

REVIEW ARTICLE

eDNA and Invasive Species detection in water bodies: A review

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ABSTRACT

Environmental DNA (eDNA) is a powerful tool in detecting invasive species and monitoring biodiversity in ecosystems. eDNA refers to genetic material shed by organisms into their environment, such as through skin cells, hair, waste, or mucus. By collecting water, soil, or air samples, scientists can analyze the DNA traces in the sample to identify the presence of various species without having to physically capture them. This technique is particularly useful for detecting invasive species, which can disrupt ecosystems, outcompete native species, and lead to significant environmental and economic consequences. Traditional methods for identifying invasive species, such as trapping, netting, or visual surveys, can be time-consuming and sometimes inefficient, especially in aquatic environments where invasive species may be hidden or in early life stages. eDNA offers a more sensitive and rapid alternative, capable of detecting even low-density populations. In this article, we provide an in-depth discussion on eDNA analysis techniques, focusing specifically on the process of DNA extraction from water samples. Additionally, we explore the application of eDNA in detecting invasive species, highlighting its effectiveness and advantages over traditional methods. Finally, we examine the environmental factors that can influence eDNA persistence and detection, emphasizing the importance of considering these variables in ecological studies.

Keywords: eDNA, species conservation, invasive species detection, species monitoring, sustainable development.

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INTRODUCTION

Invasive species are among the most driving challenges to the comprehensive biodiversity and ecosystem. The particular species time and again is inducted into an unfamiliar habitat across human activities, which outmatch the Indigenous species, disorganizing food webs and resulting in immutable changes to ecosystems. The necessity for useful surveillance and governance of invasive species has never been more extensive. Conventional methods, like netting, trapping, and steer observation, are time-gripping and simultaneously seekers of the intense labor force and usually fall flat to distinguish species at lower densities. Contrarily, environmental DNA analysis has surfaced as an innovative tool that provides sensitive, non-invasive, and competent options for monitoring and detecting invasive species.

Overview of Environmental DNA (eDNA)

Environmental DNA relates to the genetic material shed by living beings into their natural world through several biological approaches. These approaches include scales, discarded skin cells, feces, mucus and reproductive substances. In many cases, the DNA fragments prevail in the environment as short sequences counting on factors such as UV exposure, microbial activities and temperature. This endurance renders Edna a worthy tool for determining species within aquatic environments, where DNA can disseminate through water and furnish an inclusive overview of biodiversity [1]. The principle of eDNA is established in the theory that living beings outstrip the remains of their genetic material as they engage with the environment. These remains can be gathered from the samples of the environment like soil, sediment, or water, excluding the aspect of capturing or promptly observing organisms. This particular competence to secondarily detect species, primarily in environments where conventional methods of survey are unrealistic or invasive.

Basics of eDNA analysis techniques

Initial step in eDNA analysis includes the procurement of environmental samples. In terms of aquatic environments, water samples are typically used, while biofilm or sediment samples can also be of use counting on the focused species. Sterilized techniques are crucial in terms of sample assembly for decreasing contamination. Conventionally, water samples are procured through disinfected containers or units that capture eDNA by filters. The measure of water collection might differ, yet higher volumes typically improve the possibility of identifying species in low density [2]. Conservation of the assembled samples is decisive for avoiding the deterioration of eDNA, which can happen briskly in specific conditions. Different methods like freezing, refrigeration, and chemical stabilizers are engaged to ascertain that the DNA stays undamaged until studied in the laboratory. For certain instances, instantaneous filtration of water samples is carried out, succeeded by preservation of filters used for a prolonged timeframe ahead of analysis.

DNA Extraction

When the samples have been gathered and conserved, the following measure is the extraction of eDNA. DNA extraction embodies a crucial period that needs dedicated approaches to ascertain greater output and clarity of the DNA. Selection of the extraction mechanism relies on the variety of samples and the downstream applications. Generally used mechanisms encompass filtration, precipitation as well as bead-based kits with their respective merits and demerits. Filtration is commonly a preferred technique depending on the water samples, which is traversed through a filter that collects the environmental DNA. Subsequently, the DNA is extricated with specific enzymatic or chemical processing that disintegrates the cellular substance and frees up the DNA. In the context of precipitation methods, the ethanol precipitation process is exercised to concentrate DNA out of greater water volume. Magnetic bead-based kits, which attach DNA to magnetic beads following specified conditions, suggest a high-throughput choice that is continuously more accepted in eDNA studies [3]. The obtained DNA is measured and estimated for quality preceding analysis. High-quality DNA is vital for the accomplishment of downstream applications, like sequencing or polymerase chain reaction, which depend on the intensification and precise recognition of DNA target sequences.

Data Analysis

The eventual stage in eDNA study governs the discovery and recognition of target species with the obtained DNA. The procedure generally begins with the magnification of particular DNA sequencing with the polymerase chain reaction. Quantitative PCR is amongst the most broadly exercised mechanisms for eDNA analysis. The stated PCR sanctions the quantization of DNA in real-time, slotting the specter of target species with the valuation of its profusion in the environment. This mechanism is very sensitive and flawlessly identifies species at minimal densities, scoring potent for early detection of invasive species [4]. The digital PCR is a further betterment that aids a higher sensitivity and accuracy than the quantitative PCR. This mechanism splits the DNA sample to thousands of separate reactions, each having a particular measure of DNA molecules. This segregation enables the recognition of rare sequences of DNA with reduced negatives [5].

Application of eDNA in Invasive Species Detection

Invasive species stand as a major threat to comprehensive biodiversity, economic activities and constancy of ecosystem. The demand for a convenient and meticulous detection mechanism called for the acceptance of Environmental DNA analysis as a potential tool for tracking and controlling invasive species. Contrary to the customary processes, which recurrently enjoin primary observation or apprehend, eDNA approves the identification of species stalling on the genetic matter they shed in their environment.

Early Detection and Monitoring: In controlling invasive species early detection is essential, because it offers rapid operation until the species get well-rooted and results in potential economic and ecological damage. Mechanisms such as trapping, netting, or visual surveys usually fail to determine species at low densities, specifically in extensive or remote environments. eDNA study provides further responsive substitute, capable of identifying detailed volume of DNA shed by the organisms. The identification of eDNA at an early phase of invasion is possible due to the susceptibility of the DNA. In some cases, analysis has showcased that eDNA is able to find invasive aquatic species within the water bodies much earlier than they could determine by conventional procedures. This particular early information is impeccable for carrying out prompt response measures, like the utilization of barriers or targeted eviction to prohibit further circulation [6]. The monitoring of eDNA can be performed steadily or else at uniform gaps, giving a vital idea of the existence and distribution of species. The non-invasive characteristics of eDNA sampling also reduce interruption to the ecosystem as well as non-target species, stalling it as the favored option for prolonged monitoring [7].

Case Studies in Aquatic Ecosystems: The principal focal point of eDNA application have been the aquatic ecosystem because of the smooth dispersion of DNA within the water,

prevailing it as the ideal medium for identifying species. One significant case is the detection of invasive Asian Carp (*Hypophthalmichthys* spp.) at the Great Lake area of North America. The Asian carp stood as a potential threat to the local fish population and simultaneously the inclusive ecosystem of the Great Lakes. Conventional monitoring procedures many a time struggle to observe these carp at low densities, heading to matters that might institute populations before they could be actually controlled. eDNA study, although offered a solution by identifying Asian carp DNA within water samples from zones where physical detection of fishes were not recorded, providing scope for enforcement of control measures [6]. Another effective utilization of eDNA is the identification of invasive Zebra mussel (*Dreissena polymorpha*) in water bodies of North America and Europe. These species are infamous for their capability to attach to hard faces, hindering the water intake mechanisms, and outdoing the local species. eDNA has been utilized for detecting zebra mussel larvae in water samples, even at the stage where the population is below the detectable range. This early detection provides more efficient control policies like physical barriers or chemical applications [8]. Terrestrial applications: When eDNA is significantly exercised in aquatic ecosystems, its utility for terrestrial purposes is progressively approved. Observing eDNA in air, soil, or terrestrial aspects poses substantial difficulties because of the complicated nature of the habitats and the lesser mobility of DNA in contrary to water. Moreover, development in the sampling mechanisms and mechanisms of extraction are commencing new spheres of utilizing eDNA for terrestrial ecosystems. The identification of invasive species by DNA analysis of samples from soil, by determining the DNA of invasive plants in soil samples, researchers can observe the range of these species and analyze the effect of local vegetation. Like, analysis have potentially detected plants like Japanese knotweed (*Fallopia japonica*) providing fast intrusion and monitoring [9]. Studies have identified the DNA of invasive emerald ash borer (*Agrilus planipennis*) in bark of trees and soil samples granting a non-invasive mechanism for observing the account of growth for the pest. The eDNA has been mobilized to discover the existence of earthworms in soil samples, that may have a crucial effect on structure of soil and nutrient rolling [10].

Advantages of eDNA in Invasive Species Analysis:

Globally, eminent questions to biodiversity, economic operations, and ecosystems are stalled by invasive species. The efficiency to precisely observe and govern these species is important for the deemed management. The aspect of environmental DNA has surfaced as a progressive tool in the particular context, upholding several advantages over conventional mechanisms.

Non-Invasiveness: The potential best aspect of eDNA study is its non-invasive makeup. The classical processes of species detection, like netting, trapping, or focused observation, in given chances engage substantial capture or uproar for the species and the habitats. These mechanisms require major labor force, and may distress the potential species. The study of eDNA depends on procuring of environmental samples like soil, air, or water that bear DNA cast off by organisms by feces, skin cells, urine, or separate biological mechanisms. This process eradicates the necessity for straight communication with the species being observed, prevailing it worthwhile to analyze vulnerable, endangered, or evasive specie [11]. Furthermore, testing of eDNA can be performed recurrently over expanded zones than the classical methods, offering a more thorough and intruding way of governing the existence and dispensation of species. thus stalling it as a perfect fit for prior identification and uninterrupted observation of invasive species, sanctioning for further aggressive governance strategies [6]. **High Sensitivity and Specificity:** An added asset of eDNA study is the specificity and increased sensitivity in target species detection. Classical methods might find it difficult to identify species during low-density populations, specifically in complicated and large environments. In several studies, the sensitivity of eDNA has been showcased. For instance, the study of invasive fish species has stalled that eDNA holds the potential to identify specific organisms weeks or months earlier, than being observed by classical procedures [12]. The particular step-up detection is beneficial in running in-time controlling interventions that prohibit the rooting as well as propagation of the species. With the aid of species-specific probes or primers in the middle of the amplification of DNA, the study of eDNA marks and detects specific species bearing better precision. This subsequently lowers the chances of false negatives or positives, which are general contests faced in classical methods for invasive species identification. For example, digital PCR (dPCR), as well as quantitative PCR (qPCR) methodologies applied in eDNA analysis stalled to be majorly specific, offering to differentiate amongst related species or detect a specific target species in a heterogenous community [13].

Cost-Effectiveness: Taking in account the comprehensive range and extent of invasive species observation, cost-effectiveness is a highlighted aspect of eDNA study. The conventional processes repeatedly need important reserves, comprising experienced personnel, particularized equipment, and thorough fieldwork. These processes are expensive in broad or isolated areas where communication and transport difficulties double the total expense. eDNA study comparatively requires the procurement of rather general samples from the environment that is carried with very minimum equipment and learning.

These samples after collection are prepared in the laboratory by established protocols, lowering the comprehensive fieldwork and dedicated expertise in the detection of species. The upgraded approach can potentially reduce the costs related to the observation of invasive species, especially for broad-scale study [13]. Cost-effectiveness is augmented by its capability to lower the requirement for reactive management processes. With the timely detection and slotted monitoring, eDNA study offers to prohibit the rooting and dissemination of invasive species, lessening the cost and practical elimination or regulatory aspects followed on [14].

Challenges and Limitations: Environmental DNA has transformed the manner scientists observe and detect species, contributing a substantial edge concerning non-invasiveness, value-effectiveness, and sensitivity. Moreover, the mechanism is by no means devoid of contests and constraints. The credibility of eDNA may get influenced by miscellaneous components of the environment.

Environmental Factors Affecting eDNA

The fundamental obstacles in eDNA analysis is the impact of the elements of the environment on the detection, transfer, and endurance of eDNA in natural context. Elements like pH, temperature, UV rays and microbes can potentially impact the deterioration value of eDNA heading to inconsistency in identification outcomes. For example, higher microbial action and temperatures can speed up the collapse of DNA, curtailing the possibility of identification in warm, biologically dynamic environments [15]. Water flow and disturbance also take a significant position in the circulation of eDNA in aquatic environment. Fast-paced water can attenuate the concentration of eDNA creating further complications in identifying species existence, specifically in complicated and extensive bodies of water [16].

False Positives and Contaminations:

These are crucial affairs in the study of eDNA, with the capacity to entail improper findings regarding species existence or dispersion. False positives can happen when from non-target organisms or degenerated DNA, eDNA is identified resulting to a massive inference that a species exists in the area where it would probably not be [17].

Contamination, in the event of laboratory handling or sample procurement, or from surroundings, is potentially an additional origin of false positives. A minimal quantity of DNA carries the potential to contaminate, leading to the identification of species that are rationally not present in the sample region. For instance, DNA from the determined species can be accidentally inducted to a sample by reagents or tainted equipment, bringing about inaccurate information [18]. To attenuate these hazards, strict regulations must be exercised to understate contamination, in addition to disinfected instruments, rigid decontamination processes, and negative controls. The execution of these steps is crucial to ascertain the authenticity and credibility of eDNA findings and to prohibit the misapplication of invasive organisms depending on faulty information [19].

FUTURE DIRECTIONS

The analysis of environmental DNA promptly progressed as an effective instrument in species identification and biodiversity management. With the growth of the field, many potential paths are fledging that commit in strengthening the ability and uses of eDNA. **Technological Advancements:** The outlook of eDNA study will be meaningfully molded by a technological breakthrough that boosts the speed, extensibility, and precision of eDNA analysis. One of the eminent courses is the creation of field-adjustable, transferable tools that provide real-time eDNA analysis. Present eDNA processes usually need samples to be transferred to laboratories for computation, which potentially slot in delays and chances of defilement. Transferable gadgets like compact qPCR or NGS, offer analysis on location, giving instant outputs and lessening the logistical disputes linked with classical eDNA methods [20]. An additional technical progress is the rising utilization of metagenomics and next-generation sequencing. These processes authorize the concurrent discovery of several species from an individual sample, providing a thorough overview of biodiversity in a particular environment, these methodologies are likely to serve a significant slot in Edna analysis, especially in complicated ecosystems with odds of invasive species [21]. **Integration with Other Monitoring Tools:** The consolidation of eDNA with an added monitoring machinery shows impeccable prospects. The combination of classical survey processes, and telemetry information with eDNA lends a better comprehensive approach for species observation. For example, classical studies identify species that are conversely tough to monitor or bag, thus increasing the general precision and exposure of monitoring work [22].

The composition of eDNA along the breakthroughs like fixed isotope study or ecological metabolomics might give an understanding of the reciprocation of species, environmental health, and trophic kinship. With associating cascade of information, a more thorough agreement of ecological kinetics is achieved, bringing about well-informed protection and management choices of invasive species [23]. Policy and

Management Implications: With the advancement of DNA technologies, eDNA mechanisms are equipped to perform a significant role in notifying policy and schemes of management for biodiversity protection. Instituting these principles will be vital for ensuring the correspondence and dependability of information regarding eDNA over several areas and analysis, on that account will assist in its incorporation into the legal systems and monitoring progression in terms of environment [7]. The acceptance of eDNA in environmental impact evaluations and preceding alarm mechanisms for invasive species might grow globally. Strategists as well as facility controllers potentially influence the information related to eDNA for enacting aggressive measures like instant response strategies for novel species or customizable management measures that account for alterations in the dispersion of species owing to changes in climate and other environmental factors [24].

CONCLUSION

Environmental DNA has appeared as a life-changing instrument in species finding and biodiversity surveillance, presenting susceptible, non-invasive, and economical procedures for finding the target species. Its Implementation is specifically applicable in controlling invasive species like the suckermouth catfish (*Pterygoplichthys* spp.), a serious threat for the ecosystem in India. The environmental DNA grants primordial detection and persistent observation of such species, giving crucial information for prompt intervention and control. Regardless of the benefits, its potential to identify weak population strength, and its precision in finding marked species, eDNA study encounters disputes that must be handled. Environmental aspects like pH, temperature, and flow of water influence the detection and endurance of eDNA, bringing about probable false negatives. The deficiency of regulated formalities over other studies simultaneously stances a factor of variable outcomes, and correspondence of sophisticated information. Moreover, the odds of contamination and false positives highlight the necessity of strict procedures and confirmational processes. Moving ahead, the eDNA study assures to be eminent, having probable evolution of the technology, such as the in-hand gadgets and next-gen sequencers that will elevate its efficacy. Integration of the diverse monitoring instruments with the environmental DNA, as in the telemetry and remote sensing, might offer a more extensive methodology for the regulation of the ecosystem. Likewise, the creation of regulated principles and the integration of eDNA in the policy and governing schemes will be decisive in exploiting its efficiency for defense and care.

CONFLICT OF INTEREST: Authors declare No conflict of interest.

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REFERENCES

1. Deiner, K., et al. (2017). Environmental DNA metabarcoding: Transforming how we survey animal and plant communities. *Molecular Ecology*, 26(21), 5872-5895.
2. Goldberg, C. S., et al. (2016). Critical considerations for the application of environmental DNA methods to detect aquatic species. *Methods in Ecology and Evolution*
3. Ficetola, G. F., et al. (2008). Replication levels, false presences and the estimation of the presence/absence from eDNA metabarcoding data. *Molecular Ecology Resources*, 15(3), 543-556.
4. Takahara, T., Minamoto, T., Yamanaka, H., Doi, H., & Kawabata, Z. (2013). Estimation of fish biomass using environmental DNA. *PloS One*, 8(4), e58602.
5. Doi, H., et al. (2015). Use of droplet digital PCR for estimation of fish abundance and biomass in environmental DNA surveys. *PLoS One*, 10(3), e0122763.
6. Jerde, C. L., Mahon, A. R., Chadderton, W. L., & Lodge, D. M. (2011). "Sight-unseen" detection of rare aquatic species using environmental DNA. *Conservation Letters*, 4(2), 150-157
7. Rees, H. C., Maddison, B. C., Middleditch, D. J., Patmore, J. R. M., & Gough, K. C. (2014). The detection of aquatic animal species using environmental DNA—a review of eDNA as a survey tool in ecology. *Journal of Applied Ecology*, 51(5), 1450-1459.
8. Mahon A. R., Jerde C. L., Galaska M., Bergner J. L., Chadderton W. L., et al. (2013) Validation of eDNA Surveillance Sensitivity for Detection of Asian Carps in Controlled and Field Experiments. *PLOS ONE* 8(3): e58316.
9. Gibson, J. F., Shokralla, S., Porter, T. M., King, I., van Konynenburg, S., Janzen, D. H. & Hajibabaei, M. (2012). Simultaneous assessment of the diversity of terrestrial and aquatic assemblages with DNA barcodes: A case study of riverine ecosystems. *Molecular Ecology Resources*, 12(4), 653-667.
10. Bienert, F., De Danieli, S., Miquel, C., Coissac, E., Poillot, C., Brun, J. J., & Taberlet, P. (2012). Tracking earthworm communities from soil DNA. *Molecular Ecology*, 21(8), 2017-2030
11. Dejean, T., Valentini, A., Miquel, C., Taberlet, P., Bellemain, E., & Miaud, C. (2012). Improved detection of an alien invasive species through environmental DNA barcoding: The example of the American bullfrog *Lithobates catesbeianus*. *Journal of Applied Ecology*, 49(4), 953-959.

12. Wilcox, T. M., McKelvey, K. S., Young, M. K., Jane, S. F., Lowe, W. H., Whiteley, A. R., & Schwartz, M. K. (2016). Understanding environmental DNA detection probabilities: A case study using a stream-dwelling char *Salvelinus fontinalis*. *Biological Conservation*, 194, 209-216.
13. Takahara T, Minmoto T, Doi H (2013) Using Environmental DNA to Estimate the Distribution of an Invasive Fish Species in Ponds. *PLOS ONE* 8(2): e56584
14. Thomsen, P. F., & Willerslev, E. (2015). Environmental DNA—an emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation*, 183, 4-18
15. Strickler, K. M., Fremier, A. K., & Goldberg, C. S. (2015). Quantifying effects of UV-B, temperature, and pH on eDNA degradation in aquatic microcosms. *Biological Conservation*, 183, 85-92
16. Jane, S. F., Wilcox, T. M., McKelvey, K. S., Young, M. K., Schwartz, M. K., Lowe, W. H., & Letcher, B. H. (2015). Distance, flow and PCR inhibition: eDNA dynamics in two headwater streams. *Molecular Ecology Resources*, 15(1), 216-227.
17. Darling, J. A., & Mahon, A. R. (2011). From molecules to management: Adopting DNA- based methods for monitoring biological invasions in aquatic environments. *Environmental Research*, 111(7), 978-988
18. Goldberg, C. S., Strickler, K. M., & Pilliod, D. S. (2016). Moving environmental DNA methods from concept to practice for monitoring aquatic macroorganisms. *Biological Conservation*, 183, 1-3.
19. Ficetola, G. F., Taberlet, P., & Coissac, E. (2016). How to limit false positives in environmental DNA and metabarcoding? *Molecular Ecology Resources*, 16(3), 604-607.
20. Yamanaka, H., Minamoto, T., & Kakuda, R. (2017). Real-time PCR detection of environmental DNA from an invasive fish species, the common carp, and its application for environmental monitoring. *Molecular Ecology Resources*, 17(1), 49-58.
21. Cristescu, M. E. (2019). Can environmental RNA revolutionize biodiversity science? *Trends in Ecology & Evolution*, 34(8), 729-733
22. Bohmann, K., Evans, A., Gilbert, M. T. P., Carvalho, G. R., Creer, S., Knapp, M., ... & De Bruyn, M. (2014). Environmental DNA for wildlife biology and biodiversity monitoring. *Trends in Ecology & Evolution*, 29(6), 358-367
23. Evans, N. T., Olds, B. P., Renshaw, M. A., Turner, C. R., Li, Y., Jerde, C. L., ... & Lodge, D. M. (2017). Environmental DNA (eDNA) detection and quantification of invasive rusty crayfish (*Orconectes rusticus*). *PloS one*, 12(5), e0176459.
24. Lodge, D. M., Turner, C. R., Jerde, C. L., Barnes, M. A., Chadderton, W. L., Egan, S. P. & Mahon, A. R. (2016). Conservation in a cup of water: estimating biodiversity and population abundance from environmental DNA. *Molecular Ecology*, 25(4), 731-741.

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