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The ecological importance of aquatic insects in sustaining fisheries productivity

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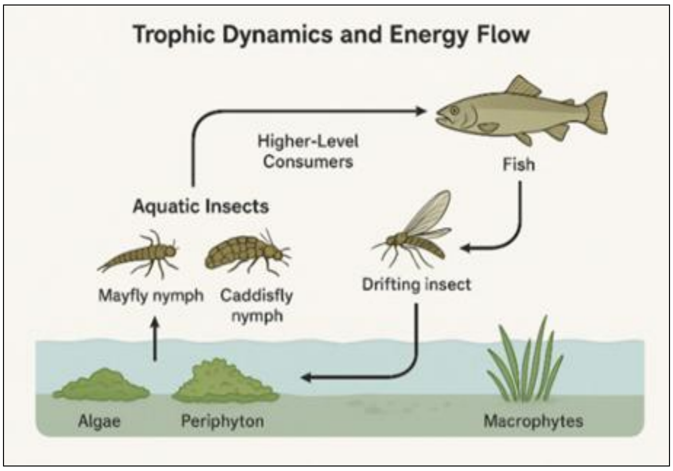
Abstract
Aquatic insects play a vital role in both freshwater and marine habitats. It plays critical roles in food web dynamics, nutrient cycling, and fish population productivity, all of which are important to the fishing sector. This study focuses on the ecological significance of aquatic insects, including their roles as primary consumers, detritivores, prey items and bio-indicators, as well as their impact on fish development, survival, and fishery yields. In aquaculture research, we discuss how aquatic insect abundance supports both natural and stocked fisheries, as well as its function in sustainable, low-input aquaculture. We discuss ecosystem health assessment and conservation, demonstrating how monitoring aquatic insects may inform fisheries management and restoration. We also discuss rising concerns such as habitat loss, pollution, climate change and present solutions such as habitat augmentation, bio-floc systems, and integrated watershed management to protect aquatic insect biodiversity and improve fishing resilience. Overall, aquatic insects are essential to fisheries, and their conservation and management are vital for ecosystem services, long-term fish production, and resilience in the face of global change.

Keywords: Aquatic insect, insect-based fish feed, bio indicator, fisheries productivity

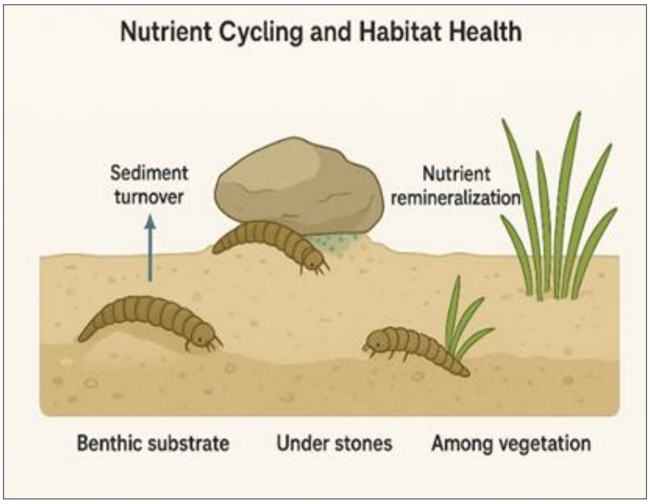
Introduction

Despite their small size and seemingly insignificant appearance, aquatic insects are vital to the economy. Agriculture benefits from aquatic insects like damselflies and dragonflies. By feeding on insects that harm crops, they aid in pest control and lessen the need for chemical pesticides. In addition to saving farmers money, this promotes farming methods that are good for the environment. With significant economic implications, aquatic insects contribute significantly to the ecology of freshwater ecosystems. Springtails, mayflies, stoneflies, alderflies, fish flies, dobsonflies, lacewings, beetles, true bugs (water striders), Hymenoptera (ants and wasps), Diptera (flies and mosquitoes), scorpion flies, Lepidoptera (moths), and Trichoptera (caddisflies) are among the orders into which aquatic insects are divided. These insects are vital indicators of water quality and essential components of aquatic food webs. The presence of these aquatic insects in freshwater ecosystems increases the attraction of outdoor activities such as fishing and bird viewing. Anglers are drawn to places rich in aquatic insects because they act as a natural food supply for fish, resulting in improved fishing experiences. Furthermore, the dynamic and diverse world of aquatic insects allows nature lovers to discover and enjoy the beauty of these habitats. Aquatic insects have some really unique habits. They have evolved to life in water, developing novel strategies to survive and prosper in their aquatic surroundings. For example, during their larval stage, they have unique adaptations such as gills, which allow them to breathe underwater. They may also move in a variety of ways, including swimming with their legs or tails, crawling, and even walking on the water's surface. When it comes to food, some water insects are predators, chasing smaller animals, whilst others are herbivores, eating algae or plants. Reproduction is another intriguing feature of their habits. Some deposit their eggs directly in the water, while others attach them to plants or other objects above it. Many water insects have distinct life stages, including larvae, pupae, and adults. Each stage serves a specific function in their life cycle. They can also exist in a variety of modes, including surface skaters, burrowers, crawlers, plankton, divers, swimmers, clingers, sparklers, climbers, shredders, collectors, scrapers, piercers, predators, chewers, scavengers, filterers, and carnivores. With such beautiful variety, one can clearly grasp their relevance and significance. In terms of ecology, aquatic insects are vital prey for fish and other aquatic creatures, constituting the foundation of the food chain in rivers, lakes, and streams. These insects primarily influence nutrient cycling and contribute to the breakdown and decomposition of organic matter in aquatic systems. Certain types of aquatic insects are susceptible to pollution and changes in water quality. Their existence suggests high water quality, whereas their absence or reduction may indicate pollution or ecological disturbances. Aquatic insects, particularly those that build structures such as caddis flies and mayflies, influence and modify their surroundings. They build structures such as cases, burrows, and nets to offer shelter for themselves and other species. These structures can also affect water flow, sediment deposition, and overall ecosystem complexity. In terms of human economics, aquatic insects perform a variety of environmental services that are critical to human well-being. They serve the fisheries and aquaculture industries by providing food for fish and other aquatic creatures. This benefits fishermen's livelihoods as well as the fishing sector as a whole. Furthermore, the presence of certain aquatic insects might signal the condition of water bodies, which is critical for businesses such as agriculture, tourism, and fisheries that rely on clean water. Some aquatic insects have potential applications in biotechnology and pharmaceuticals, which could help to boost economic growth and development. As a result, these insects have significant economic ramifications for agricultural production, water quality control, and a variety of enterprises. These small animals have hidden worth in a variety of fields, including agriculture and aquaculture, tourism, research, and education. Recognizing and valuing their economic value can lead to more sustainable practices, conservation efforts, and a better understanding of the delicate balance of our ecosystems. Aquatic insects play an important role in water quality control and have potential applications in biotechnology and medicines. As a result, they have a considerable positive impact on both the environment and the economy.

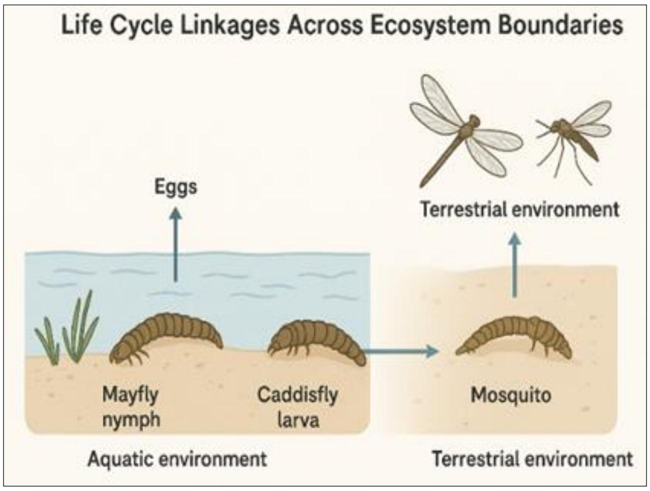
Ecological Role of Aquatic Insects



Trophic Dynamics and Energy Flow: Aquatic insects play an important role in transporting energy from primary producers (algae, aquatic plants and periphyton) to higher-level consumers like fish. Many fish species, particularly juveniles, rely significantly on insect larvae as a protein-rich food source. This connection allows for the transmission of energy and nutrients, which supports fish growth, survival, and reproductive success. For example, mayfly and caddisfly nymphs graze on algae and debris, turning primary productivity into biomass that fish can consume. In turn, floating insects (to emerging adults) provide a key subsidy to streamside and riparian predators, including fish, connecting aquatic and terrestrial ecosystems. Aquatic insects play an important role in freshwater trophic networks, connecting primary producers (algae, periphyton, and macrophytes) to higher trophic levels. Many insect larvae are herbivores or detritivores, devouring algae, biofilm, and decomposing organic debris to produce animal biomasses that fish can consume (Wallace & Webster, 1996) [24]. The transfer efficiency of primary production via insects to fish is high, making them effective energy conduits (Vannote *et al*., 1980) [22]. For example, in lotic systems, stream-dwelling mayflies and stoneflies help to break down leaf litter and recycle nutrients, thereby feeding both small-bodied fish (e.g., minnows) and juvenile salmonids (Cummins & Klug, 1979) [6]. According to Das & Maity (2019) [7], focused on two insect orders (Hemiptera, Odonata) in Kangsabati River. The study documents seasonal changes in species richness and abundance, showing clear seasonal peaks (monsoon/post-monsoon) typical of Indian rivers. Likely employed repeated seasonal sampling and diversity indices to compare assemblages across seasons.

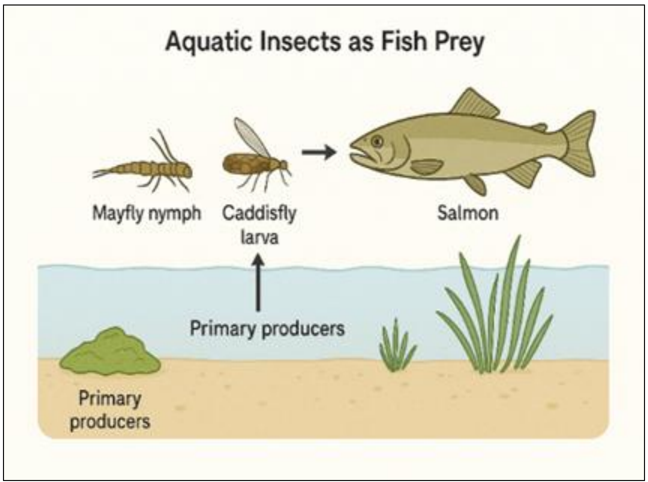


Nutrient Cycling and Habitat Health: Aquatic insect larvae live in a variety of microhabitats, including the benthic bottom, under stones, amid vegetation, and under woody debris. They help to regulate sediment turnover, biofilm dynamics, and nutrient remineralisation by feeding and burrowing. This bioturbation improves oxygen penetration and nutrient redistribution, thereby boosting primary production and ecosystem health, both of which are crucial for fishery sustainability. Insect-mediated decomposition of organic materials promotes nutrient cycling, oxygenation, and habitat complexity. Burrowing insects (such as caddisfly larvae) rework sediments, increase substrate aeration, and alter the availability of nutrients required for primary production (Characklis, 1981) [4]. These mechanisms improve the habitat appropriateness for fish spawning and feeding. Furthermore, insects can concentrate nutrients and act as "mobilizing agents," making normally inaccessible materials available to higher trophic levels (Anderson & Cummins, 1979) [2, 6]. These tasks assure the long-term productivity of freshwater systems crucial to fisheries. According to Das and Maity (2019) [7], expanded taxonomic scope to broader aquatic entomofauna near Midnapore town. This work mapped taxonomic composition and relative abundances, and likely noted the influence of urban/anthropogenic pressures on assemblage structure compared with upstream or less-disturbed sites.



Life Cycle Linkages Across Ecosystem Boundaries: Aquatic insects have complicated life cycles that frequently cross several habitats and ecological boundaries, forming vital connections between aquatic and terrestrial ecosystems. Most aquatic insects, such as mayflies (Ephemeroptera), caddisflies (Trichoptera), dragonflies (Odonata), and mosquitoes (Diptera), have amphibious life cycles, spending their embryonic stages (eggs, larvae, and nymphs) in aquatic habitats before emerging as winged adults into terrestrial systems. Because of their unique dual life, they may move energy, nutrients, and biomass between habitats, which helps to maintain ecosystem function, food web connections, and biodiversity (Power & Rainey, 2000; Nakano & Murakami, 2001). Many water insects metamorphose and emerge as terrestrial adults, frequently in large numbers (e.g., mayflies, midges), bringing pulses of biomass into terrestrial food webs. Fish also benefit from this occurrence by feasting on surface-emerging insects, which provide an energy-rich harvest. This periodic windfall influences fish physiological health and growth rates, particularly in low-production settings.

Aquatic Insects as Fish Prey

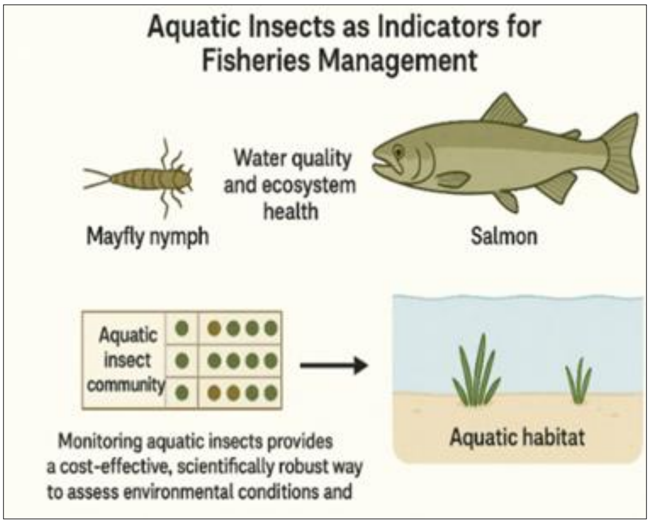


Aquatic insects are critical components of freshwater and brackish ecosystems, providing a vital food supply for many fish species. Their richness, diversity, and nutritional composition make them an important energy conduit between lower trophic levels and fish populations, especially in streams, rivers, lakes, and wetlands (Cummins & Klug, 1979; Wallace & Webster, 1996) [6, 24]. The larval and nymphal stages of insects such as mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera), midges (Chironomidae) and aquatic beetles provide year-round foraging opportunities for fish, while emergent adults cause seasonal feeding maxima. This trophic relationship has a direct impact on fish growth, survival, and recruitment, all of which are crucial in wild fisheries and aquaculture systems.

Wild Fisheries: Ontogenetic feeding shifts toward insects are common in fish species. For instance, salmonids, such as rainbow trout and brown trout, primarily consume emergent adults and larvae of aquatic insects; in many streams, mayflies and midges make up more than 80% of their diet (McCleave, 1978) [15]. Chironomid larvae in the benthos are essential to several cyprinids, including stickleback, dace, and whitefish (Craig, 1979) [5]. In littoral zones, tilapia, which are prevalent in tropical and subtropical seas, opportunistically consume insect larvae (Skulason, 1992) [21]. This dependence emphasizes how fish development rates, condition, and catch-per-unit-effort in capture fisheries can all be directly impacted by decreases in aquatic insect populations (Robinson *et al*., 2000) [18].

Aquaculture and Stocking: Fish development in semi-intensive and extensive pond aquaculture systems is supported by natural productivity, such as aquatic insects, with little feed input. For *carp, catla, rohu* and other stocked fish, insects found in pond bottom sediments and macrophyte mats frequently account for 30–60% of their diet (Singh & Singh, 2017) [20]. By improving this natural feed base through substrate variety, organic fertilization, and aquatic vegetation, feed efficiency can be increased and reliance on commercial feed can be decreased. Insect meals (made from mealworms, black army fly larvae, etc.) are being investigated in new research as sustainable, high-protein feed ingredients. Despite not being "aquatic," these insect-based feeds reinforce the idea that insects are efficient, nutrient-dense feed sources that have less of an impact on the environment than conventional fishmeal (Henry *et al*., 2015) [14, 15]. Their success highlights the idea that insects are valuable nutrient converters for fisheries and aquaculture.

Aquatic Insects as Indicators for Fisheries Management



The suitability of habitats for fish populations is reflected in aquatic insect communities, which are commonly employed as bio-indicators for ecosystem health and water quality. Due to their sensitivity to hydrological conditions, habitat structure, and water quality, aquatic insects are widely acknowledged as trustworthy bio-indicators of the health of freshwater ecosystems. They are essential to the management of fisheries since fish populations are directly related to the productivity and quality of aquatic environments, which are mirrored in the diversity and quantity of insects (Rosenberg & Resh, 1993) [19]. Aquatic insect monitoring offers an economical and scientifically sound method of evaluating environmental conditions and directing conservation and development plans for fisheries. According to Das & Maity (2021) [9], a synthetic review placing aquatic insects in the context of bioassessment. It consolidated literature (including their own field observations) on indicator taxa, common indices (e.g., richness, diversity, EPT-like groups for streams), and practicalities of using entomofauna for water quality monitoring in Indian freshwater systems.

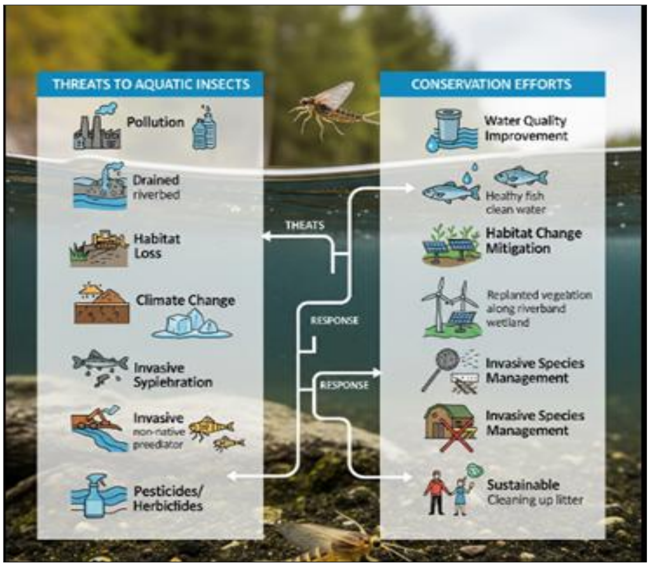
Bio-assessment Tools: Indices such as EPT (Ephemeroptera; Plecoptera; Trichoptera) richness and abundance are standard metrics in aquatic biomonitoring (Barbour *et al*., 1999) [3]. High EPT metrics often correspond to cleaner, colder, well-oxygenated waters conditions conducive to trout and other sensitive fish species (Rosenberg & Resh, 1993) [19]. Conversely, dominance of tolerant taxa like certain chironomids or oligochaetes can indicate pollution, eutrophication, or sedimentation, signaling degraded fish habitat and prompting management interventions.
According to Das & Maity (2023) [10], applied research testing a predator (*Diplonychus sp*., a backswimmer) as a biocontrol agent against mosquito larvae. Likely included laboratory and/or microcosm trials, reporting predation rates, handling times, and efficacy under varying conditions and discussed practicality and ecological risks for field application.

Adaptive Fisheries Management: By tracking changes in aquatic insect assemblages, managers can detect the early impacts of habitat degradation such as increased nutrient loading, agricultural runoff, or altered flow regimes. This allows proactive measures (e.g., riparian buffer restoration, point-source control, habitat rehabilitation) to be enacted to protect or restore fish-supporting ecosystems. For stocking programs, matching hatchery fish releases to habitat conditions with robust insect food bases can enhance survival and growth, whereas degraded insect communities may predict stocking failure.

Threats and Conservation of Aquatic Insects

Aquatic insects are important components of freshwater ecosystems because they contribute to nutrient cycling, energy flow, and act as key prey for fish and other aquatic species. Freshwater ecosystems, on the other hand, are among the most vulnerable habitats in the world, and aquatic insects are under threat from a variety of anthropogenic and natural stresses (Dudgeon *et al*., 2006). The reduction of aquatic insect diversity has a domino effect on ecological stability and fisheries yield. Understanding these challenges and applying conservation actions are critical to preserving aquatic biodiversity and sustainable fisheries.

Habitat Loss and Modification: Wetland draining, stream channelization, dam construction, and riparian deforestation can all degrade or fragment aquatic insect habitats. Reduced habitat variability and connectivity often result in lower bug diversity and abundance, limiting fish food availability (Poff *et al*., 1997) [17]. According to Das & Maity (2025a) [11, 12], Aaspecies-focused ecological study on *Dineutus* (Gyrinidae-whirligig beetles). Likely covered distribution, microhabitat preferences, seasonality, life-history notes, and possible roles in the local food web. According to Das & Maity (2025b) [11, 12], Developed/applied biomonitoring frameworks combining diversity indices and biomonitoring scores to evaluate aquatic insect populations and overall freshwater ecosystem health in the Kangsabati river. This paper represents the methodological culmination of the earlier descriptive and experimental studies.



Pollution and Water Quality Degradation: Pesticide runoff from agriculture, urban pollutants, and mining effluents can all kill sensitive insect taxa, whereas nutrient excess can change community composition to more tolerant, less nutritious species (Allan, 2004) [1]. These changes deplete the food supply for fish and lower overall ecosystem productivity.

Climate Change and Hydrological Alterations: Temperature variations, changed precipitation patterns, and increasing frequency of floods or droughts can all disturb aquatic insect life cycles. Changes in emergence timing may desynchronize with fish feeding periods ("phenological mismatch"), lowering fish condition and recruitment (Wagner *et al*., 2021) [23].

Over exploitation and Fish Community Changes: Intensive fish stocking and overfishing can disrupt fish community dynamics, potentially increasing predation load on specific insect taxa and leading to imbalanced aquatic food webs.

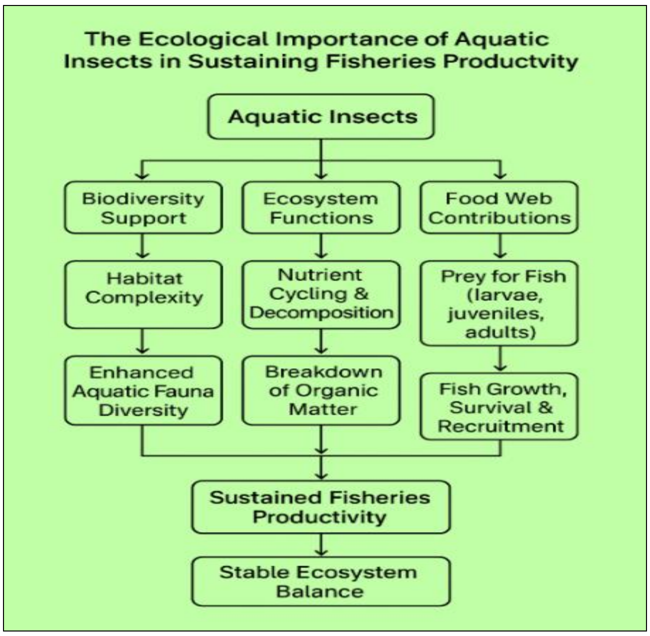


Chart 1: Sustained Fisheries Productivity Flowchart based on aquatic insect (Das & Maity, 2025) [11, 12].

Table 1: Aquatic Insect Contribution to Fish Diets, Sangpradub *et al.* (2014).

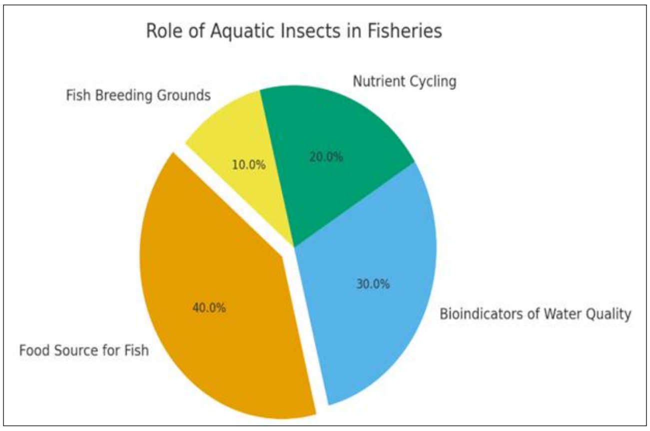
Fish Species	Dominant Insect Orders	Approx. Contribution (by weight or frequency)
Astronotus ocellatus	Ephemeroptera (~98%)	Extremely high
Leporinus reinhardtii	Diptera (60%)	High
Acipenser fulvescens	Diptera up to 78%, Trichoptera up to 60%	Very high
Gambusia holbrooki	Diptera (53%)	High
Pelteobagrus nitidus	Diptera up to 85%, Ephemeroptera up to 77%	Very high

Table 2: Functional feeding group roles.

Feeding Group	Examples	Ecological Role
Shredders	Stonefly, caddisfly larvae	Leaf litter breakdown, organic matter decomposition
Grazers	Mayfly nymphs, some caddisflies	Algal control, biofilm grazing
Collectors	Midge larvae, clams, filterers	Fine particulate recycling, nutrient capture
Predators	Dragonfly nymphs, hellgrammites	Regulation of invertebrate populations, trophic balance maintenance

Table 3: Role of Aquatic Insects in Fisheries.

Role in fisheries	Why it matters	Example
Natural forage base for wild fish	Many river/lake fishes (esp. salmonids) rely on aquatic insects for energy, growth, and condition	Trout biomass increases with invertebrate biomass ($R^2 \approx 0.22$–0.32) across streams.
Seasonal "hatch" pulses	Short windows of very high prey availability boost feeding efficiency and growth	~1-month earlier mayfly emergence where salmon densities are high (changes fish feeding timing) (Moore, J. W., & Schindler, D. E. (2010) [16].
Aquaculture nutrition (insect meals)	Cuts reliance on fishmeal/soy; closes nutrient loops; can improve health	Moderate inclusion (~10–30%) generally maintains growth; immune markers improve with insect meals. (Gougbedji, A *et al*., (2022) [13].
Management & monitoring	Insects (esp. EPT taxa) are sensitive bio-indicators; better insect communities track better fish habitat	Invertebrate indices predict trout biomass at reach scale
Global context	Fresh/inland fisheries where insects dominate food webs support nutrition & livelihoods	~11.3 Mt inland capture in 2022



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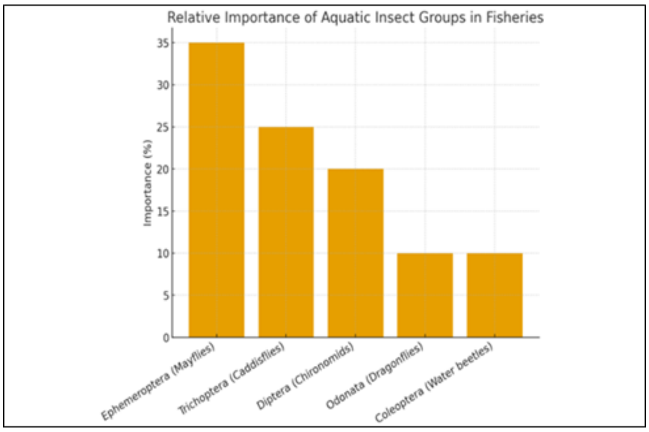

Graph 1: Relative Importance of Aquatic Insect Groups in Fisheries

Conclusions

Aquatic insect conservation is inextricably linked to fishery sustainability, as these creatures provide the trophic underpinning for freshwater ecosystems. Riparian restoration, pollution control, adaptive climate planning, invasive species management, and community participation are all strategies that can help to protect insect diversity and thus healthy fish populations. By incorporating aquatic insect monitoring and conservation into fisheries policy and management frameworks, resource managers can preserve ecological balance, increase biodiversity, and meet long-term food security objectives. Aquatic insects are not only essential for freshwater ecosystem function, but they also act as important bio-indicators for water quality and fisheries management. Their conservation is crucial for preserving aquatic biodiversity, sustaining fish populations, and providing ecological services to human societies. Aquatic insect variety can be protected by taking focused conservation actions to address challenges such as habitat loss, pollution, and climate change, thereby improving the foundation of sustainable inland fisheries.

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