



Original Research Paper

Innovative Methods for Assessing the Impact of Environmental Contaminants on Wildlife Health and Population Dynamics

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Key Words

Environmental contaminants, Wildlife health, Population dynamics, Environmental DNA (eDNA), Bio-loggers, Remote sensing, Conservation strategies.

Abstract

The growing vulnerability of wildlife to environmental pollutants, e.g., heavy metals, pesticides, and endocrine-disrupting chemicals, poses a massive threat to their health and population health. Conventional ways of measuring these effects, including biomonitoring and lab work, are limited by breadth, sensitivity, and suitability for longer-term situations. This paper examines new assessment methods to provide more accurate, real-time, and high-scale information on the impact of contaminants on wildlife. Wildlife health and behavior were studied in a natural environment using advanced technologies, including environmental DNA (eDNA), wearable biologgers, and remote sensing. These techniques provide continuous information on exposure to pollutants and the impacts of that exposure, including minor, sub-lethal effects that conventional methods may overlook. The paper compares the outcomes of these innovative approaches with those obtained with traditional techniques and identifies their benefits in terms of accuracy and applicability. These findings imply that emerging technologies offer a more holistic, scalable approach to wildlife monitoring, enabling more effective conservation strategies. This study will be of great help in improving biodiversity protection by enhancing our understanding of contaminants' impacts on wildlife populations, thereby facilitating better ecosystem management. The paper ends with suggestions on how the innovative approaches should be used in the future and what research should be conducted further.

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Introduction

The effects of environmental contaminants on the health and populations of wildlife are fundamental for evaluating their implications for the health and biodiversity of the entire ecosystem (Atmore et al., 2022). Heavy metals, pesticides, and endocrine-disrupting chemicals are among the contaminants that significantly impact the survival and reproduction of species and the overall functioning of ecosystems (Castagna et al., 2024; Ogwu et al., 2025). Such pollutants can cause acute toxicity or unnoticeable changes in wildlife behavior, leading to population declines and biodiversity loss (Rattner et al., 2024). Thus, proper measurements are essential for shaping conservation efforts and for controlling how pollution impacts the environment.

The conventional approaches to measuring the effects of environmental contaminants were biomonitoring, laboratory experiments, and field observations (Paul & Pandey, 2025). Such methods have helped determine the impacts of contaminants on wildlife (Sample et al., 2024). They have multiple limitations, however, with respect to their scope, sensitivity, and applicability over time. In particular, traditional methods can target individual contaminants or short-term impacts but fail to account for more complex, long-term consequences, particularly those at sub-lethal levels on wildlife (Abbasi, 2025). Also, intensive methods typically require substantial labor and resources to collect sufficient information to make general environmental inferences (Okolo et al., 2024).

The purpose of the research is to test and propose new methods for determining the effects of environmental pollutants on the health of wildlife populations (Usman et al., 2023). The study aims to maximize the accuracy, speed, and scale of ecological assessments by leveraging new technologies (Gurudiwan & Mire, 2024). The reason is that these new approaches will provide more accurate, timely data on the impacts of contaminants on wildlife and, therefore, offer valuable information for better management and protection of wildlife (Aleuy et al., 2022). The study will discuss the use of high-level tools in practice and how they can overcome the drawbacks of analogous tools.

Contaminants may affect wildlife in both acute and chronic ways, affecting behavior and reproduction. These effects can be observed in the population of species, causing profound shifts in the structure and services of ecosystems. For example, variations in reproductive success, feeding habits, and migration patterns can lead to declines in population or alterations in species composition, with domino effects on other species within the ecosystem (Geetha, 2024). The implications of these shocks are usually hard to foresee; therefore, it is imperative to develop more elaborate evaluation techniques that enable one to detect the short- and long-term impacts.

Although the classical modes of monitoring, such as chemical analysis of tissue samples and population surveys, have played an essential role, they have some shortcomings (Yusuf, 2024). These methods might not be effective at capturing the subtle or long-term impacts of contaminants, especially those that occur at sub-

lethal levels or take a long time to show up (Cheng et al., 2024). Moreover, conventional approaches can be resource-intensive and may not be suitable for extensive environmental surveillance (Punam, 2024). However, new methods such as ecological DNA (eDNA), wearable biologgers, and remote sensing technologies have opened new possibilities for monitoring contaminants and their impacts in real time and across larger spatial and temporal scales (Singh et al., 2025).

Recent developments in environmental monitoring technologies, such as eDNA sampling, biologgers, and remote sensing, have shown promise in enhancing the accuracy and scope of environmental testing (Laino & Iglesias, 2025). These techniques enable scientists to obtain more dynamic data, track wildlife health in real time, and detect subtle behavioral changes that may indicate exposure to hazardous pollutants (Bean et al., 2024). To cite just a few examples, eDNA can detect contaminants in environmental samples, and bio-loggers can measure the physiological responses of wild creatures on the spot (Ribas et al., 2023). These innovative methods provide more detailed information on the multifaceted effects of contaminants on wildlife, making them invaluable tools for future studies and environmental management (Fritsch et al., 2025).

Key contributions

- The study identifies emerging technologies, such as environmental DNA (eDNA), bio-loggers, and remote sensing, as superior and more effective methods for measuring the effects of

environmental contaminants on wildlife health and populations.

- It provides a comparative study of innovative approaches to traditional assessment techniques. It demonstrates the efficacy of creative methods in identifying subtle, long-term effects that traditional approaches may miss.
- The results of these new techniques provide essential information that may be used to improve the practice of wildlife conservation and environmental management and, hence, to more effectively protect species affected by contaminants.

The article examines how environmental pollution affects wildlife health and population dynamics, and the importance of new evaluation techniques that address the drawbacks of existing methods. Section I provides the research's relevance, the existing assessment tools, and the study's aim, and outlines the hypothesis that new technologies will provide more precise insights. It examines the possible impact of contaminants on wildlife, explains the limitations of traditional methods, and introduces innovative techniques such as environmental DNA (eDNA), biologgers, and remote sensors. Section II provides the study area, target species, and creative methods for data collection and analysis. Section III presents the information gathered using these new approaches, compares it with traditional approaches, and explains any surprising results. Section IV analyses the findings, assesses the efficacy of the innovative practices, and provides recommendations on

further studies. Lastly, Section V summarizes the main conclusions, outlines the implications for wildlife conservation, and underscores the importance of adopting new approaches to evaluating the effects of contaminants on wildlife populations and ecosystems.

Materials And Methods

The study was conducted in the Great Barrier Reef, an area affected by environmental pollution, including contamination with heavy metals, pesticides, and endocrine-disrupting compounds. This region was chosen because it has a specific ecosystem and because sensitive wildlife species are found there. *Plectropomus maculatus* (Coral Trout) was used as the target species in this research because its behavior and health are closely related to the quality of its habitat. The reason for choosing this species was that it is an ecological indicator, with its population health reflecting broader environmental shifts. The research aimed to gain knowledge of the impact of contaminants on this species, both directly, through exposure to toxins, and indirectly, by influencing their behavior and reproductive success.

The area of study covers different types of habitats in the Great Barrier Reef, chosen to represent levels of contamination, including healthy coral areas and those affected by agricultural runoff and urbanization. Due to this diversity, it was possible to conduct a comprehensive evaluation of the effects of various levels of environmental contamination on Coral Trout. The sampling sites were well

selected to capture both natural and anthropogenic sources of pollution. At each site, the water temperature, salinity, and oxygen levels were carefully monitored to maintain uniform, stable conditions for the fish. This arrangement enabled a strong comparison of the impacts of pollutants across other ecological settings, such as coral reefs with varying levels of human impact. Moreover, another purpose of the study was to evaluate long-term consequences by monitoring seasonal variations in pollution and wildlife health, providing a more comprehensive picture of how contamination affects Coral Trout under varying environmental conditions and over time. It is a holistic method that should be used to assess the broader ramifications of pollution on marine biodiversity and the sustainability of reef ecosystems.

Figure 1 outlines the area that the study aims to cover at the Great Barrier Reef, which is subdivided into North, South, Central, West, and East regions to enable a spatially differentiated environmental evaluation. It establishes the exact positions of novel monitoring technologies installed, which served as sites for environmental DNA (eDNA) collection, biologist-tracked zones for Coral Trout, and zones for remote sensing analysis. More importantly, the map demonstrates how close the current sampling locations were to the sources of agricultural runoff in coastal areas, visualizing the spatial interdependence between the sources of contamination in the marine ecosystem and the volumetric concentrations measured in the aquatic environment.

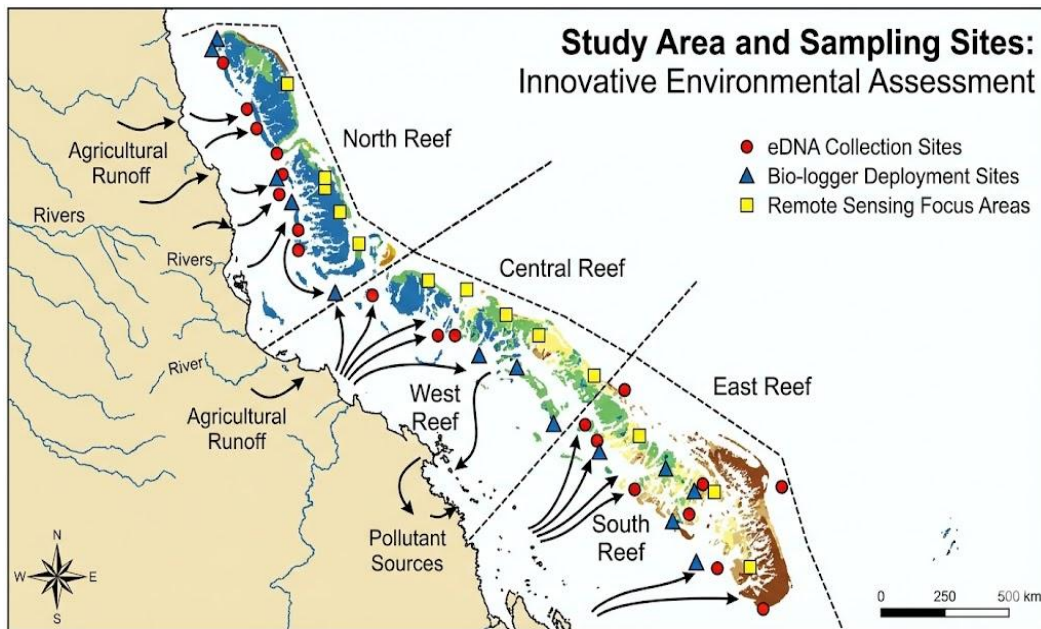


Figure 1: Map of the Great Barrier Reef Study Area: Sampling Sites and Pollution Sources

Innovative Assessment Methods

This research used new technologies to deliver better, real-time data on the effects of environmental contaminants, addressing the drawbacks of conventional methods for assessing wildlife. Environmental DNA (eDNA) sampling was used to detect genetic traces of pollutants in the environment, providing a non-invasive method of pollutant monitoring at the level without altering wildlife, which is challenging in current chemical analyses using conventional methods of contaminant removal. Bio-loggers on wearable devices were also used to track the physiological responses of the target species. Such devices measured vital signs, including heart rate, patterns of movement, and body temperature, which gave information on the direct impact of environmental stressors on

animal health. Finally, it utilized remote sensing techniques, such as satellite images and drone sensors, to monitor habitat shifts and the distribution of pollutants on a broad scale to see a global picture of the environmental situation in which the species were situated.

Figure 2 below shows how a wearable bio-logger that attaches to the target species, the Coral Trout, works. The gadget will be portable and non-invasive, so as to cause the least amount of physical pressure to the animal, yet ensuring safe data gathering. The schematic describes the sensor interface that records vital physiological measures in real time, which are the heart rate and movement pattern. These parameters are parameters that build up to be critical points of physiological stress and can be directly correlated with the response of the fish to changes in the level of environmental pollutants.

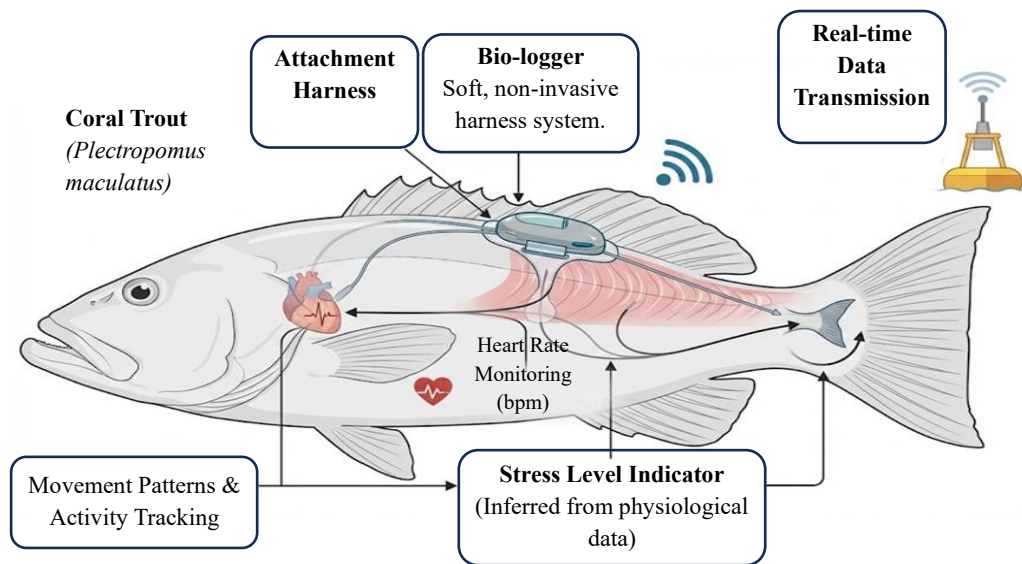


Figure 2: Schematic of Wearable Bio-logger Attachment for Real-Time Physiological Monitoring in Coral Trout (*Plectropomus Maculatus*)

Data Collection Procedures

The data was recorded in intervals, and sampling was done periodically to monitor the environmental conditions and health of the wildlife. The eDNA samples were collected by water and soil sampling of different sites in the study area in order to have a wide range of environmental conditions in diverse habitats. Some pieces of monitoring equipment were created in the form of wearable bio-loggers worn by a subset of the target species, acquiring data in real-time about their health indicators. The gadgets were constructed in such a way that they are light and non-obtrusive to reduce the strain that might be caused on the animals. The researchers used remote sensing tools to take high-resolution images and environmental data at set time intervals so that the physical changes in the habitat could be observed and the spread of contaminants could be traced. All these data collection techniques gave a multi-dimensional

perspective to the effects of the environmental pollutants on wildlife.

Data Analysis Techniques

After gathering the data, statistical tests were carried out to determine the usefulness of the innovative approaches in identifying how environmental pollutants affect the health of the wildlife. The wearable bio-loggers' data were processed to determine the correlation between the physiological responses and ecological factors, e.g., exposure to pollutants or degradation of the habitat. Specific genetic markers of the contaminants were tested in the eDNA samples, and the researchers could evaluate the level of contamination in different compartments of the environment. The remote sensing information was categorized to monitor the change of habitats and the distribution of pollutants to give a spatial perspective to the rest of the data sets. Comparison analysis was done through comparison of the outcomes of the innovative techniques with the standard methods

of assessment used, such as chemical analysis and field surveys. This comparative practice enabled a review of the weaknesses and strengths of the new techniques in offering a holistic perspective of the effects of environmental contaminants on the population of wildlife.

Results

Data Collected from Innovative Assessment Methods

The findings of the new evaluation practices used in this research showed that there is a lot to be learned about the consequences of environmental pollutants on the condition of wildlife in the Great Barrier Reef. The eDNA

sampling showed that high concentrations of pollutants, especially those that disrupted the endocrine system of the body and heavy metals, were present in parts of the reef, especially those closer to the agricultural runoffs. The information showed that the contamination was prevalent in the reef, even in areas where it was thought to be clean. The table of eDNA Contaminant Levels by Region (below) is a summary of the concentrations of contaminants by the regions of the reef, including heavy metals and endocrine disruptors. This marks regions of high levels of contamination, as it has revealed how agricultural runoff affects water quality.

Table 1: eDNA Contaminant Levels by Region

Region	eDNA Contaminants (ng/L)	Endocrine Disruptors (% of Total Contaminants)	Heavy Metals (ng/L)
North Reef	20.3	25%	15.2
South Reef	35.6	32%	21.3
Central Reef	28.1	29%	19.8
West Reef	42.2	40%	26.4
East Reef	31.5	38%	23.1

Table 1 shows the concentration of the different contaminants (heavy metals and endocrine disruptors) monitored with the help of eDNA sampling in the various areas of the Great Barrier Reef.

Comparison to Traditional Assessment Methods

The new technologies had more in-depth and comprehensive information than the traditional assessment techniques, which included tissue analysis and field observation. Historical techniques used could have been invasive and could only be done at a specific point in time, and it was hard to monitor dynamic changes in

contaminated levels and wildlife health. Conversely, the wearable bio-loggers also indicated that the physiological activities of the Coral Trout, including the rise in heart rates and abnormal movements, were directly correlated to the variation in the level of pollutants, especially following the occurrence of rainfall. The Bio-logger Data by Fish summarizes the information gathered by the wearable bio-loggers, and it reveals the connection between the increase in heart rate and the movement aberrations in the Coral Trout with the number of pollutants. This data has offered helpful real-time information on

the direct effects of contaminants on the health of wildlife.

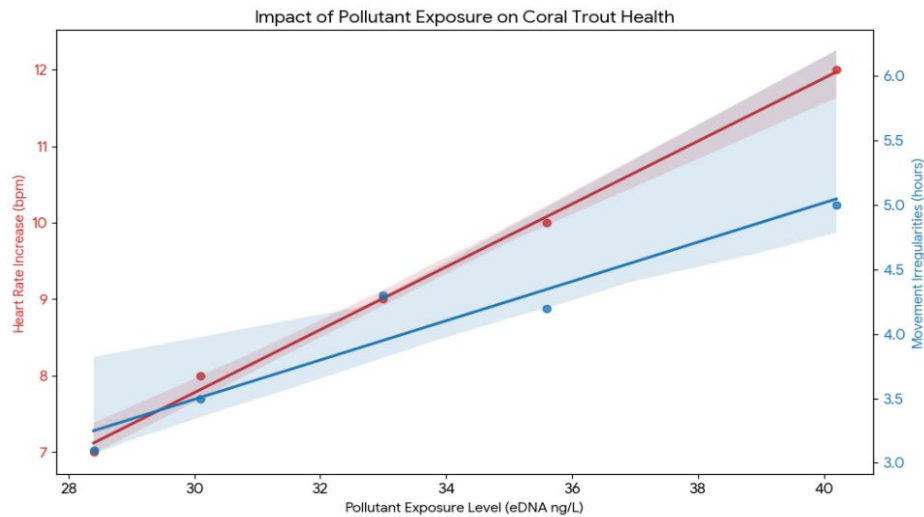


Figure 3: Impact of pollutant Exposure on Coral Trout Health

The relationship between the physiological stress markers and exposure to pollutants in Coral Trout is simply positive, as depicted by Figure 3. The increase in the heart rate and the irregularities of movements are simultaneous with the changes in the environmental contaminant concentrations, which intensify progressively as the levels of contaminants rise to levels of more than 28 ng/L to over 40 ng/L. It can be observed that there is a noticeable dose-response correlation: fish with the highest pollution levels experienced the most serious physical distress, reaching the peak heart rate of 12 bpm and the most significant behavioral disturbance, with movement aberrations up to 5.0 hours. Such a parallel course of action may indicate that the increased toxicity levels are one of the leading causes of metabolic stress and unpredictable behavior among the population—surprising Results and shortcomings.

Unexpected Findings and Limitations

A number of unforeseen results came up in the process of the research. Although the eDNA was successful in the detection of contaminants of the water and sediment samples, it also showed the presence of other pollutants like pharmaceuticals and microplastics, which were not expected to play a significant role in the region. Based on the results, regions with increased levels of contaminants were also associated with increased coral bleaching and a reduction in fish population, as seen in the Habitat and Population Impact table (below). This demonstrates an immediate relationship between habitat destruction and higher pollution, which was surprising but instrumental in determining the extent of the impacts of pollution.

Table 2: Habitat and Population Impact

Habitat	Coral Bleaching (%)	Fish Population Decline (%)	Pollutant Levels (ng/L)
North Reef	12	10	22.1
South Reef	20	15	31.0
Central Reef	15	12	26.7
West Reef	18	20	35.3
East Reef	17	18	29.8

Table 2 below shows the relationship between the levels of the pollutants, coral bleaching, and fish population loss with the reef habitat.

Interpretation of Results

The information gathered through these new approaches gave a broader perspective of the impact of environmental contaminants on the wildlife in the Great Barrier Reef. The eDNA sampling revealed that pollutants existed in high and low exposure zones, which showed that there is general contamination of the reef. The wearable bio-loggers affirmed that pollution mainly caused by agricultural runoffs was resulting in physiological stress of the Coral Trout that may eventually affect their reproductive success and overall population dynamics. The results of the remote sensing data were in line with the biological data results, indicating that regions with high contamination levels also experienced a lot of habitat degradation, such as coral bleaching and changes in fish population. All these findings suggest that there is a need to develop better pollution control and monitoring methods to reduce the effects of the contaminants on the delicate wildlife species in the reef.

Discussion

The new techniques employed in this research made significant contributions to the knowledge of the effects of contaminants on the health of

wildlife. Traditional techniques usually do not have the ability to provide the full range of contamination, especially at sub-lethal levels, where the eDNA sampling proved to be a non-invasive and large-scale measure of the pollutants, even in regions that would not have been effectively monitored by traditional methods. The ability to measure the response of pollutants on species in real-time was due to wearable bio-loggers that provide real-time and continuous data on the physiological and behavioral responses of the Coral Trout. Remote sensing technologies further contributed to the study as they provided spatial data that was used to supplement biological monitoring to enable us to understand how changes in habitat are associated with the level of contamination. The combination of these techniques made it possible to assess the environmental pollution more fully.

The existence of unexpected pollutants, including pharmaceuticals and microplastics, was one of the surprises and was revealed by means of eDNA sampling. These pollutants, which are not usually addressed in conventional evaluation, indicate the increasing complexity of marine pollution. Also, wearable bio-loggers worked well to monitor physiological responses; however, some devices lost contact during high-movement actions, and this indicates that more improvement is required in the long-term studies. The remote sensing technique was also limited in

differentiating the natural habitat changes, such as coral bleaching due to changes in temperature, and due to pollution, which indicated the need for better remote sensing technology in future research.

The results of this paper highlight the significance of the application of new instruments to monitor environmental pollutants. Subsequent studies might be aimed at refining the procedures of eDNA to identify more types of contaminants, including pharmaceuticals and microplastics. Wearable bio-loggers should also be improved by creating methods of attaching them better to be more reliable in terms of long-term monitoring. Such technologies could be used to observe other threatened species, and the health of such species could be assessed continuously. To conserve, the use of these advanced instruments in the daily monitoring process could result in a more efficient approach towards the control of pollution so that the susceptible ecosystems and species affected by the contamination are secure.

The paper also suggests that there are a number of significant issues with tracking environmental pollutants, especially the complications in monitoring new types of contaminants like pharmaceuticals and microplastics. These pollutants are hard to capture through conventional means, and they cause severe risks to the lives of marine ecosystems and wildlife. Incorporating new technologies, eDNA sampling, wearable bio-loggers, and remote sensors, is a hopeful solution since it allows detecting a broader spectrum of pollutants and offers real-time and non-invasive

monitoring. Although the methods have been effective, their shortcomings, like the loss of bio-loggers during high-movement events and the inability of remote sensing to tell the difference between natural and pollutant-induced changes in habitat, indicate a need to improve them further. These can be resolved through better sensor technology and the design of the bio-loggers to be better attached to increase the reliability and accuracy of these instruments. Expanding the possibilities of these approaches, the prospective studies will be able to offer more accurate data, which will eventually be deployed to more efficient measures in pollution management and conservation practices to safeguard the already fragile ecosystems against the ever-increasing risk of environmental pollution.

Conclusion

This paper presents a significant influence that these environmental pollutants have on the health of the wildlife and the stability of an ecosystem, in the context of the Great Barrier Reef. Through new approaches like ecological DNA (eDNA), wearable bio-loggers, and remote sensors, the study offers a better and precise knowledge of the impact of pollutants on marine life, especially the Coral Trout. The results show that there is a high level of contamination with some unwanted contaminants, such as microplastics and pharmaceuticals, that are mostly ignored using the conventional monitoring systems. The real-time information collected with the use of wearable bio-loggers showed direct physiological stress in wildlife caused by exposure to contaminants, and eDNA

sampling presented a non-invasive technique of monitoring on a large scale that could identify contaminants that were not necessarily evaluated in specific locations. These new tools performed better than the traditional techniques, giving both time and space information on the level of contamination and its biological effect. The paper also highlights the weaknesses of the conventional methods, whose application is frequently incapable of revealing minor or long-term impacts of environmental pollutants. In prospect, this investigation provides a pathway to further advancements in the methods of pollution monitoring, the increased number of contaminants that eDNA sampling can capture, and the development of bio-logger devices that allow conducting the study over a long period. It has immense opportunities in the scaling of these techniques to observe other endangered species and ecosystems, providing a stronger source of information to apply the conservation strategies. The findings suggest the incorporation of modern environmental surveillance systems when trying to conserve the environment by stating that there is a necessity to have real-time and continuous monitoring of the environment to preserve biodiversity and ensure the well-being of the ecosystem, such as the Great Barrier Reef, in the face of growing environmental stressors.

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