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The FishWorld – A Monthly Magazine (ISSN: 3049-130X) is a premier open-access publication dedicated to the fields of fisheries, aquaculture, and aquatic ecosystems. Launched with the vision of connecting fish farmers, researchers, academicians, policymakers, and industry stakeholders, the magazine offers a unique platform for sharing success stories, innovations, expert opinions, and developments in the aquatic domain. With its reader-friendly approach and national reach, The FishWorld serves as a knowledge bridge between science and practice—empowering the fish farming community and celebrating their contributions to India's blue economy.

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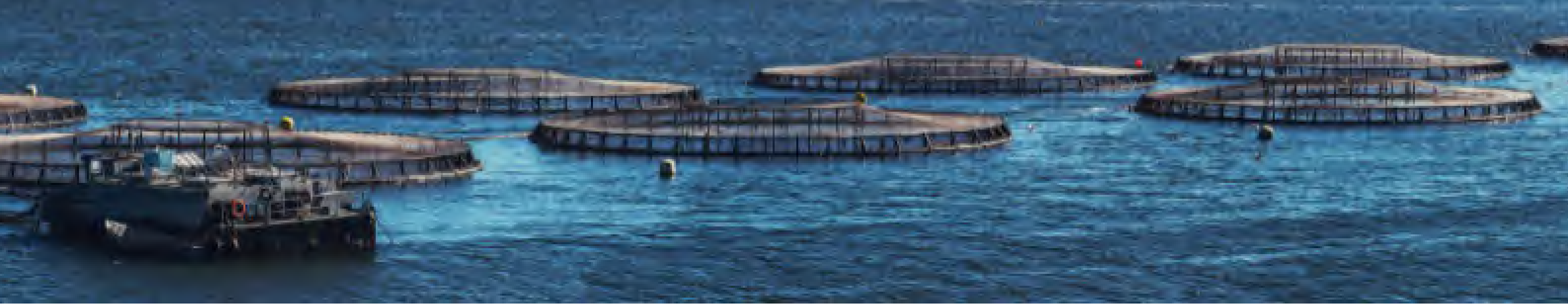

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Best Articles

The Fish World a Monthly Magazine

Official Announcement

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Announcement of Best Article Awards – May 2025 Edition

We are pleased to announce the results of the Best Article Awards for the May 2025 issue of The Fish World – A Monthly Magazine. After a comprehensive evaluation by our editorial and review committee, the following articles have been selected for their exceptional contribution to fisheries knowledge, environmental awareness, and sustainable aquaculture practices:

🥇 **First Prize:**
"Guardians of the Ocean: The Value and Preservation of Coral Reefs"
By Chonyo Shinglai, Binal Rajeshbhai Khalasi, Prabhutva Chaturvedi, and Paramesh Prasad Lenka
(Vol.2(5), May 2025, pp. 398-408)

🥈 **Second Prize:**
"Pool of Wonders: A Tidal Enchantment"
By Ms. Rudira Darishana Dhanasekaran and Ms. Geetha M
(Vol.2(5), May 2025, pp. 386-390)

🥉 **Third Prize:**
"Culture Methods of Shrimp Farming in Pond"
By Shivm Saroj, Dinesh Kumar, Laxmi Prasad, Rahul Kumar, and Nikita Viswas
(Vol.2(5), May 2025, pp. 331-334)

We extend our heartfelt congratulations to all the authors for their outstanding contributions. Their work not only enriches the scientific community but also promotes sustainable and responsible practices in fisheries and aquaculture.

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Popular Article

Hygiene Practices in Seafood: Ensuring Safety and Freshness

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DOI:10.5281/FIshWorld.15387980

Introduction

Important part of foodborne diseases is related to improper preparation practices in home kitchen. Global concern about food safety has prompted research to evaluate domestic food handling practices and food safety knowledge. Food safety is a featured issue in terms of human health protection. Regulatory agencies control food processing facilities on food safety, but it is the consumer's responsibility to ensure the right conditions at home Many of the food poisoning cases at home are not reported to the public health authorities and there is little interest in the news media. For this reason, the public generally associates foodborne illnesses with dining out and does not realize the importance of home practices in terms of food safety. Whereas, the number of coliform and faecal coliform bacteria in the home kitchen may be even higher than the toilet. The consumer's practices at home may lead to disadvantages such as cross contamination or bacterial growth, as well as providing benefits such as pathogen reduction via cooking or retarding bacterial growth by cooling. Consumer education about proper practices is of great importance in terms of preventing foodborne poisoning. For an effective communication, the behavioural differences of the people should be determined and a risk communication plan should be made accordingly. Determination of consumer behaviour also leads the industry to improve its applications such as product design, distribution system, packaging, logistics. Thus, it is possible to make a significant contribution to marketing by establishing permanent, mutual and beneficial relationships between suppliers and consumers.

Seafood and foodborne pathogens

Nowadays food poisoning is a major social and scientific issue. Food poisoning is caused by those foods which looks normal when we see it, smells normal and even tastes normal when we eat it. Only special scientists can analyze food quality by checking its all-sensory parameters. Food poisoning caused by foodborne pathogens. These pathogens can be bacteria, viruses, fungi and algae. Pathogens mostly attack on those foods which stored in humid environment, high temperature and which have more water content. According to these conditions' seafood is more susceptible food for contamination. Seafood can be contaminated by pathogens at any stage from harvesting to fork. Sometime fish can become poisonous even in water by some bacteria's or by some algal toxins. Most common pathogens which involve in seafood poisoning are Vibrio, Salmonella, Listeria, Shigella, Staphylococcus, Clostridium and Escherichia coli. Poisoning diseases which can occur are scombroid poisoning, amnestic shellfish poisoning and diarrheic poisoning, etc. Some viruses also involved in seafood born infections. These infections can be avoided by using proper cleanliness and care in handling fish. In this review the most common food-borne pathogens in fish and fish products are discussed

Eating customs vary worldwide and the types of food that people consume vary across 53 countries. People in numerous countries consume ready-to-eat (RTE) and raw food, including 54 seafood products, and these individuals are most vulnerable to foodborne illness. Seafood 55 includes various species of mollusks, marine mammals, finfish, crustaceans, and fish eggs 56. Because seafood is high in nutritional value, containing high-quality 57 proteins, omega-3 fatty acids, essential micronutrients, and certain minerals and vitamins 58, it is increasingly incorporated as a part of a healthy 59 diet worldwide. Recently, the Food and Agriculture Organization (FAO) estimated the amounts of seafood consumed annually: according to the FAOSTAT Database (faostat.fao.org), the 61 largest amount of seafood consumed is in Japan (53.70 kg/person/year), while the consumption 62 in China is 32.80 kg/person/year (FAO, 2014). The FAO declared the USA to be the third-largest 63 seafood consumer in the world (21.70 kg/person/year). An annual report released by the National 64 Oceanic and Atmospheric Administration (NOAA) indicated that commercial fishermen in the 65 USA gathered 9.6 billion pounds of seafood in 2012, which was valued at US$ 5.1 billion 66 (NOAA, 2011). Furthermore, the world's fish and seafood consumption has grown exponentially 67 over the past few decades from 137 to 143 million metric tons, which is valued at US$ 208 68 billion (FAO, 2010). Globally, seafood is a major traded food product that is often shipped over 69 long distances (FAO, 2002). As such, a large amount of seafood is imported by the USA each 70 year (FAO, 2009). Concurrent with the increase in consumption of seafood, the disease burden 71 associated with these products increased in the USA between 1998 and 2008. Meanwhile, 72 general awareness of seafood-related illnesses also increased during this period (Morbidity and 73 Mortality Weekly Report (MMWR), 2013). During this 10-year period, seafood-related products, 74 such as finfish, molluscan shellfish, seafood dishes and other seafood products were reported to be responsible for 5,603 cases of diseases that included 657 outbreaks of foodborne illnesses in 76 the USA (Center for Science in the Public Interest (CSPI), 2013). Globally, Aeromonas 77 hydrophila has been isolated from aquaculture products, including crabs and fishes (Nielson et 78 al., 2001), and septicemia due to motile Aeromonas spp. has been estimated to have caused 79 greater than US$ 12 million in losses to catfish aquaculture facilities in the USA. Mizan et *al.,(*2015).

Food safety practices in seafood hygiene

Food safety practices in seafood hygiene are critical to preventing contamination and ensuring the safety of consumers. Seafood, due to its high moisture content and perishable nature, is particularly vulnerable to bacterial, viral, and parasitic contamination. To prevent foodborne illnesses, strict hygiene practices must be followed from the moment seafood is harvested until it reaches the consumer.

At the harvesting stage, proper handling and storage are key to preserving the freshness and safety of the product. Fishermen and aquaculture workers must ensure that all equipment, such as nets, boats, and storage containers, is thoroughly cleaned and sanitized before use. Additionally, seafood should be kept at safe temperatures (below 4°C or on ice) immediately after harvest to inhibit bacterial growth. During transportation, seafood must be stored in refrigerated or insulated containers, ensuring that the product remains cool throughout the journey.

Once seafood reaches processing facilities or retail outlets, the hygiene practices become even more critical. All surfaces, tools, and equipment used in processing, such as cutting boards, knives, and packaging materials, should be cleaned and sanitized regularly to prevent cross-contamination between raw and cooked products. Workers in processing plants and retail environments must follow strict personal hygiene protocols, including frequent handwashing and wearing protective gear like gloves and aprons to avoid direct contact with the product.

At home, consumers also play an important role in maintaining seafood hygiene. Raw seafood should always be stored separately from other foods in the fridge to prevent cross-contamination. Hands, cutting boards, and utensils should be thoroughly cleaned before and after handling seafood. Cooking seafood to the proper internal temperature is essential, as this kills harmful bacteria and parasites. For example, fish should reach an internal temperature of 63°C (145°F), while shellfish should be fully cooked until opaque. Following these food safety practices ensures that seafood is safe to eat, preserving both its quality and nutritional value while minimizing health risks.

1.Hygiene During Harvesting and Collection

Microorganisms such as bacteria, viruses, and parasites are in all waters, and can be found on fish and crabs. These microorganisms may come from combined sewer overflows (CSOs*), faulty septic systems, and animal waste. After heavy rains, levels of faecal contamination can be higher in waters. Assume that all waters can have faecal contamination.

In case of raw sewage, avoid fishing by following advice on any sewage-related signs. By keeping hands away from your mouth, eyes, ears, and nose while fishing and cover open wounds to avoid contact with the water. This reduces the chances of getting sick from microorganisms that can enter into consumers body through these pathways. By washing hands after fishing, especially before eating, and shower if had contact with the water these hygiene practices can be followed during collection and harvesting.

Handling and Preparing Fish

Fish and crabs, even from waters with high levels of microorganisms, can be eaten if you follow these good hygiene practices: • Only keep fish that act and look healthy. • Wear nitrile, rubber or plastic protective gloves while gutting, filleting, and skinning the fish. Avoid directly handling and preparing fish when you have cuts or open sores on your hands. • Remove and discard the guts (internal organs) soon after harvest, and avoid direct contact with the intestinal contents. • Keep fish cool (with ice or refrigerated below 450 F or 70 C) until filleted and then refrigerate or freeze. • Wash hands, utensils, and work surfaces before and after handling any raw food, including fish. • Unlike PCBs, mercury and other chemicals, most microorganisms can be destroyed by cooking. Cook fish thoroughly until internal temperature is 1450 F or until flesh is pearly and opaque and separates easily with a fork Viji *et al*., (2024).

2. Hygiene During Transportation and Storage

Hygiene during the transportation and storage of seafood is paramount to ensuring both the safety and quality of the product, as seafood is highly susceptible to spoilage and contamination due to its perishable nature. From the moment seafood is harvested until it reaches the consumer, maintaining strict hygiene standards is essential to prevent bacterial growth, preserve freshness, and reduce the risk of foodborne illnesses. During transportation, the seafood must be kept at optimal temperatures—typically between 0°C and 4°C (32°F and 39°F)—to inhibit bacterial growth and maintain its quality. This requires the use of refrigerated transport (such as refrigerated trucks, boats, or containers) equipped with temperature monitoring systems to ensure consistent cold storage throughout the journey. Additionally, ice or gel packs are often used to keep the products cool, especially when transportation times are long. The containers used for transportation should be clean, sanitized, and designed to prevent cross-contamination between different batches of seafood or other food items, as well as to protect the seafood from exposure to any contaminants in the environment.

At the point of arrival, seafood must be promptly moved into appropriate storage conditions. For fresh seafood, cold storage at a temperature close to freezing (0°C to 2°C or 32°F to 36°F) is essential to maintain freshness. For frozen seafood, storage should occur at temperatures of -18°C (0°F) or lower to preserve the quality and prevent thawing, which could encourage bacterial proliferation. All storage facilities, whether cold rooms, freezers, or chillers, must be regularly cleaned and sanitized to prevent the buildup of bacteria or Mold, and temperature controls should be routinely checked to ensure that the environment is consistently maintained at the required levels. Furthermore, seafood should be stored away from raw meats and other products that could cause cross-contamination. Storage practices should also prevent contact with surfaces that could harbour contaminants, such as floors or unclean shelves. Proper ventilation is also crucial to avoid moisture buildup, which can contribute to spoilage or bacterial growth. The seafood should be stored on pallets or raised surfaces to prevent direct contact with the floor and minimize the risk of contamination.

Labelling and traceability also play an important role in hygiene during storage. Proper documentation that tracks the origin, transportation conditions, and expiration dates of seafood helps to ensure that any quality or safety issues can be identified quickly and addressed. Regular monitoring of hygiene standards, temperature controls, and cleanliness within the storage and transportation environments is necessary to ensure that seafood remains safe for consumption and maintains its desired quality. Adherence to these rigorous hygiene protocols throughout the transportation and storage phases helps to minimize the risk of contamination, preserve the nutritional value and taste of the seafood, and ensure compliance with food safety regulations Trafialek *et al.*, (2016).

Conclusion:

In conclusion, adhering to strict hygiene practices is essential for ensuring the safety and freshness of seafood. From proper personal hygiene for handlers to maintaining clean and sanitized equipment, every step in the seafood supply chain plays a critical role in preventing contamination. Storage hygiene, including appropriate temperature control and separation of raw and cooked products, ensures the integrity of seafood during transportation and retail. Regular cleaning, proper packaging, and compliance with food safety regulations are non-negotiable for maintaining quality. By implementing these measures, seafood businesses can protect consumer health, extend product shelf life, and build trust in their products, highlighting the vital importance of hygiene in the seafood industry.

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Popular Article

Ecological Importance of Biodiversity

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Abstract

Fish biodiversity plays a crucial role in maintaining the health and stability of aquatic ecosystems. It contributes significantly to ecological processes such as nutrient cycling, energy flow, and food web dynamics. High fish diversity enhances ecosystem resilience, enabling aquatic environments to better withstand and recover from disturbances such as climate change, pollution, and habitat degradation. Biodiverse fish communities support a wide range of ecosystem services, including water purification, carbon sequestration, and the regulation of algal populations. Moreover, they provide critical resources for human livelihoods, food security, and cultural values, particularly in communities dependent on fisheries. The conservation of fish biodiversity is therefore essential not only for sustaining ecological balance but also for promoting sustainable development and environmental stewardship. Understanding the ecological importance of fish biodiversity is therefore critical for guiding conservation strategies and sustainable fisheries management. This article aims to synthesize current knowledge on the ecological roles of fish diversity, highlight the consequences of biodiversity loss, and advocate for integrative approaches that prioritize ecosystem-based conservation and management.

Keywords: Biodiversity, Ecological importance, Fishes, Strategies

Introduction

Biodiversity within fish populations is a cornerstone of ecological stability and functionality in aquatic ecosystems (Garcia, 2003). Fish represent the most speciose group of vertebrates, with an estimated ~34,000 species worldwide and India ~3500 species occupying both fresh and marine waters (Jorgen, 2018). This extraordinary diversity underpins critical ecosystem functions in lakes, rivers, estuaries, coral reefs, and open oceans (Robinson et al., 2024). Diverse fish communities contribute to the stability and resilience of aquatic ecosystems: by spreading interactions across many species and habitats (the so-called "portfolio effect"), fish assemblage buffer environmental variability and ensure more reliable ecosystem services (Elmqvist et al., 2003). Fish contribute significantly to a range of ecological processes, including nutrient cycling, sediment dynamics, trophic interactions, and the maintenance of habitat structure (Villéger et al., 2017). Their diverse roles span across both freshwater and marine systems, where species richness and functional diversity enhance ecosystem resilience, productivity, and adaptive capacity in the face of environmental change (Elmqvist et al., 2003). The loss of fish biodiversity driven by overfishing, habitat degradation, pollution, climate change, and the introduction of invasive species poses a profound threat to ecosystem integrity (Arthington et al., 2016). Declining species diversity can disrupt food web dynamics, impair nutrient fluxes, and diminish the ecological services upon which human societies depend. Moreover, reductions in genetic and functional diversity limit the ability of fish communities to respond to ecological stressors, potentially triggering irreversible ecological shifts (Barnes et al., 2018).

Nutrient Cycling and Biogeochemical Roles of Fish

Fish play active roles in nutrient and chemical cycling within and between ecosystems. Many fish excrete and egest (excrete via feces) nutrients that fertilize primary producers. In nutrient-poor systems, fish can provide critical nutrient subsidies (Chakraborty and Chakraborty, 2021). For example, coral reefs rely on tightly recycled nutrients and recent studies show that reef fishes' feces are rich in nitrogen, phosphorus, and micronutrients. One study found that the nutrient composition of reef-fish feces varies across species and trophic guilds, with some fishes providing unique micronutrients (e.g. iron, zinc) essential for coral growth. Conservation of the *full suite* of reef fish thus "ensures the availability of nutritional pools" on coral reefs, because each species contributes distinct nutrient inputs (Van Wert et al. 2023). Similarly, in riverine systems, migratory fish transport nutrients across ecosystems. Anadromous salmon, for example, spawn in rivers after growing in the ocean; their decaying carcasses and excretions deliver marine-derived nitrogen, phosphorus and carbon to streams and forests. When salmon runs are cut off by dams or overfishing, those nutrient subsidies collapse. One global analysis calculated that blocking salmon migrations (1960–2018) resulted in losses of ~2.74 million t C, 0.6 million t N, and 0.1 million t P that would otherwise have enriched freshwater ecosystems ((Van Wert et al. 2023; González Ortiz et al., 2025). Such losses likely reduced stream productivity and forest growth.

Even non-migratory fish drive cycling: by feeding, defecating, and moving sediment, fish continuously redistribute nutrients. In large lakes, benthic-feeding fish stir up lake-bottom nutrients; in seagrass beds, fish grazing controls algal blooms and recycles organic matter (Petr, 2000). Collectively, these biogeochemical roles mean fish diversity helps maintain ecosystem processes like primary productivity and nutrient retention. Fish excretion and waste support plankton growth in lakes and reefs; and when fish populations decline, nutrient cycling often slows or becomes imbalanced, potentially leading to algal blooms or loss of aquatic vegetation. Fish link trophic levels with nutrient flows, making biodiversity crucial for robust nutrient cycling and water chemistry regulation (Van Wert et al. 2023).

Food Web Dynamics and Trophic Interactions

High fish diversity promotes complex food web structures and keystone interactions. Fishes occupy many trophic roles from apex predators (sharks, pike) to herbivores (parrotfish, freshwater minnows) to detritivores and their varied feeding habits connect organisms across levels (Lévêque, 1995). The removal of even a few fish species can trigger trophic cascades that ripple through an ecosystem. Classic examples include coral reefs where overfishing of large predators (groupers, sharks) leads to mesopredator release (smaller predatory fishes increase) and concomitant declines in herbivores or shifts in coral-algae dynamics (fortuna et al., 2025). On temperate reefs and kelp forests, loss of top predators or herbivores has led to unchecked grazers (e.g. urchins) decimating kelp. Evidence abounds that declines of large predatory fishes alter community structure: with sharks and tunas depleted, prey species densities shift and overall diversity often drops. In coral-reef reserves, for instance, healthy predator populations maintain smaller fish in check, resulting in healthier corals. In Puerto Rican reefs, marine reserves with more predators had fivefold higher grazers (herbivores) and 20-fold more juvenile corals than fished areas) (largely by controlling algae through predation) (fortuna et al., 2025). Conversely, if a predator is removed, mesopredators or algae can surge. The loss of sea otters in the North Pacific, for example, allowed purple urchins to overgraze kelp forests: a classic cascade effect (Smith. 2021). Thus, diverse fish assemblages help balance food webs: each missing species or trophic guild weakens these natural checks and can precipitate system wide changes (Thompson et al. 2012).

Habitat Structure and Ecosystem Engineering

Fishes themselves can engineer habitats and influence physical structure. Many reef and lake fishes modify their surroundings through feeding, nesting, or movement. Coral-reef fishes such as *Bolbometopon muricatum* (the bumphead parrotfish) literally reshape reefs by consuming and bioeroding coral (Kobayashi et al., 2011). Bumphead parrotfish can ingest and excrete over 5 tons of coral rock per year as sand, contributing to sandbanks and reef contour. In this way, parrotfishes and other herbivores prevent algae from smothering coral, enhancing coral recruitment. Similarly, herbivorous surgeonfish and tangs rapidly graze algae off reef surfaces, keeping corals exposed to sunlight and aiding productivity (Marshell and Mumby, 2015). On sandy shores and mudflats, other fishes (e.g. certain gobies or mullets) stir sediments during feeding, affecting turbidity and nutrient release (Göltenboth and Schoppe, 2006). In freshwater, species like dorado or carp can clear vegetation or redistribute sediment during spawning, subtly reshaping wetlands. Fish activities create, maintain or modify aquatic habitat complexity from stabilizing sand banks to sculpting reef surfaces which in turn supports biodiversity of other organisms (Seaman, 2022).

Freshwater vs Marine Ecosystems

Fish biodiversity plays vital roles in both freshwater and marine realms, though the contexts differ. Freshwaters (rivers, lakes, wetlands) cover <1% of Earth's surface but harbour roughly 12,300 fish species worldwide, including many highly endemic groups (e.g. African cichlids, Amazonian characins) (Wanjari et al., 2025). Freshwater fishes often link terrestrial and aquatic systems (through insectivore or nutrient transfers) and support riverine food webs. They recycle nutrients in lakes, control zooplankton populations, and even influence water quality in small lakes via trophic cascades (Petr, 2000).

In contrast, the marine environment contains around 16,000 fish species globally, with greatest richness in tropical oceans and along productive coasts. Marine fish often undertake large migrations (e.g. reef fish moving between habitats, pelagic fishes moving vertically or horizontally) and are key prey for birds, marine mammals, and other predators (Secor, 2015). They regulate plankton populations (e.g. sardines controlling zooplankton), and their collective biomass drives biogeochemical cycles (see later). Coastal fish diversity in mangroves, estuaries and coral reefs supports nursery functions for many species. Pelagic fishes (tunas, sardines, mesopelagics) dominate open-ocean processes by transporting nutrients

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vertically through daily migrations and packaging carbon (via fecal pellets) to deep waters (Whitfield et al., 2022).

Both realms are interlinked: diadromous fish (salmon, eels) connect sea and stream, transferring nutrients and energy. The high diversity of freshwater fishes (24% of freshwater species are threatened) is mirrored by vast marine biodiversity (the Coral Triangle alone holds 6,000+ marine fish species) (Costa-Dias, et al., 2029). Despite differences in scale, the functional importance of fish biodiversity is clear in both: it underwrites food webs, maintains ecosystem functions, and provides resilience against disturbances across all aquatic systems (Thompson et al., 2012).

Recent Trends and Global Data (2020–2025)

Recent assessments highlight worrying declines in fish biodiversity and biomass worldwide. The 2024 FAO report notes that global fisheries and aquaculture production reached ~223 million tonnes in 2022, underscoring humanity's dependence on fish (FAO, 2024). However, this harvest masks the underlying pressures: one-third of assessed marine stocks were classified as overfished by 2017. Conservation scientists recently applied machine learning to data-deficient marine fishes and estimated that ~12.7% of marine teleost fish species are actually at risk of extinction (compared to only 2.5% formally listed by IUCN). This suggests hidden vulnerabilities. Freshwater fish fared even worse: analyses of IUCN Red List data show roughly 24–25% of freshwater species are threatened with extinction (one of the highest rates for any vertebrate group). These threatened species include many habitat specialists and migratory fishes (Arthington et al., 2016).

Regionally, most fish biodiversity hotspots are under pressure. Freshwaters of Southeast Asia and the Amazon face rapid change: for example, the Mekong supports ~1,200 species, and fisheries decline by >30% is projected if dam construction continues (McAllister et al., 1997). The Amazon Basin – with a newly compiled database of 2,406 native fish species – is experiencing fishery collapses and shifts toward smaller, fast-growing species. In oceans, coral reef surveys document parallel declines in coral cover and reef fish diversity over the last few decades, signaling deteriorating habitat health. Arctic waters, once less exploited, are warming rapidly: polar cod (*Boreogadus saida*), a keystone forage fish, has declined sharply as sea ice retreats (Frederiksen, 2017).

Global biodiversity reports (e.g. IPBES) emphasize these trends: over 40% of marine mammals, one-third of reef-building corals, and significant fractions of fish and other aquatic taxa are threatened (Blasiak et al., 2023). The bottom line is clear: recent data from surveys and satellite monitoring show declines in fish stocks, shrinking catch sizes, and rising exploitation in many regions. This underscores an urgent need to incorporate fish biodiversity into conservation planning worldwide (Lorenzen et al., 2016).

Key Threats to Fish Biodiversity

Fish face a suite of anthropogenic threats that imperil diversity. Habitat destruction and modification is another major threat. Coastal development, dredging, and destructive fishing (blast or cyanide on reefs) degrade marine habitats. Mangroves and seagrass beds (nurseries for many fishes) are lost to aquaculture and urbanization (Nichols et al., 2019). In rivers, damming and water diversion fragment habitats, block migrations, and alter flow regimes. For instance, recent research in the Mekong shows that new hydropower dams have reduced fish biodiversity: in dammed tributaries the number of species fell dramatically (e.g. from 60 to 42 species in the Sesan River) over a decade, whereas free-flowing rivers maintained or gained species (Baird and Hogen, 2023). Dams in the Amazon also block sediment flows and impede migratory catfish. Pollution (nutrient runoff, plastics, industrial contaminants) further degrades fish habitat and health, causing eutrophication, toxic effects, and endocrine disruption in fish populations (Lopes, 2022). Overexploitation is pervasive intensive fishing (commercial, artisanal, illegal) removes millions of tonnes of fish annually, often targeting large predators and high-value species (Teh et al., 2020). The Amazon provides a telling example: long-term catch records from major ports show that the average size of captured fish has steadily declined, indicating depletion of large species (Raffino. 2014).

Climate change is increasingly critical to rise temperatures, acidification, and hypoxia are shifting fish distributions and life cycles. Cold-water Arctic polar cod, a cornerstone of Arctic food webs, losing habitat, is predicted to suffer a recruitment collapse if ice loss continues (Kayode-Edwards et al., 2024). In tropical seas, warmer waters contribute to coral bleaching, which in turn removes vital reef habitat for thousands of fish species. Sea-level rise and altered precipitation patterns can also change freshwater habitats. Climate synergizes with other threats: warming waters can favour invasive species (e.g. lionfish in the Caribbean) and reduce resilience to overfishing (Amidon et al., 2021).

Invasive species pose another threat in many regions. Non-native fishes (and their parasites) introduced by shipping or canals can outcompete or prey upon native species (Olenin et al., 2017). The Laurentian Great Lakes are a prominent example: over 180 non-native aquatic species are established in the basin, including zebra and quagga mussels, sea lamprey, and the looming threat of Asian carp. These invasives have disrupted food webs (lampreys decimated lake trout, mussels altered nutrient cycling) and continue to threaten native fishes like sturgeon and trout (Lower et al., 2024).

Cascading Ecological Consequences

The loss of fish diversity triggers cascading ecosystem impacts. When key species are removed or decline, community and ecosystem structure can reorganize in dramatic ways (Zavaleta et al., 2009). Overfishing of predators often leads to trophic cascades: for example, shark and tuna declines in tropical seas have been linked to increases in mid-level predators and declines in herbivores, undermining reef resilience. Likewise, the collapse of forage fish (e.g. sardines, anchovies) can starve marine predators and cause plankton blooms (Bierwagen, 2019).

In freshwater systems, damming and deforestation can reduce migratory fishes, cutting off nutrient flux and simplifying river food webs. The Amazon provides a stark case: as larger catfish and characins have been overharvested, fisheries are now dominated by smaller species, with uncertain ecological outcomes (Castello and Macedo, 2016). Large predatory fish once kept prey populations in check; without them, prey or competitor species may surge and alter the food web. Similarly, in Lake Victoria (not a case study here but illustrative), Nile perch introduction wiped out cichlid diversity, drastically altering nutrient cycles and food chains (Christensen, 1996).

Coral reef declines also cascade. In marine reserves where corals have died (e.g. after bleach events), fish diversity plummets: a classic study showed >75% loss of reef fishes following coral decline, even when fishing pressure was low (Williamson et al., 20014). In temperate zones, warm-water intruders and declining cold-adapted fishes change predator-prey dynamics. For instance, in the Barents Sea climate warming allowed capelin to expand northward and compete with polar cod, altering plankton-fish links. In all cases, the weakening of one link – whether a predator, prey, or habitat-forming species – reverberates through the ecosystem, often reducing overall productivity and resilience (Smith et al., 2023).

Ultimately, these cascades mean that fish diversity loss is not an isolated issue: it can undermine the integrity of entire ecosystems, leading to regime shifts (e.g. coral reefs converting to algal mats, or clear lakes becoming turbid) (Prachett et al. 2011). Maintaining multiple fish species across trophic levels provides insurance against such shifts by allowing ecological functions to persist even as conditions change (Fréon, 2005).

Case Studies

Amazon Basin (South America) Junk et al., 2007

The Amazon River basin is the largest river basin in the world and discharges about one-sixth of all freshwater from the continents to the oceans of the world. The age of this ecosystem, its position near the equator and the enormous diversity of its aquatic habitats, have produced the most diverse fish fauna on the planet. About 2,500 fish species have already been described and it is estimated that more than 1,000 new species remain to be discovered. Knowledge concerning this multitude of fish species is still insufficient, which makes their management and protection difficult. About 50% of the species are thought to occur in the large rivers and connected floodplains and another 50% in headwater streams. Inland fisheries give rise to 450,000 t of fish each year and thus contribute substantially to the protein supply of local populations. However, despite their economic importance, these fisheries receive little attention from the respective governments. The fisheries are highly selective and several stocks of large species with high market value have been over fished. Fish culture is still in its infancy but its development is expected to provide high-quality species during periods of low supply. Over large areas, aquatic habitats are still in near-natural conditions because of the low densities of resident human populations. Nonetheless, over the last few decades, the pressure on aquatic ecosystems and habitats has steadily increased, mainly due to large-scale destruction of natural vegetation cover by agro-industries in the savanna belt (cerrado), small-scale agriculture in the Andean hill slopes, and logging in rain forests. These activities have placed aquatic biodiversity, including fishes, at serious risk. Many headwater species have restricted distributions and are therefore particularly vulnerable to largescale environmental degradation. Moreover, the construction of large reservoirs for hydroelectric power generation has serious consequences for fish fauna. Currently, about 16.4% of the Amazon River basin is protected, and another 15.2% is under partial protection in indigenous reserves in Brazil. Another 9.1% will be implemented as reserves in the next 10 years in the Brazilian part of the basin. The formulation by the Amazonian countries of a coherent policy that integrates long-term management of the river basin with sustainable management of aquatic and wetland habitats, including their fauna and flora, is urgently needed.

Coral Triangle (Indo-Pacific) Hemrah, 2020

The Coral Triangle (CT) Region has the highest concentration of marine biodiversity. Anthropogenic stresses have been threatening the status of all coral reef systems worldwide. Reefs are in rapid decline, with marine ecosystem degradation and it is important that initiatives like the Coral Triangle Initiative are in place to protect these important habitats. This paper analyzed the management of the Coral Triangle Initiative (CTI) within the countries of the Coral Triangle. This study aimed to specifically analyze the management of the Coral Triangle Initiative within the countries of the Philippines, Indonesia, Malaysia, Papa New Guinea, Solomon Islands and Timor Leste. Methods used in this paper included qualitative document and thematic analysis. Coral reef management was explored with a literature review and was used to create a thematic framework to compare the action plans of the CTI to. Prevalent themes found in marine conservation and coral reef management include marine protected areas, marine threatened species status and marine resource extraction. These themes can directly translate to conservation efforts. These efforts and results depend heavily on the dynamics of the conservation strategy. Looking at the structure of the CTI action plans, these themes were directly encompassed in their goals and throughout the years, have seen many successes within the marine realm. However, with their efforts, there were challenges these plans faced. Based on the CTI document analysis of the Regional Plan of Action, National Plans of Action and Senior Officials' Meetings, recommendations for the CTI were made based off of the challenges encountered. This consisted of more development of modelling and marketing about sustainable marine economy, finding more sources of alternative funding, creating positions for locals as CT community liaisons, including more initiatives on marine waste management and increasing and continuing to support women in conservation efforts in this line of work. The CTI has many strengths with reef values that they uphold but struggle financially and with stakeholder participation. The CTI has the ability to become the leading organization in food security in the marine realm and marine resources management but needs continued support.

Great Lakes (North America) McKenna Jr, 2019

Climate change effects are already significant, but can also magnify other ecological problems. This can be clearly seen in the Laurentian Great Lakes, which have suffered habitat degradation, fishery overharvest and dramatic alterations by invasive species. Thermal changes are expected to cause extensive loss of suitable fish habitat, and changing precipitation patterns will aggravate the problems with our highly modified lotic and lentic systems. A brief summary of the historic ecological context provided by the Great Lakes case is presented, followed by the descriptions of selected tools that help to understand and evaluate both ecological and climate change problems. Species distribution models and habitat classification combined with climate change predictions can identify the distribution and extent of optimal habitats, and identify which are most vulnerable to climate change. Ecological flow modelling can help to identify when critical flow changes are likely. Mechanistic simulation modelling specifies understanding of how aquatic systems function and can reveal cause and effect relationships. These tools can be used to help managers to protect optimal habitat, resist climate change effects to other habitats and adapt cultural systems to climate-altered aquatic systems.

Mekong River (Southeast Asia) Baird and Hogen, 2023

The Mekong River basin is a global freshwater biodiversity hotspot, with roughly 1,200 fish species in the lower Mekong alone. Its floodplain wetlands and seasonal flows support massive fish migrations (akin to the Amazon's – tens of millions of fish moving upstream annually). These migrations supply protein for tens of millions of people. Fish such as giant carp and catfish are both cultural icons and ecological engineers (their feeding digs sediment and releases nutrients).

Over the last few decades, considerable concern has been expressed about the threat of Mekong River Basin hydropower dams to a range of important freshwater riverine fisheries, particularly for fish that seasonally migrate long distances. However, much less attention has been given to the threat of hydropower dams to fish biodiversity in the high-diversity Mekong River Basin. Through reviewing the existing state of knowledge regarding Mekong River Basin fish biodiversity, and threats to it, we argue that even though no species are definitively known to have been extirpated from the Mekong River Basin to date, hydropower dam development and various other developments nevertheless pose a serious threat to fish biodiversity. Indeed, dams typically significantly block fish migrations and fish larvae distribution, cause river fragmentation, fundamentally alter river hydrology, and change water quality, all factors that have the potential to intersect with each other and lead to significant species extirpation and extinction, or in some cases, functional extinction, when a small population remains but the important larger population is lost permanently. The circumstances are further exacerbated by the lag time between impact and when that impact becomes evident, cumulative impacts, a lack of consistent data collection, including the collection of base-line data, and insufficient post-project research related to biodiversity. We contend that much more could and should be done to ensure that the Mekong River basin's exceptional fish biodiversity is not variously diminished and destroyed during the coming years.

Arctic Marine Systems Adeniran-Obey et al., 2024

Arctic marine environments, focusing on their unique biodiversity and the crucial role of keystone species in maintaining ecosystem stability. It examines the complex food webs and ecological interactions, highlighting their vulnerability to contaminants such as persistent organic pollutants (POPs), heavy metals, and microplastics. The chapter explores the sources, pathways, and bioaccumulation of these pollutants, particularly their impact on top predators like polar bears and marine mammals, and the associated risks to human health through seafood consumption. It also emphasizes the importance of environmental monitoring, international regulations, and integrated policy approaches in mitigating contamination. Climate change challenges, including melting ice and shifting ocean currents, further complicate pollution management. Ultimately, the chapter stresses the need for coordinated efforts to protect Arctic ecosystems and the communities that depend on them.

Ecosystem Services and Fish

The significance and value of ecosystem services for human wellbeing is well known (e.g. Butler and Oluoch-Kosura, 2006; Costanza et al., 1997; Daily, 1997; de Groot et al., 2002; Harrison et al., 2010). Ecosystems provide four types of service: provisioning (e.g. food), regulating (e.g. water quality regulation and pollination), cultural (e.g. recreation) and supporting (e.g. nutrient cycling) (Millennium Ecosystem

Assessment, MA, 2005). The importance of biodiversity in underpinning the delivery of both ecosystem services and the ecosystem processes that underlie them is well recognised (Díaz et al., 2006; MA, 2005), and our understanding of the nature of the biodiversity–ecosystem services relationship and the possible effects of biodiversity loss on the delivery of ecosystem services is increasing (e.g. Balvanera et al., 2006; Cardinale et al., 2006). Consequently, there is an increasing trend to integrate ecosystem service arguments within the management plans and strategies of protected areas (e.g. García-Mora and Montes, 2011), as well as the wider landscape (e.g. TheScottishLandUseStrategy, Scottish Government, 2011). However, ecosystem service-related argumentation is not undisputed (Schrö ter et al., 2014). Early work on the biodiversity–ecosystem services relationship explored the contribution of habitats to different ecosystem services (Chan et al., 2006) and of individual species to the functional structure of ecosystems, as well as the impact of interactions, both between species, and between species and the environment, on ecosystem function (Balvanera et al., 2005).

The link between ecosystem services and biodiversity has further been examined, not only in terms of species, but also genotypes, populations, species functional groups and traits in an ecosystem (Díaz et al., 2006). Much recent work has focused on functional relationships between biodiversity and ecosystem services. Functional diversity is one of the most important biodiversity attributes affecting ecosystem services by impacting the underlying ecosystem processes (e.g. de Bello et al., 2010; Díaz et al., 2006). Research has focused on single species (Luck et al., 2009) and groups of species (Díaz et al., 2007; Hooper et al., 2005), in addition to a number of broader scale syntheses (e.g. Conti and Diaz, 2013). Other studies have tended to examine a small selection or individual ecosystem services (Kremen, 2005; Luck et al., 2009; Seppelt et al., 2011), with few spanning multiple ecosystems (Bastian, 2013; Lavorel and Grigulis, 2012). Trait3 analysis (e.g. Balvanera et al., 2006; de Bello et al., 2010; Díaz et al., 2006; Hooper et al., 2005; Lavorel and Grigulis, 2012; Luck et al. 2012) has been shown to be useful in identifying specific links between species, ecosystem processes and ecosystem service delivery and can demonstrate the complexity of processes and interactions which occur in ecosystems (Fagan, et al., 2008; Gaston, 2000; Lavorel, 2013). Population dynamics are another factor impacting ecosystem functioning and service provision. This was first highlighted by Luck et al. (2003), who proposed the concept of a Service Providing Unit (SPU) to describe the ecological unit which provides the ecosystem service. Subsequently, Kremen (2005) suggested identifying Ecosystem Service Providers (ESP) and the concepts were combined into the SPU–ESP continuum by Luck et al. (2009), showing how the ESP concept can be applied at various levels, for example population, functional group and community scales. Knowledge on the links between biodiversity and the provision of ecosystem services is key for furthering arguments for ecological restoration (Rey Benayas et al., 2009; Bullock et al., 2011). It could also contribute to the management of protected and restored areas (Bastian, 2013) in order to meet the dual goal of optimising the delivery of ecosystem services and supporting biodiversity conservation (Palomo et al., 2014). However, despite a number of metaanalyses, and advances in research and understanding of this relationship (Balvanera et al., 2006; Bastian, 2013; Cardinale et al., 2006, 2012; Hooper et al., 2005; Luck et al., 2009; Mace et al., 2012) there remains much uncertainty over the effect of the complexity of biodiversity components on the ecosystem functioning that underlies service provision (Balvanera et al., 2014; Schrö ter et al., 2014). Current knowledge has been poorly integrated and few studies incorporate a wide range of both biodiversity attributes and ecosystem services. Also, there are few studies using empirical evidence to examine the role of biodiversity in providing ecosystem services (Mertz et al., 2007), and the quantitative relationships between components of biodiversity and ecosystem services are still poorly understood (Carpenter et al., 2009; de Groot et al., 2010).

Conservation Strategies and Future Directions

Maintaining global fish biodiversity requires a multi-pronged approach. Protected areas and habitat conservation are cornerstone strategies (Madhubhashini, 2024). Expanding and enforcing marine and freshwater protected areas (MPAs, river reserves) can safeguard refuges for critical species and habitats. The recent global commitment (“30×30” under the Kunming-Montreal framework) to conserve 30% of land and water by 2030, if properly implemented, could significantly benefit fish by protecting spawning grounds, migratory corridors, and refuge zones (Perera-Valderrama, et al., 2023). For example, large MPAs have been shown to increase fish biomass and biodiversity inside reserves, often replenishing adjacent fisheries. Restoring degraded habitats (reef restoration, dam removal or fish ladders, reforestation of floodplains) is also vital; reconnecting rivers to allow migrations and restoring mangroves to support juvenile fish can recover lost ecosystem functions (Roni, 2021).

Sustainable fisheries management is critical. This includes science-based catch limits, size and gear restrictions, and bycatch reduction (Pons et al., 2020). Harvest strategies that maintain trophic structure (e.g. protecting top predators, conserving herbivores) help preserve ecosystem functions. Innovative approaches like rights-based management (catch shares), co-managed small-scale fisheries, and community engagement can enhance compliance and local stewardship. Aquaculture can alleviate pressure on wild stocks if done sustainably (e.g. using low-impact feeds, avoiding escapes and pollution) (Allison and Badjeck, 2004).

Controlling invasives and pollution is also needed: ballast-water regulations, early detection of invaders, and aggressive rapid response can help protect native fish. Reducing nutrient runoff and plastics will benefit fish health and habitats (Kennish, 2002). Additionally, climate adaptation strategies such as preserving cold refugia and migratory corridors can help fish cope with warming. Global policy integration (SDGs, Convention on Migratory Species, etc.) is important to align fisheries with biodiversity goals (Hee, 2023).

Research and monitoring gaps must be addressed. Many fish species remain poorly studied or unassessed. New tools (environmental DNA, remote sensing, acoustic surveys) should be applied to fill data gaps on species distributions and population trends (Bolgan et al., 2023). Research on fish functional diversity (traits, ecosystem roles) is needed to predict how biodiversity loss will affect services. Moreover, better understanding of cumulative impacts (fishing + climate + land use) will guide management. Investing in long-term monitoring (e.g. global fishery-independent surveys, habitat mapping) and open data sharing will be essential (Trice et al., 2021).

In all these strategies, an ecosystem-based approach is needed: managing fish populations in the context of whole ecosystems, rather than single-species (Fogarty, 2014). Transboundary cooperation is critical, since many fish migrate across national borders (e.g. salmon, tuna, Mekong catfishes). Conservation must also involve local communities and respect Indigenous knowledge, as many traditional practices have long sustained fish stocks (e.g. seasonal closures, taboo species) (Caillaud et al., 2004). Research gaps remain. The deep ocean, tropical lakes, and high-latitude waters are under-sampled, and new species are still being discovered. The roles of microbial symbioses (e.g. fish gut microbiota in nutrient cycling) and sub-lethal pollutant effects on fish ecology need study. Predicting how fish biodiversity will respond to novel stressors (e.g. simultaneous warming and acidification) is a frontier. Finally, socio-ecological research on how communities adapt to changing fisheries is crucial for linking biodiversity to human well-being (Pörtner et al., 2021).

Conclusion

Fish biodiversity is fundamental to the health of global aquatic ecosystems. Through nutrient cycling, food-web regulation, and habitat engineering, diverse fish communities sustain the very fabric of aquatic ecosystems and deliver essential services to humanity. Freshwater and marine fishes alike play irreplaceable roles in stabilizing ecosystems and enabling productivity. Yet modern pressures are eroding this heritage at an alarming rate. Recent data (2020–2025) document declining catch sizes, shrinking populations of large species, and high proportions of threatened fishes in both rivers and seas. Without concerted conservation action protecting habitats, managing harvests sustainably, and addressing climate change to risk the cascading loss of ecosystem functions that fish diversity provides.

In the coming years, integrating fish biodiversity into global policy (e.g. the 30×30 target), expanding marine and freshwater protected areas, and strengthening fisheries management will be imperative. Bridging research and governance, filling data gaps, and supporting sustainable livelihoods are all needed to safeguard fish diversity. For university researchers, the challenge is to develop interdisciplinary solutions: from understanding the mechanisms by which fish diversity confers stability, to quantifying the full value of fish-mediated services, to innovating new management strategies for a changing world. Only by illuminating and preserving the ecological importance of fish biodiversity can we ensure that lakes, rivers, and oceans remain resilient and productive for future generations.

Sources: This synthesis draws on recent literature and reports (2020–2025) on fish ecology, biodiversity assessments (IUCN, FAO, IPBES), and regional case studies, as well as specialized studies on nutrient cycling and ecosystem dynamics.

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Modern Aquaculture Techniques

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Abstract

Aquaculture is a fast-expanding industry that is now essential to the provision of sustainable food. Traditional aquaculture techniques do, however, confront several difficulties, such as high operating costs, water scarcity, and environmental degradation. This study examines how cutting-edge technologies like cage culture, aquaponics, Recirculating Aquaculture Systems (RAS), and Biofloc Technology (BFT) provide contemporary ways to improve fish farming's sustainability and output. Aquaculture is becoming a more eco-friendly and efficient practice thanks to integrated systems like Integrated Fish Farming (IFF) and Integrated Multi-Trophic Aquaculture (IMTA) and the Internet of Things (IoT). Together, these developments help aquaculture's future by providing creative, sustainable ways to satisfy the world's growing food needs while reducing its negative effects on the environment.

Keyword: Modern Aquaculture, Recirculating Aquaculture Systems (RAS), Biofloc Technology (BFT), Cage Culture, Aquaponics, Integrated fish farming, Integrated Multi-Tropic Aquaculture, Internet of Things and Aquamimicry.

Introduction

Fish, crustaceans, mollusks, and aquatic plants are among the aquatic animals that are cultivated under controlled conditions in aquaculture, often known as fish farming. Given its humble origins in private ponds and coastal enclosures, aquaculture currently provides more than 50% of the seafood consumed worldwide, according to the Food and Agriculture Organization (FAO). However, conventional fish farming practices have come under fire for contaminating rivers, dispersing illness, and causing overfishing (by procuring feed). The aquaculture playbook is being rewritten as a result of new, high-tech methods.

Innovative technologies that optimize resource use, improve environmental sustainability, reduce water usage, improve feed availability, and improve waste utilization—like Biofloc Technology (BFT), cage culture, aquaponics, and Recirculating Aquaculture Systems (RAS)—have significantly advanced the industry (Avnimelech, 2012; Jena *et al*., 2017). Together with strategies like Integrated Fish Farming (IFF) and Integrated Multi-Trophic Aquaculture (IMTA), these systems seek to increase productivity while reducing environmental damage and increasing profits through various cultures. In order to maintain the ideal level of water quality parameters and replicate estuarine conditions, aquamimicry is a novel new concept that involves producing blooms of zooplankton, primarily copepods, which serve as a good source of nutrition as a supplemental form for the cultured shrimps and promoting the growth of beneficial bacteria.

Biofloc Technology (BFT)

The aquaculture industry is under increasing pressure to increase output while reducing environmental effect as worries about global food security grow. In order to overcome these obstacles, Biofloc Technology (BFT) has become a ground-breaking method that converts waste into useful nutrients for aquaculture systems. First presented by Ifremer-COP (French Research Institute for Exploitation of the Sea, Oceanic Center of Pacific) in the 1970s, this ground-breaking technique has undergone substantial development over the years to become a vital component of contemporary, sustainable aquaculture methods (Avnimelech, 2012).

Working Principles

BFT's basic idea is to keep the carbon-to-nitrogen ratio between 10:1 and 20:1 at an ideal level in order to encourage the growth of helpful microorganisms that turn waste materials into premium single-cell microbial protein (Gómez-Gil *et al*., 2020). These microorganisms, which are referred to as bioflocs, are collections of bacteria, protozoa, algae, and other organic particles that are bound together by a loose mucus matrix. According to Goddek *et al*. (2015), this microbial community improves water quality, gives cultured organisms extra nourishment, and increases system biosecurity overall.

Benefit of biofloc technology

- Eco-friendly culture system.
- It reduces environmental impact.
- Judicial use of land and water.
- Limited or zero water exchange system.
- Higher productivity (It enhances survival rate, growth performance, better feed conversion in the culture system of fish).
- Higher biosecurity.
- Reduces water pollution and mitigate the risk of introduction and spread of pathogens.
- It reduces utilization of protein rich feed and cost of standard feed.
- It reduces the pressure on capture fisheries.

Cage Culture in Aquaculture

Fish raised in floating or submerged cages in man-made or natural water bodies, such as lakes, rivers, or reservoirs, are known as cage culture. These cages, which are usually constructed of mesh or netting, keep the fish contained while allowing water circulation. This method optimizes the use of existing water resources while offering a regulated environment for fish farming (Hossain *et al*., 2021; Tacon *et al*., 2020). Cage culture has several benefits, including as minimal startup costs, straightforward maintenance techniques, and harvesting simplicity. Feeding methods are simple, and effective management of water resources is made possible by resource flexibility. There are other uses for cage systems, such storing fish for sale. By employing open water enclosures, this technique has the potential to increase fish productivity and lessen reliance on land-based farms (Naylor *et al*., 2020; Sinha *et al*., 2022).

Benefit of cage culture

- Numerous water resources that would not normally be able to be harvested, such as lakes, reservoirs, ponds, strip pits, streams, and rivers, can be utilized. Consult your state's fish and wildlife agency as certain state regulations may limit the use of "public waters" for fish production.
- A relatively low initial investment is all that is required in an existing body of water.
- Harvesting is simplified.
- Observation and sampling of fish is simplified.

Aquaponics

Hydroponics and aquaculture are combined in aquaponics. According to the Food and Agriculture Organization of the United Nations (1988), aquaculture is the production of aquatic creatures such as fish, mollusks, crustaceans, and aquatic plants. With hydroponics, plants are grown without soil and nutrients are delivered by water (Diver, 2006). According to Rakocy *et al*., (2006), Endut *et al*., (2010), and Thomas *et al*., (2019), aquaponics is a symbiotic system in which fish and plants are cultivated together. The fish's waste supplies nutrients to the plants, while the plants assist purify the water, resulting in a healthy environment for the fish.

Toxic chemicals like nitrite and ammonia must be controlled in aquaculture operations since they can stress fish if left behind. The ecology will be greatly impacted by this quickly expanding industry, which is predicted to provide 54% of the 200 million tons of fish that will be required by 2030 (Food and Agriculture Organization of the United Nations, 2018). Aquaponics can be utilized successfully in controlled circumstances because it doesn't require soil, which makes it appropriate for metropolitan locations with limited land.

By using nitrifying bacteria to transform ammonia into nitrate (NO_3^-), which plants need as fertilizers, aquaponics offers a solution. This technology aids in water treatment in RAS systems and lessens the demand for additional nutrients in hydroponics. Leafy greens with low to medium nutrient requirements, such as capsicum, tomatoes, lettuce, cabbage, basil, spinach, chives, herbs, and watercress, are frequently grown in aquaponics. Even though the setup cost is significant at first, there are good returns because of the lower recurring costs. Aquaponics recycles waste and requires less water, land, and labor overall.

Working Principle of Aquaponics System

The waste-filled water is sent to a filtering system, which collects solids and encourages the growth of good bacteria. These bacteria are essential to a two-step process known as nitrification. Certain bacteria first change ammonia (NH_4) into nitrite (NO_2), which is subsequently changed into nitrate (NO_3) by further helpful bacteria. Since nitrate is a type of nitrogen that plants can readily absorb and use for growth, this conversion is crucial. Following nitrification, the aquaponics system's plants receive nutrient-rich water that has been adjusted with nitrates. The plants receive the nutrients they require to flourish from this water, which serves as a natural fertilizer. In addition to absorbing these nutrients, the plants aid in filtering the water, eliminating surplus nutrients and enhancing its purity. The cycle is completed by returning the clean water to the fish tank once the plants have consumed the nutrients. The foundation of an aquaponics system is the reciprocal link between fish and plants, whereby both are dependent upon one another for growth and sustainability. The plants help maintain the water clean and healthy for the fish, and the fish provide the plants nourishment.

The system is made efficient by these interrelated processes, which also produce a sustainable ecosystem that maximizes productivity and minimizes waste. Aquaponics systems may produce large quantities of fish and vegetables by utilizing the innate connections between fish and plants, providing a sustainable substitute for conventional agricultural practices. This collaboration demonstrates how aquaponics may preserve valuable natural resources while assisting in meeting the growing need for wholesome, fresh food.

Advantages of Aquaponics

Resource Efficiency: Aquaponics maximizes resource use by recycling water and nutrients within the system. It uses much less water than conventional soil-based agriculture and eliminates the need for synthetic fertilizers.

Environmental Sustainability: Aquaponics reduces the release of harmful substances into the environment. Its closed-loop system lowers the risk of water pollution, and the absence of chemical fertilizers and pesticides helps preserve ecosystems.

Increased Productivity: The mutual relationship between fish and plants enhances productivity. The nutrient-rich water promotes faster plant growth, leading to higher yields than traditional farming practices.

Year-Round Cultivation: Aquaponics allows for year-round cultivation, unaffected by seasonal changes. The controlled environments of greenhouses or indoor setups enable continuous production regardless of external conditions.

Recirculating Aquaculture System (RAS) Technology

The term "recirculating aquaculture system" (RAS) technology describes land-based closed systems that use serial reconditioning to minimize water consumption while cultivating aquatic species. By effectively reusing water, these systems improve food security and reduce environmental effects (Jena *et al*., 2017). In order to safely reuse water, RAS consists of a number of treatment procedures that efficiently eliminate organic compounds and other oxygen-demanding components from wastewater, including suspended particles, nutrients, fats, oils, and pathogens (Jena *et al*., 2017). The bulk of solid materials are first removed from wastewater by running it through mechanical filters, such as settlement tanks, sand filters, drum filters, and screen filters, which remove larger suspended particles, debris, and floating materials (including wood, paper, rags, and plastics).

Working principle of RAS

The biofilters used in recirculating aquaculture systems (RAS) treat liquid waste by passing it through a microbial film, also known as a zoological film, which is normally between 0.2 and 2.0 mm thick. Numerous microorganisms, such as bacteria, fungi, protozoa, and algae, make up this film. The film's naturally occurring microorganisms efficiently decompose organic components and purify the liquid by changing the fish's expelled ammonia (NH_4^+ and NH_3) into less toxic nitrates. Since oxygen is necessary for fish growth and food metabolism, reoxygenating the system's water is essential to reaching high output densities. Aeration and oxygenation can raise the amount of dissolved oxygen. Aeration increases the surface area available for oxygen dissolution by pumping air through an air stone to produce tiny bubbles in the water column. It is crucial to maintain the ideal pH level in RAS, which is usually achieved by adding materials like sodium hydroxide (NaOH) or lime (CaCO3). Fish may be poisoned by high levels of dissolved carbon dioxide (CO_2), which can result from a low pH. Aeration systems can also be used to degas CO_2 in order to control pH (Jena *et al*., 2017). Each species of fish has a recommended temperature range and going beyond these can have detrimental health effects or even cause death. Temperature also influences dissolved oxygen concentrations and can be regulated through submerged heaters, heat pumps, chillers, or heat exchangers (Piedrahita, 2003). Finally, before the water is reused in culture units, it is disinfected using UV radiation or ozone treatments to eliminate pathogens and ensure water quality (Chamberlain *et al*., 2021).

Benefits of RAS

- Low water requirements.
- Low land requirements.
- Water quality parameters can be easily rectified.
- Independence of adverse weather conditions.
- High stocking density of desired species and productions.
- Most efficient; feed conversion is near 1:1.
- Reduce or eliminate vaccine, antibiotic and pesticide uses.
- Consistent production.
- Eco-friendly.
- Improve health and performance of the fish species.

Integrated fish farming (IFF)

Integrated farming is the term used to describe the progressive links between two or more farming operations that are related to agriculture. one in which farming is the main element. When fish is the focal point of the system, it's known as integrated farming (Ayyappan, 2011). On the other hand, aquaculture, agriculture, and livestock are all used, managed, and produced together in integrated fish farming systems, with an emphasis on aquaculture. A sustainable farming approach that improves resource efficiency, reduces risk through crop diversity, boosts edible fish production for small-scale farming, and makes money is the integration of fish farming with agriculture and animal husbandry.

Working principle of IFF

In an integrated fish farming (IFF) system, the byproducts or wastes from one system, such as minor agricultural commodities, become inputs for fish culture systems. For example, byproducts from fodder plants, fruit plants, and agricultural crops such as rice bran, rice polish, flour, oil cake, and soybeans are processed and used as feed in aquaculture (FAO, 2018). Additionally, waste from livestock—such as urine and dung from cows, poultry, chickens, pigs, rabbits, goats, sheep, and silkworms—serves as manure to generate fish food organisms, supporting the aquatic food web (Sharma *et al*., 2019).

Agri-based and livestock-fish systems are the two primary IFF system types used in India. While paddy-fish, mushroom-fish, seri-fish, and vermicompost-fish are minor agricultural techniques, aquaculture is the main component of agri-based systems (Das *et al*., 2020). By optimizing the synergies between the components, livestock-fish systems—such as cattle-fish, pig-fish, goat or sheep-fish, duck-fish, and rabbit-fish—are intended to boost agricultural productivity (Yadav *et al*., 2021). A sustainable farming method, IFF promotes biodiversity, ecological balance, and the integration of soil and water fertility management techniques while increasing food production (FAO, 2018).

Benefits of IFF

There are many advantages to integrated fish farming. It has enormous potential to boost production and improve food security. The system diversifies farmers' sources of income while making the most use of the natural resources that are available. Additionally, it increases the fertility of soil and water, which lessens the need for chemicals like fertilizers, insecticides, and antibiotics. Integrated farming helps environmentally friendly activities by encouraging sustainable practices and the conservation of aquatic biodiversity. It also recycles trash and byproducts, uses agricultural area efficiently, and runs organically without the use of artificial fertilizers. In the end, this approach improves economic viability and lowers production costs.

Integrated Multi-Trophic Aquaculture (IMTA)

It is a technique for concurrently raising several freshwater or marine species from various trophic or nutritional levels in the same environment (Barrington *et al.*, 2009). This method makes it possible to collect and repurpose the leftover feed, waste, nutrients, and byproducts of one species for use as fertilizer, feed, or energy by other species. By doing this, IMTA improves sustainability and resource efficiency by utilizing the complementary ecological activities of different species to produce synergistic interactions.

Working principle of IMTA

In Integrated Multi-Trophic Aquaculture (IMTA), inorganic extractive species like seaweed and organic extractive species like shellfish and herbivorous fish are cultivated alongside feed species like shrimp or finfish. By encouraging improved management techniques, this method develops a sustainable, well-balanced strategy for social acceptability, economic stability through product diversification, and environmental bio mitigation. Higher trophic level carnivorous species in IMTA release particulate organic materials (such fish waste), phosphorus (orthophosphate), and soluble inorganic ammonia. Seaweeds immediately absorb these inorganic nutrients from their surroundings, whereas deposit feeders and shellfish devour organic particles (fish excrement and uneaten feed) and transform them into excretory products that seaweeds then absorb. This nutrient recycling across different trophic levels supports biodiversity, biosecurity, and ecosystem health while increasing food production in a sustainable manner.

IMTA can be summarized as: Fed Aquaculture (e.g., finfish) + Organic Extractive Aquaculture (e.g., shellfish) + Inorganic Extractive Aquaculture (e.g., seaweed).

Benefits of IMTA

- Integrated Multi-Trophic Aquaculture (IMTA) offers great potential for increasing food production and ensuring food security.
- It promotes both economic and environmental sustainability by converting by-products, wastes, and uneaten feed into useful resources.
- IMTA helps reduce eutrophication, supports economic diversification, and minimizes negative environmental impacts.
- This eco-friendly system efficiently utilizes all trophic levels, making it a sustainable approach to aquaculture.

Internet of Things (IoT)

The need for food is rising along with the world's population. However, agricultural land is declining as a result of causes like resource depletion and the greenhouse effect. Due to their high protein content and ease of cultivation, fish have emerged as a vital resource. Global fish consumption averaged 20.5 kg per person per year, according to the FAO's 2018 report, and is predicted to increase over the next ten years.

Aquaculture has grown rapidly as a result of declining wild fish populations brought on by overfishing, pollution, and climate change. More than half of the aquatic products produced worldwide are now sourced from aquaculture thanks to innovations like big data, AI, and the Internet of Things. To preserve water quality and fight infections, some farms, however, rely on chemicals, which can be detrimental to both human health and the environment. Aquafarms need to control water quality without using chemicals because consumers are becoming more interested in sustainable and organic products.

Aquaculture depends on the quality of the water. Fish, ecosystems, and human health can all be harmed by poor water quality. Conventional techniques for evaluating water are labor-intensive and slow. The IoT-based Smart Aquaculture System (ISAS) was created in order to solve this. Temperature, pH, dissolved oxygen, and water hardness sensors are used, and they are linked to Arduino and Raspberry Pi platforms. By sending data to the cloud, the technology enables users to keep an eye on situations and get notifications. Depending on the quality of the water, it can also automatically regulate feeders and aerators. Key benefits of the ISAS include:

- Automated operation of aerators and feeders using a fuzzy logic system.
- Remote monitoring of water quality through mobile devices.
- Real-time monitoring of key water parameters to create an optimal environment.
- A 33.3% increase in shrimp survival compared to traditional methods.

Aquamimicry System

A new aquaculture technique called aquamimicry makes it easier to introduce organic carbon without having to keep the carbon-to-nitrogen (C) ratio at a certain level. The blossoming of phytoplankton and zooplankton, particularly copepods, which provide shrimp with more food, is naturally encouraged by this system.

The Aquamimicry system's beneficial bacterial growth also improves shrimp growth performance and stabilizes water conditions (Khanjani *et al*., 2022a). By promoting the growth of advantageous microbes and plankton, such as phytoplankton and zooplankton, aquamimicry mimics the circumstances seen in natural shrimp farming. While preserving the best possible water quality, these organisms—especially copepods—can provide as an extra food source for shrimp (Romano, 2017). By simulating natural environmental conditions, the system lowers feeding costs and promotes ecological stability (Panigrahi *et al*., 2019).

Copepods and their Role

The main source of aquamimicry technology is natural goods, such copepods, which are used as live shrimp feed. This technology is known as "Copefloc." Copepods are more nutritious than rotifers and contain a lot of polyunsaturated fatty acids (PUFAs), which are essential for shrimp growth and development. These PUFAs include arachidonic acid, eicosapentaenoic acid, carotenoids, peptides, vitamins, and minerals (Satoh *et al*., 2009; Taher *et al*., 2017). Copepods have been shown to boost feed conversion efficiency, boost immunological function, and improve post-larval (PL) shrimp growth performance in shrimp nursery culture systems, particularly in Penaeus vannamei shrimp (Abbaszadeh *et al*., 2022).

Fermentation Process in Aquamimicry

In the Aquamimicry system, rice bran is fermented with probiotics and water, with hydrolyzing enzymes used for a 24-hour fermentation process. This fermentation occurs at a rate of 500 to100 kg per hectare, and within a week, the bloom of live feed, such as copepods, can be observed (Khanjani *et al*., 2022).

Advantages of the Aquamimicry System in Aquaculture

- The culture environment in Aquamimicry systems is more stable than in traditional systems, providing better environmental control (Deepak *et al*., 2020).
- It creates an unfavourable environment for harmful bacterial pathogens, and the risk of black soil formation is significantly reduced (Romano, 2017).
- Aquamimicry can increase shrimp production yield while reducing expenses, enhancing profitability. The system minimizes the production of suspended solids and waste, leading to a reduced dependency on commercial feeds. This decreases the biological oxygen demand and reduces the need for intensive aeration, optimizing energy consumption (Romano, 2017).
- Simulating natural culture conditions in the Aquamimicry system triggers better growth performance in shrimp (Romano, 2017).
- The system is relatively easy to establish and operate, requiring less technological infrastructure and knowledge. It is accessible to aquaculture farmers with lower technical expertise (Catalani, 2020).

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Conclusion

The goal of this fastest-growing industry is to minimize its ecological impact while addressing the global food security concern. The traditional system has a number of issues, including However, disease outbreaks provide serious difficulties, resulting in financial losses and environmental issues. Numerous approaches have been developed to solve these issues, and integrated systems are opening the door to fish farming that is more productive and sustainable. The sector is changing as a result of innovations like Biofloc Technology (BFT), Cage culture, Integrated Fish Farming, RAS, Aquaponics, and IMTA, which enable effective resource use and less environmental impact. When taken as a whole, these developments show aquaculture's future and provide viable answers to the world's problems, ensuring both environmental sustainability and food security.

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Popular Article

Culture Methods of Shrimp Farming in Pond

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Abstract

Pond-based shrimp farming is a prevalent aquaculture technique that substantially enhances worldwide seafood. This technique entails the cultivation of shrimp species, chiefly *Penaeus monodon* and *Litopenaeus vannamei,* within regulated pond ecosystems. Essential elements comprise pond preparation, water quality control, stocking density, regulation and the application of formulated diets. Sustainable pond-based shrimp farming prioritizes biosecurity, disease control, and environmental management to optimize productivity and minimize ecological impact. Aeration, regular water exchange and sediment control are vital for sustaining ideal growth conditions. The use of best management practices (BMPs) and technological advancements, such as automated feeding and real-time monitoring, has enhanced yields and sustainability. Pond-based shrimp aquaculture presents economic prospects in coastal areas; yet, it necessitates meticulous management to mitigate obstacles including disease outbreaks, environmental degradation, and market volatility.

Keywords: Aquaculture, Shrimp farming, Sustainability, Best Management Practices (BMPs).

Introduction-

Shrimp farming is an important part of aquaculture. The global status of shrimp farming was 5.6 million metric tonnes in 2022, with an anticipated increase of 5.88 million metric tonnes. India is a prominent global producer of shrimp, especially whiteleg shrimp *(Litopenaeus vannamei).* Andhra Pradesh dominates shrimp production, with over 70% of India's total output. Additional significant producing states comprise West Bengal and Gujarat. In the 1990s, the culture of the species *Litopenaeus vannamei* and *Penaeus* monodon were defined by low risk and high profit. In 1995, shrimp production was seriously affected by viral infections, particularly the White Spot Syndrome Virus (WSSV).

Culture species in shrimp farming.

1. *Penaeus monodon*
2. *Litopenaeus vannamei*
3. *Penaeus indicus*

Site Selection for Shrimp Culture

The selection of a suitable site always plays a major role in shrimp farming. Brackish water should be available throughout the culture period. The water source should be free from any industrial or agriculture Selection of good quality seed for stocking into a pond is the first important step of the shrimp grow-out management.

Pond management

Pond cleaning

The maintenance of a pond or the elimination of waste materials. Particularly the organic and phosphate residues that have accumulated at the pond's bottom. These approaches adversely affect the water and soil quality in the pond, perhaps leading to a reduction in the pond's production capacity.

Desiccated pond

This method is used when the pond bottom can be dried completely. Ponds were completely sundried until the bottom cracks 5-10 cm deep.

Ploughing and leveling

After drying ploughing had been completed with the help of tractor up to 5inch deep in soil ploughing mainly vertically and horizontal was done.

Liming

Liming increases the pH level in pond. For liming mainly Agriculture lime ($CaCo_3$) are used. Dose – fresh pond =250kg /ha Use Pond = 500kg /ha.

Water filling

Usually, the water is filled in the pond by using the pump.

Installation of aerators

The selection of aerator is dependent upon the water's depth. Paddle wheel aerators with one horsepower are suitable for ponds with a water depth of less than 1.2 meters, while those with two horsepower are appropriate for ponds beyond 1.2 meters in depth.

Fencing

Fencing is done around the pond as well as on the upper side also. It protects the shrimps from the predatory birds and animals.

Stocking

Litopenaeus vannamei is the most appropriate species for aquaculture in India. The stocking density is influenced by the accepted system and the chosen species for cultivation. In an intense culture, a properly managed pond with stable water quality can accommodate 25-30 post-larvae per square meter at a water depth of 1.2 meters and up to 40-50 post-larvae per square meter at a depth of 1.5 meters or above.

Technique of Stocking

Seeds are typically transported in plastic bags. The bags are typically filled to one-third capacity with water, oxygenated, and subsequently placed within boxes. If transportation exceeds

6 hours, little bags of ice should be placed in the boxes to lower the water temperature and maintain it at 20-22°C. The densities of PL in a bag are 1,000-2,000 seeds/l for PL 15 and 500-1,000 PL/l for PL 20. The optimal times for transit are early morning or night-time.

Water quality management

All measured water quality parameters, including dissolved oxygen (DO), pH, NH3, NO2, and turbidity, should not exceed the appropriate levels for white-leg shrimp culture (Schneider et al.,2005).

Parameter	Range
Temperature (°C)	27-28.5
DO (mg/L)	5.5-6.5
NH3 (mg/L)	0.02-0.03
NO2 (mg/L)	0.28-0.35
Ph	7.5-8
Turbidity (NTU)	52-57
Salinity (PPT)	32-35

Acclimatization

Acclimatization of seed to the water pH and temperature of the pond must be rendered upon arrival. (Jayasankar *et al.,* 2009) According to acclimatization to temperature and salinity is a crucial determinant influencing the efficacy of low-salinity shrimp aquaculture. Acclimatization strategies for the stocking of shrimp juveniles are categorized into one-step acclimatization and progressive acclimation.

Feed and feeding

Help to faster growth. 4 times feeding is done in a day (07:30am, 10:30am, 01:30pm,04:30pm). After 1hr distribute of feed check the check tray. Start the aerator just check the check tray for 1:30hr high protein feed are given 5% of body weight first 30 days The percentage of protein & fat in feed is 36-42% & 6-8%.

Feed Quality

The utilization of high-quality feed will enhance shrimp output and profitability while reducing environmental degradation associated with shrimp farming.

Feed Conversion Ratio (FCR)

Only the superior quality of feed can achieve an FCR of 1.2. (Fleckenstein *et al.,* 2020) reported low feed conversion ratio (FCR) values, varying from 1.0 to 1.1 in low-density (2.3 kg/m3) broiler feed regimens. Thus, the enhancement in enzyme activity is facilitating improved feed efficiency and diminished FCRs.

Harvesting and Handling

Successful harvesting is achieved if the shrimp can be obtained in optimal condition within a short amount of time. The harvesting method must neither harm nor infect the shrimp with debris. Complete harvesting can be executed by emptying the pond water using a bag net and manually collecting the contents. The typical culture period needed is approximately 120-150 days, during which the prawns will attain a size of 20-30 grams, contingent upon the species.

Conclusion

Pond-based shrimp aquaculture substantially enhances the world seafood supply and provides economic advantages, particularly in coastal areas. Implementing sustainable techniques like such as biosecurity, water quality control, and technological integration is crucial for achieving success. Efficient management is essential for addressing difficulties such as disease, environmental damage, and market volatility, while guaranteeing long-term productivity and sustainability.

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Popular Article

Novel Feed Ingredients in Aquaculture

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1. Introduction

Aquaculture, which is the fastest growing food production sector globally, is facing increasing pressure to meet the demand for protein of the growing population, as well as solving the challenges of stability. Traditional aquatic agricultural feed depends a lot on fish food and fish oil obtained from wild pelagic fishes, causing excessive fishing, ecosystem effects and resource instability (FAO, 2018). To reduce these issues, the industry is turning to new feed material innovative options that reduce dependence on limited marine resources, increase cyclicity, and maintain nutrition quality for cultivated species. New components include unconventional protein and lipid sources, such as insect food (eg, black military fly larvae), microbial protein for example, single-cell protein from algae or yeast and plant-based concentrations (Henry *et al*., 2018). These ingredients have been developed through extensive research to ensure that they meet the dietary requirements of aquatic species, support growth performance, and maintain fish health and well-being (Herrero *et al*., 2021). For example, insect protein provides a permanent solution by converting biological waste into high-quality nutrient, while giving the required omega-3 fatty acids (EPA and DHA) without reducing microalgae marine stocks such as Schizochetrium (EPA and DHA) required.

Adopting new components aligns with circular economy principles' stability and broad goals. Agricultural-food industries (eg, fish clipping, rice husk) or biotechnology using by-products from resources for example fermented algae, can reduce aquatic agricultural waste and reduce their environmental footprints. However, challenges remain, including measuring, cost-effectiveness, regulatory approval, and consumer acceptance (Gosco *et al*., 2023). Cooperative efforts between researchers, feed manufacturers and policy makers are important to remove these obstacles and ensure the business viability of the next generation aquafeeds (Glencross *et al*., 2007).

2. Drivers of Innovation in Aquafeeds

The search for novel feed ingredients is driven by several interlinked factors:

1. **Environmental Sustainability:** Overfishing of forage fish for fishmeal production threatens marine biodiversity. Alternatives help reduce pressure on wild fish stocks.

2. **Economic Volatility:** Fishmeal and fish oil are subject to price fluctuations based on supply, leading to unstable production costs.

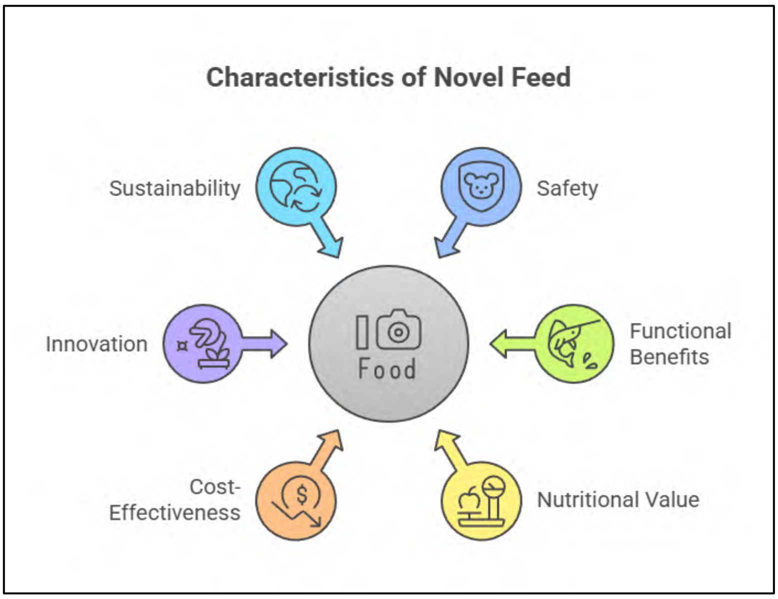
3. **Food Security:** Novel ingredients can make aquaculture more accessible and affordable, ensuring long-term food security.

4. **Nutritional Advancements:** New ingredients can be tailored to meet species-specific dietary needs more precisely than conventional feeds.

3. Characteristics of Novel Feed

The products may not be dangerous to animals which are feed.

1) **Functional benefits**: Some ingredients boost immunity, disease resistance, and growth performance in fish.



2) **High nutritional value**: Rich in proteins, lipids, essential amino acids, and omega-3 fatty acids.

3) **Cost-effective**: Potential to reduce feed costs compared to fishmeal, depending on availability and production scale.

4) **Unconventional and Innovative**: Derived from non-traditional sources like plants, insects, microbes, and agro-industrial by-products.

5) **Sustainable and Eco-Friendly**: Reduces reliance on marine resources, lowers environmental impact, and supports circular economy practices.

4. Categories of Novel feed ingredients

4.1 Insect based meals

Insects are gaining popularity due to their high protein content and efficient bioconversion of organic waste. Common species used include black soldier fly larvae (*H. illucens*), mealworms, and crickets. Insects provide essential amino acids and are naturally part of the diet of many fish species.

- **Black Soldier Fly Larvae (*H. illucens*)-** Rich in protein (40-65%) and lipids (30%), making it an excellent alternative to fishmeal (Henry *et al*., 2015).
- **Mealworms (*Tenebrio molitor*)-** Contain around 50% protein and are highly digestible for fish (Van Huis, 2013).

1. Lesser mealworm (*Alphitobious diaperinus*)
2. House cricket (*Acheta domesticus*)
3. Field cricket (*Gryllus assimilis*)
4. Banded cricket (*Gryllodes sigillatus*)


Fig.1 BSF Larvae


Fig.2 Mealworms


Fig.3 Field Cricket

Fig Source: https://www.feedipedia.org/node/16388?utm_source
https://www.shutterstock.com/search/meal-worm-farming

Advantages:
- Sustainable and low environmental footprint
- Can be reared on organic waste streams
- High digestibility and palatability

Challenges:
- Regulatory barriers in some regions
- Limited scalability and high production costs

4.2 Single-Cell Proteins (SCPs)

SCPs include bacteria, yeast, and microalgae cultivated using fermentation. They are rich in protein and can be produced on non-arable land using industrial byproducts.

Examples:

Fig.4 *Saccharomyces cerevisiae*

Fig.5 *K. marxianus*

Fig source: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences

Advantages:

- High protein and lipid content
- Stable production independent of climate
- Can be engineered to enhance specific nutrients (e.g., omega-3 fatty acids)

Challenges:

- High production and purification costs
- Limited availability at commercial scale

4.3 Plant based proteins

While not entirely novel, plant derived proteins such as soybean meal, pea protein, and rapeseed meal are increasingly refined to reduce anti-nutritional factors. Advancements include genetically modified (GM) crops designed for aquafeeds and fermentation-enhanced plant proteins.

Advantages:

- Readily available and well-established supply chains
- Cost-effective

Challenges:

- May lack essential amino acids
- Digestibility and anti-nutritional factors need to be addressed
- Competition with human food and livestock sectors

4.4 Macroalgae (Seaweed)

Seaweeds like kelp and red algae can supplement fish diets by providing vitamins, minerals, and bioactive compounds. Brown, red, and green seaweeds like ***Ulva lactuca*** and ***Gracilaria edulis*** are rich in bioactive compounds, essential fatty acids, and minerals beneficial for fish growth (Hemaiswarya *et al*., 2011). **Examples:** *Ulva Lactuca, Gracilaria edulis*

Fig. 6 *Ulva Lactuca*

Fig.7 Gracilaria *edulis*

(**Fig source:** Sudhakar and Narayana, 2025)

4.5 Microalgae

Known for their high protein (50-70%) and omega-3 content, these serve as sustainable lipid and protein sources in aquafeeds (Beal *et al*., 2018).

- Spirulina (*Arthrospira platensis)*
- Chlorella (*Chollera vulgaris)*

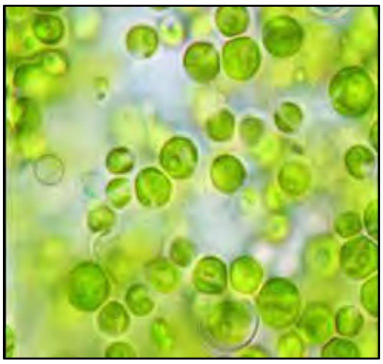


Fig. 8 *Arthrospira platensis*

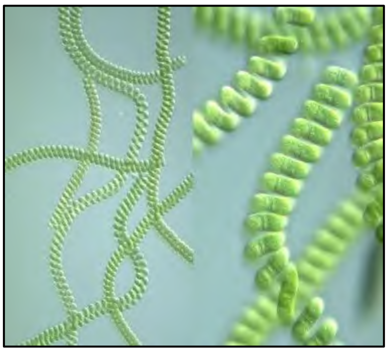


Fig 9 *Chollera vulgaris*

Advantages:

- No need for freshwater or arable land
- Carbon sequestration and ecosystem benefits
- Functional properties (e.g., immune boosting)

Challenges:

- Low protein content compared to other sources
- Variable nutritional composition

4.5 Terrestrial Animal By-products

Rendered products such as poultry meal, feather meal, and blood meal are being re-evaluated as sustainable feed options. These are typically by-products from the meat industry and offer high protein concentrations.

- **Poultry By-Product Meal**- Derived from rendered poultry waste, it contains 55-65% protein and is a cost-effective alternative to fishmeal (El-Haroun *et al*., 2009).
- **Blood Meal-** High in protein but require processing to improve digestibility and reduce anti-nutritional factors.

Advantages:

- Cost-effective
- High nutrient density
- Supports circular economy

Challenges:

- Consumer perception and regulatory limitations
- Potential biosecurity concerns

5. Nutritional considerations and Feed formulation

The shift to novel ingredients requires reformulating feeds to ensure they meet the specific nutritional needs of different aquaculture species. Key considerations in this process include digestibility, palatability, amino acid profile, and the presence of anti-nutritional factors. To address these challenges, modern feed formulation is increasingly relying on precision nutrition techniques. These include enzyme supplementation to enhance nutrient absorption, nutrigenomics to better understand gene diet interactions, and precision fermentation to tailor nutrient profiles according to the specific requirements of target species.

6. Economic and Market Considerations

Although many novel ingredients offer long-term sustainability, their commercial adoption is constrained by several challenges. These include high initial investment and production costs, lack of economies of scale, limited supply chains and market infrastructure, and consumer perception, especially concerning genetically modified or unconventional ingredients. Despite these hurdles, collaborations between startups, feed companies, and academic institutions are accelerating progress in the field. Moreover, both public and private investment play a crucial role in scaling up production and reducing costs, thereby enhancing the feasibility of these sustainable alternatives.

7. Case Studies and Commercial Applications

Many leading commercial undertakings have demonstrated the practical viability of new feed components in aquatic agriculture, which outlines their ability to increase stability and reduce dependence on traditional resources. Protics, headquartered in the Netherlands, specializes in the production of Black Soldier Fly larvae (*H. Illusance*), which offers a high protein for traditional fish food, and environmentally durable options. In the United States, Calista has developed a microbial protein feedcind® derived from methane fermentation, providing land-independence and resource-skilled protein sources suitable for various aquatic agricultural species. Corbion, which is also located in the US, produces algae-based omega-3 oils that serve as a direct replacement for fish oil in salmon feeds, helping to preserve the marine ecosystem by maintaining the required fatty acid profile. Meanwhile, Unibio, a Danish biotechnology firm, employs methane using bacteria to produce a single-cell protein (SCP), providing a scalable and ecological alternative protein input for aquatic feed. Collectively, these case study examples of successful integration of new biotechnology in professional aquatic agriculture, and highlights the transformative ability of new diet components in increasing the stability and flexibility of global aquatic dietary systems.

8. Future outlook

The future of aquaculture feed lies in diversification, innovation, and sustainability. Novel ingredients are no longer fringe concepts but are entering the mainstream through technological advances and policy support. Key trends expected to shape the future include:

- Integration of circular economy principles
- Use of AI and big data in feed optimization
- Consumer-driven demand for sustainable seafood
- Advances in synthetic biology and fermentation technologies

9. Conclusion

Novel feed materials are very promising to convert aquatic agriculture into a more durable, flexible and efficient industry. While challenges remain in terms of cost, regulation and consumer acceptance, both environmental and economic benefits make them an important component of future feed strategies. Through continuous research, innovation and investment, these options can reduce industry dependence on limited marine resources and support the global demand for responsible seafood production.

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Utilization of Black Soldier Fly Larvae (BSFL) feed: protein source for sustainable Aquaculture

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Abstract

Aquaculture plays a pivotal role in meeting the growing global demand for protein. However, conventional protein sources face challenges such as overfishing, environmental impact, and rising production costs. This study explores the potential of Black Soldier Fly Larvae (BSFL) as an alternative and sustainable protein source for fish feed. Black Soldier Fly Larvae, rich in essential amino acids and nutrients, offer a promising solution to address the shortcomings of traditional fish feed ingredients. Black soldier fly larvae (BSFL), *Hermetia illucens* have proven to convert organic waste into high-quality nutrients for pet foods, fish and poultry feeds, as well as residue fertilizer for soil amendment. The larvae's ability to thrive on organic waste materials further contributes to waste reduction and environmental sustainability. Preliminary results indicate that BSFL-derived protein can serve as a viable and eco-friendly alternative, showcasing positive effects on fish growth parameters. Furthermore, the cost-effectiveness analysis suggests potential economic benefits for aquaculture producers. This presentation aims to provide valuable insights into the utilization of Black Soldier Fly Larvae in aquaculture, addressing the pressing need for sustainable protein sources in the face of increasing global demand. The findings contribute to the ongoing discourse on environmentally responsible practices in aquaculture and sustainable food production.

Keywords: BSFL, Sustainable aquaculture, Protein source, Alternative feed

1. Introduction

Aquaculture plays a vital role in India's fisheries sector, contributing significantly to its economy and providing a sustainable source of seafood. With its diverse fisheries resources, including marine, inland, and brackish water ecosystems, India has witnessed remarkable growth in aquaculture production over the past few decades. This section of the literature review explores the state of aquaculture in India, emphasizing its importance and the challenges it faces, while also drawing connections to the utilization of black soldier fly larvae (BSFL) as a potential solution. India's fisheries boast an impressive array of fish and shellfish species, with more than 10% of the world's aquatic biodiversity found within its borders. The country's extensive coastline, exclusive economic zone, and continental shelf provide rich marine fisheries resources, while inland fisheries utilize rivers, lakes, ponds, and other water bodies (Siddiqui, 2022). Aquaculture in brackish and saline water has thrived in India, particularly in the cultivation of shrimp. Shrimp production, which witnessed substantial growth from 20 metric tonnes (MT) in 1970 to 7.47 lakh MT in 2020, has significantly contributed to fisheries export revenues. The sustainability of fish feed ingredients has become a critical concern in the aquaculture industry, as the increasing demand for fish and the decline of capture fisheries drive a shift towards commercial high-intensive fish farming. The production of fish feed is a significant cost component, accounting for 60 to 70% of the total production cost (FAO, 2012). The black soldier fly, native to temperate zones in America, has successfully established populations in various tropical and temperate regions worldwide, including Africa (Leclercq, 1997). This non-pest fly has distinctive characteristics that differentiate it from other insects. Adult black soldier flies have a sleek, wasp-like appearance, but with two wings and without a stinger (Diclaro & Kaufman, 2009). They exhibit a range of colours, including black, metallic blue, green, purple, or brightly collared black and yellow patterns (Drees, 1998). With a length of 15-20 mm, they possess elongated antennae with three segments and white coloration near the end of each leg (Diclaro & Kaufman, 2009). Traditional feed ingredients, such as fishmeal, are facing challenges in terms of sustainability and cost-effectiveness, necessitating the exploration of alternative protein sources like Black Soldier Fly Larvae (BSFL). Black Soldier Fly Larvae (BSFL) have gained significant attention as a potential alternative protein source for fish feed production.

2. Materials and method:

Efficient harvesting and processing methods are essential to obtain high-quality BSFL meals for fish feed production. Physical separation techniques, such as sieving and density-based separation, have been employed to separate mature larvae from the substrate (Surendra *et al.,* 2016). Post-harvest processing methods, such as freeze-drying, oven-drying, and sun-drying, have been utilised to preserve the nutritional value of the larvae and convert them into meal form (Surendra *et al.,* 2016). It is important to optimise these techniques to ensure minimal nutrient loss and maintain the desired nutritional profile of the BSFL meal.

2.1. The breeding facility setup, including the love cage and dark cage:

A. Love Cage:

1. **Purpose:** The love cage serves as the mating area for adult BSFL and facilitates the egg-laying process.
2. **Structure:** The love cage should be a spacious enclosure made of mesh or fine netting material to allow air circulation and prevent fly escape.
3. **Connection:** The love cage is connected to several dark cages through a tunnel-like

structure. This connection allows for a constant and stable density of flies within the love cage and ensures same-aged flies for efficient nursery operation.

4. **Lighting:** Place a light source at the end of the tunnel leading into the love cage. The light attracts the flies to fly from the dark cages into the love cage for mating.
5. **Environmental Enrichment:** The love cage should be equipped with a wet cloth to allow the flies to hydrate. Additionally, provide eggies (oviposition substrates) and a box with a smelly attractant to stimulate egg-laying.

B. **Dark Cage:**

1. **Purpose:** The dark cage provides a suitable environment for egg incubation, pupation, and protection from changing environmental conditions.
2. **Structure:** The dark cage should have solid walls or be covered with dark materials to create a dark and secluded atmosphere.
3. **Pupation Containers:** Within the dark cage, place pupation containers filled with moist soil-like substrate (compost) where the prepupae can bury themselves for pupation.
4. **Pupation Cage:** The pupation containers are placed inside a pupation cage within the dark cage. This pupation cage is completely dark and ensures that emerging flies remain motionless and do not mate.

2.2 Breeding Process:

1. Adult BSFL flies are introduced into the dark cages.
2. When required, emerged flies are collected from the dark cage through the tunnel and transferred into the love cage.
3. The light at the end of the tunnel attracts the flies to fly from the dark cage into the love cage for mating.
4. Flies that have mated in the love cage then lay their eggs on the provided eggies and in the presence of a smelly attractant.
5. A total 14 5. Eggs are collected from the love cage and transferred into pupation containers within the dark cage.
6. The pupae undergo the pupation process inside the pupation containers within the dark cage.
7. After two to three weeks, the emerged flies are ready to fly out of the pupation containers but remain contained within the dark cage

3. Results

3.1 **Growth Performance:**

i) The inclusion of BSFL meal in aquafeed significantly influenced the growth performance of the test species. Fish and shrimp fed the High treatment showed a remarkable increase in average weight gain (AWG) and specific growth rate (SGR) compared to the Control group. Additionally, the Low treatment exhibited intermediate growth rates, indicating a dose-dependent response.

ii) Feed Utilization Feed conversion ratio (FCR) and feed intake (FI) were significantly affected by the dietary treatments. Fish and shrimp fed the High treatment demonstrated superior FCR values, while the Low treatment displayed intermediate feed utilization efficiency.

iii) Physiological Responses: Hematological and biochemical analyses indicated no adverse effects on the health of the aquaculture species across all dietary treatments. In fact, fish and shrimp fed the BSFL meal-based diets showed enhanced levels of essential fatty acids, resulting in improved physiological responses.

iv) Statistical Analysis: Pearson correlation analysis was conducted to explore potential correlations between BSFL meal inclusion levels and growth responses.

4. Conclusion

The findings from this study demonstrate the potential of BSFL meal as a sustainable and nutritious protein source for aquaculture species. The positive growth responses observed in fish and shrimp fed the BSFL meal-based diets indicate the viability of this alternative feed ingredient in promoting aquaculture production. Furthermore, the absence of adverse effects on the physiological responses of the test species underscores the safety and acceptability of BSFL meal in aquafeed formulations.

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Popular Article

सर्दियो के मौसम में पंगेशियस मछली की देखभाल कैसे करे

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मात्स्यिकी महाविद्यालय, आचार्य नरेन्द्र देव कृषि एवं प्रद्योगिकी विश्वविद्यालय कुमारगंज अयोध्या-224229

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परिचय

पंगेशियस जिसका लोकप्रिय नाम पगास है, यह सर्वप्रथम वियतनाम देश के मेकांग नदी में पायी गयी, भारत में सर्वप्रथम पंगास का पालन पशिचम बंगाल में किया गया पंगास मछली मीठें पानी में पाली जाने वाली दुनिया की तीसरी सवसे बढी प्रजाति है। भारत में सबसे ज्यादा पंगास का उत्पादन आन्ध्रप्रदेश राज्य में होता है।

पंगास मछली की विशेषताऐ

सम्वन्धित है, यह एक वायुश्वासी मछली है, जो कि कम घुलित आँक्सीजन में भी जीवित रह सकती है, और कुछ समय तक विना पानी कें भी रह सकती है। इस मछली का पालन मिट्टी के तालाबो, सिमेंटेड तालाबो, वायोफ्लाक, आर.ए.एस. एवं मछली पिजरो में सफलता पूर्वक किया जा सकता है। इस मछली में कांटे बहुत पतले होते है, इसलिए यह प्रसंस्करण के लिए अच्छी मछली मानी जाती हैं, जिसका मांस फिलेट बनानें के लिए बहुत उपयुक्त माना जाता है। पंगेशियस मछली पूरी तरह सें पूरक आहार पर निर्भर रहती है, यह मछली 6-8 माह में 1-1.5 किलो की हो जाती है। इसकी मांग घरेलू एवं विदेशी बाजारों में बहुत अधिक है।

पंगास मछली

सर्दी के मौसम में देखभाल

सर्दी के दौरान पंगास मछली पालन में निम्नलिखित सावधानिया-

जलीयें गुणवत्ता

पंगेशियस मछली के पालन के लिए सर्दियों में जलीये गुणवत्ता कों व्यवस्थित करना अति आवाश्यक होता है, क्योकि ठंड कें मौसम में पानी का तापमान कम होनें के वजह से मछलीयों में तनाव बढ जाता है, जिसके वजह सें बीमारियों का खतरा वढ जाता है। पानी कें तापमान को बढानें के लिए किसनों को रात के

समय प्रति दिन ताजा पानी चलाना चाहिए, सर्दी के मोसम में जलीए तापमान किसी भी तरीकें से 20 डिग्री सेल्शियस कें ऊपर ही रखना चाहिए। अत्यधिक ठण्डक में किसान अपने तालाब कें 70-80 प्रतिशत हिस्से को पालीथीन से ढक के रखे जिससे पानी का तापमान व्यवस्थित रहे 15 डिग्री सेल्शियस से नीचे तापमान पर मछली तनाव में आ जाती है, एवं तापमान अधिक नीचे जाने पर मृत्यु होने लगती है, जलियें तापमान के अतिरिक्त पी.एच. 6.5-8 एवं घुलित आक्सीजन 5 पी.पी.एम. से अधिक होना चाहीए।

आहार प्रबन्धन

ठण्ड के दिनो में पंगास मछली कों उनकें आदर्श विकास एवं स्वास्थ को सुनिश्चित करनें के लिए विशेष आहार प्रबन्धन की आवाश्यकता होती है। शीत काल में पंगेशियस मछली की चयापचय दर कम हो जाती है जिससे उन्हे कम आहार की आवश्यकता होती है, शीत काल में मछली को दिन में एक ही बार आहार देना चाहिए, तथा आहार 32-35 प्रतिशत प्रोटीन से समृध्द होना चाहिए, जिससे मछली के विकास एवं रख-रखाव कों समर्थन मिल सकें मछली कें समग्र स्वास्थ एवं प्रतिरक्षा तंत्र को बढावा देना के लिए आहार में विटामिन एवं खनिज को जोडना चाहिए मछली को दिन के सबसे गर्म समय मे आहार देना चाहीए जिससे आहार का उपयोग बेहतर हो सके, मुख्यता मछली के भूख की निगरानी करके आहार की मात्रा कों सुनिश्चित करनें चाहिए, ताकि आहार का नुकसान ना हो, क्योकि बचा हुआ आहार जल में अनावश्यक अमोनिया उतपन्न करेगा जो की मछली के स्वास्थ के लिए हानिकारक होता है।

मछलियो की प्रतिरक्षा प्रणाली एवंम आहार तंत्र को बढावा देने के लिए आहार में निरन्तर प्रोवायोटिक्स एवं इमनियोस्टुम्युलेंट को समलित करना चाहिए। इन आहार प्रबन्धन रणनीतियों को ठण्डी के मौसम में लागु करकें आप अपनी पंगास मछली की उचित स्वास्थ को बनाये रखनें में मद्द कर सकते है।

रोग प्रबन्धन

सर्दी के मौसम में पंगास मछली ठण्डे पानी कें तापमान के कारण रोगो के प्रति सम्वेदनशील हो जाती है, जिससे उनकी प्रतिरक्षा तत्र भी प्रभावित होती है। ठण्डी के मौसम में किसानो को मछली में उत्पन्न होने वाली बिमारी एंव तनाव कें लक्षणों की निगरानी करनी चाहिए। जलीय आयोडीन को सेनेटाइजर कें रुप में हर सप्ताह में एक वार एक ली. प्रति एकड की दर सें तालाब में छिडकाव करना चाहिए। आयोडीन एक समान्य सेनेटाइजर है जिसका उपयोग मछलियों में विशेष रुप सें शीतकालीन में किया जाता है, जो कई प्रकार कें रोगाणुओ को नियंत्रित करनें में मद्द करता है, नियमित आयोडीन सेनेटाइजेसन रोग के जोखिम को कम करने में मद्द करता है, तथा यह पानी में जैवीक प्रदार्थों कों आक्सीडाइज करनें मे भी मद्द करता है, और पानी की समग्र गुणवत्ता में भी सुधार करता है।

आयोडीन कें अतिरिक्त प्रोटैशियम परमैगनेट (लाल दवा) का उपयोग भी किसानो को शीत काल में कीट नाशक कें रुप में करना चाहिए।

निष्कर्ष

शीतकाल में पंगेशियस मछली कि उचित देखभाल करना बहुत ही महत्वपूर्ण है, ताकि मछली की सेहत और विकास दर उचित बनी रहे, पानी का तापमान, घुलित आक्सीजन, आहार प्रबन्धन एंव स्वास्थ पर विशेषरुप से ध्यान देना चाहिए। उपरोक्त बताए गए सुझाव का पालन करकें आप आपनी पंगेशियस मछली को शीतकाल में भी स्वास्थ एवं सुरक्षित रख सकते है।

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Assay of Growth and Nutritional Quality of Two edible fishes collected from Kullursandai Dam, Virudhunagar with relation to Physio- chemical factors

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INTRODUCTION:

Artificial barriers, built across streams that flow year-round or seasonally, have numerous functions. Approximately 70% of the Earth's surface is comprised of water, which is essential for human existence. Human population growth, industrialization, the use of fertilizer in farming, and human-induced activities have significantly contaminated water sources (Ramachandra Mohan, 2018). Regular water quality testing is essential, with physical and chemical analysis being a top priority for evaluating water quality for drinking, irrigation, fish stocks, and industrial uses (Salve et al., 2006). This analysis aids in comprehending the intricate relationships and interactions between climatic and biological factors in water bodies. Length-weight relationships, denoted by the abbreviation LWRs, serve as essential tools for calculating the weight and biomass of fish, especially when direct field measurements are unfeasible. The connection between fish length and weight serves as a useful indicator for comprehending fish survival rates, growth patterns, maturity stages, reproductive capabilities, and overall health, as described by Le Cren (1951). Furthermore, LWRs enable the distinction of small taxonomic groups, given that variations occur within populations from diverse localities.

Fish is a vital source of nutrition, furnishing energy and critical fatty acids that impact its nutritional composition and quality. Studies highlight that eating fish lowers the risk of developing long-term health conditions, such as heart disease, atherosclerosis, and heart attack (Blanchet et al., 2000). Fish flesh biochemical composition, especially moisture content, is a reliable indicator of its protein, carbohydrate, lipid, and energy content. Lower moisture levels are associated with higher energy density (Aberoumad and Pourshafi et al., 2010). Fish is a high-quality protein source, offering vital amino acids. In a number of underdeveloped nations, fish plays a key role in the diet, helping to alleviate protein and amino acid shortages (Eyo et al., 2001). Generally, low water content in fish muscle is linked with high fat and protein levels, suggesting stored energy reserves (Dempson et al., 2004). Freshwater fish, especially Oreochromis mossambicus and Labeo rohita, are economically significant due to their high nutritional value. As consumers become more concerned with the nutritional content of their food, biochemical studies on fish are necessary to assess the environmental implications of their consumption and understand their physiological requirements more effectively. Understanding the nutritional value of fish is crucial, and studying their tissues is vital for determining their disease susceptibility, as noted by Hultin (2005).

The investigation, undertaken at the Kullursandai Dam between December 2023 and February 2024, sought to examine the physical and chemical properties of dam water and their association with fish body length and weight. The study also assessed the nutritional values, encompassing the carbohydrate rate and protein content, of the gill, skin, and muscle tissue of Oreochromis mossambicus and Labeo rohita. This research will offer advice for fishermen on the most cost-effective fish species and provide information on the growth and nutritional benefits of these species during the post-monsoon period.

METHODOLOGY:

SITE SELECTION:

The research study was conducted at the Kullursandai Reservoir, situated close to the Kowsiga Mahanadi, which is a tributary to the Arjuna River (Latitude: 9.550612, Longitude: 77.972437). Located in Tamil Nadu's Virudhunagar District, the reservoir is approximately 6 kilometres from Virudhunagar town. Built in 1979, this reservoir holds a total of 127 million cubic feet of water. It includes two irrigation sluices that supply water to 2,891 acres of land via the right and left main canals, situated on either side of the reservoir. The right main canal is approximately 3,500 meters in length, whereas the left main canal measures around 6,500 meters, with a discharge rate of 32.79 cusecs. The right and left main canals supply water to 1,431 acres and 1,450 acres of paddy fields, respectively. The Kullursandai Reservoir has a total catchment area of 278.64 square kilometers, with a water spread area of 6.14 square kilometers. The reservoir is impacted by both the northeast monsoon and the southwest monsoon.


KULLURSANDHAI DAM

Rainfall in the area fluctuates between a low of 110 mm and a high of 279 mm each year.

I. ANIMAL SELECTION:

Two species of fish, Tilapia (Oreochromis mossambicus) and Rohu (Labeo rohita), were sampled from the Kullursandai dam, as depicted in Plates 2 and 3. Taxonomic identification was conducted by referring to established sources like Wikipedia.

PLATE-2 -TILAPIA **PLATE -3- ROHU**

CLASSIFICATION AND DESCRIPTION OF TILAPIA:

Phylum :	Chordata
Class:	Pisces
Order :	Perciformes
Family:	Cichlidae
Genus :	***Oreochromis***
Species :	***mossambicus***

This fish, known as Oreochromis mossambicus, has a medium body shape and is flattened from side to side. It also has two long fins on its back which contain between 10-13 rays and spines. Tilapia is well known by this name, with its scales being relatively large on the forehead and smaller elsewhere on the body. The colouration is a dull greenish-yellow hue with a faint banding pattern. The length of adult fish varies from 25 cm in females to 35 cm in males,

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with an average male weight of 2.5 pounds and an average female weight of 2 pounds. Oreochromis mossambicus displays sexual dimorphism, showcasing distinct characteristics such as the width of the premaxilla, fin height, snout length, and nesting behavior.

CLASSIFICATION AND DESCRIPTION OF ROHU:

Phylum :	Chordata
Class:	Pisces
Order :	Cypriniformes
Family:	Cyprinidae
Genus :	***Labeo***
Species :	***rohita***

The Rohu, scientifically known as Labeo rohita, is a sizeable fish that belongs to the carp family and has an omnivorous diet. Widespread use of it is observed in aquaculture, and it can be located in rivers throughout South Asia. This fish, the Rohu, is characterised by its large size and silver colour, along with a distinctive arched head, typical of the cyprinid family. Typically, adults can attain a maximum weight of 45 kg and a maximum length of 2 meters, but they usually measure around 0.5 meters on average. The Rohu fish is found in rivers across India, Pakistan, Nepal, and Vietnam. During its early stages, its diet is primarily comprised of zooplankton, later shifting to phytoplankton as it matures, and then to submerged vegetation once it reaches juvenile or adult stages.

II. PHYSICO- CHEMICAL PARAMETERS OF WATER:

This research was conducted from December 2023 to February 2024, specifically during the post-monsoon period. Water samples were taken every two weeks to examine the physical and chemical properties of the water in the Kullursandai Reservoir. Digital instruments were submerged into collected water in a clean beaker to measure atmospheric temperature, dissolved oxygen, and electrical conductivity. For laboratory analysis, a sterile, 1000 ml polythene bottle was employed to collect water samples from various sampling locations. The water samples were taken to the laboratory at V.H.N.S.N. Situated in Virudhunagar, this autonomous college is about 5 kilometres from the Kullursandai reservoir.

PHYSICAL PARAMETERS:

In-situ surface water temperature readings were taken in the morning using a mercury thermometer. Measurements were collected from various sites around the reservoir to derive representative averages. Atmospheric temperature was recorded in degrees Celsius. In the morning, on-site atmospheric temperature was recorded with a mercury bulb thermometer. The ability of a substance or solution to conduct electricity was assessed through the use of a conductivity meter. The electrical conductivity of salts is due to the presence of ions, and this property is typically measured in terms of µS/cm.

CHEMICAL PARAMETERS:

The total dissolved solids in the water sample were determined by drying a filtered sample in a Petri dish and then weighing the remaining residue. The experiment was conducted on three separate occasions, with the average results being recorded each time. The modified Winkler method was used to estimate dissolved oxygen levels. Alkaline KI and MnSO4 were added to water samples to stabilise dissolved oxygen. The formation of a brown precipitate suggests the presence of oxygen. The sample was then titrated against sodium thiosulphate, with starch serving as the indicator. Water quality assessment relies heavily on pH as a crucial parameter, which in turn affects numerous biological and chemical processes. The concentration of hydrogen ions is essential in evaluating water quality.

III. GROWTH PARAMETER:

Evaluating the relationship between length and weight is crucial in determining the growth of fish in aquaculture. This method is employed to assess the nutritional value of fish. The research was conducted on five separate occasions over a period of five days. Specimens with comparable body lengths and weights were selected, encompassing diverse species, and transported to the laboratory in an icebox. Measurements of length and weight were taken using a meter scale and a weighing machine.

IV. BIOCHEMICAL ANALYSIS OF FISH:

Estimations of biochemical components like protein (Lowry et al., 1951), as well as carbohydrates (Dubois et al., 1956), were made from the fish's gill, skin and muscle.

ESTIMATION OF CARBOHYDRATES:

Homogenization was carried out on 10 mg of fresh liver tissue and tilapia fish muscle tissue using 5 ml of a 30% potassium hydroxide solution. The homogenate was pipetted into a sterile test tube and immersed in a hot water bath for 15 minutes, while being occasionally agitated, before subsequently being cooled with a stream of running tap water. One milliliter of 95% ethanol was then cooled and allowed to stand for five minutes. The contents were then spun at 3000 rpm for 5 minutes. Supernatant was decanted and the precipitate was cooled in the ice bath.Precipitate was dissolved in 2 ml of distilled water kept in the ice piece beaker. To this test tube 4ml of 0.2 %Anthrone reagent was added gradually by pipette and rapidly mixed to develop light green color. Then the tube was cooled to room temperature and the OD value was measured at 620 nm against the blank using a spectrophotometer. From the obtained OD value, the concentration of glucose was noted from the standard graph.

ESTIMATION OF PROTEIN:

After separating the liquid portion, the precipitate was then dissolved in 2 ml of a newly made alkaline CuSo4 solution. The precipitate was collected after decanting the supernatant and dissolved in 2 ml of freshly prepared alkaline CuSo4 solution. The solution was left to sit at room temperature for 10 minutes. Freshly prepared Folin-Ciocalteu reagent, 0.2 ml, was added and thoroughly mixed following this step. The solution was left to stand for 30 minutes in order for the blue color to develop, and its total volume was then increased to 5 ml using distilled water. The solution's absorbance was determined by comparing it to a blank at a wavelength of 650 nm via a spectrophotometer. A standard graph was constructed by plotting the absorbance values for various concentrations of Bovine serum Albumin, which were prepared using the same reagents previously mentioned. The protein quality in tissue samples was quantified using a standard graph.

RESULT AND DISCUSSION:

This study examined the growth patterns of Tilapia and Rohu, examining several key factors and comparing physical and chemical characteristics with the fish's length and weight. The findings revealed a steady rise in surface temperature (24.75°C to 26.5°C), atmospheric temperature (25.7°C to 27.45°C), electrical conductivity (322.6 to 347.5 µS/cm), total dissolved solids (85.55 to 91.15 mg/l), pH (6.25 to 6.45), and dissolved oxygen levels (4.46 to 7.45) between December and February. The growth was accompanied by increases in length and weight for both Tilapia and Rohu. The analysis revealed that small fish had greater carbohydrate levels in the gill, skin, and muscle areas than medium and large fish in both Tilapia and Rohu. Furthermore, small fish exhibited higher protein content in the gill, skin, and muscle areas than their medium and large counterparts in both species. The temperature of surface water is closely linked to the temperature of the surrounding atmosphere. According to the current research, atmospheric temperature rose steadily from 24.7°C to 26.5°C. Tilekar (2013) noted a rise in surface water temperature from 21.6°C to 27°C over the period from December to February. Possible factors in the heightened atmospheric temperature include solar radiation and clear skies, as suggested by Mohemad Toufeek (2009). Physical parameters such as atmospheric temperature were recorded during the post-monsoon period, which spans from December to February, in the Kullursandai reservoir. The findings revealed a rise in atmospheric temperature

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from 25.7°C to 27.4°C. Research conducted at the Thodga reservoir in Maharashtra revealed a comparable pattern (Patel, 2008; Tilekar, 2013). The rise in atmospheric temperatures signals the shift from meteorological events to changing seasonal patterns (Aruna Kumar Namdeo, 2013). The electrical conductivity and mineral accumulation levels change with the season and type of water body (Baijio et al., 1997). This research found that electrical conductivity rose from 322.6 µS/cm to 347.5 µS/cm between December and February. The measured value is in line with the electrical conductivity range of 312-380 µS/cm reported in the Limboti Dam of Maharashtra (Chaudhari, 2014). The rise in electrical conductivity is thought to be due to the concentration of minerals and salts within the water (Sayyed Hussain, 2012). The present investigation found that total dissolved solids levels varied over a range of 85.55 to 91.15 milligrams per liter. The highest level of TDS was observed in February at 91.15 mg/L, whereas the lowest level was noted in December at 85.55 mg/L. According to Alaka's study in 2014, the water samples from Borgaon contained a broader range of TDS levels, specifically between 347.16 and 738.0 mg/L. The rise in total dissolved solids is attributed to an increase in salts that include bicarbonate, chloride, phosphate, sulfate, nitrate, iron, and manganese, in addition to carbonate (Gonzalez et al., 2004). In the post-monsoon season, the water in the reservoir exhibited minor pH variations, spanning a range of 6.25 to 6.45. Corresponding values were found by Sermamoorthy (2017). A slight pH increase is likely due to effluent from household water, small-scale industries, and the incorporation of rainwater during the monsoon season as observed by Kamble in 2008. Dissolved oxygen levels are a crucial factor influencing the survival and dispersal of plant and animal life within an ecosystem. Activity levels in water are influenced by temperature. A consistent rise in dissolved oxygen levels was noted from December to February at the Kullursandai reservoir, spanning a concentration range of 4.46 mg/L to 7.45 mg/L. The Harsul Dam in Maharashtra exhibited a comparable range of DO, as noted by Samarat (2012). A mild increase in DO during the rainy season may be due to an influx of rainwater from nearby areas and the time following the monsoon season (Bhatt et al., 1999). Evaluating the length-weight relationship proved to be a more effective method for examining the growth parameters of fish. Understanding this relationship is crucial in creating aquaculture techniques for large-scale commercial production of valuable fish species, such as those mentioned by Rajkumar et al. (2006). The present investigation focused on the growth parameters of Tilapia and Rohu. The length of the Tilapia fish (Oreochromis mossambicus) was raised from 19.8 cm to 30.8 cm, and theThe length of Rohu (Labeo rohita) was extended from 18.7 to 30 cm and the weight was raised from 183 to 539.3 gm. Comparable findings were noted in the Idukki reservoir by Gobinath Nair i.n 1988. Umaru reported in 2015 that alterations in physical and chemical parameters may impact growth parameters . In the present investigation, the carbohydrate content of the tilapia fish(Oreochromis mossambicus) was high in small fish (Gills- 86.mg/g ;Skin-87.3 mg/g and in muscle -93.66 mg/g)and lesser in large fish (Gills- 61.3 mg/g; Skin- 60mg/g and in muscle -62 mg/g) and in rohufish(Labeo rohita) . The carbohydrate content was found in higher amounts in larger fish (Gills: 60mg/g; Skin: 59.6 mg/g; and in muscle: 55.3 mg/g) compared to larger fish (Gills: 47.3mg/g; Skin: 52.3mg/g; and in muscle: 48.3mg/g). Smaller fish are still developing and may allocate more resources towards growth rather than detoxification or elimination of substances. Higher levels of the substance could accumulate in their tissues as a result. (Phillips, 2017). The current study found that the protein content in tilapia fish (Oreochromis mossambicus) was higher in smaller individuals, specifically 78.66mg/g in the gills, 67mg/g in the skin, and 87.3 mg/g in the muscle, whereas in larger fish, it was lower at 72.3mg/g in the gills, 65.3mg/g in the skin, and 75.3 mg/g in the muscle. Similarly, in Rohu (Labeo rohita), the protein content was higher in smaller fish, at 65.6 mg/g in the gills, 64.3 mg/g in the skin, and 63.3 mg/g in the muscle, whereas in larger fish, it was lower at 43.3mg/g in the gills, 55.6 mg/g in the skin, and 60.3 mg/g in the muscle. Varying fish species exhibit distinct protein requirements and metabolic rates. The differences in protein content observed between tilapia and Rohu fish are likely due to factors unique to each species. Conditions like water temperature and purity can impact the accessibility of nutrients and impact fish metabolic rates and development. Differences in environmental conditions between the habitats of small and large fish may be responsible for variations in protein content (Weatherly et al., 1988). Variations in environmental conditions between habitats inhabited by small and large fish could contribute to differences in protein content (Weatherly et al.,1988).

FUTURE DIRECTION:

Future research on the Kullursandai reservoir's ecosystem and its fish populations' growth patterns should concentrate on extending the study duration to encompass a whole year, thereby enabling a thorough examination of seasonal fluctuations. Comprehensive studies on nutrient accessibility, histological transformations in fish tissues, and population fluctuations are crucial. Furthermore, evaluating the effects of human-induced activities, performing genetic examinations to determine potential markers linked to growth, and testing microbial loads will yield a more comprehensive understanding of the factors affecting fish growth. Future studies will aid in creating effective conservation and management plans, guaranteeing the long-term use of this highly valuable aquatic resource.

CONCLUSION:

The recent study showed a clear link between rising physicochemical factors, including temperature, conductivity, TDS, pH, and dissolved oxygen levels, and the growth of Tilapia and Rohu fish in the Kullursandai reservoir following the post-monsoon season. Significantly, the research found that smaller fish of both species had higher levels of carbohydrates and proteins in their tissues compared to the larger fish, indicating that more resources were devoted to growth during their early life stages. These results offer significant insights into the ecological dynamics of the reservoir, and underscore the impact of environmental factors on fish growth and physiology.

SUPPLEMENTARY MATERIALS:

A comprehensive dataset, featuring a table of all values and various graphic representations including bar charts, has been compiled in a document format and made available as supplementary material in a Google Drive folder located at https://drive.google.com/drive/folders/1V7a8omOJ4qY8rIXzmtJoKOaasEeSz9Pt

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Popular Article

Forecasting Change: The Role of Advanced Meteorology in Climate Adaptation and Fisheries

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Introduction

Meteorology plays a crucial role in combating climate change by helping us understand and adapt to shifting weather patterns. Meteorologists play an important role in anticipating change by providing critical data and insights that enable communities, governments, and enterprises to adjust efficiently. The world is suffering severely from climate change especially in terms of rise in temperature, and climate varies around the globe. Climate change is caused by both anthropogenic and natural factors, including a lack of vegetation and a significant increase in total carbon dioxide, methane, and other greenhouse gas emissions. The increased temperature are projected to hasten desertification (Sissakian et al., 2013), affecting agriculture (Osman et al., 2019), land use, land cover changes, and water resources in many countries. Conventional risk assessments and infrastructure diagnostics often rely on inspections, which are augmented by conventional monitoring and analytics. Consequently, they fail to provide a comprehensive strategy for prompt decision-making. Moreover, risk-based infrastructure management overlooks recovery from a "beyond-design-life" situation and is insufficient for handling "low-probability, high-consequence" disasters like the 2011 Tohoku earthquake and tsunami. This is because existing risk modeling and assessment frequently fail to account for such situations, while legislation and budgetary restrictions preclude them by adopting several strategies. This article examines meteorology's critical role in climate adaptation and how advances in discipline are impacting our response to the climate catastrophe.

Fisheries management does not function on 50–100-year scales, necessitating shorter-term projections (Hare et al., 2010). The climate modelling community is dedicating significant resources to creating decadal-scale forecasts that encompass both externally induced changes (e.g., CO_2 emissions) and internal variability (e.g., Atlantic meridional overturning circulation, El Niño–Southern Oscillation) (Keenlyside et al. 2008). In the future, various climatic projections about fish population statuses (5–20 years, 20–50 years, 50–100 years) may be made available to scientists, managers, and fishermen (Brander, 2010). However, these projections must include the impacts of both fishing and climate on population dynamics (Planque et al. 2010).

Climate Dynamics

Meteorology is the study of atmospheric phenomena and the complex interconnections that determine weather patterns and climate change. Meteorologists may understand the complicated dynamics of climate systems by evaluating historical data and using advanced models. This understanding serves as the foundation for projecting future climate trends, such as temperature changes, precipitation patterns, and extreme weather occurrences. There is a shift in the climate system caused by internal changes within the climate system or the interplay of its components, as well as changes in external force caused by natural or manmade activity. Climate variability is defined as variability observable in the climate record during periods when the condition of the climate system does not change. If the climatic state changes, which is often defined by a shift in means, the frequency of previously unusual occurrences on the shifted side of the mean may increase with rising climate variability (Salinger, 1994). Global climate models are widely used to evaluate climate risk (Hassan, 2021). These models are effective instruments for simulating the three-dimensional climate system through the application of equations defining energy (first law of thermodynamics), momentum (Newton's second law of motion), mass conservation, and water vapor (ideal gas law). At discrete locations on the surface of the Earth, each equation is approximated for different layers of the atmosphere identified by a regular grid during predefined time intervals (Mohammed et al., 2022). In order to comprehend the future climate and its progression, this was used to compare the expected and actual climatology in a climate model spanning the target region. There are two well-known techniques for downscaling: statistical downscaling (like LARS-WS and SDSM) and dynamical downscaling (like Regional Climate Models; RCMs) (Semenov et al., 2002). In recent years, Statistical Downscaling Models (SDSM) and the Long Ashton Research Station Weather Generator (LARS-WG) have been developed (Wilby and Dawson, 2004). While SDSM employs a regression-based methodology, LARS-WG is based on a stochastic weather generator (Zubaidi et al., 2019) (Costa-Cabralet al., 2013).

Forecasting Climate Change Impacts

Predicting how the climate will affect different areas and ecosystems is one of the main responsibilities of meteorologists. They can predict how various regions of the world will be affected by increasing temperatures, shifting rainfall patterns, and stronger storms by using climate models and simulations. Policymakers, urban planners, and disaster management organizations may create proactive measures to reduce risks and safeguard populations by using these projections, which offer essential insights as shown in table 1.

Meteorological Tool	Description	Reference
Weather Radar	Detects extreme weather events and precipitation	Boyle et al., 2005
Climate Risk Assessment	Detects climate data to identify vulnerable areas	Scholze et al., 2006
Climate Models	Projecting future trends using Earth's climate system simulation	Randall et al., 2007
Weather Stations	Collecting observational data on temperature, humidity, etc.	Cuervo-Robayo et al., 2014
Satellite Imagery	Gives access to real-time weather pattern tracking	Chiang et al., 2020
Early Warning Systems	Warns users to extreme weather conditions	Dylewsky et al., 2023

Table 1. Different meteorological tools and their functions

Early Warning Systems

When it comes to creating early warning systems for extreme weather occurrences like hurricanes, heat waves, hailstorms, and floods, meteorologists are essential. Meteorological organizations are able to promptly issue alerts and advisories, allowing individuals the chance to make preparations and take preventive action, by monitoring atmospheric conditions and applying modern forecasting techniques. In the event of climate-related calamities, these early warnings improve community resilience, save property damage, and save lives. The intended beneficiary community must accept warnings as legitimate and actionable, and they must be effectively communicated and disseminated by mandated authorities. Budgets must be decided upon, goods must be moved to the area at risk, public awareness campaigns must be created, and so on. Weather predictions only give enough warning to take limited action, and all of these activities take time. Decision-makers would be better equipped to plan an efficient response if they had more time to prepare.

Supporting Climate Resilience

By offering data-driven insights that guide adaptation plans and infrastructure design, meteorology promotes climate resilience. Meteorologists assist in identifying regions susceptible to climate impacts, such as droughts, sea level rise, and disruptions to agriculture, by evaluating climate predictions and sensitivity assessments. Decision-makers utilize this information to help them put policies like improving water management systems, developing resilient infrastructure, and encouraging sustainable land use practices into action. The promise for enhancing the climate resilience of essential infrastructure lies in emerging and disruptive digital technologies that can facilitate decision-making and adaptation by offering prompt and precise asset condition assessments. In order to succeed in this attempt, transdisciplinary roadmap adoption as well as the utilization of computational, communication, and other digital technologies, tools, and monitoring systems are crucial. However, due to a lack of agreement, coordinated strategies, and laws promoting their usage, the promise of these cutting-edge technologies is still mostly unrealized. Emerging digital technologies such as artificial intelligence, point clouds, digital twins, Internet of Things, and building information modeling can contribute to a safer society. These technologies nevertheless have a strong reliance on their operators' interdependencies and the power source.

Innovation in Meteorological Technologies

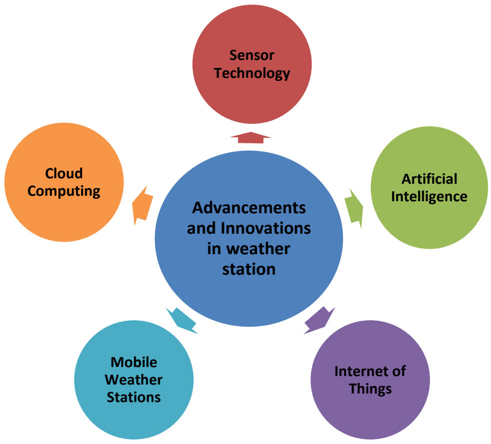
The monitoring and comprehension of climate change is being revolutionized by advances in meteorological technologies. Modern meteorological instruments provide never-before-seen levels of accuracy and precision in weather forecasting and climate modeling, ranging from satellite images and remote sensing to high-performance computers and artificial intelligence. Emerging technologies for better weather forecasting are shown in figure 1. Due to these advancements, meteorologists can now provide more accurate forecasts and customize adaptation plans for certain local conditions. By addressing the shortcomings and problems of conventional management techniques, the broad adoption of new digital technologies in the age of intelligent infrastructure is upending the way we manage our infrastructure. For instance, integrating diverse information and evidence using data mining for various infrastructure systems are made easier by 5G-enabled technologies, nearly instantly (Nguyen et al., 2021). These cutting-edge techniques give end users the ability to communicate, see, and engage with their surrounding environment while paving the path for safer infrastructure through more precise and automated decision-making.

Adaptation and mitigation strategies for climate change encompass a range of areas, including water sustainability plan, which includes comprehensive national planning and management of water resources, infrastructure restoration of water treatment facilities, and the application of substitute water sources, like reclaimed wastewater through the creation of reclaimed water facilities and water collection. To lower climate-altering emissions and enhance the environment, renewable power funding possibilities and climate-resilient infrastructure approaches such as using solar and wind energy in place of fossil fuels are required. According to the findings of Hassan et al. (2023), the LARS-WG model did a good job in downscaling daily temperatures and precipitation.

Figure 1. Emerging advancements and Innovations in meteorological analysis

Forecasting the change for aquaculture and fisheries

In the face of climate change, fisheries are increasingly vulnerable to extreme weather events, rising sea temperatures, and shifting oceanic patterns. Advanced meteorological tools,



including satellite-based monitoring, oceanographic models, and AI-driven climate predictions, play a crucial role in mitigating these challenges. Real-time weather forecasting helps fishers plan safe and efficient operations, reducing economic losses due to storms or unfavorable conditions. Additionally, climate models aid in predicting changes in fish distribution, breeding patterns, and disease outbreaks, allowing for adaptive fisheries management. By integrating meteorological data with sustainable fishing practices, policymakers and stakeholders can ensure long-term resilience in fisheries, safeguarding both livelihoods and aquatic biodiversity. The findings of the research by Hare et al. (2010) indicate that the impacts of climate on fisheries must be recognised, comprehended, and integrated into the scientific recommendations given to managers to attain sustainable exploitation in a changing environment.

Conclusion

A key component of climate adaptation is meteorology, which offers crucial data and perspectives for dealing with the problems brought on by climate change. Meteorologists help communities and decision-makers prepare for and lessen the effects of global warming by predicting change, creating early warning systems, and promoting resilience initiatives. Meteorology's role will remain crucial in constructing a more resilient and sustainable future as we face the challenges of climate change. Climate change, in especially the rise in temperatures in arid and semi-arid regions, is one of the most significant environmental problems faced by human civilization today and has been the focus of multiple studies in recent years. To increase socioeconomic systems' long-term durability in the face of upcoming disruptions, one should not sacrifice efficiency in the name of building resilience. Further study is required to develop adaptive capability that takes into account the profound uncertainties related to climate change that are supported by digital technology. In this context, standards, design norms, and guidelines are essential. These can include resilience analytics, which is based on management, deployment of digital data, associated cloud architecture, infrastructure monitoring, and regulation of digital technologies, especially with regard to cyber security.

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Black Gills, Silent Killer: The Hidden Threat in Our Waters

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Abstract

In global shrimp aquaculture, black gill disease possess an emerging health threat that causes substantial economic damages and affecting the sustainability of farming processes. Firstly this disease was reported in *Penaeus japonicus* in Japan. This disease is recognized by darkening or blackening of the gills due to an innate immune response to various stressors. Different causative agents, such as *Photobacterium damselae*, *Fusarium* spp., *Aspergillus flavus*, and the ciliate *Hyalophysa chattoni*, have been found responsible for this disease. It has been extensively reported in Asia, North America, and the Middle East, affecting both wild and farmed shrimp populations. Reduced feeding, sluggishness, and respiratory distress are exhibited by infected shrimp that often results in high mortality. Sometimes disease outbreaks caused due to the contribution of environmental factors, pollutants, and poor pond management. Though it is not transmissible to humans, It possess a serious aquaculture challenge. The preventive measure depends on regular health monitoring, proper water quality management, biosecurity, and probiotic use. With no single causative agent identified, integrated management strategies are essential to controlling its spread and sustaining shrimp farming industries.

Introduction

Aquaculture serves as a vital source of nutrition and provides employment of millions people in worldwide. Shrimp farming has gained significant attention for its high nutritional value, but disease outbreaks during cultivation remain a major challenge (Pushparajan and Soundarapandian, 2010). Different environmental conditions, along with infectious agents like fungi, viruses, and protozoans, as well as chemical and biological pollutants, can causes mass mortalities in shrimp ponds. These factors are threaten to the sustainability of shrimp farming as well as directly hinder growth and survival rates in grow-out culture ponds (Burgents et al. 2004). Black gill disease was primarily recognized in the Japanese Kuruma prawn (*Penaeus japonicus*) by Ishikawa in 1968. The disease was caused by Fusarium species, which were later recognized as the most harmful pathogens affecting Kuruma prawns in Japan (Khoa et al. 2004). Severely darkened gills, a state known as black gill, black spot gill syndrome, brown gill, or black necrotic disease, has been observed in different crustaceans, with epidemics in some penaeid and pandalid shrimp populations. Black gill disease is linked to gill tissue darkening (melanization), which represents an innate immune reaction to various gill irritants, including pathogens, parasites, pollutants, and nutrient deficiencies in different crustacean species (Jiravanichpaisal et al., 2006). Different chemical pollutants such as oil, zinc, cadmium, ozone, copper, potassium permanganate, ammonia, nitrate, and even a lack of ascorbic acid have been related to black gill disease. Moreover, environmental factors such as heavy siltation and excessive organic waste from leftover feed, debris, and feces accumulating on the pond bottom also contribute to its occurrence (Lavilla et al. 2000). In diseased shrimp, At first the gills appear yellowish to brown, gradually turning black as the disease advances, especially if rearing conditions are not improved (Velmurugan & Ayyaru, 2014).

What is Black Gill Disease?

A pathological state identified as "black gill disease" affects crustaceans and is typified by a marked blackening (melanization) of the gills. The crustaceans' innate immune system's reaction to stress or infection causes this darkening (Karthikeyan et al., 2015). The phenoloxidase system, which produces oxidative and toxic intermediates that ultimately causes the production of melanin, is related to the innate immune response that turns black the gills of infected animals (Lightner and Redman, 1977). The thin carapace protecting the gill chamber makes the melanised, blackened gills easily observable (Landers et al., 2020).

Sign and symptoms

The most prominent sign is the darkening of the gills, which causes due to melanin deposition resulting from inflammation or tissue damage. Affected shrimp often shows sluggish behavior, moving less actively than healthy individuals, and may show a less appetite, leading to decreased feeding. As the disease progresses, respiratory distress becomes more ostensible, as the damaged gills impair the shrimp's ability to breathe efficiently. This may cause them to swim to the surface more frequently in an attempt to access more oxygen. Black gill disease is known as one of the most important diseases in shrimp aquaculture, causes high mortality (Souheil et al., 1999; Khoa et al., 2004). As the name suggests, the disease is identified by the gills turning black, a result of melanin buildup due to inflammation or tissue injury caused by the causative agent (Lightner & Redman, 1977; Bian & Egusa, 1981; Maestracci & Vey, 1988).

Causative agents

Black gill disease does not have a single cause. Numerous studies have connected the disease to Fusarium species (Bian & Egusa 1981, Khoa et al. 2004). However, other studies have found other causes, such as Photobacterium damselae (Wang et al. 2020), Aspergillus flavus (Dewangan et al. 2015), and the ciliate Hyalophysa chattoni (Frischer et al. 2018). Only Maestracci & Vey (1988) have discovered that F. oxysporum is the cause of crayfish black gill disease thus far. According to Zhang et al. (2022), this fungus, which is typically benign but can infect various animals, caused gill damage, altered bodily fluids, and ultimately resulted in the crayfish's demise.

Geographical distribution

Shrimp black gill disease, which affects different shrimp species in different regions, is a serious threat to aquaculture worldwide. The disease has been documented in both wild and farmed prawn populations in Asia, including Taiwan, China, India, Indonesia, Malaysia, and Japan. According to genetic testing, Fusarium solani is the cause in China, where infected prawns have a high mortality rate of 88.66% (Yao et al. 2022). Black gill disease has also afflicted wild and farmed prawns in North America, especially along the Gulf Coast and in southeastern states like Georgia, South Carolina and North Carolina. Hyalophysa chattoni has been connected to the disease, according to research from the University of Georgia, and environmental factors like warming seas have been implicated in its spread. In the Middle East, particularly along the coast of Bushehr in Iran, histopathological studies have shown a prevalence of black gill disease in marine shrimp populations, with Fusarium infections causing gill damage and melanization.

Impact on Aquaculture

Black gill disease has a substantial impact on aquaculture, principally in shrimp farming, where it can cause considerable economic losses. The disease leads to high mortality rates in infected shrimp, which directly reduces production and yield. As the disease progresses, shrimp show symptoms like darkened gills, reduced feeding, and slower growth, making them less valuable in the market. In severe cases, entire batches of shrimp can be lost, leading to financial strain for farmers. The disease also affects the quality of the shrimp, rendering them less appealing for consumption, which can further diminish their market value. Besides, outbreaks of black gill disease can generate troubles in the international trade of shrimp, as countries with infected populations may face export restrictions. Overall, the disease poses a serious threat to the sustainability of shrimp farming operations worldwide.

Prevention and Management

For the effective prevention of this disease in shrimp there is needed to monitor water quality such as pH, salinity, temperature, DO, and ammonia levels regularly (Pazir et al. 2024). Also there is should be careful about proper pond preparation and stocking densities. The use of probiotics in shrimp aquaculture increases shrimp immunity, while regular health checks help detect symptoms early for prompt action. Managing environmental stressors, such as temperature and salinity fluctuations, is crucial to reducing vulnerability. Infected shrimp may require antifungal or antibacterial treatments, but these should be used cautiously. Strict biosecurity measures, including controlling the movement of stock and ensuring new shrimp are disease-free, help prevent pathogen introduction. By integrating these strategies, shrimp farmers can reduce the impact of black gill disease and sustain their operations.

Can It Spread to Humans?

Black gill disease in shrimp does not spread to humans and is not considered a zoonotic disease. The primary pathogens associated with black gill disease such as *Fusarium solani*, *Aspergillus flavus*, and *Hyalophysa chattoni* affect shrimp and other aquatic organisms but do not pose a risk to human health through consumption or handling of infected shrimp. However, immunocompromised individuals should still practice good hygiene when handling raw seafood, as some fungi like *Fusarium* and *Aspergillus* can, in rare cases, cause opportunistic infections but this is unrelated to black gill disease itself and extremely uncommon.

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Popular Article

मछली खाने से फायदे एवं जोखिम

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मछली स्वस्थ एवं संतुलित आहार का एक उत्तम स्रोत है। मछली में प्रचुर मात्रा में प्रोटीन एवं अन्य पोषक तत्व पाए जाते हैं। विश्व में आहार के रूप में उपयोग की जाने वाली प्रोटीन की कमी को पूर्ण करने में जलीय जंतु (मछली) की अहम् भूमिका है ।

मछली में पाए जाने वाले पोषक तत्व एवं उसके फायदे

- **प्रोटीन** से शरीर एवं मांसपेशियों की वृद्धि होती है।
- **कैल्शियम** हड्डी की वृद्धि एवं रखरखाव में सहायता करता है।
- **आयरन** हीमोग्लोबिन एवं कोशिका श्वसन के लिए लाभकारी होता है।
- **विटामिन डी** हृदय को स्वस्थ एवं हड्डियों को मजबूत बनाता है।
- **विटामिन बी 12** तंत्रिका तंत्र एवं मस्तिष्क के लिए लाभकारी होता है।
- **विटामिन ए** दृष्टि में सुधार के साथ संक्रमण के समय शरीर को प्रतिरक्षा प्रदान करता है।
- **ओमेगा–3 फैटी एसिड** हृदय को स्वस्थ, मस्तिष्क का विकास एवं लम्बे जीवन के लाभकारी होता है। ब्रेस्ट कैंसर से लड़ने में सहायता करता है ।
- **आयोडीन** थाइरोइड हॉर्मोन्स के संश्लेषण में, भ्रूण के मस्तिष्क एवं तंत्रिका तंत्र के विकास में सहायता करता है ।
- **विटामिन इ** एंटी एजिंग का काम करता है जिससे त्वचा शुष्क नहीं होती एवं चेहरे पर झुर्रियां नहीं पड़ती हैं ।

मछली खाने से जोखिम

चूँकि मछली एक जलीय जंतु है, जल प्रदूषित होने पर मछली में भी उसका प्रभाव पड़ता है। कृषि क्षेत्र से बारिश के समय बहकर आये कीटनाशक में उपस्थित कुछ हानिकारक तत्व एवं औद्योगिक क्षेत्र के अपशिष्ट सूक्ष्म मात्रा में मछली के शरीर में प्रवेश कर जाते हैं एवं मछली को प्रभावित करते हैं जिससे मछली संक्रमित हो सकती है। संक्रमित मछली के सेवन से हमारे शरीर को जोखिम उठाना पड़ सकता है। किन्तु इसका प्रतिशत बहुत कम होता है। स्वच्छ वातावरण से लायी गयी एवं अच्छी तरह से पकाई गयी मछली को खाने से इस जोखिम को समाप्त किया जा सकता है ।

मछली खाने से जुडा मिथक

मछली खाने के तुरंत बाद या पहले दूध के सेवन से सफेद दाग होते हैं, इसके पीछे कोई स्पष्ट वैज्ञानिक कारण नहीं है ।

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Popular Article

Mycotoxins In Aquaculture: An Invisible Hazard

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Introduction

Mycotoxins are compounds that occur in food, are naturally produced poisons, invisible, tasteless, chemically stable, toxic metabolic substances, produced by various secondary metabolic products of filamentous fungi (literally "fungus poisons"). Low molecular weight causes economic losses at all levels of food. Currently, 400 mycotoxins are reported. These toxins are produced by diverse groups of fungi, such as *Aspergillus*, *Penicillium*, and *Fusarium*, that contaminate crops before harvesting or during post-harvest conditions like storage.

Are Aquatic Animals Affected by Mycotoxins?

Aquaculture farmers may not see it, but a hidden hazard can wait inside every bag of pellet or grain are mycotoxins. It is increasingly recognized as a global concern in both the livestock and aquaculture industries. The rising trend of incorporating more plant-based ingredients into aquaculture feeds, driven by the high cost of fishmeal and fish oil, has heightened the risk of mycotoxin contamination. This contamination not only affects fish growth performance but also compromises the quality of the final product. The effects of t may be caused by a single toxin or the synergistic effects of multiple mycotoxins, which can be harmful even at lower contamination levels.

The five most common Mycotoxins found worldwide in aquafeed and raw material used for feed formulation are:

1. Aflatoxins (Afla)
2. Zearalenone (ZEN)
3. Trichotecenes (T-2 & HT-2)
4. Fumonisins (FUM)
5. Ochratoxin A (OTA)

Table 1. Major Mycotoxin-Producing Genera

Major Genera	Mycotoxins
Aspergillus sp.	Aflatoxin, ochratoxin, patulin, cyclopiazonic acid
Claviceps sp.	Penitrem A, clavines, lysergic acids, lysergic acid amides, ergopeptines
Fusarium sp.	T-2 toxin, HT-2 toxin, diacetoxyscirpenol, fumonisin fusaric acid, nivalenol, deoxynivalenol, fusarenon-X, Zearalenone
Penicillium sp.	Ochratoxin, citrinin, roquefortine C, PR toxin, penitrem A, cyclopiazonic acid, patulin
Neotyphodium sp.	Ergot alkaloids, lolines, peramine, loliterms

Source: (El-Sayed et al., 2022)

- The level of damage that can be caused by the Mycotoxins intake depends mainly on:
  - The type of toxin
  - Its concentration in the feed
  - Period of exposure
  - Animal species susceptibility
- They exhibit a wide range of effects related to carcinogenicity, neurotoxicity, and developmental toxicity (Kolpin et al., 2014).

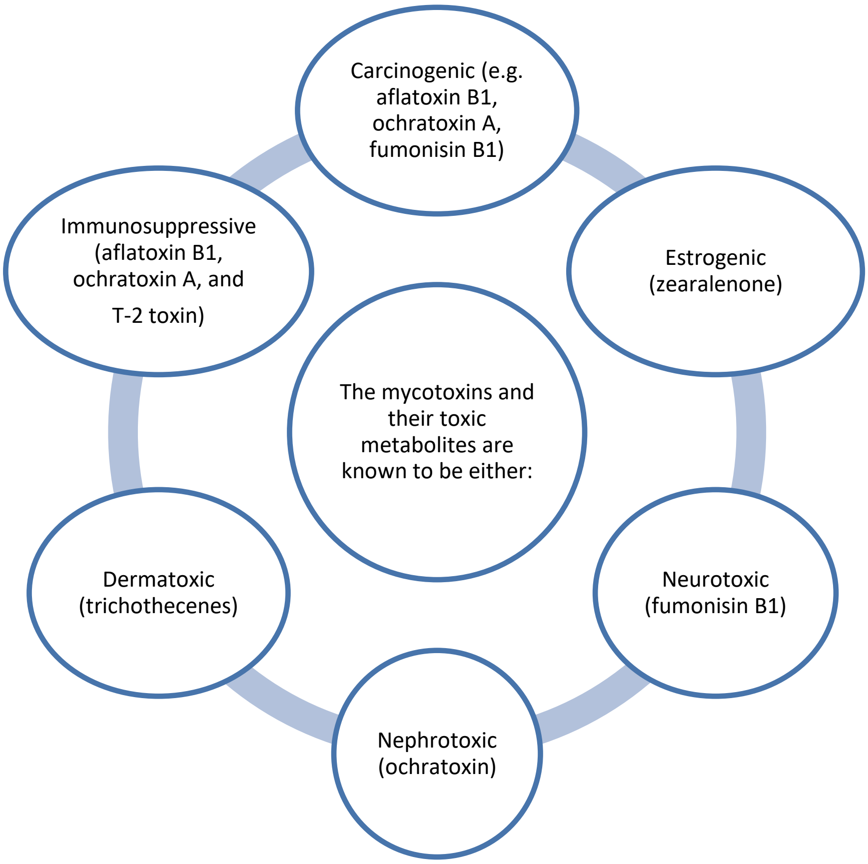

Fig. 1: The mycotoxins and their toxic metabolites

The damage of mycotoxins to fish and shrimp

The effects of mycotoxins on fish & shrimp are gradual but pose a serious threat.

The damage of mycotoxins to shrimp

- Direct damage to the shrimp hepatopancreas
- Loss of immune system function
- Slow growth
- Poor body color
- Prone to stress
- Soft shells
- Cause damage to the digestive tract of shrimps
- Causing an empty intestine and stomach

- Red intestine, red stomach
- Hepatopancreas necrosis of shrimps will cause EMS
- Secondary infection forms enteritis, white feces, and so on

The damage of mycotoxins to fish

- Organ damage
  - Liver and kidney disease
  - Scale/shell lesions
- Reproduction
  - Altered egg production
  - Reduced embryonic survival
  - Poor sperm quality
- Immunity
  - Increased susceptibility to disease
  - Increased shell diseases
  - Reduced survivability
- Gut health
  - Feed intake reduction or refusal
  - Damage and lesions to the intestinal tract
  - Altered gut microbial functions
  - Increased gut pathogens
- Performance
  - Poor efficiency
  - Reduced growth rates
  - Smaller body weight

Key mycotoxins of concern

1. **Aflatoxins (AFs)**

It is produced mainly by *Aspergillus flavus* and *A. parasiticus* and other filamentous fungi of the genera *Penicillium*, *Rhizopus*, *Mucor*, and *Streptomyces* on warm-stored grains (Agag et al., 2004). It is known as the first mycotoxin to be discovered. Feedstuffs like maize, corn, wheat, cottonseed, nuts, and others are concerned with mycotoxins. The main sources of animal feed are groundnut meal, maize, and cottonseed meal. It attacks the liver and impairs growth, even at very low concentrations, causing liver damage, bleeding, and suppressed immunity (Marijani et al., 2019). Fry are more susceptible than older fish.

2. **Fumonisins (FBs)**

It is synthesized by several *Fusarium* species. *Fusarium verticillioides* is widespread in maize and generates FBs, which are often more abundant when crops are under drought stress or get significant insect damage (Mutiga et al., 2015). Fumonisin B1 is the most toxic fumonisin. In fish and shrimp, high fumonisin feed causes digestive issues and vulnerability to infections.

3. Ochratoxin (OTA)

It is generally produced by *Penicillium* spp. and *Aspergillus* spp. The most toxic form is ochratoxin A. In aquatic species, OTA exposure leads to stunted growth, lesions in the liver and kidneys, and higher death rates under disease challenge. Channel catfish fed with OTA-contaminated diets showed a substantial loss in weight increase, reduced feed conversion rate, shorter survival, and reduced haematocrit (Manning et al., 2003).

4. T-2 toxins

Produced by fungi of the genera *Fusarium, Myrothecium, Phomopsis, Stachybotrys, Trichoderma, Trichothecium,* and others in crops such as corn, wheat, and oats. Effect on aquatic species included decreased average weight gain, decreased production of bacterial cell wall-breaking enzymes, immunosuppression at low dosage, decreased resistance to oxidative damage, and heterogeneous growth and physiological disorders in shrimps.

5. Zearalenone

Fusarium graminearum is the main producer of the estrogenic compound zearalenone (ZEN). Zearalenone dominantly affects reproductive parameters in different aquatic species, reducing spawning frequency, accelerating sexual maturation (Schwartz et al., 2010) and leaving residues in meat.

Review about the effect of mycotoxins on aquatic species

Table 1. Impact of mycotoxins on aquatic species

Mycotoxin	Species	Dose	Duration (Week)	Effects	References
AFB1	*Litopenaeus vannamei*	100 µg/kg		Histological damages in the hepatopancreas of shrimp AFB1 level in the Pacific white shrimp diet should be <38.1 µg/kg	Fang et al (2019)
	Nile tilapia	100 ppb	12	100 ppb AFB1 negatively impacted weight gain, feed efficiency, hematological profiles, HSI, as well as liver histopathology	Mahfouz and Sherif (2005)

	Channelcatfish (*Ictalurus punctatus*)	10000µg/kg	10	Decreased leukocyte count, increased hematopoietic activity of blood-forming tissues	Jantaroaiand and Lovell (1990)
	Tilapia	2.5mg/kg	20	Abnormal Behavior	Deng et al. (2010)
Fumonisins	Gilthead seabream (Sparus aurata)	168 µg/kg		Significant impact on final body weight, feed conversion ratio, and protein efficiency ratio Also reduced fat and energy retention, and disrupted the respiratory system.	Goncalves et al. (2020)
	Red Tilapia			Observed growth depression	Tola et al. (2015)
OTA	Sea bass	277 µg/kg		The behavioural changes of sea bass were primarily observed as nervous and respiratory manifestations. Concluded that sea bass is a species highly sensitive to OTA	El-Sayed et al. (2022)
	Tiger shrimp	1000 µg/kg	8	A decrease in phenol oxidase (PO) activity Although no histopathological change was observed	Supamattaya et al. (2005)
	Channel catfish	4.0 or 8.0 mg/kg	8	The feed conversion ratio was significantly poorer	Manning et al. (2003b)
	Juvenile channel catfish	5mg/kg	8	Histopathological anomalies of the stomach, head, and trunk kidneys	Manning et al. (2003a)

T-2 toxin	Pacific white shrimp	2.4 and 4.8 mg/kg	8	Antioxidant enzymes, superoxide dismutase (SOD) and glutathione peroxidase (GPx), total antioxidant capacity (T AOC), and also glutathione (GSH) content increased.	Deng et al. (2010)
	Rainbow trout	1.0–1.8 mg/kg		Non-specific humoral immunity decreased significantly in both experimental groups. Influences the immunological defense mechanisms of rainbow trout	Modra et al. (2020)
ZEN	Zebrafish	1000 and 3200 ng/L	6	Exhibited a strong effect on the induction of VTG and reproduction in vivo	Schwartz et al. (2013)
	Black tiger shrimp	500 and 1000 mg/kg	10	Histological changes in hepatopancreatic tissue	Bundit et al. (2006)
	Juvenile rainbow trout	1.810 mg/kg	10	No effects on growth and may accelerate sexual maturation of female fish	Wozny et al. (2015)

Detection methods

Analysis of food in search of mycotoxins is part of the mechanisms of control and prevention of poisoning. The detection method involves a series of steps:

1. **Sampling**

Sampling is important in determining mycotoxin levels since mycotoxigenic fungi do not grow on the substrate, making it difficult to get a representative bulk sample. Furthermore, the current mycotoxin contamination in natural samples is not homogeneous. To standardize the sampling processes for mycotoxin analysis, Commission Regulation (EC) No. 401/2006

(EC, 2006) established the sampling and analytical methodologies for official control of mycotoxin levels in foodstuffs (EU, 2014).

2. **Preparation**

   To speed up the extraction process and identify mycotoxins, grind the sample to a particle size of around 500 µm and homogenize it to a consistency similar to whole powder (Nakhjavan et al., 2020).

3. **Extraction and Purification**

   This process begins with an extraction in acetonitrile water, followed by liquid-liquid partitioning caused by the addition of inorganic salts. Different extraction methods like liquid-liquid extraction, liquid-solid extraction, pressurized liquid extraction, etc.

4. **Detection and analysis**

   Thin layer chromatography (TLC) and high-performance liquid chromatography (HPLC) are used in conjunction with a variety of detectors, including diode array, fluorescence, and UV. LC-MS/MS and GC-MS/MS have also been frequently used. When quick mycotoxin analysis is necessary, immunoassay techniques such as enzyme-linked immunosorbent assay (ELISA) and lateral flow immunoassay (LFIA) are used. The biosensor system mainly consists of a biorecognition (biosensing) element. Biorecognition elements such as antibodies, antigens, nucleic acids, and enzymes are used to identify and sense target analytes. Biosensors can be classified into electrochemical, optical, mass-sensitive, and thermal sensors (Janik et al., 2021).

Remediation Strategies for Mycotoxin Control

Mycotoxins are heat-stable compounds and difficult to eliminate once they have been synthesized. Once these molecules are present, detoxification or decontamination of food through physical, chemical, and biological methods can be reduced or controlled. Some good hygiene practices have been established and implemented regarding the activities for aquaculture food production. Currently, to guarantee the safety of aquaculture products, animal welfare, and health, various certification standards have been developed based on good hygiene practices and the implementation of HACCP and plans such as global GAP, accredited fish farm scheme, bio-Suisse, Safe Quality Food (SQF), and others (Maama, 2014).

	Methods	**Commonly used measures and reagents**	**Decontamination efficiency**	**Reference**
	Sorting and separation	Sieving, gravity separation, photoelectric separation, etc.	Removed at least 51%, 63%, and 93% of AFs, trichothecenes, and	Matumba et al. (2015)

Physical method			fumonisins from the shelled white maize	
	Washing and solvent extraction	solvent extraction (methanol, ethanol, hexane, acetonitrile, isopropanol, and aqueous acetone)	Removed aflatoxins, trichothecenes, ZEN, and fumonisins by 51-72%, 64-69%, 52-61%, and 73-74% from the grains	Karlovsky et al. (2016)
	Heating	High temperature, high voltage	Decomposed 78-88% of AFB1 in rice by cooking, reduced 80% of FB1 while cooking rice at 100 °C for 10 min.	Becker et al. (2013)
	Irradiation	X-rays, electron beam, ultraviolet rays, infrared, and microwave	Reduced 22.0-90.7% of AFB1 by irradiation, Decontaminated 25.0-86.0% and 60.0-100% of ZEN by ultraviolet rays	Pankaj et al. (2018)
Chemical methods	Alkaline treatment	Ammonia, sodium hydroxide, potassium hydroxide and sodium carbonate, etc.	Removed 95% of AFB1 in various cereals by ammoniation and hydroxide treatments	Bretz et al., (2006)
	Ozone treatment	Ozone, hydrogen peroxide, chlorine, sodium, and calcium hypochlorite, etc.	Reduced 92-95%, 91%, and 78% of AFBs in corn, cottonseed, and peanut meal, respectively, by ozone	Sun et al., (2016)

	Mycotoxins	**Microorganisms**	**Biotransformation efficiency**	**Reference**
Biological methods	AFB1	*Aspergillus niger* *Escherichia coli* *Bacillus* spp. *Pseudomonas putida*	98.65% 93.70% 67.20% 90.00%	Qiu et al. (2021) Wang et al. (2019) Xia et al. (2017) Samuel et al. (2014)
	ZEN	*Bacillus* spp.	87.00-100%	Ju et al. (2019); Wang et al. (2017); Xu et al. (2016)
	FB1	*Saccharomyces sp.* *Bacillus* spp.	22%-50% 43%-83%	Styriak et al. (2001) Camilo et al., (2000)

Mycotoxins Binders

Due to their importance and wide range of applications in recent years, Nano-clay particles have been significantly incorporated into various fields, including aquaculture, to improve water quality parameters (Nathanail et al., 2016). Adsorbing agents are ultrafine nanoparticles, smaller than 100 nm, and have the potential to provide a good surface for mycotoxin binding (Fang et al., 2009). The mycotoxin removal efficiency rate of most nanoparticles or adsorbing agents is estimated to be between 20% and 80% (Nathanail et al., 2016). Still, the major drawback of mycotoxin binders is their ability also to adsorb other micronutrients in the animals' bodies, which may result in mineral deficiency (Kolosova and Stroka, 2011).

Aluminosilicates

Bentonites: Bentonites, or montmorillonites, are a group of silicate clay particles that are efficient in mycotoxin adsorption (Kolosova and Stroka, 2011). Usually incorporated into most commercially available aquafeeds to improve water quality indices (Hussain, 2018). These are mainly used for aflatoxin detoxification.

Zeolites: Zeolites are microporous tectosilicate crystalline aluminosilicates used extensively in aquaculture. In aquaculture, zeolites are used for multiple purposes, such as maintaining water quality and removing ammonia, improving feed utilization (Sava et al., 2019), and adsorbing mycotoxins (Dakovic et al., 2010).

Activated charcoal: These agents are highly porous and are one of the most efficient mycotoxin adsorbents (Avantaggiato et al., 2005). The capacity of activated charcoal to bind or sequester mycotoxins is affected by its size, shape, porosity, and structure

MICROBES

Various microbes have a unique cell wall structure that can bind with different mycotoxins through different interactions such as hydrogen, ionic, and hydrophobic bonding (Haskard et al., 2001). The most commonly used microbes for this purpose are Saccharomyces cerevisiae and lactic acid bacteria. Microorganisms may also, at some point in their life cycle, secrete chemicals that can either: alter the structure of mycotoxins and produce fewer toxic compounds, or destroy the mycotoxins. During this degradation process, different microbes that produce various enzymes are utilized, including aflatoxin oxidase produced by *Armillariella tabescens* (Cao et al., 2011) and peroxidase produced by *Pseudomonas* species (Zaid, 2017).

Plant-based Feed Additives

Plants display a variety of essential oils, spices, herbs, and other extracted products that can play a noble role in mitigating the health effects caused by mycotoxins (Gowda et al., 2013). They are considered eco-friendly, available, and affordable products to tackle not only mycotoxins but also many other problems in the feed and food industries (Iram et al., 2016).

Bile Acids

The liver is the detoxification centre and immune control centre of aquatic animals. The

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most important organ that is damaged by the damage of mycotoxins is also the liver. Bile acids are an endogenous active substance secreted by the animal. Therefore, improving the detoxification function of the hepatopancreas of the shrimp to fight against mycotoxins is the most important measure to reduce the risk of mycotoxins. Toxins can stimulate the liver to secrete a large amount of bile, leading to malfunctioning of the liver.

Conclusion

Mycotoxins represent a significant but often overlooked threat to aquaculture, posing risks to the health and productivity of aquatic organisms. With a potential for adverse effects ranging from growth inhibition to organ damage and mortality. Addressing mycotoxin contamination requires proactive monitoring, implementation of quality control measures, and the use of mitigation strategies in feed production and aquaculture management. By raising awareness, enhancing testing protocols, and adopting best practices, aquaculture stakeholders can better safeguard their operations against the silent threat of mycotoxins, ensuring the sustainability and success of the industry.

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Popular Article

Pool of Wonders: A Tidal Enchantment

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Introduction

The ocean is a vast and ever-changing world, filled with diverse habitats and an astonishing array of life forms. Among its many wonders, the intertidal zone stands out as a particularly intriguing ecosystem. This narrow stretch of shoreline, caught between high and low tides, is a place of constant transformation. As the tide retreats, it unveils a hidden world, tidal pool where a rich tapestry of marine life endures the challenges of fluctuating conditions. This article delves into the fascinating environment of tidal pools, uncovering the unique adaptations that enable life to flourish in such vibrant settings. Figure 1 depicts the zonation of rocky shore.

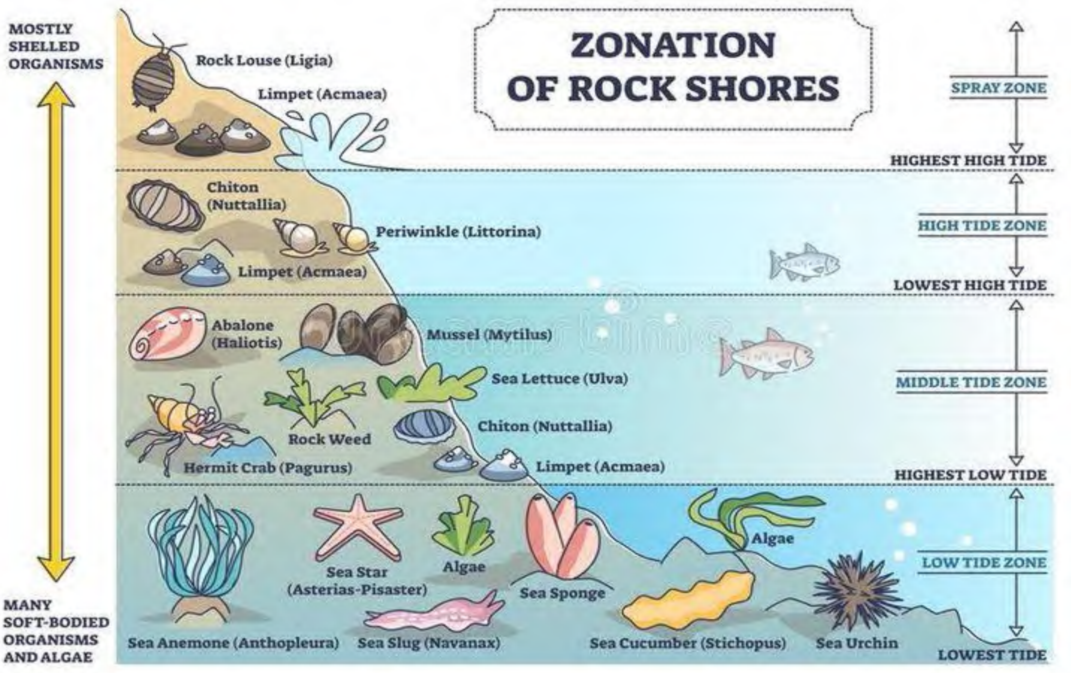

Figure 1: Zonation of rocky shore

Formation of Tidal pools:

Over millions of years, waves and wind gradually weather coastal rocks, breaking them down into sand particles and creating depressions on their surfaces (Figure 2). During high tide, these rocks become submerged, allowing normal marine activity to take place around them. As the tide recedes during low tide, water remains trapped in the depressions (Menon, 2021). Marine organisms that were present during high tide become enclosed in these pockets of water. This natural process leads to the formation of tide pools-shallow pools found in rocky or coral areas that temporarily retain seawater and marine life when the tide is out (Seaworld, 2025).

Source: Fields and Silbiger,2022

Figure 2: Tidal pools

Food chain in the Tide pools

A food chain shows "who eats what" in an ecosystem. A single tide pool contains many food chains. Algae and other plants are eaten by plant-eating zooplankton; this plankton is eaten by larger, carnivorous plankton; these are eaten by a mussel, barnacle or other marine invertebrate; the mussel is then eaten by an ochre star, which may be eaten by a gull or a sea otter. All the food chains in an ecosystem can be interconnected to form a food web. Many marine animals rely on tide pools for food and other resources. Gulls and other seabirds, as well as some mammals, forage in tide pools. Tide pools even serve as "nurseries" for some fish species (Seaworld, 2025). Tide pools show extraordinary biodiversity and the fishes play important role in the coastal ecosystems. Tidepool fishes connect marine and terrestrial communities via substantial predation upon insects and exporting energy to land as prey for terrestrial fauna (Andrades, R., González-Murcia, S., Buser, T.J., 2023).

Living condition of organisms in the tide pools

Tide pools are classified by marine biologists as one of the harshest living conditions on Earth, for a variety of reasons. From the lack of nutrition to the high temperatures, the inhabitants of tide pools need to withstand different conditions that put their bodies under stress (Menon, 2021).

During low tide conditions, different groups of creatures are trapped or herded into tide pools, with natural predators often in the same pool as their prey (Menon, 2021). Organisms trapped in tide pools experience large variations- cooler weather during high tide at night, and much higher temperatures during low tide when the pool is exposed. Most marine organisms are unable to cope with this temperature fluctuation and have resorted to evolutionary changes to regulate their body temperature (Menon, 2021).

Creatures trapped in tide pools often find themselves with a small area to survive in. For creatures such as mussels, snails, and small marine organisms, this does not pose a major problem since they are generally sedentary. Even crabs or other creatures that can survive both on land and water can leave the pools if required. However, larger fishes require a significant area to swim and stay active.

During the high tide, creatures not attached to the substratum can be seized and pushed away into the ocean or towards the shore. Here, they are an easy target for birds and other creatures that can pick them up. Creatures often have to compete amongst themselves for food such as phytoplankton and zooplankton.

Adaptations of the organisms

For all the uncertainties of the tide pool, the only constant is that life for these creatures is challenging, and they often undergo evolutionary adaptations to increase their chance of survival. To keep smaller creatures safe from being hunted by larger predators within the tide pool, organisms have evolutionary features such as stings and spines. This prevents predators from attacking and eating smaller organisms. Other species have evolved to regenerate when they are attacked.

High temperatures are a part of life for organisms trapped within the tide pool (Satyam&Thiruchitrambalam,2018), and the most common evolutionary feature is enhanced resistance to heat-related illnesses. Creatures have adapted to slow down their body functions, produce less heat, and improve their heat regulation systems. By slowing down and staying sedentary, creatures in these tide pools can quickly bring down their temperature. Some of them also pass out by-products that further bring down their temperature, similar to how human beings sweat when the temperature increases (Menon, 2021).

When evolution encourages creatures trapped in tide pools to reduce their motion, the problem of a reduced area to swim in is automatically countered. To survive in this environment, tide pool inhabitants often cling very tightly to any rock to which they can adhere. Barnacles, for example, produce a fast-curing cement that lets them stay put. This natural substance is among the most powerful glues known to exist. In fact, researchers are trying to figure out if and how it can be harvested or reproduced for commercial use (NOAA, 2024).

Competition for food is an evolutionary problem irrespective of whether it is a tide pool or land. Charles Darwin's maxim still stands and summarizes the life of a creature in a tide pool- survival of the fittest. The space in a tide pool may be limited, but the food there is plentiful. Every wave at every high tide delivers fresh nutrients and microscopic organisms, such as plankton, to support and replenish the pool's intricate food chain. Washed in by the waves, these organisms nourish the smallest animals, which in turn sustain the larger ones (NOAA, 2024).

Tourism Potential of Tidal Pools

Tidal pools, located within the intertidal zone, represent ecologically rich environments that offer significant potential for eco-tourism. However, these natural features are not consistently visible or accessible throughout the day or year. Access to tidal pools is considered safe primarily during low tide, when the receding water reveals a variety of marine life. Visitors can observe diverse marine organisms, including grazing sea snails, various crab species, and both small and occasionally large fish that remain trapped in the pools (NOAA, 2024). Rare sightings may include larger organisms such as eels, sea snakes, or Nudibranchs—vibrant sea slugs known for their striking colors . In low located pools, whelks, mussels, sea urchins and Littorina littorea are common. Periwinkles and Littorina rudis are found in high located pools. Other organisms that are commonly found in pools are flatworms, rotifers, cladocerans, copepods, ostracods, barnacles, amphipods, isopods, chironomid larvae and oligochaetes (Satyam & Thiruchitrambalam,018). Vertical zonation also has been documented in tidal pools. Due to the challenging conditions within tidal pools, such as hypoxia and elevated temperatures, resident organisms are highly sensitive to external disturbances. Direct contact with these species should be minimized to prevent undue stress or injury to the organisms. Additionally, caution must be exercised when walking on corals or rocks to avoid damaging small, often camouflaged marine life. Tidal pools are frequently designated as protected zones due to the presence of rare and endangered species. Responsible tourism practices are critical in these areas: littering is strictly prohibited, and visitors are encouraged to collect and dispose of any residual waste properly. While appreciating the delicate ecological balance of these habitats, individuals should remain alert to potential hazards. For example, certain species such as sea urchins may pose physical risks if accidentally contacted. Furthermore, close monitoring of tidal patterns is essential when exploring tidal pools. The intertidal zone can quickly become submerged with the incoming tide, presenting a significant safety concern. Thus, all exploration activities should be planned with consideration of tidal schedules to ensure both visitor safety and environmental protection.

Conclusion

Tide pools, as dynamic microcosms within the intertidal zone, showcase a remarkable diversity of life, where organisms have evolved specialized adaptations to survive the constantly changing conditions of exposure to air and fluctuating water levels. Their unique ecosystem provides a valuable opportunity to study complex food webs and the intricate relationships between marine species.

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Popular Article

Offshore Aquaculture: Sustainable Expansion of Mariculture Beyond Coastal Waters

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Abstract

In response to growing demand for seafood and space constraints in coastal areas, offshore aquaculture represents a revolutionary change in mariculture by relocating fish, shellfish, and seaweed farming into deeper, open-ocean environments. The main elements of offshore aquaculture are examined in this report, including farming systems, cultivated species, site selection criteria, and technological advancements. Better waste dispersion and less of an impact on delicate coastal ecosystems are two ecological benefits of offshore systems. Offshore operations are becoming more robust and efficient thanks to technological developments like environmental sensors, automated feeding, and remote monitoring. But there are still issues like exorbitant prices, complicated regulations, the need for technical know-how, and possible ecological hazards. Diverse strategies and achievements in the development of offshore aquaculture are highlighted by international case studies from Norway, China, Japan, the United States, and India. Offshore aquaculture can make a substantial contribution to climate mitigation, the Blue Economy, and sustainable seafood production with the right planning, policy support, and stakeholder engagement.

Key words: Offshore aquaculture, mariculture, sustainability, technology, Blue Economy

Introduction

Due to growing demand for seafood, technological advancements, and restrictions on expanding wild fish harvests, marine aquaculture is expanding into deeper offshore waters, making sustainable growth crucial. In order to do this, precise evaluation and mitigation of possible effects on marine ecosystems and other ocean-based activities are needed, along with science-based spatial planning. Even though there isn't much direct evidence in the scientific literature today to support such planning, this study takes an ecological stance and combines research from several fields to investigate the interactions between offshore aquaculture and its surroundings at various spatial scales. Notwithstanding current gaps in knowledge, there is enough research to support the growth of a sustainable offshore aquaculture industry that complements other marine uses and to guide site selection decisions (Gentry et al., 2017).

Mariculture has traditionally been concentrated close to the coast, especially in protected bays, estuaries, and intertidal zones. The calm waters and accessibility of these locations make them popular. However, environmental concerns and competition with other marine activities are becoming more prominent as coastal regions become more crowded. Even in more tumultuous open-ocean conditions, aquaculture operations can now expand farther offshore thanks to advancements in farming techniques and aquaculture technology (Shainee et al., 2012). This move to offshore farming has a lot of potential to increase seafood production and open up new business opportunities.

Site Selection Criteria

Physical Parameters:

- Depth and Distance from Shore: Generally, locations with water depths of more than 30 meters are chosen that are at least 3–10 km offshore. This promotes nutrient dispersion and lessens coastal conflicts.
- Water Flow and Current: Consistent currents promote oxygenation and waste dispersion. Depending on the species, ideal flow rates usually fall between 10 and 100 cm/sec.
- Salinity and temperature must be within the tolerance range of the species being cultivated. Better growth and survival rates are encouraged by stable and ideal ranges (Benetti et al., 2010).

Environmental Considerations:

- Benthic Impact: Assessing the seafloor to avoid suffocation from organic deposition.
- Water Quality: Pure, unadulterated water with minimal concentrations of contaminants and pathogens.
- Weather-related factors: To avoid equipment damage and stock loss, it is essential to assess the risk of storms, hurricanes, and seasonal variability (Cardia et al., 2017).

Legal and Logistic Considerations:

- Permits and Regulations: National and international maritime laws must be followed when conducting offshore operations.
- Infrastructure Access: Despite being offshore, it is crucial to have access to ports, hatcheries, feed supplies, and processing facilities (Benetti et al., 2010).

Species Cultured in Offshore Aquaculture

Category	Species	Scientific Name	Key Features	Cultivation Regions
Finfish	Atlantic Salmon	*Salmo salar*	Requires high-protein feed and well-oxygenated water	Norway, Canada
	Cobia	*Rachycentron*	Fast-growing, tolerant to	Various tropical and

		canadum	offshore conditions	subtropical regions
	Amberjack	*Seriola* spp.	High-value fish, thrives in offshore cages	Japan, Mediterranean
	Tuna	*Thunnus* spp.	Cultured in offshore ranching systems	Japan, Australia
Shellfish	Mussels	*Mytilus* spp.	Grown on suspended ropes or rafts; filter feeders	Nutrient-rich offshore waters
	Oysters	*Crassostrea* spp.	Suitable for Integrated Multi-Trophic Aquaculture (IMTA); water filtration role	Coastal and offshore environments worldwide
	Scallops and Clams	—	Cultivated using baskets or seabed planting methods	Various coastal regions
Seaweeds	Kelp	*Saccharina* and *Laminaria* spp.	Grown in temperate waters; used for food and biofuel	China, Korea, Norway, USA
	Gracilaria	*Gracilaria* spp.	Red alga used in agar production	Tropical and subtropical waters
	Eucheuma	*Eucheuma* spp.	Cultivated for carrageenan; thrives in tropical conditions	Philippines, Indonesia, Tanzania

Source: Cheney et al. 2010; Morro et al. 2022; Visch et al. 2023

Types of Offshore Farming Systems

- Floating net cage: Square or circular cages that float on the water's surface and are composed of steel or HDPE. equipped with mooring systems for anchoring. Ideal for the culture of finfish.
- Submersible Cages: These cages provide improved protection and less surface impact because they can be lowered below the surface during inclement weather.
- Longline Systems: Mainly used for shellfish and seaweed. consist of lines that are horizontal and hung in the water column.
- In order to create a balanced, environmentally friendly system, Integrated Multi-Trophic Aquaculture (IMTA) combines species from various trophic levels, such as seaweed (nutrient absorbers), shellfish (filter feeders), and finfish (waste producers).

- Drifting or Mobile Systems: In the early stages of development, these systems seek to lessen the need for permanent infrastructure and anchoring by using ocean currents for slow drifting (Chu et al., 2023).

Technological Innovations

In order to overcome the difficulties posed by offshore aquaculture, technological developments are essential. Using sophisticated monitoring systems is one of the major innovations. Real-time monitoring of environmental parameters like temperature, pH, oxygen levels, and current speed is commonly accomplished through the use of remote sensing technologies, underwater sensors, and Internet of Things (IoT) devices. Furthermore, satellite communication and GPS tracking are necessary for accurate cage placement and efficient surveillance, particularly in dynamic offshore environments.

There have also been notable developments in feeding technologies. Drones and automated feeding systems have improved feed management and significantly decreased labor costs, allowing for precise and timely feed delivery. Feed sensors increase overall efficiency by minimizing waste and optimizing feed conversion ratios. The application of robotics and remotely operated vehicles (ROVs) is another technological advancement. By eliminating the need for divers, these instruments improve operational efficacy and safety by facilitating effective cage inspection, maintenance, and fish stock monitoring. The creation of robust aquaculture species now heavily relies on breeding and genomics. To improve characteristics like growth rates and disease resistance, selective breeding and genetic tools are being employed. Furthermore, the year-round availability of high-quality seeds is being supported by cryopreservation and creative hatchery techniques, which is essential for reliable offshore farming operations (Ma & Qin, 2024).

Environmental and Socioeconomic Considerations

Compared to nearshore systems, offshore aquaculture has a number of environmental benefits. The risk of nutrient accumulation and benthic pollution is decreased in offshore regions due to the deeper waters and stronger currents that aid in the more efficient dispersion of nutrients. Additionally, interactions with delicate coastal ecosystems like coral reefs and mangroves are reduced in this setting. Even with these advantages, poor management techniques can still be dangerous. These include genetic dilution from escapees breeding with wild species, the possibility of disease and parasite transmission to wild fish populations, and microplastic pollution from artificial cage materials.

Socioeconomically speaking, offshore aquaculture can ease the strain on coastal land use and create jobs in isolated coastal areas. Integration with current marine infrastructure, like offshore wind farms, is another area in which it excels. Conflicts with shipping lanes, marine conservation areas, and traditional fishing communities could occur, though. Therefore, to guarantee the fair and sustainable growth of offshore aquaculture, inclusive stakeholder engagement and carefully crafted policy mechanisms are crucial (Watson et al., 2022).

Challenges in Offshore Aquaculture

Offshore aquaculture has a lot of obstacles to overcome despite its potential. The high startup and ongoing costs of installing and maintaining offshore infrastructure are one of the main obstacles. A significant amount of money is needed to deploy mooring systems, cages, ROVs, and other equipment. Furthermore, continuous maintenance is resource- and labor-intensive due to the severe sea conditions.

Another difficulty is technical expertise because offshore aquaculture needs qualified workers for data management, equipment handling, and remote operations. In many areas, there is also a great deal of regulatory uncertainty. The growth and development of offshore farming may be impeded by unclear legal frameworks and jurisdictional ambiguity in exclusive economic zones (EEZs). Environmental hazards like disease outbreaks, biofouling, and fish escapes are still major worries. Conflicts with biodiversity conservation programs and marine protected areas may also arise, which must be handled carefully (Shuanglin et al., 2023).

Global Case Studies

Numerous nations have advanced offshore aquaculture significantly, providing others with useful models and insights. With businesses like SalMar running semi-submersible rigs like Ocean Farm 1, Norway is a world leader in offshore salmon farming. Strong legal frameworks and significant R&D expenditures underpin Norway's industry's success. Another significant player is China, especially in the production of seaweed and shellfish. In order to promote resource efficiency and environmental sustainability, it has put in place integrated offshore systems that combine fish cages with longlines for kelp and oysters. Almaco jack are raised in open-ocean cages in the United States by Kampachi Farms in Hawaii, which places a strong emphasis on technological innovation and stringent biosecurity protocols.

Japan has concentrated on offshore tuna ranching, which uses sophisticated feeding and transportation systems to raise wild-caught juveniles to market size. While still in its infancy, India has started testing offshore cage farming for species like cobia, seabass, and milkfish in states like Tamil Nadu and Kerala. The Central Marine Fisheries Research Institute (CMFRI) is in charge of these trials, which show how offshore aquaculture is becoming more and more popular in India (FAO, 2020).

Future Prospects and Sustainability

The growth of the Blue Economy is expected to be significantly influenced by offshore aquaculture. It lessens reliance on overfished wild fisheries while providing a scalable answer to the world's seafood demand. Aquaculture is more climate-resilient in offshore locations because they are typically more resilient to seasonal variations and coastal runoff. Furthermore, seaweed cultivation offshore improves ocean alkalinity and aids in carbon sequestration, both of which help to mitigate climate change.

Circular economy principles have a lot of potential in offshore aquaculture as well. Fish farming waste can be used to grow algae and shellfish, and the resulting sludge can be recycled for composting or the production of biogas. Support from research and policy is essential to achieving these advantages. This entails creating unambiguous maritime zoning regulations, encouraging public-private partnerships for infrastructure investment, and incorporating offshore aquaculture into plans for blue growth and national food security (Buck et al., 2008).

Conclusion

A promising area for sustainable mariculture is offshore aquaculture, which can help address issues with overfished fisheries and nearshore farming constraints. Innovative farming systems and ecological design, like Integrated Multi-Trophic Aquaculture, offer special chances to meet the demand for seafood around the world, promote economic growth, and improve climate resilience. But in order to reach its full potential, issues with governance, the economy, and the environment must be resolved. Reducing conflicts and guaranteeing ecological sustainability require careful site selection, ongoing technological development, strong regulatory frameworks, and inclusive stakeholder participation. Integrating offshore aquaculture into national and international food security and environmental policies will be essential to ensuring its long-term success as countries place a greater emphasis on ocean-based economies.

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Guardians of the Ocean: The Value and Preservation of Coral Reefs

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Abstract

Coral reefs are vital to marine life and coastal communities—they support an incredible variety of species, help protect shorelines from erosion, and contribute significantly to local economies through fishing and tourism. These ecosystems are essential for ocean health, but they're under serious threat from climate change, pollution, and overfishing. To protect them, we need to take meaningful action, such as setting up marine protected areas, promoting sustainable fishing and tourism, and investing in coral restoration efforts. It's a shared responsibility, and the collaboration of governments, scientists, and local communities is key to preserving coral reefs for the future.

Keywords: Coral Reefs, Coral Bleaching, Marine Protected Areas, Coral restoration

Introduction

The coral reefs are considered some of the most vibrant ecosystems on earth and are often referred to as "rainforests of the sea" due to their vast variety of marine life and complex ecological relationships. These underwater structures come to life primarily through associations of small creatures called coral polyps and jellyfish and sea anemones. Polyps secrete a hard exoskeleton made of calcium carbonate, whilst the various skeletons through calcareous deposits gradually pile and form the massive limestone framework of the reef. Corals grow in clear, shallow waters of the tropics and subtropics, aided by sunlight supporting symbiotic algae called zooxanthellae existing in their tissues. This symbiosis is vital to the corals' survival, as the algae supply nutrients via photosynthesis, whereas the corals give a very mild shelter and sunlight for photosynthesis. These and thousands of species of fish, invertebrates, and other marine organisms rely upon the ecosystem for shelter; in turn, reef ecosystems suggest coastal protection, fisheries, and tourist opportunities to millions of people on this planet. Coral reefs are, undoubtedly, under threat from climate change, pollution, overfishing, and habitat destruction. Conservation thus needs to be put on the global front burner.

What is Coral reef management?

The coral reef management refers to coordinated efforts and strategies meant to protect, conserve, and restore coral ecosystems under the threat conditions of climate change, pollution, overfishing, and coastal development. This is done for the ultimate goal of keeping coral reefs healthy and resilient so that they may continue to provide ecological, economic, and social services on which we depend. Coral reef management is a multifaceted approach that uses scientific, policy, and local action to deal with both current threats and long-range challenges faced by these important ecosystems.

Key actions include:

- **Marine Protected Areas (MPAS):** establishing zones with restricted fishing and tourism to conserve biodiversity.
- **Pollution reduction**: managing land-based runoff, sewage, and industrial discharge to improve water quality.
- **Sustainable fisheries**: implementing fishing regulations to prevent overfishing of keystone species.
- **Coral restoration**: actively restoring degraded reefs using techniques like coral gardening and artificial reefs.
- **Climate action**: reducing greenhouse gas emissions to mitigate ocean warming and acidification.

Effective coral reef management requires integrated approaches that combine local action with global efforts to address climate change.

❖ Economic importance of coral reefs

Coral reefs hold immense economic significance globally, supporting millions of livelihoods and generating billions of dollars annually through fisheries, tourism, and coastal protection. They are the foundation for commercial and subsistence fisheries, producing about six million tons of fish each year, with Southeast Asia's reef fisheries alone valued at $2.4 billion annually. Reef-related tourism is a major economic driver, with global estimates ranging from $36 billion to as high as $3.3 trillion depending on the scope of services considered, highlighting their critical role in coastal economies. Additionally, coral reefs act as natural barriers, reducing wave energy by up to 97% and saving billions in potential storm and flood damages, which is especially vital for coastal communities and infrastructure. Collectively, these ecosystem services make coral reefs one of the most valuable and productive environments on Earth.

Key points:

- Support fisheries and provide food security for millions.
- Attract tourists, generating billions in tourism revenue.
- Protect coastlines from storms and erosion, saving on infrastructure costs.
- Source of new medicines and bioactive compounds.
- Contribute to beach formation and ocean health.
- Globally, their ecosystem services are valued up to $11 trillion annually.

❖ Ecological role of coral reefs

Coral reefs have been considered to occupy an especial ecological niche occupying land among the most productive and biodiverse ecosystems and are often called the "rainforests of the sea." Covering less than 1% of the ocean floor, these coral reefs host around 25% of marine species, including fish, invertebrates, plants, and other organisms. These ecosystems are nurturing grounds for a number of marine life forms with spawning, nursery, breeding, and feeding capabilities, thereby sustaining a huge biological and genetic library for the future. The chatter and din of life, in other words, are fostered by intricate coral systems that provide stabilizing shelter, so helping innumerable species engage in complex food webs and ecosystems that support their growth and reproduction.

Apart from housing biodiversity, coral reefs are essential for the health and functioning of marine and coastal ecosystems. They are the rays of ecosystem builders creating the life possibilities for this community. Thus, they maintain the grounds for evolving competition and cooperation among various reef organisms. Coral reefs are involved in nutrient cycling, carbon cycling, and biomass production, hence supporting marine food webs and operating nearby ecosystems. Also, reefs, by their physical form, cause sediment stabilization, obstructing the erosion of shorelines, and filtering of water to enhance itself-lucid clarity and quality for neighboring habitats. Hence maintaining the ecological integrity of coral reefs is very crucial for marine life and for the resilience and sustainability of broader ocean ecosystems.

❖ **Major Threats to Coral Reefs**

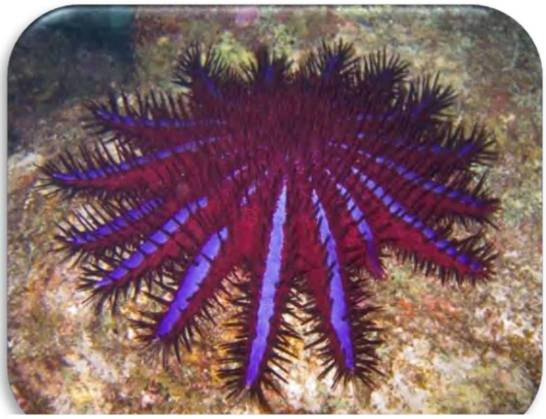
Coral reefs face a series of threats mostly resulting from human activity and climate change. Foremost among them is the rise in ocean temperature that causes widespread **bleaching of corals -** a bleaching episode where corals expel the symbiotic algae (zooxanthellae) that feed and colour them. Bleaching be prolonged or severe, it may lead to mass mortality of corals like the ones observed in the ongoing global bleaching event of 2023–2025, wherein 84% of the world's reefs have been affected. Absorption of atmospheric carbon dioxide increases **ocean acidification**, which is detrimental to coral skeletons, growth of the reef structure, and its recovery.

Coral bleaching

Image Source: Great Barrier Reef Foundation

Pollution, too, is one of the biggest threats, where algal blooms caused by excess nutrients from agricultural runoff, sewage, or industrial wastes, smother the corals, and suck the oxygen out of the water. Plastics, chemicals, and oil spills further kill or damage coral tissues, making them compounded with disease. **Overfishing and destructive fishing** especially blast fishing and cyanide fishing upset their ecological balance, moving important species from them, while also physically destroying coral habitats. **Coastal development**, which includes sand dredging, land reclamation, engineering construction, paucity of environmental awareness at the onset of such engineering activities, increased sediment; laden runoff from construction activities, destruction of mangroves etc., adversely affect water quality; suspended sediments from all of these activities obstruct sunlight, causing hindrance to coral health. Unregulated tourism and recreational activities would furthermore give damage to the reefs directly through anchoring, trampling, and pollution. Finally, **coral diseases and outbreaks of predators** like the **crown-of-thorns**

starfish, often triggered by environmental stressors, further threaten reef health and resilience. Collectively, these threats endanger the survival of coral reefs and the invaluable ecosystem services they provide.



Coloured crown-of-thorns starfish

White Band Disease in Caribbean coral

Image Source: Wikipedia

- **Restoration of Coral Reefs**

Restoration of coral reefs involves a range of techniques aimed at repairing damaged or degraded reefs and supporting their recovery and resilience in the face of growing threats. The most common and effective approach is **coral gardening**, where small coral fragments are collected from healthy reefs, grown in nurseries (either in the ocean or on land), and then transplanted onto degraded reef areas once they have reached a suitable size. These nurseries provide a controlled environment that can accelerate growth and increase survival rates before corals are returned to the wild.

Another widely used method is **coral fragmentation**, which involves breaking larger coral colonies into smaller pieces that are then attached to substrates and allowed to grow into new colonies. This technique is especially useful for fast-growing coral species and allows for rapid expansion of coral cover on damaged reefs. **Larval propagation** is a more advanced technique, where coral larvae are collected from the wild, reared in laboratories or tanks, and then released or transplanted onto restoration sites to promote genetic diversity and natural recruitment.

Additional strategies include **artificial reef deployment**, where engineered structures such as concrete blocks, steel frames, or even sunken ships are installed to provide new substrates for coral growth and habitat for marine life. **Substratum enhancement** techniques, such as mineral accretion (using low-voltage electricity to stimulate calcium carbonate deposition) and algae removal, help create favourable conditions for coral settlement and growth. Restoration efforts are most successful when combined with broader conservation measures, such as the establishment of marine protected areas, pollution control, and sustainable fisheries management. Community involvement and stakeholder engagement are also crucial for ensuring the long-term success and sustainability of restoration projects.

Coral Gardening

Image Source: NOAA (National Oceanic and Atmospheric Administration)

❖ **Challenges**

Coral reef management faces numerous challenges, both ecological and socio-political, that complicate efforts to protect and restore these vital ecosystems.

Ecological and Environmental Challenges

i. **Climate Change**: Ocean heating and marine heatwaves led to rapidly recurrent strong coral bleaching events, weakening and killing corals. The acidification of the ocean, as a result of increased atmospheric CO_2, further obstructs corals' ability to grow by decreasing the calcium carbonate which is require for their skeletal formation.

ii. **Pollution**: Nutrient-rich runoff from agriculture, sewage, and industrial activities causes algal blooms that smother corals and deteriorate water quality. Sedimentation produced through land clearing can bury corals and block sunlight, modern photosynthesis of the algae living with corals.

iii. **Physical Damage**: Destructive fishing practices (bribing), coastal developments, dredging, or recreation (anchoring, trampling, or even coral collecting)-all of which are threats to reef structures and biodiversity.

iv. **Diseases and Invasive Species**: Few diseases affecting corals spread fast enough to wipe out entire reef communities, like the Stony Coral Tissue Loss Disease (SCTLD) and White Band Disease in Caribbean coral. Invasive species brought in through human activities upset ecological balances and outcompete native organisms.

Socio-Political and Logistical Challenges

i. **Limited Resources and Expertise**: Coral restoration and management require specialized skills, long-term planning, and significant financial investment. Finding appropriate personnel and financing larger or longer-term projects become difficult.

ii. **Governance and Compliance**: Incomplete or weak property rights, deficient customary management systems, and lacking enforcement of regulations hinder in the implementation of management measures. Compliance with conservation measures is often lacking, particularly in loci where economic interest is in conflict.

iii. **Short-Term Vs. Long-Term Tradeoffs**: Balancing short-term economic benefits (fish capture and revenue from tourism) and long-term maintenance of the reefs is a continuing challenge.

Local communities' side with short-term benefits more than conservation, rendering the sustainable management a difficulty.

iv. **Community Involvement**: For any management program to be successful, it would need to ensure that local communities are involved and that they feel a sense of ownership, but this can be hard to do when local priorities diverge from those of scientists and conservationists, or when there are knowledge gaps or a general lack of interest.

v. **Climate Litigation and Policy**: It is increasingly recognized that large-scale threats like climate change require integration of legal advocacy and policy changes, but there is relatively little collaboration between scientists, policymakers, and legal advocates in most areas.

- **Emerging techniques**
  - ✓ **Assisted evolution**: breeding heat-tolerant corals.
  - ✓ CRISPR- **gene editing** (in early research) to enhance resilience. CRISPR-**cas9** is a revolutionary gene-editing tool that enables precise modifications of DNA.
  - ✓ **3d printing**: custom-designed reef structures.
- **Global initiatives**
  - ✓ **UN decade on ecosystem restoration (2021–2030)** includes coral reefs.
  - ✓ Programs like **coral restoration foundation**, **reef resilience network**, and **great barrier reef restoration** are leading efforts.

Conclusion

Among the most useful, highly diverse, and ecologically important ecosystems in the world, coral reefs are surely among the most important. They support economic, ecological, and cultural benefits to millions of people worldwide. However, climate change, pollution, overfishing, and coastal developments are an onslaught and pose challenges to coral reefs. Coral reef management is very pertinent, involving marine protected areas, restoration, pollution control, climate adaptation, community involvement, along with strong policy frameworks in the conservation of these vital habitats. By imparting communities with knowledge and simultaneously creating international partnerships, enhancing the resilience of coral reefs and ensuring that coral reefs continue to provide marine life, shore protection, and human sustenance will be a task for all generations. The future existence of coral reefs will be decided through the shared conservation and sustainable management initiative.

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Domestication of indigenous fish species of river Beas, study zone from Sathana district Kangra to Milwan, Tehsil Indora, District

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Channa marulius (Saul) giant snakehead fish

Abstract

Extinction of some of indigenous fish fauna from our river system has been a deep concern of worrisome with the major issue of broken food chain and disappearance of commercially important fish species with the view point of sport fisheries, source of livelihood of fisher folk. Various apparent manmade actions might have eroded the spawning grounds of these indigenous inhabitant species by unscientific approach of mining, reduced environmental flow and over fishing of riverine fish fauna. No appropriate policy action to minimise the adverse effects of manmade disasters has lead to generate the gap between availability of fish and to regulate the enhancement of fish populations in the rivers. This situation leads me to conclude that there is an urgent need to enhance the abundance of fish populations and to increase the catch volume in the food basket of fishermen communities. In order to fill this gap of availability of fish catch and auto recruitment of indigenous fish populations, a mechanism has to be developed at our project to put the wild fish stock to domestication by rearing the fingerlings on artificial feeds and to grow them as brooders for breeding in captivity & seed production for commercial aquaculture and river ranching. For the development of this concept, a fish candidate of channa species namely Channa marulius (Giant Snake head) was selected and collected from the river Beas. Fries and fingerlings with average weight 8-10gm body weight and 6-8cm in length with similar age & size were collected and subjected to rearing in ponds. Brood stock prepared from these ponds were again subjected to pond breeding (Happa breeding) and encouraging results were obtained indicating suitability of the species for domestication, pond culture, commercial aquaculture and establishment of technology for hypophysation and happa breeding and commercial seed production.

Key words: Giant snakehead, channidae, labyrinth organs, invasive species , air breathing fish, ecological damages, apex predator, channids, murrels, nest building, monogamous, carnivorous, ecological barrier.

Introduction:

Domestication of carnivorous species is a continuous process of adaptation to customize the acceptance of formulated supplementary feed under controlled conditions reducing its dependence on predation upon the natural live feeds scarcely available in natural habitats resulting in delayed growth, low fecundities resulting in thin populations. Development of cannibalism mechanisms & struggle for existence in natural habitat. To minimise this struggle for existence, domestication of cannibalistic species is an appropriate tool. Domestication is a long-time consuming process of modification in food habits of wild species in the modified habitats with limited space of movement and consumption of nutritionally balanced feed and growth promoting feed additives to achieve the desired weight gain, making it economic & commercial venture of aquaculture.

In order to enhance the fish populations in natural aquatic habitat, a hardy, fish species which can resist the deficiency of oxygen, depleted oxygen contents in a habitat with developed accessory respiratory system, derelict waters, suitable for aquaculture especially for pond waters needed to select a species to develop the mechanism of domestication in freshwaters. Predominantly, available in low flow rivers, ponds, stagnant waters channid, Channa marulius (saol local name) was selected to establish the mechanism of domestication and new candidate species for freshwater aquaculture in the region until now the production of snake head fish depends on the catch from reservoirs, rivers, and natural habitats because of non-availability of good quantity. Hatchery reared, standardized fish fingerlings in the country. Another constraint in the snakehead fish farming is high mortality on juvenile rearing phase. The major market demand towards channid fish is still fulfilled from wild catches. The supplies of channid juveniles for grow out rearing and restocking in their habitat through natural spawning shown great results. While a massive juvenile production still constrained by low survival rates (War et al., 2011 Siriappagouder et al., 2014). The low survival rate was caused by the unestablished nursery rearing system, lack of nutritional information and high in cannibalism at the nursery phase (Qin & Fast, 1996). An optimal rearing system of channid is definitely required to increase juvenile production and survival rates. Higher rate of cannibalism of the species could be a Possible reason behind its poor rates of recovery at nursery stage. This could be possibly due to non-availability of adequate natural live food in that habitat which can be fulfilled by supplying the formulated and fortified animal protein rich feed. Higher stocking densities in a particular habitat further deteriorate the condition of protein rich live food in that habitat resulting minimal recoveries of adult fishes in natural waters.

Domesticated brood stock of channids brought to artificial, supplementary feed, accustomed to a formulated feed was reared in freshwater culture ponds for two years, then subjected to pond breeding (Happa breeding) and the juvenile produced from this parent stock domesticated pond demonstrated the acceptance of formulated feed. (Raw). This performance of the species to demonstrate the good growth on artificial feeds, its acceptance, gonad development, then breeding in confined waters have demonstrated the scope of commercial production of good quality hatchery seed for large scale aquaculture in the region. This demonstration explores the potential and possibility of improvement of aquaculture in warm waters, provides a solution to promote air breathing fish culture of a species which is already in higher demand in the Indian markets and hence economic activity. Morphologically, the channa marulius do has a black white edged a callus on basal portion of caudal fin present lateral line 60-70 scales. In life 5-6 dark oval blotches on flank which terminate below lateral line. Juveniles with an orange/golden band running from eye to middle of caudal fin. Systematic position of the species is as:

Scientific Name: Channa marulius (Hamilton)
Local name : Saul(Sol)
Common name : Giant snakehead
Order- Perciformes
Sub-order – channidei
Family – Channidae
Genus – Channa
Species – Marulius . the species is commercially important and distributed in India, Pakistan, Nepal, Bangladesh, Myanmar, Sri Lanka, China & Thailand etc.

MATERIALS & METHODS:

It includes the following steps in the experimental site. The location of the trial site is situated on the bank of river Beas passing through the village Haled (Mand Bhogarwan) in Tehsil Indora of district Kangra and in between the village Sathana of Fatehpur Tehsil to Milwan of Tehsil Indora, Kangra Himachal Pradesh.

i. Golden striped laterally fingerlings of about 500 no. Were collected from this stretch of river Beas and were stocked in pond No.1 & 2 of the project farm.

ii. Stocked fingerlings were fed upon artificial feeds with initial non-acceptance of artificial feeds.

iii. Grown stock of about 600-700gm of channa marulius was subjected to pond breeding during early May 2023.

iv. Good quality channa fries were reported in these breeding ponds I & II.

v. Baby fishes were collected and subjected to rearing in rearing ponds under controlled artificial feeds from where they will be reared in pen cages installed in the running water lake of tributary of river Beas passing through the project area.

Materials:

1. Fingerlings of the stock of C.marulius collected from wild conditions and riverine habitat.
2. Formulation of feed for rearing stock of highly cannibalistic in nature.
3. Feeding rate fixation, water quality management.
4. Collection of brood stock from culture ponds, then subjected to pond breeding method with natural conditions way of spawning & parental care was noticed.
5. Production of active fries from breeding ponds and hence completion of life cycle of the species in confined waters and sustaining on artificial feed was studied.

Methodology applied:

I. **Collection of wild stock from natural habitat**: - wild stock of channa marulius fingerlings weighing6-10gm each with a strip of golden band along with lateral line of body having length 4-6 inches was collected from the breeding ground of the species pools formed along the running water of the river Beas by the fisherman Zakir Husain and counted in a bucket. This stock was released in pond 2 &4 of the farm. 500 fingerlings were stocked in these ponds. This stock was fed upon a supplementary formulated feed rich of plant proteins and multi mineral supplements etc.(soya bean meal and soya bean oil were also used in the formulation as a coating material to prevent the dissolution of water-soluble minerals and vitamins in the pond water. Though recovery of the stock is poor but acceptance of supplementary feed by the candidate species is a positive step towards advancement in domestication of the species like channids in confined waters and makes the species useful & suitable for aquaculture on commercial grade.

II. **Feed Formulation**: - In the design of freshwater fish feed formulation, the main considerations are proportions of animal proteins, vitamins and minerals. Proteins are generally the first considerations in the formulations nutritional elements fish needs twice or thrice times number of proteins then other live stocks like birds, four legged animals whether lactating or non-lactating, because of poor ability of using carbohydrates, fish needs to consume part of the proteins as source of energy. Feed practice mainly determined by the level of the protein to the design of the feed formula. Often, firstly consider the level crude protein, but the attentions need to pay is considering balance of digestible protein (DP) and amino acids more important in addition to considering the level of crude protein (CP)

The fish has short intestinal, the type and quantity of bacteria is rare, so the synthesising ability of some vitamins is poor. A lot of vitamins need provided by the feed such as vitamin C does not need to be added in the feeds of other live stocks and poultry feeds, but in fish feeds do need it can improve the fish free immunity and anti-stress ability.

Fish absorbs most of the mineral elements from the water through gills and skin, especially calcium; fish will not appear calcium deficiency even if the feed does not supply calcium. Fish have different absorption rates for various minerals, when adding minerals in the feed; we should choose the inorganic salts, organic salts or chelate salts with high rate of absorption. It is necessary to add right amount of trace elements in the fish feed. General requirement of basic raw materials for cat fish can be soya bean pulp 24%, peanut dregs 24%, fish meal 5.1% rice bran, 43% bone meal 2% (Crude protein 28%) and additives 1.9% Feed coefficient is about 2.2.

Keeping in view the conditions of habitat and natural source of water & rearing ponds a modified formulation without animal protein following feed formula was applied for the rearing of channa fingerlings.

MOC 10%, soya nuggets 12%, wheat flour 24%, rice bran 30%, maize flour 20%, vegetable oil (ground nut oil) 1% agrimin powder 2%, & common salt 1%. (Table 2)

Sr.No.	Ingredient	Percentage proportion
1.	Fish meal	22.0%
2.	Mustard oil cake (MOC)	11%
3.	Soya bean grit	12%
4.	Wheat bran	13%
5.	Rice polish	14%
6.	maize	20%
7.	Wheat flour	23%
8.	Vegetable oil	2%
9.	Common salt	1%
10	Vitamin premix	2%

Formulation published in 2015 under **Introduction of indigenous raw materials in fish for snakehead Murrel Channa Striatus (Bloch, 1801) and their effects on its growth and feed utilisation. By N.Akter**. floating pellets were prepared and served in advanced fingerling stage where as dry mixed powder of this formulation 1, were broad casted twice a day in the rearing pond under study.

The stock size of fingerlings remained about 8-10gm each with average length 6-8cm with golden line on the lateral side of the body of fingerling. Water of the pond remained 1m to 1.2m deep. The dose of feed applied to rearing stock was kept 2-3% of the body weight. However, the feeding dose was enhanced to 4-6% of the body weight and frequency of feeding was also doubled. This practice eased out the phenomenon of cannibalism in the grow out stock and stress of predation. In this method the practice of natural farming was adopted. Ideal temperature of pond water remained 20-30^{0}C. Controlling the temperature is highly essential for optimum growth and maximum produce. The fingerlings were stocked in the farm ponds on 30.4.2022 and were collected on 7.5.2023. with average weight of the fish 800gm-900gms.each. Water quality was maintained by filling the ponds of freshwater from the tube well installed at the farm. No mortality at any stage of fish during culture period has been reported due to environmental stress in the experimental ponds filled with water plants like hydrilla, Vallisneria, potamagiton, lab lab & Typha angustifolia.

Breeding Method: Natural and induced breeding are the two common methods available for murrels. In this case we opted to undergo with natural breeding method. In this method selected brood pairs with average weight of 800-900gm were stocked in a cemented tank of 5mx10mx2m size filled with water up to ¾ of depth and live plants like hydrilla Vallisneria, spirogyra, algal ramifications in the first week of April 2023. The phenomenon of nesting with aquatic weeds was observed in the IInd week of April. The eggs laid in the nest were allowed to develop under the parental care of the parent stock. Low response of breeding was observed for about 20-30% of its fecundity. Aquatic weeds act as simulation of breeding. Low production of fries could be linked with feed formulation served without animal proteins or partial breeder in nature. Induced breeding method shall be planned after the species is completely domesticated and switched over to artificial feeds and standardisation feed formulae or feeding practices. Thus production of healthy, active fries of C.marulius was achieved. The fries were shifted to nurseries and brought to powder form feed broadcasting on nurseries. After rearing the fries in nurseries for a fortnight, the fingerling stage will be subjected to rearing in pen cages placed in running water lake of the project.

Results & Discussion

The freshwater fish family Channidae. The Saul can be recognised by the shape of their head which resembles that of snake. These fishes are elongated, more or less cylindrical with long entirely soft rayed dorsal and anal fins, large mouth with toothed jaws and palate and head depressed with large shield – scale above with dorsolateral eyes. They have two accessory air breathing pharyngeal air cavities. Sols live in fresh water bodies sometimes derelict waters of village ponds, swampy areas, flood plains, reservoirs, lakes and rivers (Froese and Pauly., 2014). All of them are carnivorous and highly cannibalistic especially at the fingerling /advanced fingerlings stage and mainly feeds upon different aquatic organisms and sometimes in the absence of live feed or supplementary feeds, larger fish attack on the small ones, hence cannibalistic species. It has to be observed that with the increase the feeding rate from 2-3 body weight to 4-6 % of the body weight and frequency of feeding has minimised the cannibalistic behaviour of the species and demonstrated better recovery rates @ 50 to 60% at the stage of fry & fingerlings stage. The survival rate further can be enhanced by improving the feed and intake behaviour of the fish. It has also been observed that surviving rate of fingerlings is better when stocked at the density of 1-2 fingerlings per cubic metre water volume @ of 76.7% it could be due to regular supply of feed in the form of crustaceans, earth warms & tubifex and supplementary feeding. The floating feed is much preferred by the species. The quantity of feed has to be increased as long as cannibalism continues. Fingerlings need 40 to 45% protein for better survivals. The stock size of this fish has to be 10gm. They grow at the rate of 600- 800gm per year. The rearing of the murrels should be done such that the same size & age group murrels are put together otherwise there is huge risk of cannibalism. Harvesting of murrels is done in the summer season. Before harvesting the ponds, it is required to be completely drained off. The species are monogamous and show highly developed parental care (Adamson et al., 2011). Nest building behaviour is predominant in this species perhaps due to high degree of intraspecific cannibalism and threat to young ones from attacks of larger fishes of another carnivore dwelling in natural habitat. This phenomenon also ensures the better recovery of fry stage of the fish under study.

Observations & Recommendations:

i. It is yet to be established and validated that whether happa breeding or hypophysation is more effective method of quality seed production without disturbing the gene set up of the species than natural breeding in ponds.

ii. Whether the collection of fries from wild habitat, rearing on artificial feeds in captivity, brood stock production from them and breeding of these brooders is more appropriate and effective than direct collection of brooders from wild habitat and then put them to breeding process for seed production.

iii. It is yet to be established that which above mentioned method will be more useful and appropriate in producing the quality seed free from cannibalistic behaviour, appropriate to promote large scale murrel culture.

iv. Standardization of plant protein-based feed formulation is still required to reduce the cost factor of feed as to avoid or minimise the cannibalism more frequency and high rate of feeding is required.

v. Present demonstration of domestication used the large quantity of supplementary feed in comparison to carps feeding. Feed form of dry mixture of feed at the stage of fry rearing and pellet form at the grow out and fingerlings stage was applied during the culture of the fish.

Conclusions:

Domestication is an adaptation to be brought about in a particular species to a new modified environment from a primitive or wild habitat to manmade environment by modifying the physical parameters like controlled temperature, maintenance of BOD & COD, water quality, modified food chain at the stage of fries & early fingerlings with nutritionally balanced feeds. In the present study case, the juveniles of murrels were collected from wild environment and reared in a controlled environment of ponds in which all physical parameters were maintained. The stock/fries & fingerlings were fed with artificial modified feeds firstly in mixed powder broadcasting then pellets of appropriate size depending upon the size of the mouth opening of the fish under culture. The modified feed in the absence of wild food chain was accepted by the growing out murrels and became suitable brooders for the next breeding. On the basis of these observations, it can be concluded that the feeding habit of the C.marulius can be modified from carnivorous to omnivorous at the first stage. It is evident from less (30%) recovery of stock under rearing indication of the phenomenon that cannibalism trait of the fish at first stage cannot be eliminated from the F_1 generation completely. It could be due to the non inclusion of the animal proteins in the feed formulation used. Inclusion of chicken intestine in the feed formulation may help to improve the cannibalistic behaviour, survival and growth rates in the species. But it has been asserted that use of fingerlings in rearing & brood stock production is much better responsive mechanism of domestication than direct stocking of brooders caught from wild habitat and then subjects them to breeding process of seed production.

It is also observed that domesticated brood stock has better growth rate, in seed production and for aquaculture use. Better recoveries of fingerlings also indicate the minimisation of cannibalism in the domesticated stocks at this stage. Thus, seed produced from the domesticated brood stock is ideally suitable for the warm water aquaculture and can meet out the huge demand of this fish in the Indian market. Retention of cannibalistic trait in the species even rearing in forced manmade pond environment can be eliminated in the next generation by modifying the feed formula used in the experiment. Being possessed with modified accessory respiratory system in the species, it can be cultured in the seasonal village ponds with low oxygen levels and less water quantity, which may have low physical parameters, can resist with such adverse environment. Concrete tanks can be used for producing seed of murrels. Development of a concrete breeding technology, which provides hatchery conditions, will make a boost in murrel aquaculture. Furthermore, research has to be done to understand the concept of domestication for better recoveries, good growth in a crop, demands of murrel nutrition and breeding so that it can help in the commercial farming of murrels.

Murrel farming can increase employment opportunities among the rural youth and can gain better returns in comparison to carps and trout and is considered as the best alternative source of aquaculture besides catfish and carps.

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Impact of Disinfectants and Insecticides on Fish Physiology

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Abstract

Aquaculture is vital for global food security, but the routine use of disinfectants and insecticides essential for disease and pest control can threaten fish health and ecosystem balance when mismanaged. Chemicals like Didecyldimethyl Ammonium Chloride (DDAC) and Cypermethrin are effective at controlling microbes and parasites, yet even low doses can cause significant harm to non-target species such as fish. These substances can accumulate in aquatic environments, damaging fish gills, disrupting nervous and endocrine systems, weakening immunity, and altering behaviour and reproduction. Chronic exposure often results in reduced growth, higher mortality, and poor fish welfare. To ensure sustainable aquaculture, it is essential to use these chemicals judiciously, favour eco-friendly alternatives like hydrogen peroxide, and implement strategies like biofilters, vegetative buffers, and biological pest control. Educating farmers on proper chemical handling and monitoring water quality can help reduce environmental impact. A balanced, science-based approach is critical to protect aquatic life while maintaining productivity in aquaculture.

Key words: Disinfectants and Insecticides, Chronic exposure, sustainable aquaculture, eco-friendly alternatives, environmental impact

Introduction

Aquaculture is expanding rapidly, now supplying a significant portion of the global fish supply. To ensure the well-being of cultured fish, the sector has embraced proactive measures in disease prevention and environmental management. Integral to these measures are disinfectants and insecticides. Disinfectants such as chlorine-based compounds, hydrogen peroxide, and quaternary ammonium compounds like Didecyldimethyl ammonium chloride (DDAC) are extensively used to sanitize water, equipment, and surfaces in hatcheries and grow-out systems, thereby reducing the microbial load and preventing disease spread (Austin and Austin, 2016). Likewise, insecticides including cypermethrin and various organophosphates are applied to control insects and ectoparasites that act as disease vectors or otherwise compromise fish welfare (Boyd and Gross, 2020; World Organisation for Animal Health, 2009; Boyd and Tucker, 2012).

While the benefits of these chemical agents come with potential risks that demand careful management. When disinfectants and insecticides are misused, overapplied, or poorly managed, they may escape their target areas via surface runoff, leaching, or accidental spills, exposing not only the intended pathogens or pests but also non-target aquatic organisms (Faria *et al.,* 2021; Rand *et al.,* 1995). For instance, even at low concentrations, cypermethrin can disrupt neural signalling in fish and trigger severe behavioural changes (Bradberry *et al.,* 2005). Similarly, DDAC, while effective as an antimicrobial, has been linked to damage in gill tissues and compromised respiratory functions. After a time, such chronic exposures can lead to physiological stress, impaired immunity, reduced reproductive success, and an overall increased vulnerability to environmental changes (Sinha *et al.,* 2020; Sharma and Ansari, 2013). These insights underscore the critical need for sustainable and strictly regulations on chemical usage in aquaculture to safeguard both fish welfare and broader aquatic ecosystem health.

Disinfectants in Aquaculture: Types and Functions

For maintaining a disease-free environment is critical in aquaculture to safeguard fish health and ensure optimum productivity. Disinfectants are extensively used in hatcheries, grow-out systems, and processing facilities to eliminate bacteria, viruses, and fungi that could otherwise trigger disease outbreaks (Austin and Austin, 2016). Yet, their application must be managed carefully, since imprecise dosages may jeopardize fish physiology.

Chlorine-Based Compounds

Chlorine-based disinfectants such as Calcium Hypochlorite and Sodium Hypochlorite are popular due to their potent oxidizing properties. These agents work by disrupting microbial cell walls and denaturing proteins, effectively neutralizing pathogens (Heidi, 2024). However, if applied beyond safe limits, residual chlorine can induce gill irritation, epithelial sloughing, and hinder oxygen exchange, creating severe risks for sensitive fish species (Marking, 1994; Sinha *et al.,* 2020).

Phenols

Phenolic disinfectants like Triclosan and methylated phenols are deployed to sanitize tanks, equipment, and nets. They interfere with the enzymes of microbes, rendering pathogens inactive. Despite their efficacy, these organic compounds are environmentally persistent. Chronic exposure in fish may lead to hepatic stress, neurotoxicity, and disruptions in metabolic and reproductive functions raising concerns over thyroid hormone balance and detoxification pathways (Brown *et al*., 2014).

Hydrogen Peroxide

Regarded as an eco-friendly option, hydrogen peroxide decomposes into water and oxygen. It is widely used to control fungal infections and bacterial gill diseases, enhancing dissolved oxygen while reducing microbial loads. Nonetheless, excessive or poorly timed applications can irritate gill tissues and produce oxidative stress, especially among juveniles (Rach *et al.,* 2000).

Quaternary Ammonium Compounds (QACs)

Didecyldimethyl Ammonium Chloride (DDAC) is a common QAC that disrupts microbial membranes. Its cationic nature, however, enables binding to fish tissues, causing gill inflammation, reduced oxygen uptake, and potential bioaccumulation, with residual impacts on benthic organisms and aquatic food webs (Rach *et al*., 2000; Faria *et al*., 2021).

Importance of DDCAC

Didecyldimethyl Ammonium Chloride (DDAC) is a quaternary ammonium compound (QAC) widely used in aquaculture disinfectant protocols. Its significance lies in its high toxicity even at trace levels fish gills are extremely sensitive to QACs, and even minimal amounts of DDAC can impair gas exchange and disrupt osmoregulatory functions. Furthermore, DDAC is a persistent chemical; it adheres to sediments so that even when the overlying water appears clean, the bottom layers can continuously release toxic residues. Over time, this persistence leads to bioaccumulation within fish tissues, potentially resulting in chronic health effects such as reduced growth, impaired immunity, and long-term physiological stress (Rach *et al.,* 2000; Faria *et al*., 2021).

Insecticides in Aquaculture: Types and Concerns

Insecticides are routinely applied in aquaculture to manage pests such as lice, midges, water beetles, and mosquito larvae that not only directly affect fish health but may also serve as disease vectors. However, while insecticides help maintain biosecurity, their off-target effects present substantial environmental and physiological risks. Once introduced into aquatic systems whether through agricultural runoff, spray drift, or improper disposal these chemicals are absorbed via gills, skin, or ingestion, thereby affecting multiple fish systems (Boyd and Tucker, 2012; Faria *et al*., 2021).

- **Organophosphates (e.g., malathion, chlorpyrifos)** inhibit acetylcholinesterase, leading to continuous nerve stimulation. Affected fish may show abnormal swimming, lethargy, and impaired predator avoidance with chronic exposure disrupting neurodevelopment and reproduction (USEPA, 2017; Rao *et al*., 2005; Martin and Wilson, 2019).

- **Carbamates (e.g., carbaryl)** also inhibit acetylcholinesterase but degrade more rapidly; nonetheless, they can cause gill hyperplasia and oxidative stress, reducing fish survival (Tomlin, 2000; WHO, 2004).
- **Organochlorines (e.g., DDT)**, although largely banned, are concerning due to their environmental persistence and bioaccumulation, resulting in liver damage and hormonal imbalances (UNEP, 2001; Turusov *et al*., 2002).
- **Pyrethroids – Focus on Cypermethrin** is particularly dangerous to fish. Cypermethrin disrupts voltage-gated sodium channels, leading to hyperexcitation, erratic swimming, respiratory distress, and, with long-term exposure, developmental delays and reproductive failure (Bradberry *et al.,* 2005; Casida, 2011; Rodriguez *et al*., 2020).

Mechanism of Toxicity in Fish

Fish in contaminated aquatic environments are continuously exposed to chemical pollutants from both disinfectants and insecticides. The primary entry point is the gills, which owing to their vast surface area and dense capillary networks essential for gas exchange quickly absorb dissolved toxins from the water (Rand *et al.,* 1995). The skin, while serving as a protective barrier, is also permeable, especially in juvenile or scaleless species like catfish, leading to increased toxin uptake upon direct contact with contaminated water. Ingestion further adds to internal exposure, as fish consume polluted water or prey tainted with chemical residues (Faria *et al.,* 2021).

Many of these substances, such as the insecticide cypermethrin and the disinfectant DDAC, are lipophilic they dissolve readily in fats and tend to accumulate in fatty tissues, including the liver and brain. Even low daily exposures can result in bioaccumulation that eventually leads to chronic toxicity. As these toxins build up, they disrupt essential physiological processes by impairing growth, reproductive performance, and immune defence, thereby increasing fish susceptibility to diseases and environmental stressors. The penetration of toxins through multiple routes, combined with their persistence in tissues, represents a significant threat to aquatic life. Thus, the continuing exposure to these chemicals can compromise the long-term health of fish populations and destabilize aquatic ecosystems. This underscores the urgent need for improved pollution management strategies globally.

Effects on Fish Physiology

Fish exposed to disinfectants and insecticides such as Cypermethrin and Didecyldimethyl Ammonium Chloride (DDAC) often suffer from widespread physiological disruptions, affecting several organ systems. One of the most immediate impacts is on the respiratory system, particularly the gills. These chemicals can trigger excessive mucus production, epithelial swelling, and fusion of gill lamellae, severely hindering oxygen exchange. Affected fish may display laboured breathing, gasping at the surface, and reduced activity symptoms that point to declining oxygen uptake and increased vulnerability to infections (Sinha *et al.,* 2020).

Neurological

Neurologically, compounds like Cypermethrin interfere with nerve function by affecting voltage-gated sodium channels. This results in uncontrolled nerve firing, leading to muscle spasms, convulsions, and erratic swimming patterns. In contrast, organophosphates work by inhibiting acetylcholinesterase (AChE), causing prolonged nerve stimulation (Rao *et al.,* 2005). These disruptions severely impact normal behaviours like feeding, schooling, and predator avoidance.

Endocrine and Reproductive Effects

Chemical exposure can also cause endocrine and reproductive disturbances. Pyrethroids, such as Cypermethrin, and certain disinfectant by-products may mimic or block hormones, leading to abnormal sex development, skewed sex ratios, and reduced fertility. Long-term exposure may result in intersex conditions or diminished reproductive success, threatening population stability over time (Jobling *et al.,* 1998).

Blood and Biochemical Changes

On a biochemical level, disinfectants like DDAC induce oxidative stress, producing reactive oxygen species (ROS) that damage vital organs like the liver and kidneys. This oxidative damage can also lower haemoglobin content and suppress immune function, making fish more susceptible to diseases and environmental stressors (Velisek *et al.,* 2009).

Behavioural changes

Behavioural changes often serve as early warning signs. Fish may exhibit abnormal swimming patterns (spinning, zig-zagging), social withdrawal, or feeding avoidance. These disruptions affect not only growth and survival but also social and reproductive behaviours essential for healthy populations (Rodriguez *et al.,* 2020; Scott and Sloman, 2004).

Mitigation Straitgies

To mitigate these effects, careful and minimal use of chemicals is essential. Eco-friendly alternatives like hydrogen peroxide are recommended due to their low environmental impact (Rach *et al.,* 2000). Additionally, the integration of biofilters, vegetative buffers, and routine water quality monitoring can help manage residues. Promoting education and biological control methods further ensures the long-term sustainability of aquaculture practices (Carvalho, 2017).

Conclusion

The use of disinfectants and insecticides such as Didecyldimethyl Ammonium Chloride (DDAC) and Cypermethrin in aquaculture, while effective for disease control and pest management, poses significant environmental and physiological risks when improperly applied. These compounds exhibit high toxicity toward non-target aquatic organisms, particularly fish, leading to adverse effects on respiratory function, neurophysiology, reproduction, and behaviour. Chronic or repeated exposure can result in immunosuppression, impaired growth, reproductive failure, and increased mortality, thereby compromising the long-term sustainability of aquaculture systems. Furthermore, the environmental persistence and bioaccumulation potential of these chemicals exacerbate their ecological impact. Effective mitigation requires the application of scientifically recommended dosages, routine water quality assessments, and the substitution of hazardous compounds with eco-friendly alternatives such as hydrogen peroxide. Additional strategies, including the use of biofiltration units, vegetative buffer zones, and biological pest control agents, can further reduce chemical runoff. Promoting farmer education on safe handling practices is essential for minimizing risks and ensuring environmentally responsible aquaculture.

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