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Assessment Of Odonata Diversity Supported By Machine Learning Tool And Its Correlation With Ecosystem Health In Kuttanad Wetland, Vembanad Ramsar Site - A Decadal Study

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Abstract

The presence and absence of Odonates (dragonflies and damselflies) in a region indicates the quality of the land, the water bodies and the health of the ecosystem they provide. Odonates spend most of their life as nymphs (water bugs) in wetlands and streams. Each species requires specific conditions to survive, making them useful as bioindicators. For instance, *Brachythemis contaminata* thrives only near contaminated water bodies, tolerating pesticide-laden waters, while others prefer freshwater bodies like mountain streams. This study examines the decline in Odonata diversity in Kuttanad wetlands over the past decade, revealing a one-third reduction in their population. Advanced machine learning tools were used for automated species identification, and the study evaluated ecosystem health to identify potential causes of this decline, focusing on the relationship between Odonata diversity and water quality. The findings highlight Odonata diversity as a more reliable indicator of water quality than chemical tests, offering a comprehensive and long-term assessment of ecosystem

health. The research involved a systematic survey and classification of over 21 species, revealing significant reductions in Odonata diversity within the wetland.

Keywords:

Odonata, *Brachythemis contaminata*, Water Quality, Bio- Indicator, Machine learning.

Introduction

Odonates, including dragonflies and damselflies, occupy top- or mid-level trophic positions in freshwater ecosystems and are characterised by their extensive predatory habits. They are crucial in controlling harmful insects and pathogens, regulating prey populations, and mediating community processes. Odonates are also important indicators of water quality and ecosystem health, as they are sensitive to changes in environmental settings and habitat integrity. The distribution and abundance of aquatic insects such as Odonata in freshwater habitats are very much dependent on their sensitivity to pollution of habitat alteration (Scheffer et al., 1984; Vinson, 1998; Che Salmah et al., 2005; Subramaniam, 2005; Sivaramakrishnan, 2002; Nurul et al., 2017), especially to a condition that may affect the pH, DO content, water temperature, turbidity and other water parameters. Odonates undergo incomplete metamorphosis with aquatic nymph and terrestrial adults, providing opportunities to investigate ontogenetic diet variation and trophic links between different species Corbet, (1999). Recent studies have also investigated the role of Odonata in local adaptation and community processes. The diversity of Odonata in a particular region may be attributed to the presence of many water bodies, streams, and cascades. Overall, Odonata plays a crucial role in freshwater ecosystems and is an essential component of the food chain Sentis et al. (2022).

This study aims to understand the changes in the Odonata population in the lowlands of Kuttanad, India, by comparing current observations with existing documentation from about a decade ago. The research focused on three regions of Kuttanad, which were systematically observed from March to December 2019. The study revealed a significant decline in Odonata diversity compared to the previous decade and a disproportionate increase in species-specific to contaminated water. This decline is alarming, as Odonata are crucial in controlling harmful insects and pathogens May, M.L (2019). The study sheds light on the potential impact of human activities on the Odonata population and the broader ecosystem, emphasising the urgent need for conservation efforts to address this concerning trend. The research also highlights the importance of Odonata as an ecological indicator, underscoring the significance of ongoing and future studies in this field. Using odonates as water quality indicators is a reliable and cost-effective method for evaluating the biological ecosystem. Odonates, such as dragonflies and damselflies, are sensitive to environmental changes and can provide insights into the effects of urbanisation on biodiversity. Monitoring odonate species density and correlating it with environmental changes makes it possible to detect potential issues and develop strategies to mitigate negative impacts.

Additionally, odonates play a crucial role in maintaining the balance of the ecosystem as predators, making them valuable indicators of environmental quality. Their sensitivity to stressors in aquatic and terrestrial habitats further emphasises their importance in assessing the ecosystem's health. Therefore, using odonates as indicators can help understand and preserve the ecosystem's harmony.

Materials and Methods

The study used periodic field surveys and visual identification to create a database of odonates in the Kuttanad wetland in Kerala, India. Kuttanad is a unique deltaic formation with rich biodiversity and is below sea level, making it a haven for migratory birds, amphibians, and odonates. Four significant rivers enrich the wetland basin, and farming is below sea level. The study area is a Ramsar site that has been declared a globally substantial agricultural heritage system. The population of Kuttanad is 193,007, and families are often affected by floods and pollution.

The site selected for periodic surveys,

Kuttanad, with about 1600 sq Km, is a vast area to be studied within the scope of this thesis. However, for a preliminary study, it was decided to identify three sites from three regions of Kuttanad for periodic surveys. To set things in the proper perspective, a set of more generalised surveys were also done across the state systematically but in a much more relaxed period. Based on its topological characteristics, Kuttanad is divided into different regions. Figure 5 shows the geographical distribution of these regions. Three stations from Kuttanad were selected for this study. **Pathinarichira** is from **Kayal Land** in Kuttanad, **Ambalapuzha** is from **Lower Kuttanad,** and **Kavalikkara** is from **Upper Kuttanad**.

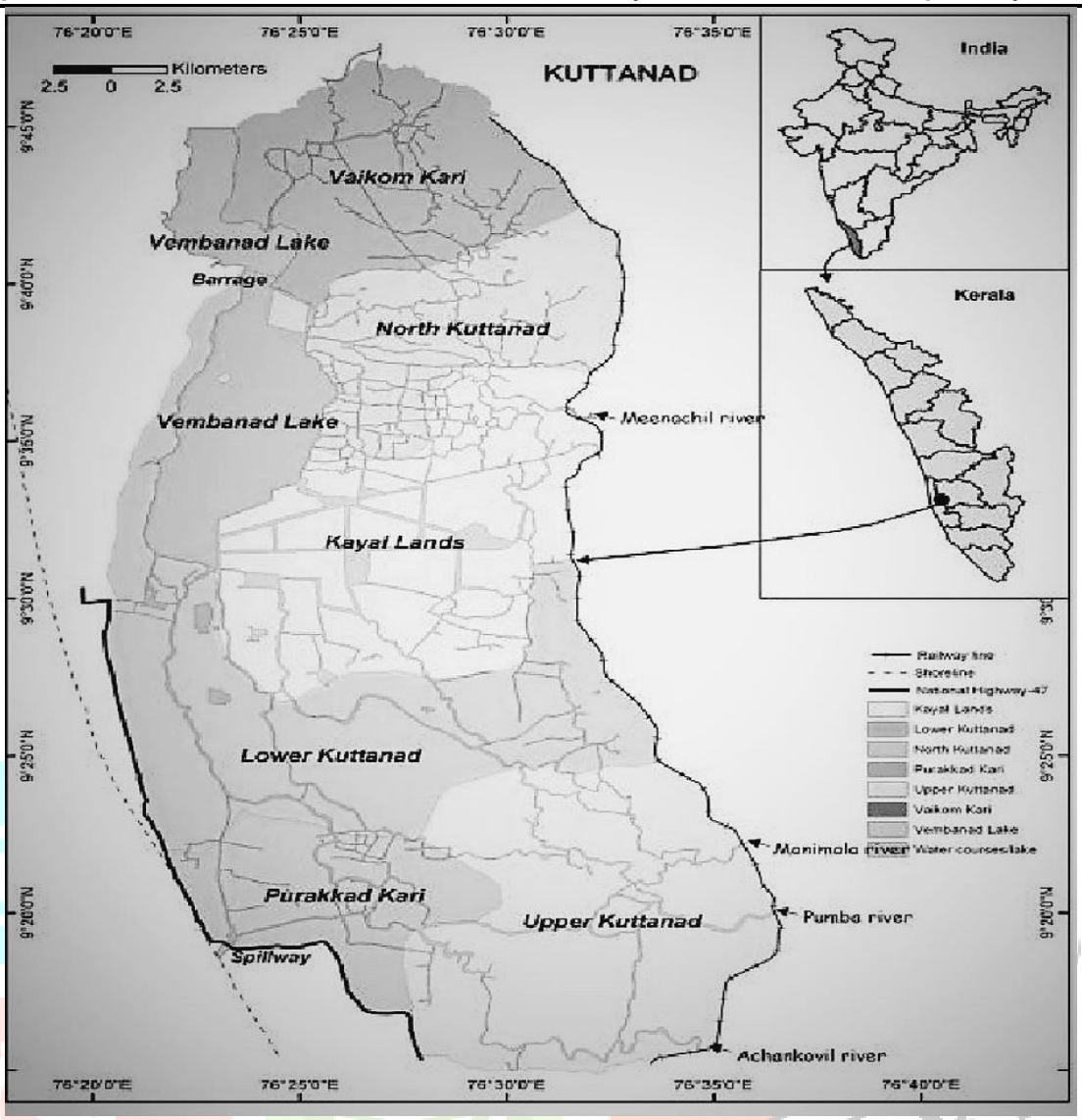

Figure 1: The topological distribution of Kuttanad on the west coast of Kerala state is shown. The regions selected for the periodic survey are displayed on the map as Kayal Land, Lower Kuttanad, and Upper Kuttanad.

The **Kayal land** is south of the Meenachil River and is mostly below sea level. Possibly because of its proximity to Kottayam (Kumarakom) and Alappuzha townships and the absence of rivers that flow through it, it was observed to be one of the most polluted sites out of the three. The region right to the *Pathinarichira bridge* was selected for periodic observations based on a preliminary survey to identify suitable sites for observation across the seasons.

The land south of Kayal Land and north of Purakkad Kari is called the **Lower Kuttanad**. A suitable land was found in Ambalapuzha along the coast of the Pampa river. Due to its proximity to the Pamba River, this land was found to recover and restore species diversity following the monsoon rains.

The wetland site selected for periodic observation from **Upper Kuttanad** is just on the outskirts of Changanassery, a Kavalikkara township. Though there is a small stream called the Kondoor Riverlet here, it is always filled with water plants and small bushes with hardly any flowing water. The region flooded during the monsoon season, and the residents had to move to safer rescue homes.

Odonata as Water Quality Indicators

The correlation between Odonata diversity and water quality is well-established through various studies. For the present work, the present study used the inverse correlation to estimate the water quality in the study areas by observing the population of observed odonates in those regions. The method is followed since odonates spend a long life cycle in aquatic habitats and can thus give more reliable estimates of the ecosystem's health in contrast to local and temporal chemical tests.

The inverse correlation of wetland habitat in the present study is done based on the work of Jacob et al. (Jacob et al., 2017), and their findings are duplicated in Table 1 for completeness.

It is to be noted that *Brachythemis contaminata* is found only in Very Bad conditions and is thus a sure indicator of contaminated water. Most other species have varying adaptability, though they are only found marginally in similar circumstances. The most probable reason for this could be their inability to breed and survive in polluted environments, plus the inability of their feeding habitats to adapt to such environments.

The Mode of Data Collection

The study was conducted to document the species diversity of odonates (damselfly and dragonfly) from the Pre- to post-monsoon periods of the Kuttanad region. The survey was conducted periodically and systematically from March to December 2019. The period for the study was selected to overlap with the period when the Odonata activity in the region peaks.

The survey was carried out using the famous 'Line transect method'. Observations were made by walking along a fixed *transect* of 1.5 km. The species encountered in 5m breadth on either side were considered, and their number and species richness for each biotope were recorded (Roberts et al., 2016). The exact track of the transect is followed in all the subsequent observations. Since odonates are most active during sunshine, the study made observations from 8 am to noon and from 3 pm to 5 pm. It was observed that the odonates started to perch as the sun moved to the horizon.

The standard instructions for the **transect method** are given below for completeness.

Selected the transect routes carefully and identified the start and end points. Make sure that the transect route passes through various zones so that the completed transect can give meaningful information. Once the route has been selected, it should be surveyed in the same time frame in subsequent visits. The study used the "My Tracks" android application to record and mark our transit route during all visits. All possible observations of interest, including other species diversity, weather, etc, were recorded to complete the transect. This will help one to analyse data efficiently. This method was followed systematically throughout the survey period, and the species list, their numbers, and habitat features were noted in a field diary.

Study Seasons

The Southwest Monsoon arrives in June to July, and the Northeast Monsoon in mid-October brings rain to Kerala. The present study refers to the Southwest Monsoon as the Monsoon period, the months of March-May as Pre-Monsoon and August-December as Post-Monsoon periods. The Northeast Monsoon period was not distinctively noted in the study regions and was thus not separately considered.

Odonata Identification and their classification methods

The order Odonata, meaning "Toothed ones", consists of both dragonflies and damselflies. Odonates are classified into three groups: Anisoptera, which includes the dragonflies; **Zygoptera, which** consists of the damselflies; and **Anisozygoptera,** which consists of the two species of roberflies. Many characteristics distinguish Odonata from other groups of insects. Odonates are insects with incomplete metamorphosis(hemimetabolous). That means no pupal stage exists between the larval, nymph, and adult stages. Odonates lay their eggs in water and hatch into miniature nymphs or larvae. After eight to eighteen instars, the nymph leaves the water and emerges as the winged miniature adult or imago. The body of an adult dragonfly and damselfly consists of a head, thorax and abdomen. A large head with huge compound eyes (filling most of the head), two pairs of transparent membranous wings with venation, legs that facilitate catching their prey in flight, and a long slender segmented abdomen with anal appendages are characteristic of odonates. Among living odonates, there are 26 families of dragonflies and damselflies. Of all their characteristics, the easiest way to distinguish them from other insects is by the size of their eyes, the absence of antennas, and the shape of their abdomen. If the eyes are enormous in proportion to the head, the abdomen is long and thin, and the absence of a long antenna, it is almost sure to be a member of the Odonata family.

Figure 2: The two copera species of damselflies differ only in the details of their tail morphology.

However, species identification of odonates is a very challenging task, and sometimes, even experts require detailed observation of the species to classify them visually. Besides, there are differences in the colours and appearances of male, female and juvenile species.

Machine Learning as Species Identification

All statistical analysis heavily depends on data availability. The more data there is, the better the reliability of the study would be. However, manual classification of the data is a laborious process. In such a situation, the best bet is to automate the labelling classification process with reliable machines. Machine learning is the branch of computer science that allows a machine to learn the complexities of a given data so that the trained machine can automate the classification process in the future. The latest machine learning frameworks have been developed to handle big data (a name coined to represent vast volumes of data) using deep learning networks. For this study, the survey's volume of data was minimal to train any deep learning network. The study used a

method known as transfer learning that allows machines to update the learning of vast volumes of data, explicitly fine-tuning for more minor data as a shortcut to overcome the limitations due to smaller training datasets generated in the present survey. Though not 100% reliable, the tool could initially classify the different species that were visually verified later. Being a learning tool, it learns from mistakes and makes better predictions as more data is added to the system.

A machine learning tool needs to be trained before it can be used. For that purpose, a species inventory was prepared through a Visual Encounter Survey (VES) and photographic identification. Field dairy, binoculars, Nikon DSLR-d5100, Nikon DSLR-d5200, and Nikon Coolpix cameras were used during the survey. The survey was done periodically, weekly, from pre-monsoon to post-monsoon seasons. The survey used a standard line-transect method. The species encountered within 5m breadth on either side were considered, and their density and richness were recorded for each biotope along a set track distance of 1- 2 km. A diagrammatic representation of the Machine learning process is shown in Figure 4.

The machine learning tool was developed and tested mainly in 3 stages. Initially, photographs of the species were taken from all possible orientations during the periodic visits. This was followed by the second step, in which each species was identified, grouped, and labelled according to their respective genera and species types with the help of domain experts. The images of each group were then put into different folders denoted by their scientific names. As the third step, these labelled images were used as the training data for the machine learning algorithm. The training was done on a dedicated high-performance computing facility at airis4D, taking about 9 to 10 hours in each training epoch. The trained network could classify most odonates with above 90% confidence and correctness.

Recent studies have explored the use of machine learning for species identification of odonates, which can be challenging even for experts due to differences in colour and appearance among male, female, and juvenile species. Machine learning can automate the classification process, and recent advancements in deep learning networks have made it possible to handle big data. Transfer learning is a method that allows machines to update the learning already done of vast volumes of data, explicitly fine-tuning for more minor data as a shortcut to overcome the limitations due to smaller training datasets generated in the present survey. The taxonomy and systematics of odonates are helpful for field entomologists in recognising beneficial insects quickly and accurately. Odonates are also good indicators of water quality, and their abundance in an area is considered a good indicator of the quality of water in the area. Recent studies have used machine learning methods based on deep CNN models to develop an automated odonates identification system. These studies demonstrate the potential of machine learning for species identification of odonates and other insects, which could reduce the impact of the taxonomic impediment.

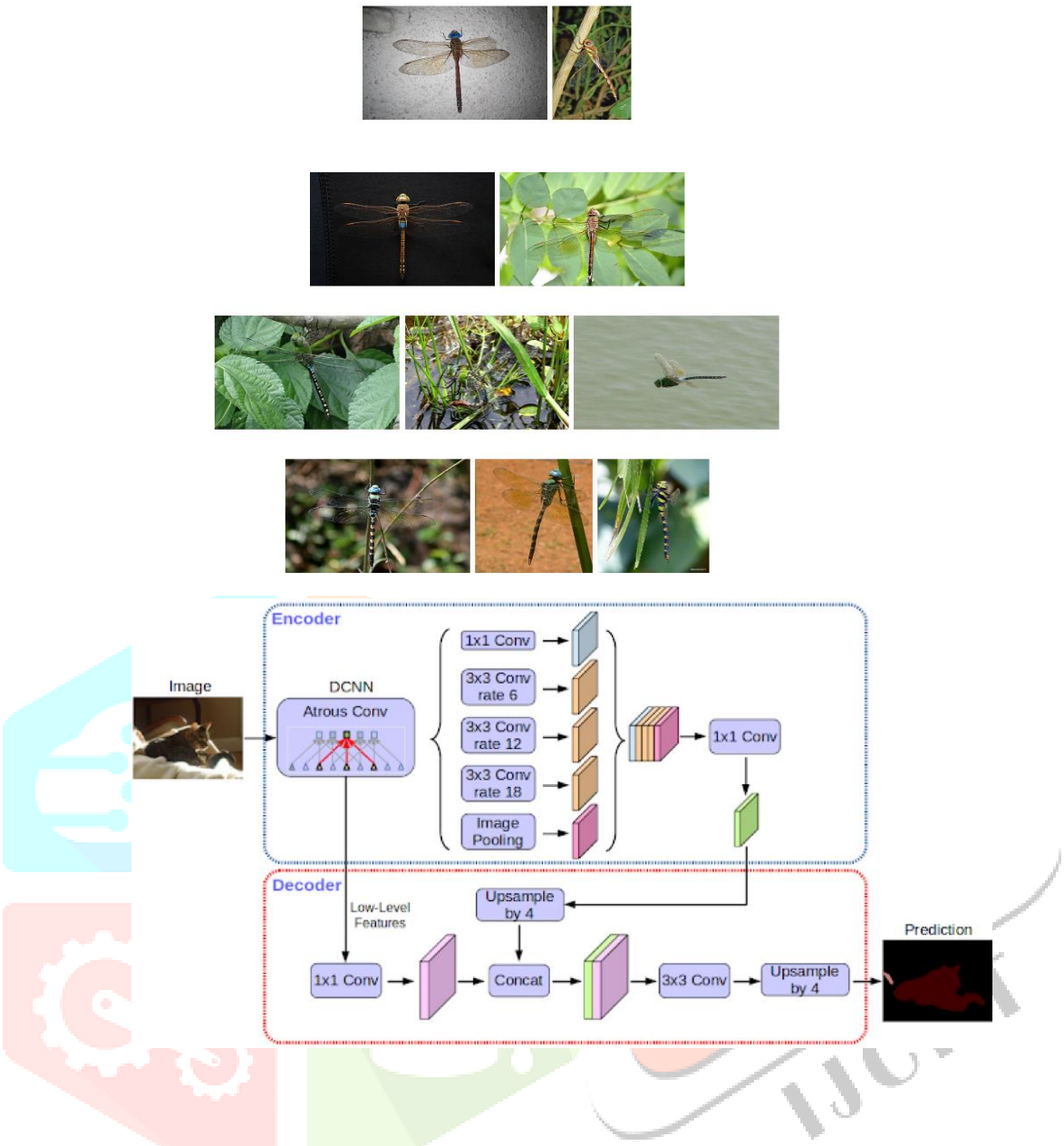

Fig 3. The Machine Learning process is illustrated here. First, photographs are taken and based on the identification of the species, they are labelled. A fraction of those labelled images are used to train the Machine Learning Model, and the remaining are used to verify if the learning is proper. Once it is found that proper learning has taken place, the machine should be able to identify and label images from new photographs without human aid.

Results and Discussion

The photographs taken from the sites were first visually classified into their respective classes and were used to train the Machine Learning model. The training was done as described earlier, and the trained model was used to classify photographs taken in subsequent surveys automatically. The algorithm's predictions were periodically monitored, and training with additional photographs was done for failed predictions. The process was repeated until predictions with more than 90% accuracy were made with fresh images not used for training.

This significantly reduced the human involvement required at the initial stages of the classification. Visual verifications were required only in case of more complex species subclassifications. It is to be noted that *Brachythemis contaminata* is found only in **Very Bad** conditions and is thus a sure indicator of contaminated water. Most other species have varying adaptability, though they are only found marginally in similar circumstances. The most probable reason for this could be their inability to breed and survive in polluted environments, plus the inability of their feeding habitats to adapt to such environments.

Species Diversity

In the entire survey over the three sites across the three seasons, a total of 21 species were observed; of that, six species were damselflies (Zygoptera). The remaining 15 species were dragonflies(Anisoptera). All the species recorded during the study period belong to the Least Concern (LC) category under the IUCN classification. Most of the odonates recorded were from the largest dragonfly family, Libellulidae (Rambur 1842), consisting of skimmers or perchers and damselflies belonging to the Ceonegroinideae and Chlorocyphidae family.

The six species of damselflies seen were *Agriocnemis pygmaea, Ceriagrion cerenorubellum, Ceriagrion coromandelianum, Pseudagrion microcephalum and Ischnura senegalensis* of **Ceonegrionideae** family and *Libellago indica* belong to the **Chlorocyphidae.** The remaining 15 species of dragonflies are *Acisoma panorpoides, Aethriamanta brevipennis, Brachythemis contaminata, Brachydiplax chalybea, Diplacodes trivialis, Neurothemis tullia, Orthetrum chrysis, Orthetrum sabina, Pantala flavescens, Rhodothemis rufa, Rhyothemis variegata, Trithemis pallidinervis, Trithemis aurora, Tholymis tillarga, Urothemis signata* etc, belong to the most prominent family called the **Libellulidae.**

Table 1:

Odonate diversity in Kuttanad showing the 'Rare, Common & Abundant Status in the observed sites.

Sl. No.	Scientific Name	PreMonsoon	Monsoon	Post Monsoon	Observed Site
	Anisoptera (Dragonflies**)** **Family: Libellulidae:**				
1	*Acisoma panorpoides* (Rambur, 1842)	Rare	Common	Common	Kayal land, Upper Kuttanad Lower Kuttanad
2	*Aethriamanta brevipennis* (Rambur, 1842)	Rare	Rare	Rare	Upper Kuttanad
3	*Brachythemis contaminata* (Fabricius,1793)	Abundant	Abundant	Abundant	Kayal land, Upper Kuttanad, Lower Kuttanad

4	*Brachydiplax chalybea* (Brauer,1868)	Common	Common	Common	Kayal land, Upper Kuttanad. Lower Kuttanad
5	*Crocothemis servilia* (Drury, 1770)	Rare	Rare	Common	Kayal land Upper Kuttanad Lower Kuttanad
6	*Diplacodes trivialis* (Rambur ,1842)	Rare	Common	Common	Kayal land Upper Kuttanad Lower Kuttanad
7	*Neurothemis tullia* (Drury, 1773	Common	Common	Common	Kayal land Upper Kuttanad Lower Kuttanad
8	*Orthetrum sabina* (Drury, 1770)	Common	Common	Common	Kayal land Upper Kuttanad Lower Kuttanad
9	*Pantala flavescens* (Fabricius, 1798)	Rare	Rare	Abundant	Kayal land Upper Kuttanad Lower Kuttanad
10	*Rhodothemis rufa* (Rambur,1842)	Common	Abundant	Abundant	Kayal land Upper Kuttanad Lower Kuttanad
11	*Rhyothemis variegata* (Linnaeus,1973)	Common	Abundant	Abundant	Kayal land Upper Kuttanad Lower Kuttanad
12	*Trithemis pallidinervis* (Kirby, 1889)	Rare	Common	Common	Upper Kuttanad Lower Kuttanad
13	*Trithemis aurora* (*Burmeister,1839*)	Rare	Rare	Rare	Upper Kuttanad Lower Kuttanad
14	*Tholymis tillarga* (Fabricius, 1798)	Rare		Common	Lower Kuttanad
15	*Urothemis signata* (Rambur, 1842)	Rare		Common	Upper Kuttanad Lower Kuttanad
	Zygoptera (damselflies) **Family: Coenagrionidae**				
16	*Agriocnemis pygmaea*	Rare	Common	Abundant	Upper Kuttanad

	(Rambur,1842)				Lower Kuttanad
17	*Ceriagrion coromandelianum* (Fabricus, 1768)	Rare	Common	Abundant	Kayal land Upper Kuttanad Lower Kuttanad
18	*Ceriagrion cerinorubellum (Brauer)1845*	Rare	Common	Abundant	Kayal land, Upper Kuttanad, Lower Kuttanad
19	*Ischnura senegalensis*	Absent	Absent	Rare	Lower Kuttanad
20	*Pseudagrion microcephalum*	Absent	Rare	Common	Upper Kuttanad, Lower Kuttanad
	Family-Chlorocyphidae				
21	*Libellago lineata* (Burmeister, 1839)	Absent	Absent	Common	Kayal land

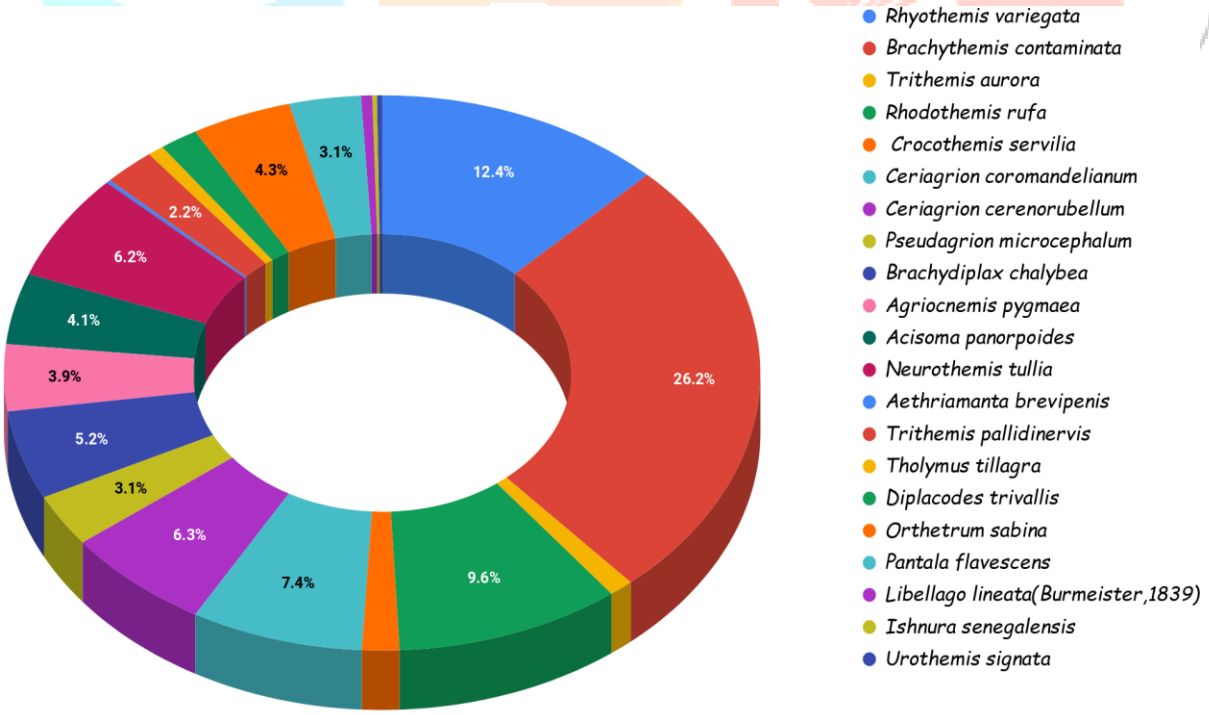

Figure 4: Observed species diversity in the three study areas *(names are labelled in the clockwise direction).*

A total of 4019 odonates were photographed and recorded, and these were composed of 21 species of odonates that may be subdivided into 15 species of dragonflies and six species of damselflies, respectively. The listed

dragonflies belong to the Libellulidae family and the damselflies of the family **Coenagrionidae** and **Chlorocyphidae.** The relative abundance of observed species and their scientific names are shown in Figure 9.

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Metadata

Site location maps

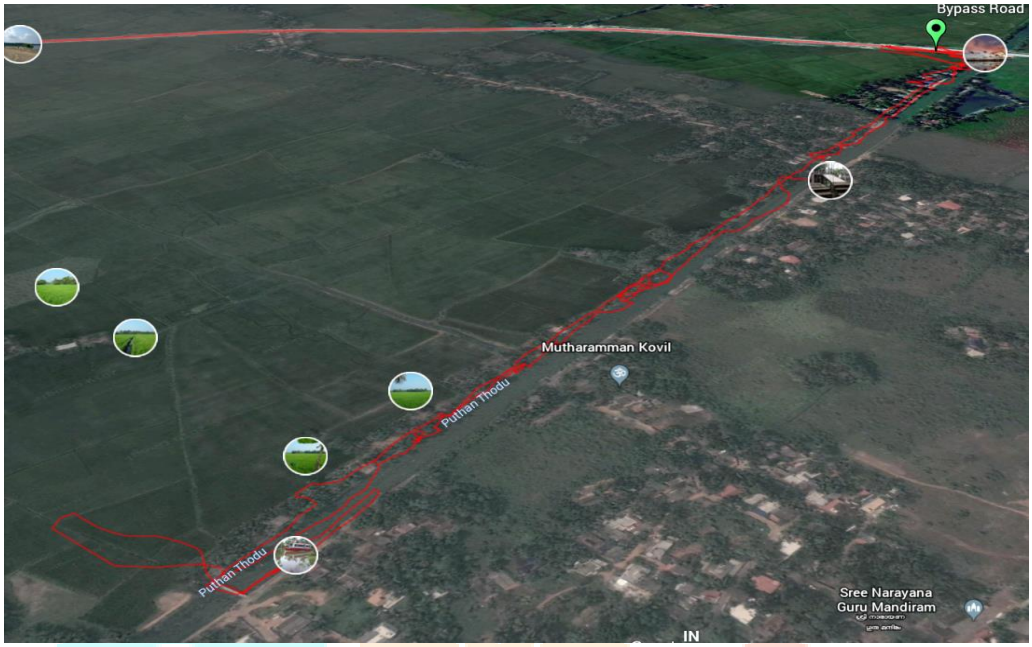


Fig1: Shows the Line transect route map of Pathinarichira Station in Kayal Land of Kuttanad.

Fig 2: Show the Line transect route map of Ambalapuzha Station in Lower Kuttanad

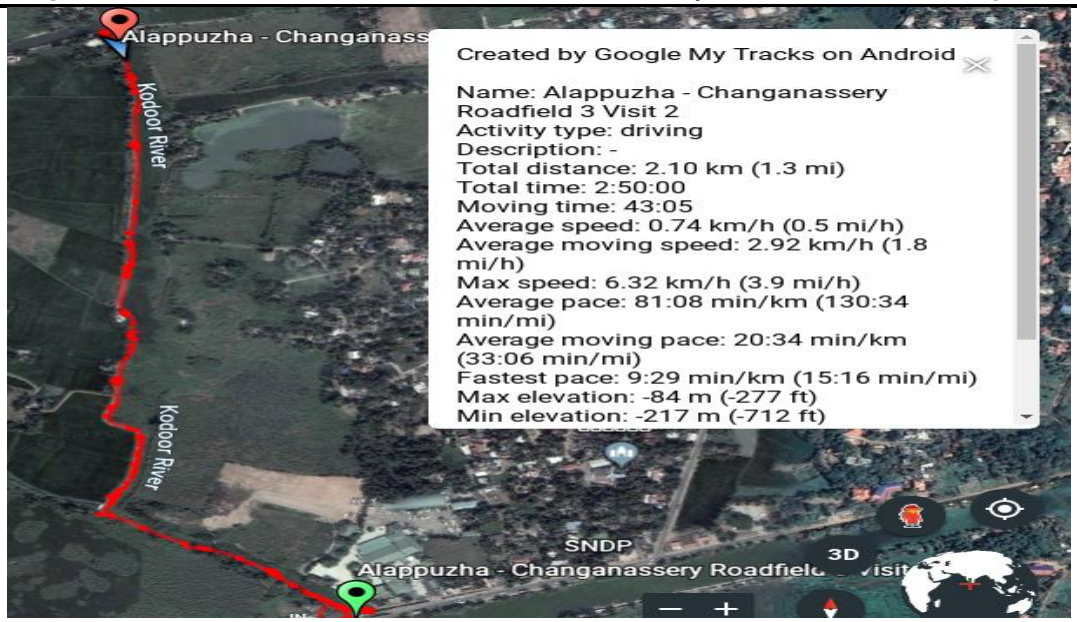


Fig: 3 Show the Line transect route map of **Kavalikkara Station in Upper Kuttanad.**

Taxonomic Description

The morphological features of the observed species are described below. These features helped the visual classification of their kinds and were also used to verify whether the machine learning tool could predict the species class correctly.

Odonates may be visually classified by closely observing the colour and patterns on their forehead, prothorax, thorax, abdomen and wings. Depending upon the species' kind, the details may vary. The colours and patterns may differ between male and female species as well. A brief description of the detailed features followed for classifying the species identified in the present survey, along with their images, are described in Figures 10(a) to 10(u).

Male **Female**

Figure 10(a): ***Agriocnemis pygmaea*** (Rambur, 1842) Family: **Coenagrionidae**

Male- Small damselfly with black-capped green eyes, black thorax with apple green stripes on lateral sides. Labrum is glossy blue. Fore wings with pale yellow spots and hindwings with black wing spots(Pterostigma). Anal appendages are brick red.

Female- Looks stronger and healthier than males and exhibits several colour morphs. Pterostigma yellow in all wings and anal appendages brick red

Male **Female**

Figure 10(b): ***Ceriagrion cerinorubellum*** (Brauer,1845) Family: **Coenagrionidae**

Male - Greenish orange in colour, the base of the abdomen and the anal tip reddish-orange in colour.

Female- The abdomen is similar to the male, and the anal tip is greenish-red in colour.

Male **Female**

Figure 10(c): ***Ceriagrion coromandelianum*** (Fabricius, 1798) Family: **Coenagrionidae**

Male- The abdomen is lemon yellow without markings, and the thorax is greenish yellow.

Female: The body is greenish yellow and olivaceus uniformly—abdomen with markings and dorsally pale golden.

Male **Female**

Figure 10(d): ***Pseudagrion microcephalum*** (Rambur,1842) Family: **Coenagrionidae**

Male: Light blue-coloured abdomen with black stripes, blue colour below the eyes and ventral side, a black cap dorsally above the eyes on the head, and a black line connecting both eyes with blue dots.Thorax black with light blue stripes.

Female Pale greenish blue. Thorax light green with brown stripes.Black patch of lines on the dorsal side of the abdomen.

Male **Female**

Figure 10(e): ***Libellago indica (Fraser, 1928)*** Family: **Chlorocyphidae.**

Male: Dorsally dark brown in colour and light brown colour towards the ventral side. Eyes are also dark brown from the top. Forewing with black wing spot(pterostigma) in adults, and hindwings are shorter than the forewings. Yellow abdomen with pointed black-tipped segments.

Female: Looks similar in shape to the male, but the females are pale and rusty brown. The abdomen is round and cylindrical—no (pterostigma) black wing spot on forewings like males.

Male **Female**

Figure 10(f):***Ischnura senegalensis*** (Rambur,1842) Family: **Coenagrionidae.**

Male- The body is green, the eyes are light green with a yellow base colour, and the upper portion of the eyes has a black cap. The upper part of the thorax has two black lines, shining metallic blue-black on segment two of the abdomen and azure blue on segment eight and the sides of segment nine.

Female Females are polymorphic and can occur in olive and golden orange forms. There is a characteristic broad, dark, dorsal band on the thorax of all females. Another rarer female form resembles the male and is called an andromorph—no black colouration in the abdomen.


Male **Female**

Figure 10(g):***Acisoma panorpoides*** (Rambur,1842) Family: **Libellulidae**

Male: Light sky blue with black patches in the thorax and abdomen. Eyes are blue, with a light yellow head tip and a lengthwise vertical black line on the abdomen. The stomach bulges in the middle and tapers towards the tip, which is black, and the claspers are white. The legs are black.

Female: Yellowish brown. When mature, they reach almost the same colour as males but are pale. The shape of the female is the same as that of the male.


Male **Female:**

Figure 10(h): ***Aethriamanta brevipennis*** (Rambur, 1842) Family: **Libellulidae.**

Male: Blackish brown in colour, hairy head and thorax. Broad and round red-coloured abdomen. Legs are black, with a red spot between the first and second segments.

Female: Brownish yellow, brownish tint above the eyes, and yellow spots on leg.Thorax and abdomen with broad yellow lines. Females can be seen near the water bodies only during the mating period.


Male **Female:**

Figure 10(i):***Brachydiplax chalybea*** (Brauer,1868) Family: **Libellulidae.**

Male: Greyish blue, thorax yellowish brown, the front part of the head is deep metallic blue, the upper part of the thorax is greyish blue, and the sides of the abdomen are golden brown. The abdomen is blue, and from the eighth segment to the tip is black.

Female: Brownish yellow, with black rings and lines on the thorax and abdomen.


Male **Female**

Figure 10(j): ***Brachythemis contaminata*** (Fabricius,1793) Family: **Libellulidae.**

Usually seen as lined groups on grasses above stagnant water or dried twigs in contaminated waters.

Male: The body is orange, with a pale white colouration below the eyes; legs are brown and deep, and shiny orange-coloured pterostigma is present in the outer edge of the wings.

Female: Golden yellow, the abdomen has black coloured lines. Wings are transparent.

Male

Female

Figure 10(k): ***Crocothemis servilia*** (Drury, 1770) Family: **Libellulidae.**

Male: Body is red, Abdomen is red and with a straight vertical line. Wings are transparent with a light orange tint. The legs are red.

Female: The body is yellowish brown. A vertical line on the top of the abdomen. They droop their wings while they are at rest.

Male **Female**

Figure 10(l):***Diplacodes trivialis*** (Rambur, 1842) Family: **Libellulidae.**

Male: The body is bluish-black, seen mainly on the ground; the last segments of the abdomen are black. The tip of the abdomen is white., Wings are transparent.

Female: The body is light yellow, the upper part of the eyes are brown, the thorax has black stripes, and both sides have yellow spots.

Male **Female**

Figure 10(m): ***Neurothemis tullia*** (Drury, 1773) Family: **Libellulidae.**

Male: Body is black and white, Eyes are blackish brown. The wings are black, and the tip of the wing is transparent with a white marking. The tip of the abdomen is white.

Female: Body is shiny brown, eyes are brown, and wing ends are black with a brown marking in the mid portion. The tip of the abdomen is white.

Male **Female**

Figure 10(n): ***Orthetrum sabina*** (Drury, 1770) Family: **Libellulidae**

Male - The body is green with black lines on the thorax and abdomen. The front tip of the head has a yellow colouration. Eyes are green with black spots. The legs are black, and the wings are transparent. Two ends of the abdomen are swollen and thickened, and the middle part is thin with white markings.

Female- Looks are very similar to the male sabina, but the last segment of the abdomen is not swollen.

Male **Female**

Figure 10(o):***Pantala flavescens*** (Fabricius, 1798) Family: **Libellulidae**

Male: The body is reddish brown, and the eyes, neck, and thorax are light brown; the abdomen is orangish brown with a longitudinal line in the middle. Wings are transparent—brown-coloured pterostigma.

Female: The body is yellowish-orange in colour.abdomen orange in colour.

Wings are transparent and are without pterostigma.

Male **Female**

Figure 10(p): ***Rhodothemis rufa*** (Rambur, 1842) Family: **Libellulidae**

Male-Eyes are glittering red, and the head, thorax, and abdomen are red, with a longitudinal mid-grooved line. Legs are reddish black in colour.

Female- The body is golden brown, with a yellow longitudinal line. Eyes are light brown.

Male

Female

Figure 10(q): ***Rhyothemis variegata*** (Linnaeus, 1763) Family: **Libellulidae**

They are seen as groups hovering in the sky, basking in the sunlight and still flickering their wings.

Male- Wings are broad and transparent, golden with big yellow and black spots, and look like a butterfly. The eyes, neck, thorax, and abdomen are glittering black.

Female- Looks similar to male, except for the more yellow and black colouration on their wings.

Male

Fem

Figure 10(r):***Trithemis pallidinervis***(Kirby, 1889) Family: **Libellulidae**

Male: The body is light yellow with brown stripes in the thorax; the abdomen is black with yellow spots on it. Legs are black and are comparatively more prolonged than others.

Female: The body has a look similar to that of males. The upper portion of the head and eyes are yellow. They are usually seen on windy lands. They usually lay their eggs in waterlogged marshlands.

Male **Female**

Figure 10(s): ***Urothemis signata*** (Rambur 1842) Family: **Libellulidae**

Usually seen near marshlands, streams and backwaters of Kerala.

Male -Eyes, thorax and abdomen are deep red. The abdomen has big and small black spots and a transparent brown spot at the base of the two hindwings.

Female- Eyes are reddish brown, and the thorax and abdomen are yellow in colour with black rings.

Male **Female**

Figure 10(t):***Trithemis aurora*** (Burmeister, 1839) Family: **Libellulidae**

One of the common dragonflies of freshwater wetlands, streams, rivers and ponds.

Male: They usually perch on dry twigs, aquatic plants and overhead cables. One of the most beautiful and eye-catching dragonflies, with their crimson colour habit of perching on exposed twigs, is often seen in obelisk posture during hot weather.

Female: Less common when compared to male, olive-brown in colour, often seen in obelisk posture, and the wings drooped down. Wings have wing spots, the prothorax is light brown in colour, and the eyes are greyish blue.

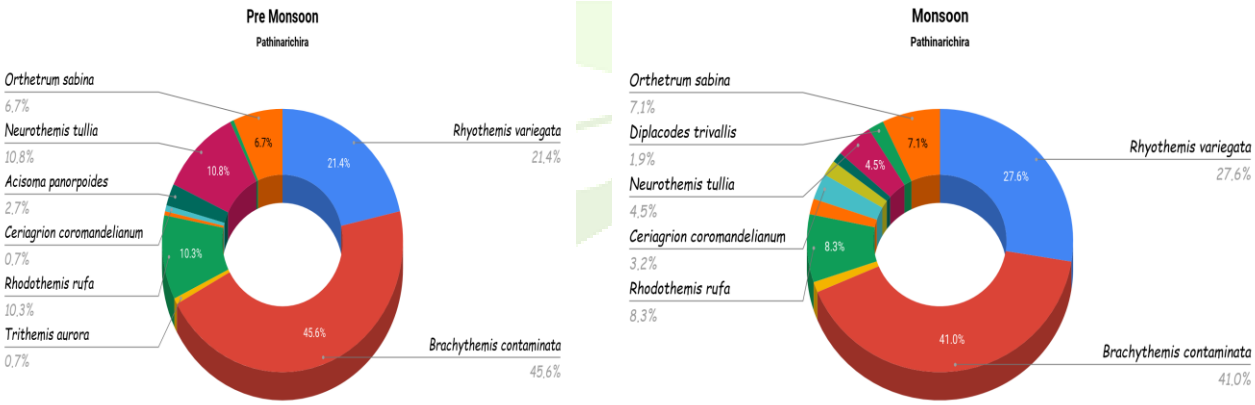
Male **Female**

Figure 10(u): ***Tholymus tillarga*** (Fabricius, 1798) Family: **Libellulidae.**

They are swift fliers, usually hiding in bushes during the daytime. During dusk, they fly left to right, to and fro in the same route above the water body and catch their prey.

Male: Red dragonflies with white spots on their wings. The eyes and legs are reddish brown, and the wings are transparent. Hind has a big golden and cloudy white patch in the middle.

Female: The body is golden yellow, and the thorax and abdomen are red. Legs are brownish red. The female's hind wing does not have a cloudy white patch. Instead, they have a golden yellow patch on their hind wings.



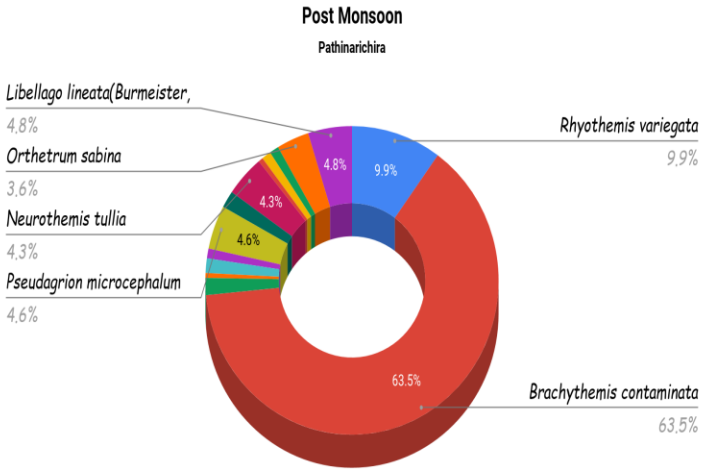
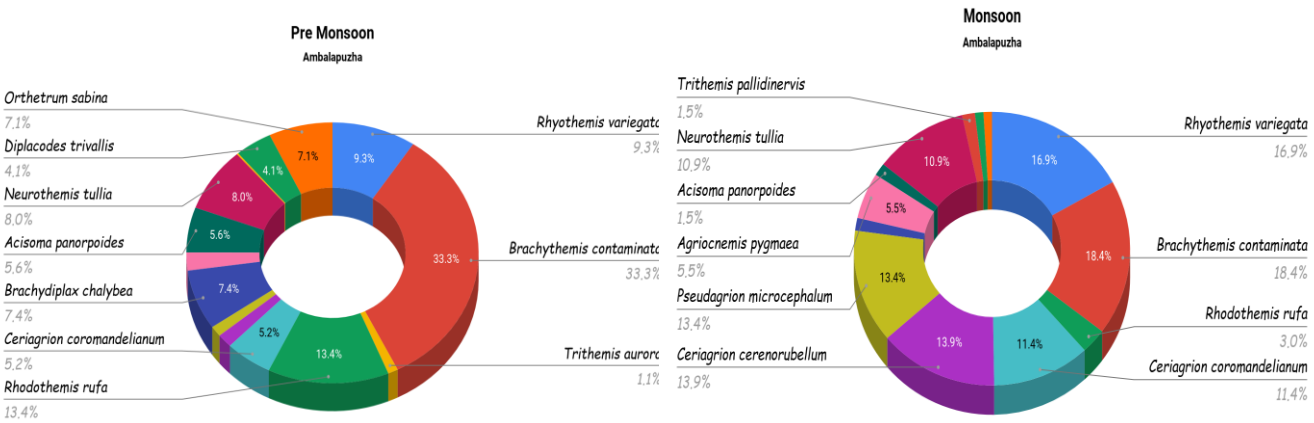


Figure 11: The relative abundance of observed species in **Pathinarichira** across the three seasons is shown above. It may be noted that the *B. contaminata* population increased after the monsoon at this site.



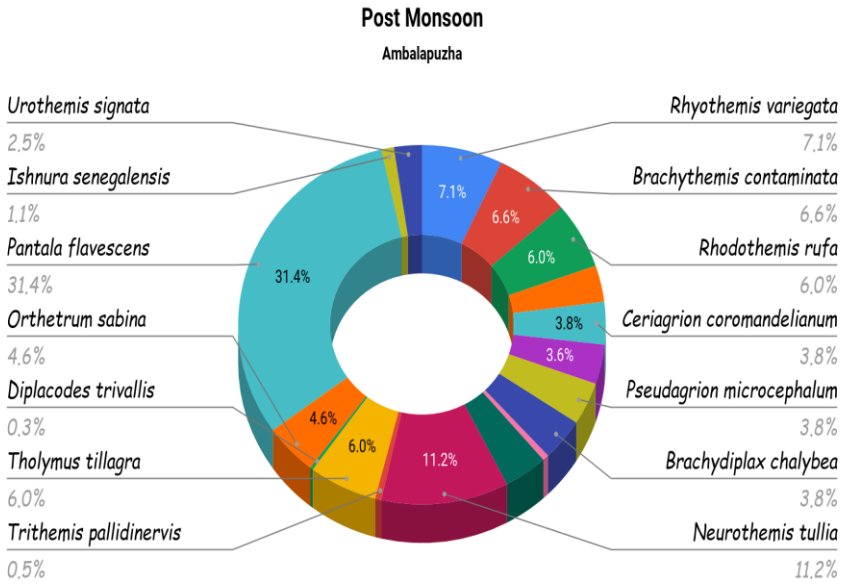
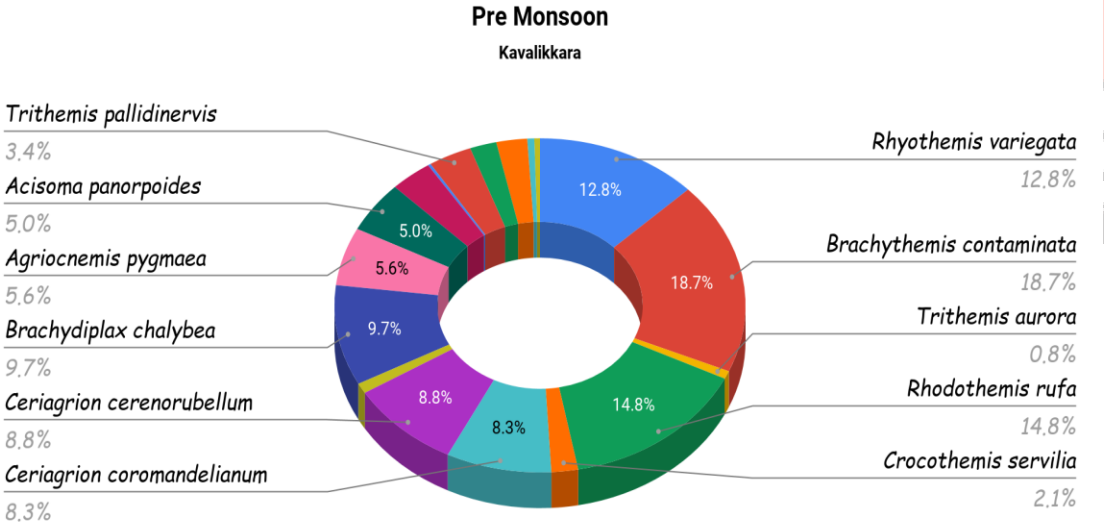


Figure 12 shows the relative abundance of observed species in Ambalapuzha across the three seasons. It may be noted that the species diversity recovered, and the *B.contaminata* population decreased after the monsoon.



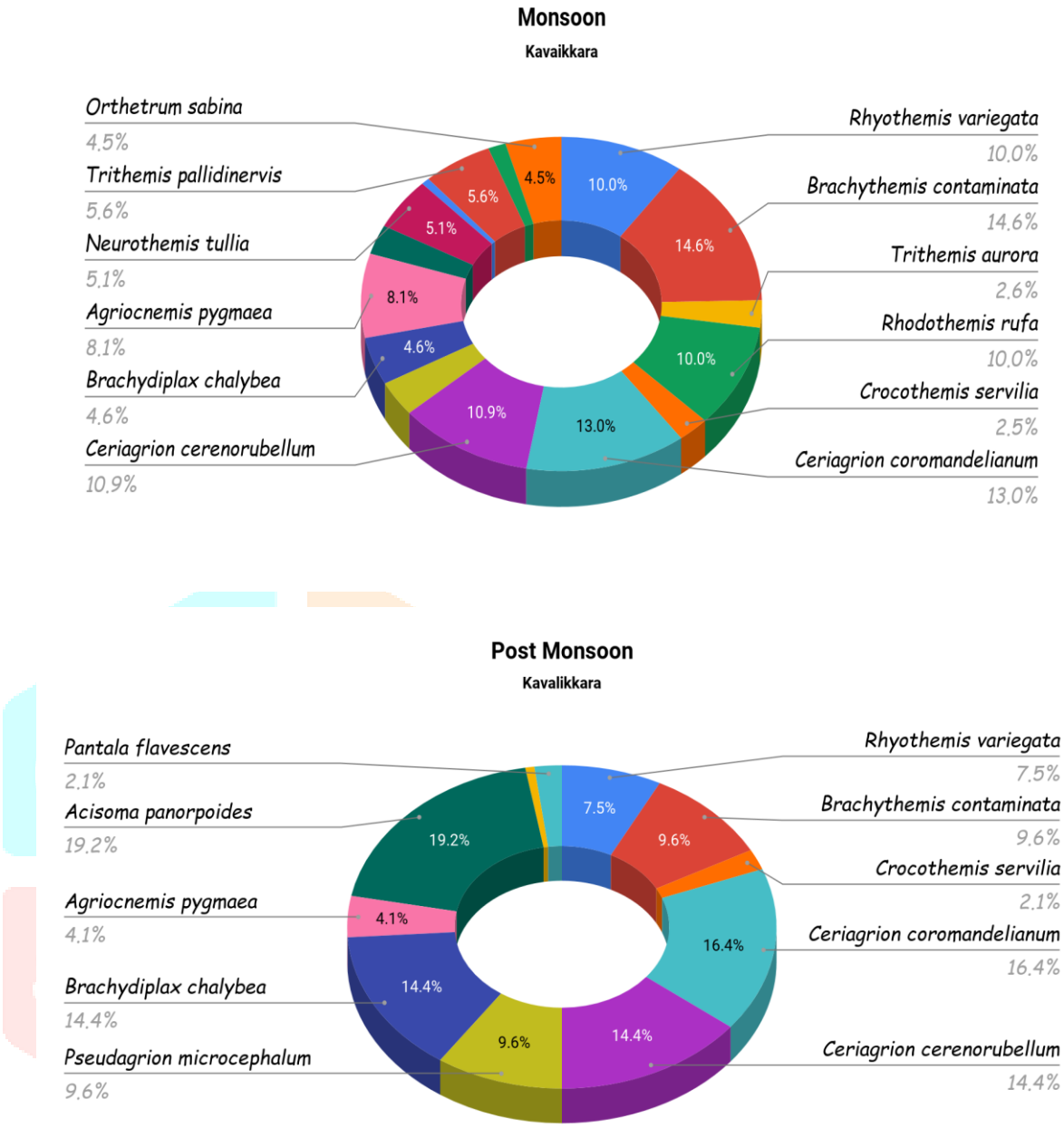


Fig 13 shows the relative abundance of observed species in Kavalikkara across the three seasons.