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RESEARCH PAPER

Diversity and community structure of predators in *surjan* (polyculture) and *lembaran* (monoculture) paddy fields

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ABSTRACT

Predator diversity decreases because of low ecosystem quality in modern agriculture that applies monoculture systems. However, polyculture systems in paddy fields can improve biodiversity, including pests, natural enemies, and microorganisms. *surjan* is a local polyculture farming practice that originated in Yogyakarta. This farming practice consists of raised beds for cultivating *palawija* or horticultural crops and sunken beds for rice cultivation. *Surjan* farming may have an impact on predatory diversity and abundance, although this has not been studied. To address this issue, research was carried out to investigate the diversity, abundance, and structure of the community of predators in the paddy fields of *surjan* (polyculture) and *lembaran* (monoculture). The field experiment was conducted in three pairs, *surjan* and *lembaran*, in Panjatan District, Kulon Progo Regency, Yogyakarta Special Region, Indonesia. In each field, five random plots arranged in a cross pattern were used to collect a sample of predators. Several traps, including sweeping, pitfall traps, yellow adhesive traps, and yellow pan traps, were used to determine the abundance and diversity of predators. Results showed that species diversity, abundance, species composition, and biodiversity index in *surjan* farming were significantly improved compared to *lembaran* farming. Ceratopogonidae and Formicidae were the most abundant families in both *surjan* and *lembaran* farming, although they are more abundant in *surjan*. It can be concluded from the study that *surjan* farming could improve ecosystem quality by implementing predators for pest management.

Key words: abundance, biodiversity, *lembaran*, natural enemy, paddy field

INTRODUCTION

In Indonesia, paddy fields are predominantly cultivated using monoculture. However, rice plants in monoculture farming systems are more susceptible to pest attacks (Andrén & Kätterer, 2008). According to Luo et al. (2014), arthropod biodiversity, including natural enemies, decreases due to the low ecosystem quality and agricultural system stability in modern agriculture that employs monoculture systems. By cultivating multiple plant species, a practice known as polyculture farming, it is possible to manipulate the environment to enhance ecosystem stability (Kurniawati, 2015). Polyculture systems in paddy fields can improve biodiversity, including that of pests, natural enemies, and microorganisms (Hadi & Aminah, 2012).

Yogyakarta has developed a local polyculture farming system known as the *surjan* system. *Surjan* farming is applied by coastal farmers in Yogyakarta to to address poor field drainage in areas that were formerly back swamps (Marwasta & Priyono, 2007). Raised and sunken beds are the two planting areas in *surjan* farming. The raised beds are the elevated, terrestrial areas for cultivating *palawija* or horticultural crops, while the sunken beds are lower, aquatic areas for rice production (Susilawati & Nursyamsi, 2014). The *surjan* system can promote ecological balance because the variety of plants increases the diversity of pests that serve as prey for predatory insects, thereby increasing the diversity of predatory insects (Aminatun et al., 2014; Trisnawati et al., 2022a).

The existence of natural enemies, such as predators, can be utilized as an alternative method for the ecologically benign control of pests (Tooker et al., 2020). The presence of predators contributes significantly to the maintenance and improvement of the ecosystem balance (Mortuja et al., 2021; Tiwari et al., 2021). The agricultural system impacts both the species richness and the abundance of predators (Nurkomar et al., 2023; Trisnawati et al., 2022a). Polyculture production techniques may enhance the role of predators and parasitoids as natural controllers of pest populations, exemplifying the growing recognition

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of the functional interactions represented by natural enemies (Greenop et al., 2018; Staab & Schuldt, 2020; Straub et al., 2014). Polyculture systems may increase the search behavior of generalist predators more than monocultural systems, which may, in turn, increase the spillover of generalist predators between crop patches. This can enhance the offspring and survival rate of generalist predators, as well as the predation capacity, by improving their fitness (Thomine et al., 2020). *Surjan* agricultural practices may impact predatory insect diversity and abundance, although this has not been studied. Therefore, it is necessary to conduct research on this subject.

According to the findings of our previous research, *surjan* paddy fields impact the diversity of detritivores, pollinators, neutral insects, and pest insects (Herdiawan et al., 2021; Trisnawati et al., 2022b). As a result, it is essential to study the diversity of predators found in *surjan*'s paddy fields to establish credible insights regarding the ecosystem's condition and the relationships between its components. To address this issue, research was carried out to investigate the diversity, abundance, and community structure of predators in the paddy fields of *surjan* (polyculture) and *lembaran* (monoculture).

MATERIALS AND METHODS

Research Site. The field experiment was conducted in Panjatan District, Kulon Progo Regency, Yogyakarta Special Region, Indonesia (7°56'00.2"S 110°08'57.0"E). Yogyakarta is located in a tropical region, and therefore, it experiences both dry and wet periods throughout the year. The annual precipitation was 213.56 mm, and the mean temperature was 26.5 ºC (max: 32.5 ºC; min: 24.2 ºC).

Farming Methods. Panjatan district is a coastal area located at an elevation of 7 meters above sea level (ASL). The district has a total land area of 1242 ha available for agricultural purposes, with rice being one of the most important agricultural products (BPS, 2021).

As a result of inadequate drainage conditions, farmers in Panjatan developed a local agricultural system as known as *surjan*. Differences in the height of the planting surface across a field are one of the defining characteristics of the *surjan* system. *Surjan* fields are constructed by excavating some of the topsoil and using it to alevate adjacent land, thereby protecting it from flooding and inundation. The raised beds in *surjan* are terrestrial and are often used for the cultivation of *palawija* or other horticultural crops (Figure 1). On the other hand, the sunken beds in *surjan* are aquatic and are typically used for the cultivation of rice (Susilawati & Nursyamsi, 2014). The term *surjan* derives from the design of the rice field, which resembles a striped Javanese *surjan* robe. *Surjan* fields in Panjatan District cover an area 450 ha (BPS, 2021).

To investigate the diversity, abundance, and structure of the predator population in the paddy fields of *surjan*, three sites of *surjan* fields sites were chosen as sampling locations. To facilitate a direct comparison with other farming methods, we also selected three *lembaran* field sites in the same area as the *surjan* fields. At each site, there are three separate fields that serve as the plots for the replications. As a result, nine *surjan* paddy fields and nine *lembaran* paddy fields were utilized in this study. In *lembaran* farming, paddy fields are cultivated using a monoculture system. The management practices for *surjan* and *lembaran* farming are compared in Table 1.

Sampling of Predators. In each field, five random 3 × 1 m plots arranged in a cross pattern were used to collect samples of predators. Predator sampling was conducted four occasions: twice during the vegetative period (at two and four weeks of plant age) and twice

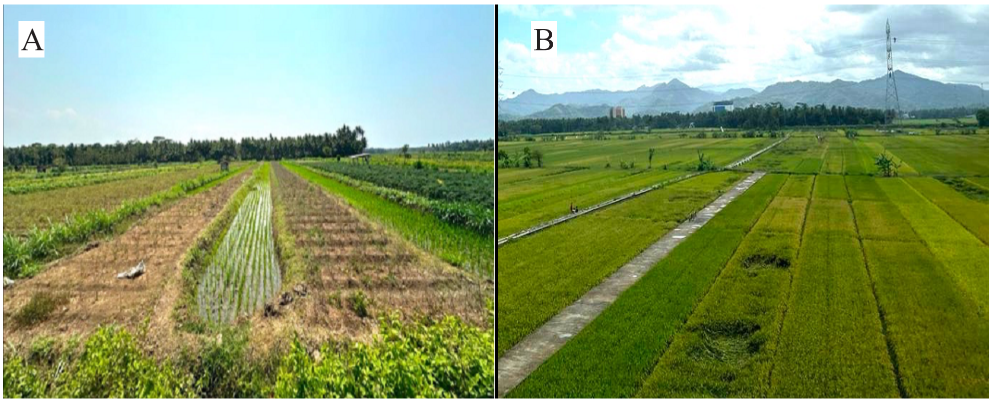

Figure 1. Local farming methods of paddy fields in Kulon Progo, Yogyakarta, Indonesia. A. *Surjan*; B. *Lembaran*

Table 1. Farming management in *surjan* and *lembaran* paddy fields

Characteristics	*Surjan* paddy fields	*Lembaran* paddy fields
Intercropping plants	Corn, chili, melon, spinach, shallot, cassava, mung bean, peanut, papaya, banana	None
Field Cultivation	Field ploughing 2 day before transplanting	Field ploughing 2 day before transplanting
Fertilizer	Organic fertilizer, urea, amonium sulfat, NPK	Urea, amonium sulfat, NPK
Irrigation	Surface irrigation from Pekik Jamal dam	Surface irrigation from Pekik Jamal dam
Weed control	Manual weeding	Manual weeding, synthetic herbicide
Pest control	Organic pesticide, synthetic pesticide	Synthetic pesticide

during the generative period (at seven and nine weeks of plant age). Sampling was carried out in the morning (between 06:00 and 07:30 WIB). Several traps, including sweep nets, pitfall traps, yellow adhesive traps, and yellow pan traps, were used to determine the abundance and diversity of predators. For the sweeping trap, twenty sweeps of a 36-cm-diameter sweep net were performed on five diagonally arranged plots in each field. The yellow sticky traps (size: 20 cm × 25 cm; height: 1 m) and the yellow pan traps (size: 25 cm × 14 cm; height: 1 m) were placed in five different plots around the paddy field for 24 hours. Plastic cups (8 cm in diameter × 15 cm in height) were used to create pitfall traps that were placed overnight in holes dug in the rice field embankment. Predators were collected and then identified and categorized in the laboratory according to their taxonomic and functional groupings.

Identification of Predators. In the Plant Protection Laboratory at Universitas Muhamamdiyah Yogyakarta, predators were identified using an SMZ18 digital stereo microscope (Nikon, Japan). Predators were classified into distinct orders, families, and morphospecies based on their unique physical characteristics. The identification of predators was based on various sources, including Kalshoven (1981), McGavin (2010), Shepard et al. (1987), and Triplehorn & Johnson (2005).

Data Analysis. To understand the effects of *surjan* and *lembaran* paddy fields, the species number and abundance of predators were analyzed using a generalized linear mixed model (GLMM). The farming method (*surjan* or *lembaran*) was treated as a fixed effect, and the field was treated as a random effect using the identity link function (lme4 package; maximum likelihood estimation) (Zuur et al., 2009). The field was designated as a random effect due to the natural variation between different fields. Several factors influence agricultural outcomes, including soil quality, land processing methods, plant variety, plant age, and surrounding plant species. Shannon-Wiener index (H), Evenness index (E), and Simpson index (D) were used to identify the diversity of predators in *surjan* and *lembaran* paddy fields. These indices were analyzed using paired t-tests to identify the different effects of *surjan* and *lembaran*. The Bray-Curtis index was utilized for beta diversity analysis. Beta diversity was determined to analyze the predator community composition in the *surjan* and *lembaran* paddy fields. The Bray-Curtis index is presented alongside non-metric multidimensional scaling (NMDS) ordinances to provide a graphical representation of the differences in the structure and composition of predators present in each farming system. R, a statistical program developed by the R-Core-Team (2023), was used to carry out the analysis, with the vegan package installed (Oksanen et al., 2007).

RESULTS AND DISCUSSION

There was a significant difference between the number of predator species in *lembaran* and *surjan* paddy fields (df = 1, $p < 2e\text{-}16$, Figure 2A). *Surjan* paddy fields had 135 morphospecies identified, while *lembaran* paddy fields had 85 morphospecies with 69 morphospecies found in both farming systems (Figure 3). Several morphospecies of predators were exclusive to either *surjan* or *lembaran* paddy fields (Supplementary 1).

The abundance of predators (number of

individuals in each field) was also significantly higher in the *surjan* paddy fields compared to the *lembaran* paddy fields (df = 1, p < 2e-16, Figure 2B). The abundance of predators in *surjan* was 294.45 (mean individual/field) and in *lembaran* was 268.08 (mean individual/field).

The predator morphospecies and abundance in *surjan* paddy fields have improved as a result of *surjan's* implementation of a polyculture system, in which numerous intercropping plants are grown in raised beds. In *surjan* farming, paddy fields were planted with other crops such as corn, chili, banana, melon, spinach, shallot, and casava (Table 1).

Surjan fields utilize a polyculture farming system that encourages biodiversity, strengthens ecological resilience, and decreases the likelihood of crop failure (Aminatun et al., 2014). Blending diverse plant species in polyculture simulates natural ecosystems and enables beneficial interactions between plant species, such as pest control, nutrients exchange, and soil health improvement (Adamczewska-Sowińska & Sowiński, 2020; Iverson et al., 2014). The presence of a wide range of plant species positively correlates with an increase in the abundance and diversity of natural enemies, such as predators and parasitoids (Stemmelen et al., 2022).

Many studies have also found that plant diversity in polycultures increases the diversity of predators as the diversity of prey species also increased (Ebeling et al., 2018; Farooq et al., 2022; Guo et al., 2021). These findings are supported by our previous study, which showed that the species richness of pests as predator-prey in *surjan* was significantly higher than in *lembaran* fields (Trisnawati et al., 2022b). The correlation between the number of pest and predator morphospecies showed significant differences in both the *lembaran* (p = 3.489e-09, R^2 = 0.94; Figure 4a) and *surjan* (p = 1.315e-07, R^2 = 0.91, Figure 4b) paddy fields. This indicates that *surjan* farming, with its many intercropping plants, increased the effectiveness of top-down control of insect herbivores.

Nevertheless, according to Ortiz-Burgos (2016), the Shannon-Wiener index demonstrates a significant

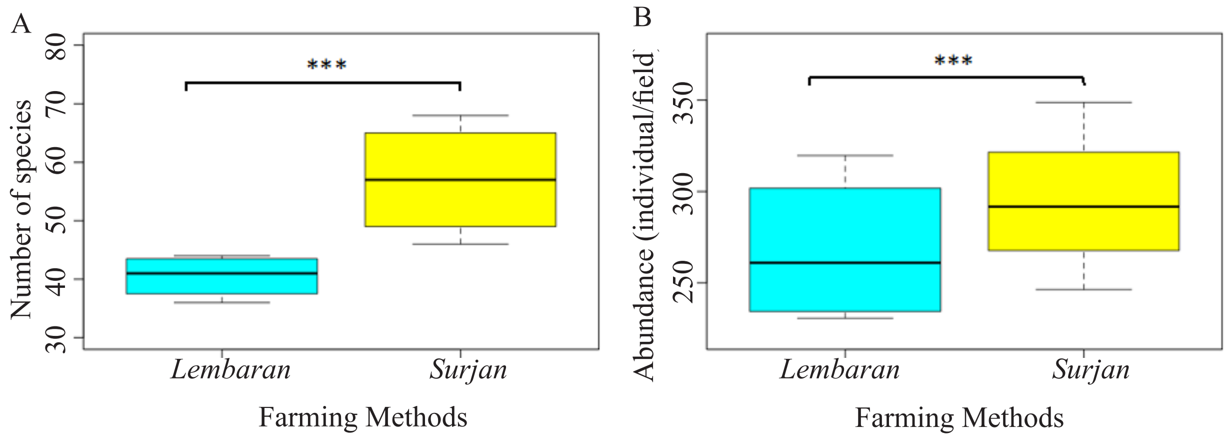

Figure 2. Biodiversity of predators in *surjan* and *lembaran* field. A. Number of morphospecies (mean ± SE); B. Abundance of predators (mean ± SE). Significant differences according to a generalized linear mixed model (GLMM) and field as a random effect [***p < 0.001, **p < 0.01, *p < 0.05, ns (not significant, p ≥ 0.05)].

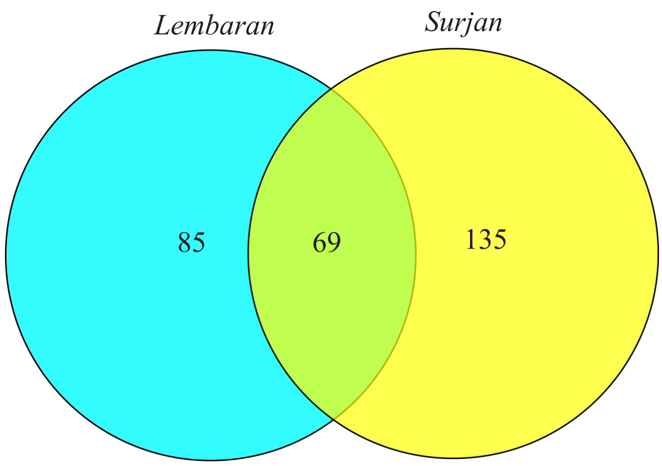

Figure 3. Composition of number morphospecies of predators in *surjan* and *lembaran* farm.

amount of diversity (H' > 3.0) in both *lembaran* (H' = 3.10) and *surjan* (H' = 3.29) paddy fields (Figure 5a). The Shannon-Wiener index in *surjan* is markedly greater than that in *lembaran* paddy fields (df = 1, p < 0.05, Figure 5a). Both *surjan* and *lembaran* paddy fields exhibit an evenness index approaching 1 (Figure 5b), indicating a uniform distribution of species throughout the community (Gregorius & Gillet, 2022). The mean evenness index in *surjan* is 0.78, whereas in *lembaran* it is 0.74, and the evenness index in *surjan* is significantly greater than in *lembaran* fields (*df* = 1, *p* = 5e-9, Figure 5b).

The Simpson index in both *lembaran* and *surjan* rice fields also surpasses 0.75 (Figure 5c), indicating a high degree of heterogeneity (Fedor & Zvaríková, 2019). In *surjan*, the Simpson index has a mean value of 0.93, whereas in *lembaran* it has a mean value of 0.90. The Simpson index in *surjan* is markedly higher than in *lembaran* fields (*df* = 1, *p* = 8e-9).

The study location in Panjatan exhibits habitat conditions characterized by agricultural practices that adhere to crop rotation guidelines mandated by the

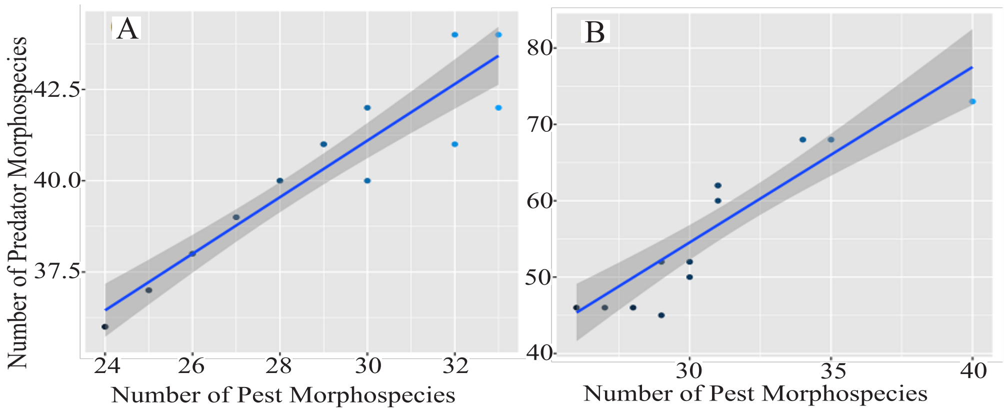

Figure 4. The correlation between the number of pest and predator morphospecies in. A. *Lembaran*; B. *Surjan* paddy fields. The correlation was analyzed using Pearson Correlation.

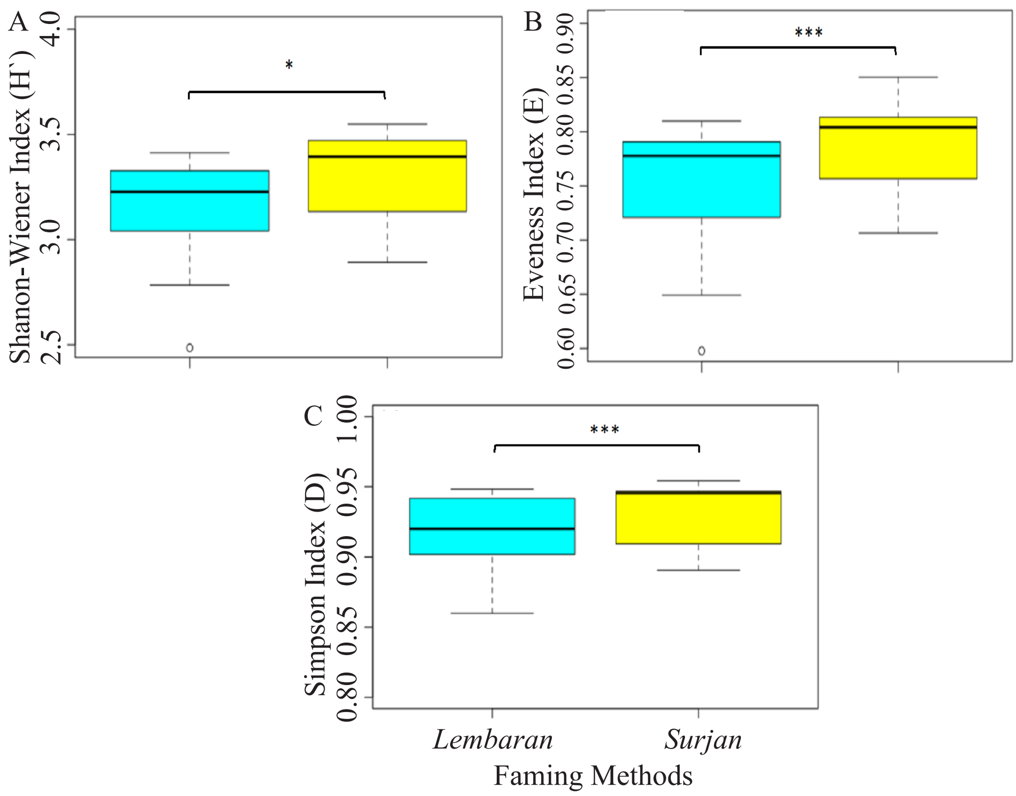

Figure 5. Biodiversity index. A. Shannon-Wiener Index (H'); B. Evenness Index (E), C. Simpson Index (D) in *surjan* and *lembaran* farming. Significant differences according to a generalized linear mixed model (GLMM) and field as a random effect [***p < 0.001, **p < 0.01, *p < 0.05, ns (not significant, p ≥ 0.05)].

Kulon Progo Regent's laws on planting procedures (Pemerintahan Kabupaten Kulon Progo, 2022). These practices aim to ensure the preservation of soil fertility and biodiversity. In addition, the integration of polyculture into the agricultural system, as seen in the *surjan* rice fields, can further increase biodiversity.

Figure 6 indicates the differences in predator morphospecies composition between *lembaran* and *surjan* fields. The adjacent ordinate planes reveal that the composition of the morphospecies in the fields is becoming increasingly similar. The morphospecies composition of *surjan* and *lembaran* differs due ro the distinct species that inhabit each method of farming rice fields. Only 69 species have been identified in both *surjan* and *lembaran* fields. However, *surjan* paddy fields were found to have 135 morphospecies, while *lembaran* paddy fields had 85 morphospecies (Figure 3).

Polyculture systems, as demontrated by *surjan* rice fields, have the potential to enhance the composition of predator organisms (Cuervo et al., 2023). Several studies have shown demonstrated that the presence of a wide variety of plant species can mitigate herbivorous insect populations by increasing

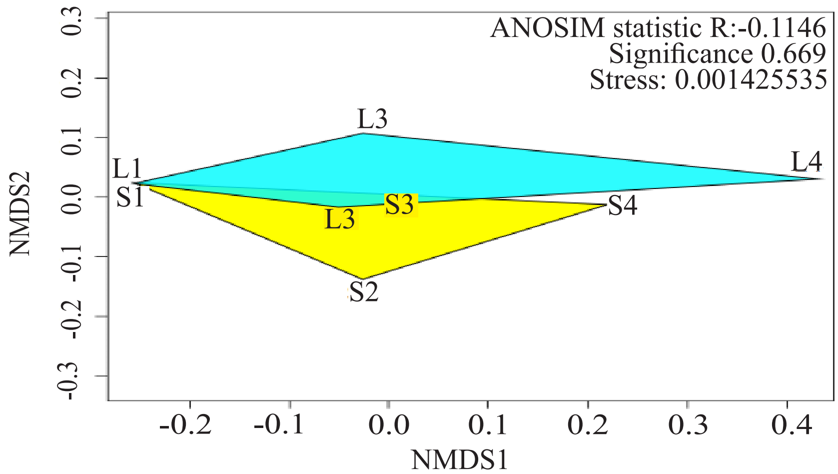

Figure 6. Non-metric multidimensional scaling (NMDS) of predator composition in *surjan* and *lembaran* farming. S is *surjan* paddy fields and L is *lembaran* paddy fields, and the number shows the study area.

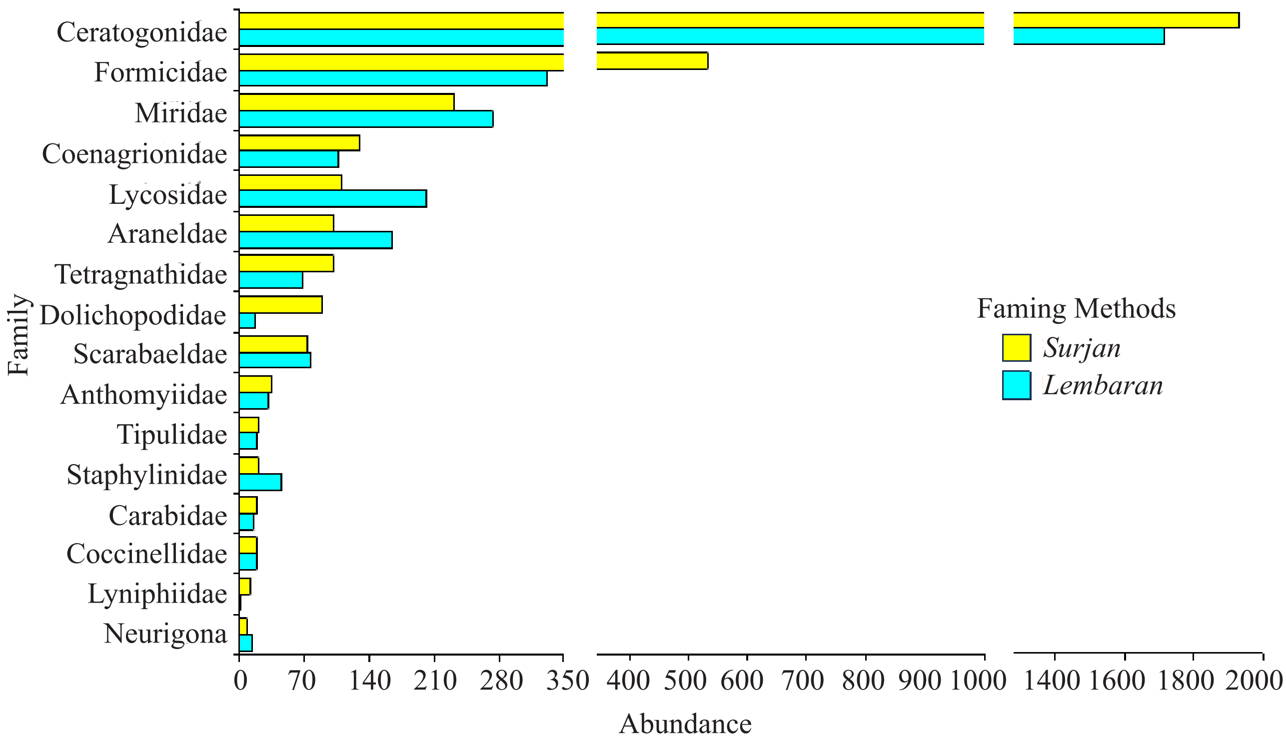

Figure 7. The abundance of predator morphospecies in *surjan* and *lembaran* farming.

the diversity and abundance of natural enemies, such as predators (Castagneyrol et al., 2014; Coco et al., 2022; Isbell et al., 2017). Agricultural fields with diverse plant species, such as *surjan* fields, tend to attract natural enemies, including predatory invertebrates.

On average, the abundance of predator families on *surjan* fields exceeds that of *lembaran* fields (Figure 7). Nevertheless, certain predator families, namely Miridae , Lycosidae, and Araneidae, exhibited increased abundance in *lembaran* fields compared to *surjan* fields ($df = 1, p < 2e\text{-}16$, Figure 7). These findings align with a study conducted by Thomine et al. (2020), which stated that Miridae predators showed decreased population density in polyculture fields, although they demonstrated enhanced predation performance. However, the observed high populations of Lycosidae and Araneidae on *lembaran* fields seem to contradict prior research findings that suggested a positive correlation between increased crop diversification and spider abundance (Cuervo et al., 2023). The decreasing predator population in polyculture fields can be attributed to the presence of some plants within the polyculture fields that are unsuitable for attracting a greater number of predators (Biondi et al., 2016).

Ceratopogonidae was the most abundant family in both of *surjan* and *lembaran* paddy fields (Figure 7). Several studies stated that the Diptera order was the most dominant in freshwater water ecosystems (Adler & Courtney, 2019; Raunio et al., 2011). Paddy fields represent a form of freshwater agroecosystem that serves as a habitat for several aquatic species, facilitating their reproductive activities and providing a source of sustenance. The morphospecies of Ceratopogonidae found were Ceratopogoninae and Forcipomyiinae. Most larvae of Ceratopogoninae are predatory, and the adults generally attack other insects. Most females of Ceratopogoninae feed on insects similar to them in size (Marshall et al., 2012). The results showed that in *surjan,* the abundance of Ceratopogonidae was higher compared to *lembaran* fields ($df = 1, p < 2e\text{-}16$, Figure 7). A previous study reported a significant abundance of larvae and pupae belonging to the Ceratopogonidae family in fields where a diverse range of plant species are cultivated (Borkent & Brown, 2015).

The abundance of Formicidae in *surjan* is significantly greater compared to that observed in *lembaran* agricultural areas ($df = 1, p < 2e\text{-}16$, Figure 7). According to a study conducted by Roeder & Harmon-Threatt (2022), polyculture farming has the potential to enhance both the diversity and abundance of ants. The morphospecies of the Formicidae family that have been identified are *Anoplolepis* sp., *Formica pallidefulva*, *Gnamptogenys* sp., *Lepisiota* sp., *Monomorium* sp., *Nylanderia* sp., *Odontoponera denticulata*, *Plagiolepis* sp., *Technomyrmex* sp., and *Tetramorium* sp. Ants play a crucial role in ecosystems due to their significant contribution to animal biomass and their role as ecosystem engineers. The biodiversity of ants is notably extensive, and these species exhibit a strong sensitivity to human activities, particularly those related to the plant production process (Folgarait, 1998).

There is a positive correlation between land productivity and biodiversity, whereby higher levels of field productivity are associated with increased species richness. Nevertheless, the increase in productivity also facilitates a rise in the number of individuals within each species, rather than increasing the total number of species (Beckmann et al., 2019). Heterogeneous environments are characterized by a greater diversity of microhabitats and microclimates compared to simpler habitats (Martin et al., 2020). Increasing the complexity of agroecosystems is of paramount importance due to its facilitation of coexistence among species at several trophic levels (Beillouin et al., 2021; Schuldt et al., 2019).

CONCLUSION

The research findings show that *surjan* paddy fields have the potential to increase species diversity, the number of individuals, and the community structure of predator populations compared to *lembaran* paddy fields. As a result, *surjan* farming could improve ecosystem quality by using predators for pest control, as opposed to *lembaran* farming.

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AUTHORS' CONTRIBUTIONS

DWT and IN designed and conceived of the experiments. The experimentation was conducted by

AA and EP. DWT, IN, AA, and EP contributed to the preparation of samples and interpretation of the results. The manuscript was primarily composed by DWT. All authors provided critical feedback and contributed to the development of the research, analysis, and manuscript.

COMPETING INTEREST

Authors are required to declare any competing interest such as financial or non-financial interests, professional or personal relationships that are directly or indirectly connected to the work submitted for publication. If there is no competing interest regarding your publication, you are also required to declare.

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