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Environmental DNA (eDNA): A Non-Invasive Revolution for Fisheries Research in India

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Abstract

Environmental DNA (eDNA) analysis has emerged as a powerful, non-invasive tool for monitoring aquatic biodiversity and fish populations. All aquatic organisms continuously release DNA into the surrounding water through mucus, faeces, urine, and shed cells. By collecting and filtering a water sample, scientists can capture this genetic material, sequence it, and identify which species are present – without ever catching a fish. This article provides a comprehensive overview of eDNA methodology, including active surveillance (PCR/qPCR) for target species and passive surveillance (metabarcoding using Next Generation Sequencing) for whole communities. It traces the global rise of eDNA research since 2012 and highlights the current gap in Indian fisheries science, where no peer-reviewed publication on fish eDNA has yet been cited. A preliminary aquarium study conducted by ICAR-CMFRI, Kochi, successfully demonstrated that eDNA concentration reflects actual species composition, confirming the method's efficacy. Key limitations are discussed, including DNA degradation, contamination risks, and the difficulty of translating eDNA concentration into exact biomass. Despite these challenges, eDNA holds enormous potential for India – from building species-specific genetic databases to enabling low-cost, real-time monitoring of exploited fish stocks in the Arabian Sea and Bay of Bengal.

Keywords: Environmental DNA (eDNA), metabarcoding, fisheries management, non-invasive monitoring, aquatic biodiversity, India.

Introduction

Environmental DNA (eDNA) is defined as the genetic material obtained from an environmental sample (such as water) that contains no distinguishing signs of the source organisms (Jayasankar et al., (2020) from MFIS-234. In aquatic systems, fish and other organisms continuously shed cells into the water via mucus, gametes, faeces, blood, and other tissues. The core idea is simple: it is easier to catch the DNA than it is to catch the fish (Erde et al., 2019).

Traditional fish surveys rely on nets, trawlers, and visual counts – methods that are time-consuming, expensive, and potentially harmful to ecosystems. Since 2012, a plethora of studies have applied eDNA metabarcoding to biodiversity conservation, fish community identification, invasive species detection, and biomass estimation (Hansen et al., 2018). However, while Indian authors have published approximately 25 eDNA-related papers on microbial biodiversity from food, soil, and

deep-sea sediments, not a single publication on eDNA in fish has been cited from India (Jayasankar et al.2020). This article aims to introduce principles, applications, and limitations of eDNA technology to Indian fisheries researchers and stakeholders.

The image represents the concept of environmental DNA (eDNA) for detecting and monitoring fish biodiversity.

The Image Specifically Shows. (U.S. Geological Survey (USGS) (2022).

Sample vial → Collected water containing eDNA

- DNA helix icons → Genetic material present in water
- Fish images around → Species detected through DNA analysis
- Connecting lines → Matching DNA sequences to species

Environmental DNA (eDNA) refers to genetic material shed by organisms into their environment through:

- Mucus
- Scales
- Feces
- Gametes

Process:

- Water Sampling: A small water sample is collected (as shown in the vial).
- DNA Extraction: DNA fragments present in the water are extracted in the lab.
- Amplification (PCR): Using techniques like Polymerase Chain Reaction, specific DNA regions are amplified.
- Sequencing & Identification: The DNA sequences are compared with reference databases to identify species.

- Biodiversity Detection

Multiple species (as shown around the vial) can be detected from a single sample.

What is Environmental DNA (eDNA)?

eDNA is the genetic material recovered directly from environmental samples (water, soil, sediment) without isolating the target organism. In fisheries research, a water sample of just 500 mL to a few litres can contain DNA from multiple fish species living in that habitat. This DNA exists as small organelles (e.g., mitochondria) or larger tissue fragments. Mitochondrial DNA is most commonly targeted because it is present in many copies per cell, increasing detection sensitivity.

Why use eDNA?

eDNA is especially useful for:

- Rare or elusive species
- Low-abundance populations
- Habitats where traditional sampling is difficult (e.g., deep water, dense vegetation)
- Large-scale, landscape-level surveys

How Does eDNA Surveillance Work?

There are two general approaches to screening eDNA (Erde et al., 2019):

1. **Active surveillance** – Uses targeted molecular techniques such as standard PCR, quantitative PCR (qPCR), or digital droplet PCR (ddPCR) to determine whether a specific species is present.
2. **Passive surveillance** – Uses High-Throughput Sequencing (HTS) / Next Generation Sequencing (NGS) to simultaneously identify many species from a single sample. This is called eDNA metabarcoding.

General Workflow

1. Water collection – Sample is taken from the habitat.
2. Filtration – Water is passed through a fine filter (e.g., 0.45 µm) to capture DNA.
3. DNA extraction – Genetic material is purified from the filter.
4. Amplification – Specific gene regions (e.g., mitochondrial 12S or 16S rRNA) are amplified via PCR.
5. Sequencing – For metabarcoding, NGS is performed.
6. Bioinformatics – Sequences are compared to reference databases to assign species or taxonomic groups

The Indian Scenario: A Pilot Study at CMFRI

Researchers at ICAR-Central Marine Fisheries Research Institute (CMFRI), Kochi, initiated a preliminary eDNA study using marine aquarium tanks. Five hundred millilitres of water were collected from each of four tanks containing known fish species (Table 1). The pooled water was filtered, DNA extracted, PCR-amplified, cloned, and sequenced.

Table 1. Particulars of fish species sampled in the preliminary study (Jayasankar et al.2020)

Tank	Fish species	Total number	Length (mm)
1	Blackbar Triggerfish *(Rhinecanthus aculeatus)*	1	70
	Threespot Dascyllus (*Dascyllus trimaculatus*),	1	90
2	Yellowtail Angelfish (*Apolemichthys xanthurus*)	1	120
	Bluestreak cleaner wrasse (*Labroides dimidiatus*)	1	80
3	Canarytop wrasse (*Halichoeres leucoxanthus*) ,	1	90
	Skunk Clownfish (*Amphiprion akallopisos*)	10	70-80
	Cerulean damsel (*Pomacentrus caeruleus*)	1	70
4	Threespot Dascyllus (*Dascyllus trimaculatus*)	1	90
	Silver moony (*Monodactylus argenteus*)	20	90-100

Of the five clones sequenced, four matched Silver moony and one matched Skunk clown fish – perfectly matching the dominant species in the tanks. This confirmed the efficacy of the methodology, even on a small scale (Jayasankar et al.2020).

Applications in Fisheries Management

Globally, eDNA is being used for:

- Biodiversity assessment – Rapid, non-invasive community profiling.
- Invasive species detection – Early warning before visual confirmation.
- Stock assessment – Correlating eDNA concentration with fish abundance/biomass.
- Migration and life history – Tracking seasonal movements and spawning events.
- Endangered species monitoring – Detecting rare species without disturbance.

However, the relationship between eDNA concentration and true biomass is influenced by many factors: water temperature, pH, microbial activity, shedding rates (species- and age-specific), degradation rates, and water currents (Jayasankar et al.2024); Erde et al., 2019).

Challenges and Limitations

eDNA is powerful but not without caveats. Detection does not always mean a live fish is present (Erde et al., 2019):

Issue	Explanation
Dead fish	DNA persists after death – a carcass can give a false positive.
Fish swam	through DNA lingers for hours to days after the fish has left.
Vectors	Birds eating fish may defecate DNA into a waterbody.
Contamination	DNA from lab equipment, field gear, or reagents.

Hybridisation	Mitochondrial DNA is maternally inherited
Degradation	Warm temperature, acidic conditions (low pH), UV radiation, and microbial activity accelerate the breakdown of environmental DNA, causing it to degrade quickly in aquatic environments.

Other technical constraints include PCR efficiency, primer specificity, incomplete reference databases (especially for Indian marine species), and the high cost of NGS and automated samplers like the **Environmental Sample Processor (ESP)**

Future Directions for India

(Jayasankar et al 2024). outline a clear roadmap:

1. **Optimise methods –** From controlled aquariums to natural environments (estuaries, coastal waters, open seas).
2. **Build India-specific reference databases** – For exploited marine fish species, enabling accurate taxonomic assignment.
3. **Quantify biomass relationships** – Use Type II regression models to account for environmental and technical variability.
4. **Adopt emerging technologies** – Smartphone-powered sequencers and automated ESPs that can be moored at sea for real-time, continuous monitoring.

Despite current challenges, eDNA-based monitoring will continue to develop and have a profound impact on futuristic fisheries research and management in India.

Conclusion

Environmental DNA is not a replacement for traditional fish surveys – but it is a powerful, complementary tool that offers non-invasive sampling, high sensitivity, and broad taxonomic coverage. India stands at an exciting frontier: with no fish-eDNA publications yet, the opportunity to lead in this novel area is wide open. By generating eDNA signatures of exploited species and linking them to biomass estimates, Indian researchers can revolutionise how we assess and manage the country's rich marine living resources.

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