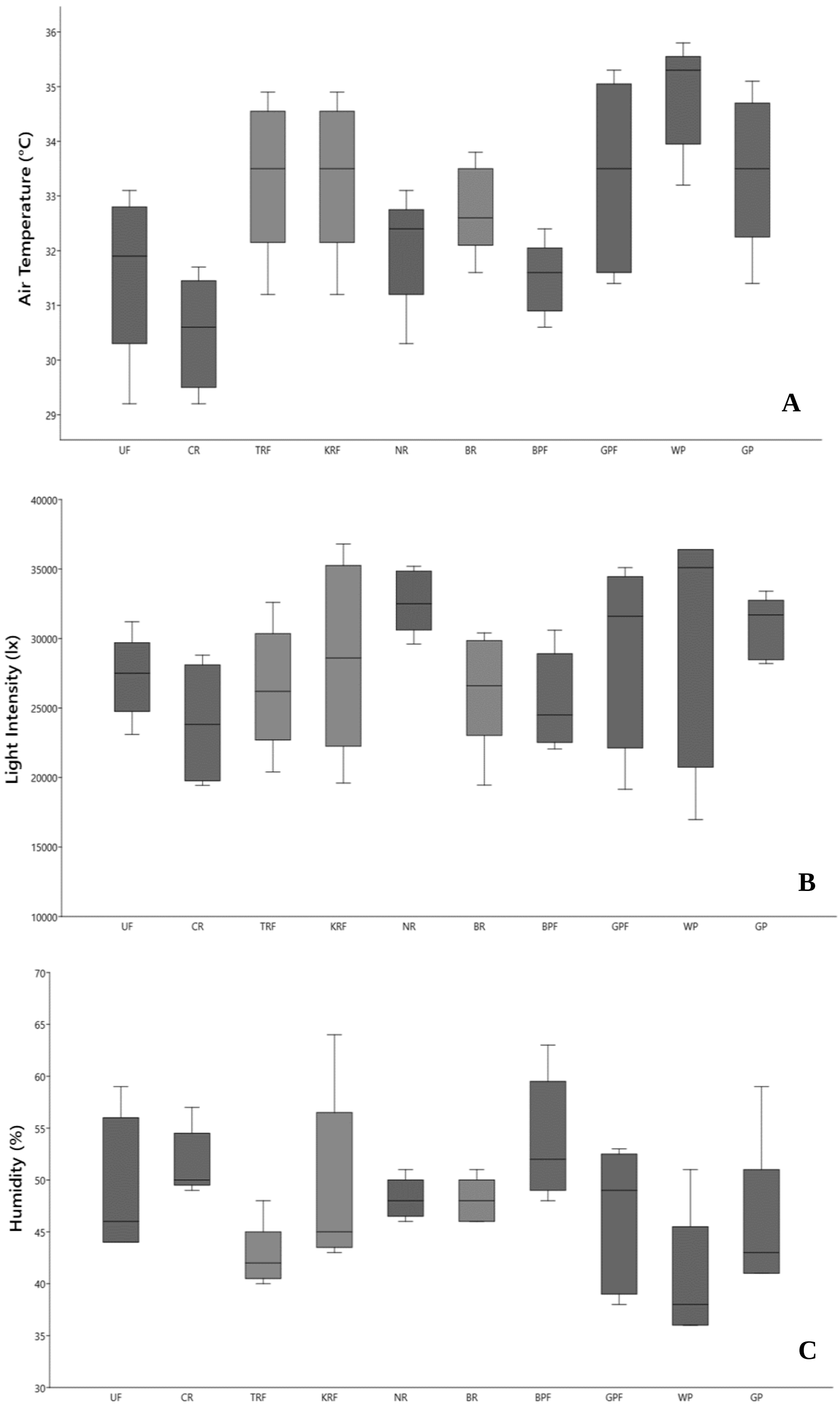

Figure 7. Boxplot graph of microclimate at study sites: A. Air temperature; B. Light intensity; C. Humidity

Cultural Reserve had the lowest air temperature and light intensity compared to all other study sites (Figure 7). As an urban forest, the Cultural Reserve is inhibited by various vegetation and adjacent to aquatic bodies, hence resulting in averagely low air temperature and light intensity. This condition is believed to be favored by *N. feralis*, as 101 individuals counted from this site and made it the most populated site among others by this dragonfly species. Ideal air temperature and light intensity are related to the abundance of *N. feralis*, in which low air temperature and light intensity can increase the abundance of dragonflies (Ball-Damerow et al. 2014).

The site with the highest air temperature and light intensity was Warugunung Pond, although it had the lowest air humidity (Figure 7). One possible explanation for this observed condition was that Warugunung Pond had an open canopy site with a lack of upper vegetation cover that was essential to block incoming sunlight. This site was near to the industrial area that was surrounded by arid land. Having the highest air temperature among other sites, Warugunung pond indeed had the lowest abundance of *N. feralis* observed during the study. Aside from this environmental condition, Warugunung Pond site still retains its capacity to be habitat for dragonflies as its average air temperature falls between the minimum air temperature threshold for dragonflies between 20-28°C (Lutz and Pittman 1970), as well as within the maximum air temperature threshold which ranges from 30-40°C. Warugunung pond also experienced drought since September due to extremely hot weather, which heavily evaporated water bodies there and caused averagely low air humidity. Low air humidity can be harsh for most dragonfly species, albeit those adapted to this condition can dominate the habitat. This situation has been observed in urban areas where air humidity significantly and negatively correlated to the evenness of dragonfly species while positively correlated with the dominance of certain adaptive species (Susanto et al. 2023).

Vegetation cover condition

Vegetation coverage is another important factor affecting the activity of *N. feralis*. Vegetation is useful for perching (Figure 8), sunbathing, and foraging of *N. feralis* as well as other dragonflies. Adult dragonflies generally utilize vegetation for perching or sunbathing (Deacon et al. 2019; Susanto et al. 2024), similarly used by dragonflies for vegetation around water bodies (Briggs et al. 2019). Vegetation is also a habitat for other insects that are considered prey for dragonflies. Thus, it is crucial for sustaining food for *N. feralis*.

Overall, terrestrial vegetation across study sites was dominated by vegetation of 20-100 cm in height (Figure 9). Based on observations, *N. feralis* preferred foraging, sunbathing, and perching at this range of vegetation height, while on several occasions, it was found perching, hiding, and resting at 100-200 cm of vegetation. Vegetation with height between 20-100 cm consisted of grasses and reeds, favoring the abundance of *N. feralis* since it provides more spacious room for this poor flight species. Anisoptera dragonfly abundance had a very strong relationship with vegetation cover of 20-100 cm (Worthen et al. 2021). Low vegetation height provides space for flying close to the ground surface and is favorable for *N. feralis* to do their daily activity.

Figure 8. *Neurothemis feralis* (A. Male and B. Female) perched on vegetation

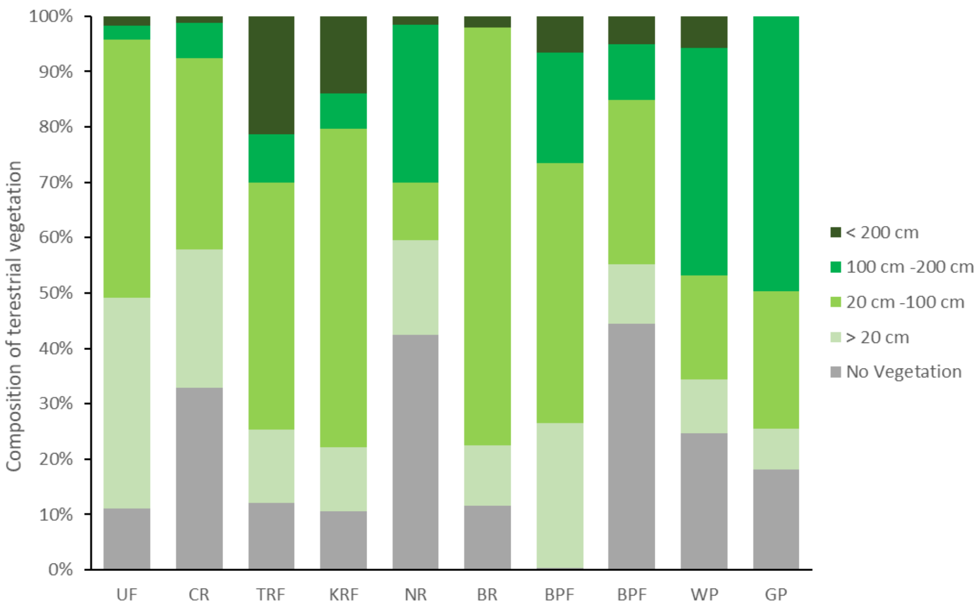

Figure 9. Composition of terrestrial vegetation at study sites

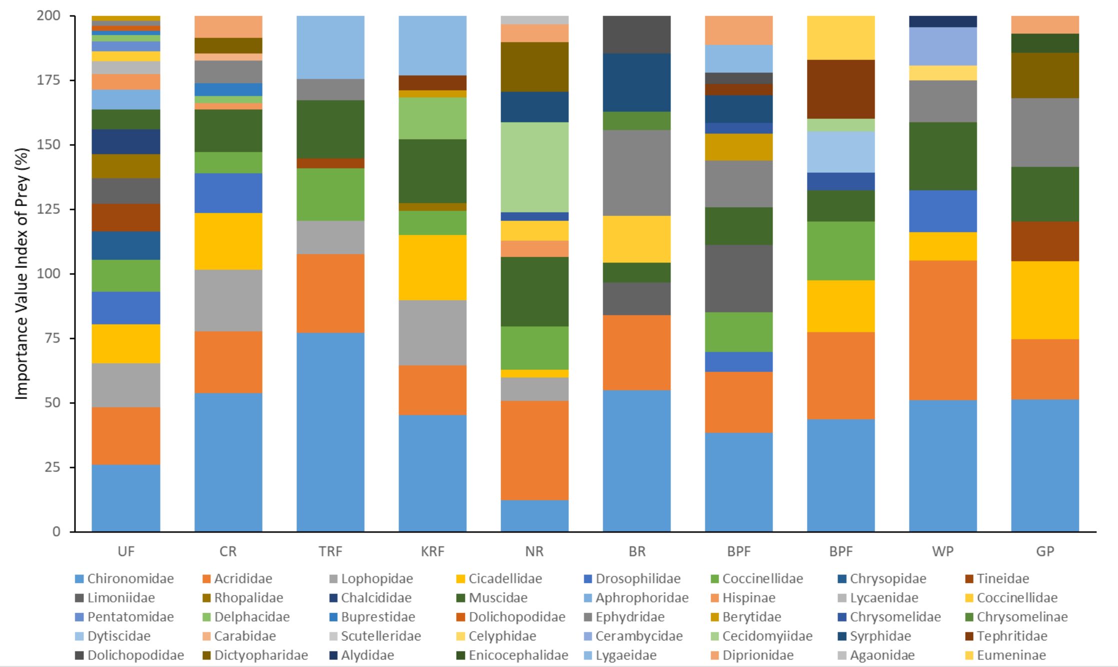

Figure 10. Importance value index of potential prey

Cultural Reserve site, which had the highest abundance of *N. feralis*, was 34.56% covered with vegetation with 20-100 cm height (Figure 9). Cultural Reserve had seriously barren land cover (32.94%) after Gununganyar fish pond and Ngipik reservoir, which might have resulted from anthropogenic interferences (vegetation cutting, land conversion) during the study. In July, Cultural Reserve was covered by 50% of vegetation with 20-100 cm height, while the barren land was only 6.20% of the total area. During this time, the abundance of *N. feralis* was counted to 54 individuals. However, during October survey, after anthropogenic activities impacted the site, the vegetated area remained at 18% of total land and subsequently increased barren land to 60.50%. Consequently, no *N. feralis* was observed during this time. This observation emphasized that major changes in vegetation coverage significantly impact *N. feralis* populations. The damage to vegetation around water bodies, especially from human activities, has been reported to have a negative impact on dragonfly diversity (De Oliveira-Junior et al. 2017).

Warugunung site, which was observed to have the lowest abundance of *N. feralis*, had 41.14% coverage of vegetation with 100-200 cm height and 24.72% barren land. During October and November, this site was impacted by drought and vegetation fires, which then extended its barren land. In July, 55.70% of Warugunung site was covered by vegetation with 100-200 cm height, while the barren land was only 5.30% of the total area; during this time, 9 individuals *N. feralis were* counted. In November, after the fire that reduced the cover of vegetation to 19.50% while extending the barren land to 50.50%, *N. feralis* ceased to exist therein.

Potential food webs

Potential prey

Potential prey at each study site had different composition taxonomically (Figure 10), as well as varying Importance Value Index (IVI) for each taxon. In all study sites (except Ngipik Reservoir), Chironomidae possessed the highest IVI (25.90-77.16%). It was followed by Acrididae, which at Warugunung Pond recorded with the highest IVI.

Aside from being observed from all sites, Chironomidae (Diptera) was counted as the highest IVI in eight sites. The highest IVI of Chironomidae at Cultural Reserve was concomitant, with the highest abundance of *N. feralis* therein. Chironomidae was presumably essential prey for sustaining *N. feralis* population at this site. As flying dipterans, Chironomidae, sized as a mosquito, have a very short lifespan, inhabit shallow eutrophic waters, and sometimes emerge in tremendously large numbers of individuals (Cranston 2004). Chironomids also prefer grassy vegetation, which makes them the most appropriate prey for *N. feralis*. Not only for dragonflies, Chironomids are also food source for most insect predators or other insectivorous organisms (Cranston 2004, Kaunisto et al. 2019).

Acrididae, a herbivorous grasshopper (Khatimah et al. 2022), was also recorded at all study sites. As grassland-inhabiting insects, Acrididae are potential prey for *N. feralis*, which co-inhabits the same habitat. Previous studies in Malang of East Java also found Acridids inhabited the same habitat of *Orthetrum sabina* (Libellulidae) with a strong indication that it became part of *O. sabina* prey (Dalia and Leksono 2014).

Potential competitor

Six dragonfly species were analyzed as potential competitors for *N. feralis*, namely *Acisoma panorpoides*, *Brachythemis contaminata*, *Crocothemis servilia*, *O. sabina*, *Ischnura senegalensis*, and *Agriocnemis femina* (Figure 11). They were found at all sites during this study, especially those with lentic aquatic habitats. All these potential competitors, except *A. panorpoides*, were generalist dragonflies with high tolerance toward various environmental conditions or relatively closed habitat conditions.

The existence of *B. contaminata* was detected at all study sites, which resulted in the highest IVI for this species in at least six sites. The high tolerance to environmental changes of this species was thought to be the reason it was recorded from all sites surveyed in this study (Rachmawati et al. 2023). It can compete with *N. feralis* in terms of foraging and space utilization, as both are typically found in the same places. In some locations where *B. contaminata* dominated, *N. feralis* seemed to avoid the co-existence. Aside from preferring open water, *B. contaminata* can often be found in large numbers of individuals (Setiyono et al. 2017).

Orthetrum sabina was another species recorded at all sites. It is also considered a high tolerance dragonfly species toward alteration in environmental quality, including its ability to breed in urbanized area, which is mostly artificial environment (Buchori et al. 2016; Potapov 2020; Rachmawati et al. 2023; Banaybanay et al. 2024). It can inhabit various altitudes (Leksono et al. 2017). Despite wide array of habitats they exist, *O. sabina* primarily resides near open water with grassy vegetation. In this study, *O. sabina* was observed to have ability as competitors for *N. feralis* with similar reasons to *B. contaminata* above.

Potential predator

Using the IVI evaluation, three potential predators have been identified, namely sooty-headed bulbul *Pycnonotus* (Pycnonotidae, Aves) and oriental garden lizard *Calotes versicolor* (Agamidae, Squamata), both recorded at nine sites, as well as common sun skink *Eutropis multifasciata* (Scincidae, Squamata) at eight sites (Figure 12). Despite being omnivorous bird, *P. aurigaster* can present predation risk similarly to the other two common lizards observed in this study; hence their commonality at the study sites gave great chance for encountering *N. feralis* and possible predation.

Calotes versicolor is a carnivorous reptile that primarily preys upon insects, including dragonflies (Sudasinghe and Somaweera 2015). It can be found in various types of habitats, such as forests, shrubs, plantations, and urban areas from sea level up to 3000 m (Cahyadi and Arifin 2019; Wogan et al. 2021). Meanwhile, *E. multifasciata* has been recorded to prey on spiders, terrestrial isopods, earthworms, millipedes, gastropods, amphibians, other reptiles, and insects (Ngo et al. 2014). In addition to its adaptivity toward various habitats, it can dwell at the altitude 0-1800 m (Shea et al. 2018). Both reptiles are invasive, intentionally or unintentionally introduced through wildlife trading or shipments of other products (Maharani et al. 2023). Aside from their invasiveness, they both also prefer similar habitats to *N. feralis*, which increases their potential as predators for this dragonfly.

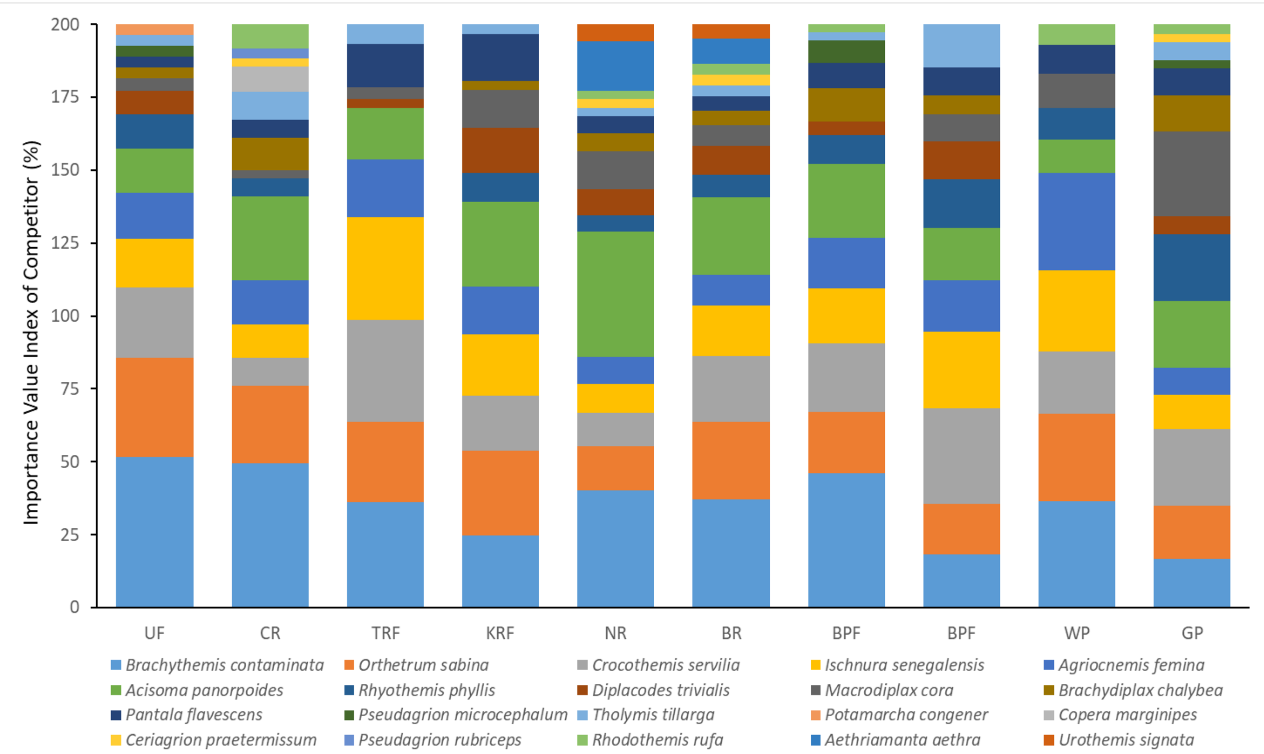

Figure 11. Importance value index of potential competitor

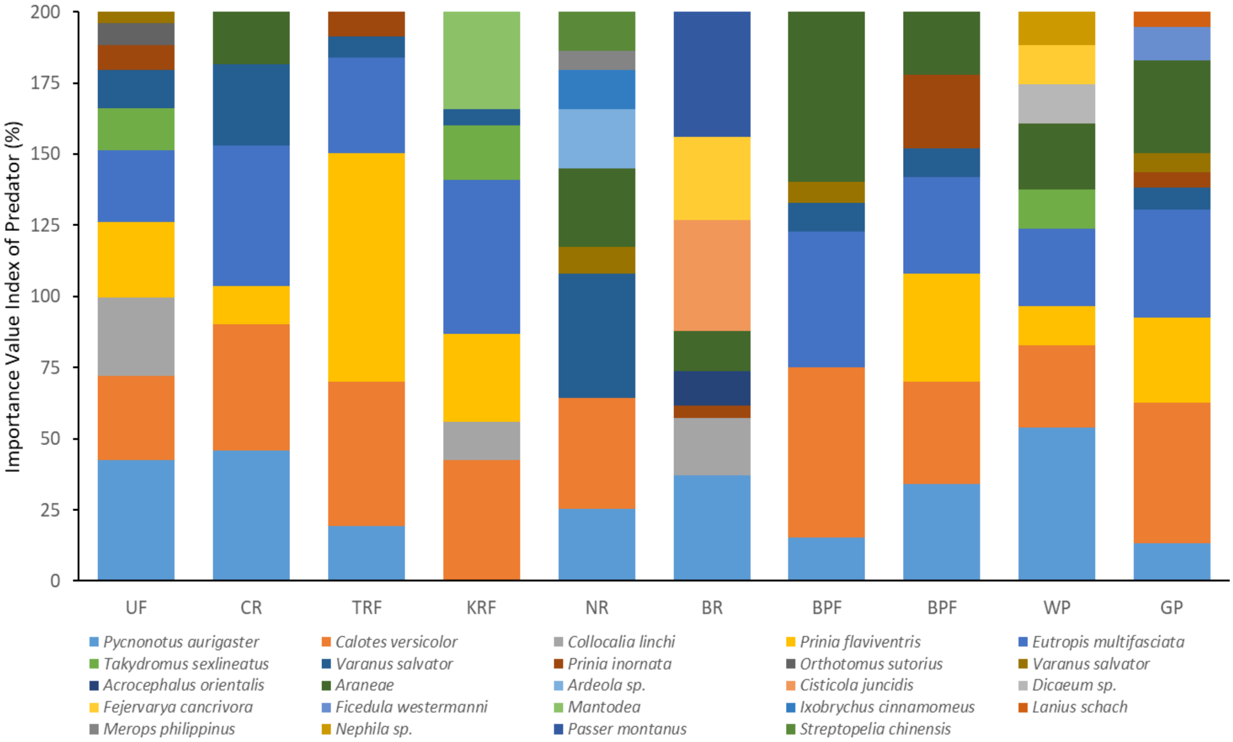

Figure 12. Importance value index of potential predator

Table 2. Composition of land use at study sites

Site	Land use (%)						
	Settlement	Rice fields and agriculture	Barren land	Road	Waters	Industry	Plantation
UF	51.00	20.08	17.43	7.91	3.58	0.00	0.00
CR	31.39	27.95	15.92	1.36	5.31	6.18	11.90
TRF	82.40	3.05	4.18	5.30	5.07	0.00	0.00
KRF	33.86	34.85	13.89	3.12	14.29	0.00	0.00
NR	0.91	8.98	18.33	1.15	28.26	20.68	21.69
BR	26.08	19.56	5.46	1.75	47.15	0.00	0.00
BPF	36.30	24.70	14.58	1.67	0.64	22.11	0.00
GPF	20.55	0.00	30.73	7.32	41.16	0.24	0.00
WP	2.37	31.59	28.10	4.84	4.50	15.98	12.61
GP	44.05	0.00	29.74	3.57	19.75	2.89	0.00

Composition of land use at study sites

The analysis of this study showed that the study sites were dominated by settlements (five sites), waters (three sites), and rice fields and agriculture (two sites) (Table 2). How land is anthropogenically utilized will affect dragonfly populations. Land use practice can modify a site into suitable habitat if provided with water bodies used by dragonflies to cater (Guadalquiver et al. 2022), lay eggs (Orr and Kalkman 2015), or place for completing developmental process of dragonfly nymphs (Choong et al. 2018). Modified habitats such as rice fields, agricultural areas, and plantations can harbor various small insects that are prey for dragonflies. The composition of land use affects the quality of habitats along with the dragonflies that live therein. Impairment to the landscape from various causes can significantly change species composition, presenting threat to local species and habitat specialists by being replaced by well-adapted generalist species (Dolný et al. 2021).

Aquatic bodies are important for *N. feralis* to use as breeding sites. Observation confirmed that *N. feralis* was present at sites with 0.64-47.15% of aquatic portion. Hence, the presence of aquatic bodies in the surrounding study sites provides buffers and refugia whenever the sites change or are damaged by anthropogenic activities. However, active fish ponds and rivers may not be a suitable alternate habitat for *N. feralis*. Active fish ponds are unsupportive for the aquatic stage of dragonflies' life cycle as the reared fishes present another risk of predation (Hsu et al. 2011). Meanwhile, rivers or streams with rapid torrents are not suitable for nymphs and are not equipped for lotic conditions.

Neurothemis feralis was recorded at sites with 0.91-82.40% settlement portion (Figure 13). Despite being highly modified into human settlements, the existence of green open land among the settlements or other artificial greeneries could provide accommodation for *N. feralis* populations. The denser the urbanized areas, the lower the quality of habitats, which in turn pose threat to the existence of various insect species (Willigalla and Fartmann 2012). Dragonflies respond rapidly to this situation by decreasing their abundance and even causing population loss (Lozano et al. 2022). Despite having 82.40% of its area as settlement, Tambakrejo Rice Field was observed with consistent existence of *N. feralis* in all study periods. The dragonflies might have been successfully using available water sources at this site or probably come from their surroundings.

Roads which used for community mobilization also present another risk for *N. feralis* population. Despite only 1.15-7.91% of all site's portion, roads can create challenges for the range and mobility of *N. feralis* when foraging and finding breeding sites. Roads with high traffic volumes negatively impact insect community due to the potential mortality from crashing with high-speed vehicles (Muñoz et al. 2015). Roads create barriers to the mobility of *N. feralis*, especially because this dragonfly flies close to the ground. Flying insects with weak flight abilities are vulnerable to the presence of roads, as they can easily run over or hit by running vehicles (Soluk et al. 2011).

Correlation of environmental factors with *N. feralis*

The results of the correlation analysis showed that the habitat component factors that were significantly positively correlated with the population abundance of *N. feralis* were air humidity, potential prey abundance, potential competitor abundance, potential prey abundance, vegetation cover of 20-100 cm height, and vegetation cover of <200 cm height (Figure 13). Air humidity and potential prey abundance are the most significant factors that positively affect *N. feralis* abundance. On the contrary, air temperature, light intensity, and barren land negatively correlated with the abundance of *N. feralis*. Knowledge of the factors that correlate positively and negatively is very important to determine the characteristics of *N. feralis* habitat and to guide future conservation efforts.

Air humidity is significantly and positively correlated with the abundance of potential prey, an abundance of potential competitors, and the existence of vegetation cover at 20-100 cm height; all three are important for the dragonfly. Ideal humidity can tremendously encourage the abundance of potential prey (e.g., small insects), which in turn favors the abundance of *N. feralis*. The decrease in prey population can disrupt the population of *N. feralis*. This can be because *N. feralis* will potentially search for new habitats that will suffice for their food consumption. This study has identified several factors that negatively correlate with the abundance of potential prey, namely vegetation loss, high air temperature, and high light intensity. On the other hand, the last two factors were detected also to have a negative impact on the abundance of *N. feralis*.

The Canonical Correspondence Analysis (CCA) showed that all study sites varied in environmental quality (Figure 14). The lumping of environmental quality variation plots of most study sites indicated their similarity in terms of environmental quality. The more adjacent and overlapping the plots in this analysis, the more similar the environmental conditions that the sites have (Koneri et al. 2022).

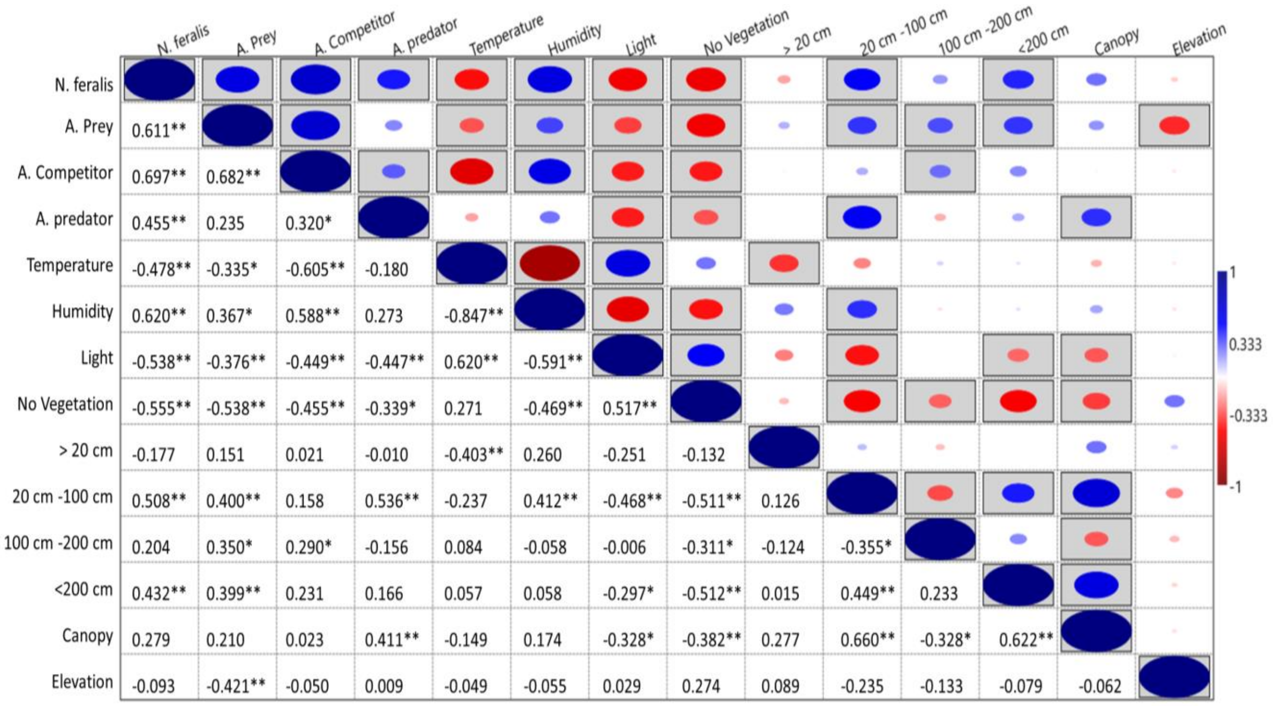

Figure 13. Correlation between environmental factors and the abundance of *Neurothemis feralis*. Note: A) is Abundance. *significance between 0.01-0.05, **significance >0.01

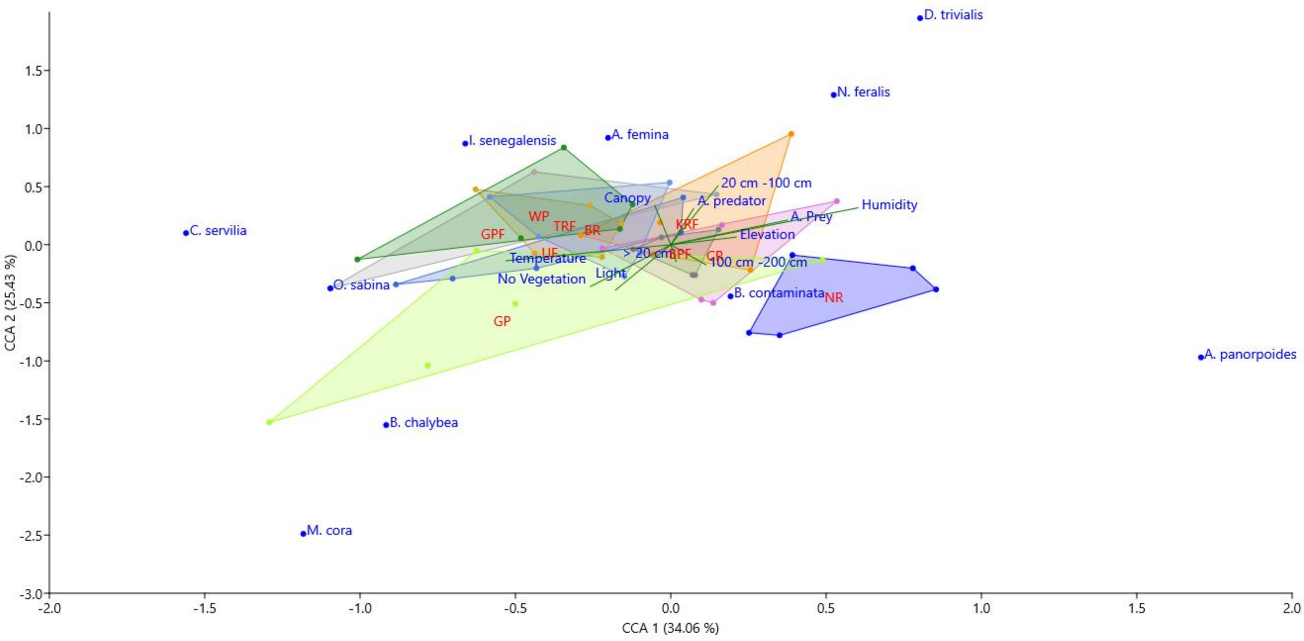

Figure 14. Ordination diagram of the Canonical Correspondence Analysis (CCA) in the ten study sites

This CCA analysis supported that *N. feralis* populations positively responded to the prey abundance, air humidity, and vegetation cover at 20-100 cm height. In addition, *N. feralis* responds to the same environmental factors similarly to *Diplacodes trivialis* as competitor, due to the semblance of habitat. This competitor was found with *N. feralis* in grassy vegetation in almost all study sites, except Cultural Reserve and Warugunung Pond. Both species have some similarities, such as flying low above the ground and perching on grass vegetation, and are generally found in lotic water types. *D. trivialis* inhabits grassy habitats at water edge (Susanto 2022), as well as at rice fields, ponds, lakes, and other aquatic habitats (Subramanian 2020).

Threats of *Neutothemis feralis* at study sites

Neurothemis feralis has a data-deficient status according to the IUCN Red List database, which inquires for further information about its population and distribution in order to assess its extinction threat (IUCN 2024). Species with data-deficient status need more information regarding population rate, due to their low presence and abundance. Species with this status tend to face higher threat risk and unknowingly experience extinction (Parsons 2016; Borgelt et al. 2022).

As recently split from its nominated species, *N. feralis* is known to be limitedly distributed in few parts of Indonesian archipelago, while its population size was not appropriately assessed in each locality. In the meantime, its main habitat in the lowlands faces continuous threats from human activities. This study recognized several threats that potentially reduce or diminish *N. feralis* population, i.e., the loss of water bodies from development process, land use changes that alter vegetation structures, fire on herbaceous vegetation, and drought. Prolonged hot weather and drought also threaten *N. feralis* populations, as well as the disappearance of green space and continuous extension of road networks in urban areas. As an insect with weak flight ability, *N. feralis* can face difficulty in searching alternative habitats and even perish beforehand.

This study strongly indicated the dependence of *N. feralis* toward lentic waters in the lowlands, influenced by two environmental factors, microclimate and vegetation. While air humidity and the coverage of vegetation with 20-100 cm height positively encourage the abundance of *N. feralis*, air temperature, light intensity, and barren land gave adverse impacts. The population of *N. feralis* conflicted mainly with the interest of the community. Hence, the involvement of community and governing authority is essential in order to conserve *N. feralis*. Protecting this endemic species means protecting its habitat, especially from burning the vegetation it needs as a habitat, as well as minimizing the land use change that impacts the aquatic bodies that are substantial for the life cycle of many dragonflies.

ACKNOWLEDGEMENTS

We would like to thank the Indonesia Endowment Fund for Education (*Lembaga Pengelola Dana Pendidikan/* LPDP), Indonesia for funding this study. We sincerely thank M. Nazri Janra and Pungki Lupiyaningdyah for their help in writing and improving the manuscript. Thanks to Farid Kamal Muzaki, who has helped provide information on the distribution of *Neurothemis feralis*. Thanks to Oki RW, MR Zumar, MA Maslukh, Alfin R, Anggun L, Adib W, and Ismu NI. for helping with the data collection process in the field. We also thank N Millah, Qathrunnada

S, NA Fitriah, Asyraf R, AM Shahroni, Febriane ED, and Akhsan FP, for helping with the study process.

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