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The Role of Odonata in Wetland Ecosystems: An Ecological Perspective

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Abstract

Odonata, comprising dragonflies and damselflies, are integral to the health and sustainability of wetland ecosystems. These insects serve as both apex predators in aquatic habitats and key prey species in terrestrial food webs, ensuring ecological balance. In their larval stage, Odonata contributes to nutrient cycling and water quality by preying on detritivores and controlling populations of aquatic pests, such as mosquitoes. As adults, they help regulate terrestrial insect populations, acting as natural pest control agents. Additionally, Odonata are bioindicators of wetland health, responding sensitively to changes in water quality, habitat structure, and climate conditions. Their presence and diversity reflect the ecological integrity of wetland systems, making them invaluable for monitoring environmental changes. This review highlights the multifaceted ecological roles of Odonata, emphasizing their importance in trophic dynamics, ecosystem services, and conservation efforts to preserve biodiversity and wetland functionality. Recognizing their ecological contributions is crucial for designing sustainable management strategies for wetland habitats globally.

Keywords: Odonata, ecology, wetland health, ecosystem, bioindicators, water quality

INTRODUCTION

Dragonflies and damselflies are accustomed to living in wetland ecosystems from their egg stage to maturity. They lay their eggs in water bodies, where their offspring undergo nymphal development before they turn into adults [1]. The set of unique morphological and behavioral adaptations that make them distinctive among other aquatic macroinvertebrates includes mandibular mouthparts for prey capture, the second largest eye-to-body size ratio among extant animals, the ability to fly at speeds up to 85 km/h, and the ability to swivel wings 180 or more degrees while hovering [2]. Furthermore, behavioral and ecological characteristics, such as carnivorous diets during both adult and larval phases, rapid mobility offered due to their winged state, the ability of terrestrial and pelagic maturation, high occurrence and species richness in dysphotic zones, long-distance migrations, large body sizes, hierarchical dominance, and reproductive success attributable to high metabolic rates and efficient energy conversion mechanisms have made Odonates popular icons for environmental awareness in addition to being effective environmental health indicators. Through keen examination of Odonate biology at different ecological levels, we explore their roles in wetland ecosystems and attempt to answer a few pertinent queries relevant to the preservation of their habitat.

Since adults can forage outside of their habitable wetland and undergo maturity in various degrees of water body quality, they may serve as a measure of habitable landscape carrying capacity [3]. Additionally, larval traits, such as burrowing, periphyton predation, and competition for

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phytoplankton and sediment-based detritus might be used to evaluate wetland function. Individually, the unusual geographic characteristics of selected species provide meaningful insights into environmental factors driving certain biological attributes. Therefore, the study of Odonates is essential for understanding the intricate biology of wetlands. Stressing the significant aspects of these animals, we begin by discussing their ecology at different levels, starting from habitat preference, foraging, breeding, and responses to altering habitats before presenting their role in ecosystem energetics. Due to sources of threats arising in the form of augmented speeds owing to high metabolic processes, low fecundity, and behavioral attributes, the contemporary Odonate ecosystem is highly endangered [4].

TAXONOMY AND DIVERSITY OF ODONATA

Odonata, a Latin word used for "toothed ones," is the order of ancient holometabolous insects. This order is divided into three suborders, 21 families, approximately 700 genera, and more than 5, 700 species of dragonflies and damselflies [5]. Based on classification, Odonates are divided into two equally advanced infraorders, the dragonflies and the damselflies. Damselflies are characterized by wings held together over the abdomen and smaller body size (1.5 to 5 cm) as compared to the resting position (hindwing elevated or below) and two pairs of almost similar wings in dragonflies. Adult individuals have long and slender bodies and two pairs of multi-veined membranous wings, which are strengthened by many crossveins. The eyes cover the head and give a 360° view; legs have developed into grasping organs, and a range of colors, which is quite impressive [6]. There are about 3,000 to 7,000 species in more than 600 genera in the order.

Odonata species occur in large numbers in the Afrotropical, Indo-Malayan, Oriental, and Palaearctic regions of the world, contributing to 30% of the entire population, whereas about 17% of total species are found in the New World or Neotropics [7]. Odonata biodiversity is generally high in tropical and subtropical wetlands where they are taxonomically described and identified based on morphological features. The scant distribution of Odonata species is mainly under threat due to climate change and habitat destruction. Taxonomy and systematics can provide basic information on ecological functions, phylogenetic relationships, and evolving lineages, while taxonomy is important for the use of DNA sequences in the barcoding of a good number of taxa. A majority of Odonates are generally very active in the diurnal period, with much active behavior evident around sunrise and sunset as compared to during the day.

Players with difficulties are known to hunt and feed over the entire day. More than 25 families and 130 taxa have been recorded from the Western Ghats, India [8]. Accurate and authentic identification of Odonata at the level of family, genera, and species is important for the conservation of wetland ecosystems and the preservation of the populations of threatened and endemic taxa.

LIFE CYCLE AND HABITAT REQUIREMENTS

Odonata undergoes an incomplete metamorphosis lacking a pupal stage and exhibits the following life cycle stages: egg, larva, and adult. Among these, larva and adult forms are the most studied because of the functional importance of these stages [9]. The distribution and survival of these life stages are closely associated with the existence of different microhabitats. For example, the larvae occur and grow in aquatic environments, while adult forms are relatively more terrestrial but return to water bodies for oviposition. The success of the larvae depends on the availability of suitable freshwater habitats.

The development of Odonate larvae takes place in either lotic or lentic aquatic systems, depending on their habitat preferences. Lentic systems demonstrate fewer harmful disease-causing agents in still-pooling areas. Pond habitats help reduce predation by larger Odonate species as a portion of microhabitat distribution patterns [10]. There is also evidence that species occurring in temporary pools grow more quickly (relative to the length of the larval stage) and disperse further from natal ponds to breed again as adults, showing an advantage in shortening the generation time to survive in habitats with limited availability. These animals show a great range of habitat specifically. Hence, Odonates occupy various types of small water bodies under different environmental conditions, and the distribution and survival of these life-history stages are closely associated with the habitat selection of these aquatic systems.

Odonata is ecologically associated with water bodies, where a complex food web operates with several organisms, from primary producers to predators. Different environmental factors, such as the type of water body (lentic vs. lotic) and other habitat factors like water quality, water depth, submerged vegetation, turbidity, and pH, have varying effects on different families and species [11]. Additionally, they survive in diverse environmental conditions according to their larval microhabitats or oviposition. Larvae live in aquatic habitats but depend on the availability of various terrestrial invertebrates for feeding. The larvae and/or reproductive populations of several Odonate species are found in wetland habitats. When wetland habitats are reduced or destroyed, the breeding or adult population of the species may be exposed to localized elimination or a reduction in genetic variability, especially in species with poor dispersal ability. Therefore, knowledge of the spatial and temporal variation in life history traits of Odonate larvae is crucial for managing protocols for the health, survival, and conservation of adult populations. The association between life history traits and both vegetation and water parameters is interpreted from an ecological point of view. It could facilitate the development of environmental protection strategies to conserve declining biodiversity in natural areas while allowing sustainable land use.

ECOLOGICAL FUNCTIONS OF ODONATA

The Odonata, from immatures to adults, provide numerous ecological functions within their ecosystems, playing a prominent role as top predators in the aquatic food web. Adults emerge in large numbers and are voracious predators of nuisance insects in terrestrial and indoor environments [12]. More generally, Odonata, such as *Aeshnidae*, are essential regulators of the density and dynamics of populations of nucleophagous organisms, predominantly fishes, and thereby influence the trophic cascades or bottom-up effects in complex food web interactions [13]. Freshly emerged damselflies and dragonflies restore trophic connectivity; they are direct links between aquatic and terrestrial environments, serving as prey to a wide variety of vertebrates, ensuring help in the biological and nutrient cycling from one habitat to another. Immatures are efficient hunters of a wide range of other aquatic organisms, especially small to medium-sized aquatic insects, and widespread varieties of worms including snails, and fish larvae.

Odonata, acting as nutrient sources and converters, are crucial bio decomposers, contributing to some aspects of nutrient cycling. They are considered prime biochemical change agents, “natural scavengers” breaking down dead organic matter that would otherwise accumulate excessively in the environment [14]. Many detailed reviews have suggested that the overall conservation benefits Odonata can provide to water bodies are significant, but relatively few studies have attempted to define these benefits in detail. Odonata diversity is linked with enhanced water body health and ecosystem function. In particular, a comprehensive review of the ecological importance of rapacious Odonata showed that the adults are among the most specialized predators in regard to both habitat and diet. This should engender a real appreciation of the threatened conservation status of mature Odonata, like stalk-eyed Odonates.

PREDATION AND TROPHIC INTERACTIONS

Predation, a common biological behavior in Odonata, serves as a compensatory agent in the control of insect pests in ecological systems. The two distinctly separated habitats of Odonata, the adult terrestrial and the larval aquatic, stimulate two forms of feeding strategies [15]. Lepidopteran larvae are probably the commonest prey of dragonfly larvae, followed by dipteran larvae, which are the most generally accepted in the insect category [16]. Adult Odonata frequently prey on large dipterans, both other terrestrial insect taxa and, unsuccessfully, other Odonates. Field and laboratory research indicate that Odonates eat accurately and have a uniformly limited prey range, as associated with other predators, but the precise prey size composition is not clear [17].

Odonates considerably affect their environment through their actions on prey animal populations. The major impact of Odonate predation is population suppression and elimination, but in various types of experiments, it was demonstrated that their feeding behavior also has a variety of other delayed impacts [18]. Because of their specific interactions with the biota, the net outcome of which is influential in the organization of field communities, Odonates are prominent species within wetland ecosystems. Odonate larvae, devoid of their devastating impacts on pest density, have, for example, important interactions with bluegill fish, another major wetland vernal pool predator [19]. Thus, through their direct and indirect impacts, bluegill also affects oviposition and, on some occasions, kills Odonates. Such trophic and other associations about the community structure and dynamics that occur in several instances, between dragonfly larvae and other predators in vernal pools, provide the context necessary to understand the community structure that we report here. They also show that the carnivorous habit of Odonates forms the nucleus of their being a crucial regulating species in their immediate ecological community and an effective conservation biological control agent in certain habitats, owing their existence to only one Odonate species.

NUTRIENT CYCLING AND DECOMPOSITION

Several studies have shown that Odonata contributes to nutrient cycling in wetland ecosystems. During their eight (or more) life stages, Odonata interacts with both microorganisms and invertebrates functional in organic matter breakdown-related processes [20]. Odonates feed on invertebrates in several stages and are consumed by vertebrate consumers. Thus, Odonata functions in a two-way trophic cascade between terrestrial ecosystems or wetland ecosystems and adjacent waters, where Odonata populations breed in their larval and newly emerged or newly eclosed life stages. Overall, by feeding on and being consumed, Odonata is involved in nitrogen and phosphorus dynamics to make them more available to autotrophs and chemoautotrophs, in line with ecological stoichiometry. Many studies indicate the importance of Odonata in prey-predator relationships and adjacent aquatic ecosystem dynamics associated with nutrient dynamics.

Odonata facilitate the movement of nutrients through an aquatic-terrestrial transfer and an aquatic-aquatic transfer in small patchy wetlands by means of their predatory feeding behavior mediated by nutrient release in their gut and surrounding environment and in their offspring [21]. Odonata and their food web interrelations therefore provide the useful ecosystem function of nutrient export from their habitat. Furthermore, nutrients stored in Odonata can be excreted outside the wetland habitat by the movement of Odonata or their offspring to another habitat [22]. Spiders and mosquitoes have also already shown signs of an aquatic-terrestrial prey-related nutrient ecology. In turn, Odonata are part of the aquatic food web of the wetland habitat, and their predation moves nutrients that have accumulated from the invertebrate prey. As Odonata are consumed directly and indirectly through several stages of their life course, they can accelerate further nutrient cycling in and outside the wetland habitat. In this way, Odonata contribute to other ecological processes and biodiversity conservation in wetlands.

CONSERVATION AND MANAGEMENT STRATEGIES

Odonata and wetland habitats are currently threatened worldwide by different factors, such as the destruction of natural habitat, climate change, and over-exploitation. There are several pressing issues that need to be addressed in relation to the conservation of Odonata in the wetlands. A major issue is the degradation of wetland habitats. The Wetland area has been lost at an alarming rate, with a significant share converted or degraded because of urbanization, agricultural expansion, and industrial activities. The impact of climate change, especially increased drought incidents, affecting the hydro-period and altering the water quality parameters of freshwater wetlands, is a severe immediate threat to wetland biodiversity, including Odonata systems. Odonata habitats are also highly threatened by water pollution. Conservation of wetlands thus naturally conserves Odonata populations as well. Governments and other conservation bodies are directed to work hand in hand in wetland conservation.

Currently, attention to Odonata and the wetland ecosystems is limited in many parts of the world, and conservation initiatives are primarily focused on charismatic species. Biodiversity indicators are essential for efficient wetland management. The selection of Odonata species for SSIs should be extended to other societal groups and regions, including biodiversity, such as invertebrates and terrestrial forms. Integration of Odonata in the SSI of Kedros wetland and the Greek inventory for the progress check of the PAs and their contributions is expected to lead to wetland biodiversity conservation, mainly by applying monitoring and specific species management efforts. Ex-situ conservation initiatives are ineffective because of the intricate life history traits of Odonata. Compatible goals of wetland management, environmental legislation, and conservation should thus guide the prioritization of restoration or study of suitable areas for promoting the conservation of a particular species. Tailoring Odonata conservation-oriented research in the areas that threaten the survival of a particular species is a significant conservation effort. Systematic surveys of threatened wetlands in the long term will reveal the population trends of Odonata species and the responses to conservation initiatives if practiced.

CONCLUSIONS

Odonata are important bio-indicators or indicator species of aquatic ecosystems as they play significant ecological roles. They are also some of the most striking and charismatic insects. The contribution of predacious Odonates to the biodiversity of permanent ponds has been widely accepted. Odonates perform many ecological functions in an ecosystem, namely, predation, as prey, niche differentiation, biological control, and recycling of dead organic matter.

Heavy metals, such as copper, zinc, lead, nickel, and cadmium can suppress the activity of various digestive enzymes and interfere with the nutrient cycling of Mediterranean temporary wetlands. Larval Odonates contain these metals and energy in relation to body weight, which can give nutritional advantages to their respective predators.

It is evident that, besides being affected by abiotic factors described previously, the various physiological and metabolic processes are also controlled by Odonata, thereby influencing the number, biomass, and density of the prey population. The use of larva, adult Odonata, exuviae, and the presence of breeding adults to assess environmental degradation has been discussed briefly in an inclusive manner. Many of the new questions that we have raised need additional research, both experimental and theoretical, to provide insight and resolve the complexities of the relationships between Odonates and their diverse ecosystems. However, the developmental cycle of Odonates highly links it to the environment as migratory adults prefer to breed where they grow. Holistic conservation is both cost-effective and efficient for the successful management and conservation of Odonate habitats alongside other associated biodiversity in ecosystems.

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