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Original Research Paper

Pollution and Marine Life Investigating the Effects of Chemical Contaminants on Marine Species and Habitats

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Key Words

Marine pollution, Chemical contaminants, Habitat degradation, Bioaccumulation, Marine species, Water quality, Ecotoxicology, Biodiversity, Pollution management.

Abstract

In this study, the researcher analyzes the effect of chemical pollution on the marine organisms and ecosystems with some reference to the concentration of the pollutants in the marine environment and the biology of their effects. The main goal was to evaluate the abundance of dangerous chemical substances in the water (e.g., heavy metals, organic contaminants) and in sediment and in the marine organisms and to analyze the impact of these substances on the health, biodiversity, and quality of habitat of the species. Sampling was carried out in Persian Gulf and a comparative sampling against polluted and control sites was done. The water and sediment samples underwent chemical analysis to identify the concentration of the contaminants whereas, bioaccumulation of marine species, healthy indicators, and population were measured. Results showed that the levels of contaminants in polluted locations were very high, which were associated with reduced species diversity, ill health indicators of organisms, and degraded habitat. The results demonstrate the dire consequences of environmental pollution by chemicals, and the importance of developing efficient ways of managing the pollution and additional studies on the long-term impacts. The article highlights the need to monitor the marine environments and enact regulation that would reduce the effects of chemical pollutants that are hazardous to marine life and ecology.

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Introduction

Marine pollution is a worldwide environmental catastrophe, which endangers the biodiversity, ecosystem and human life. With the rising cases of industrialization and urbanization, oceans and coastal zones have turned out to be reservoirs of a large number of pollutants such as heavy metals, persistent organic pollutants (POPs), plastics, and agricultural run-offs (Ahamad et al., 2024). Chemical pollutants, especially, can be very dangerous to marine creatures and their ecosystem. These contaminants frequently find their way into the marine environment as a result of direct discharge or atmospheric deposition or through rivers, which influence the water quality, composition of the sediments, and the biological systems. Marine pollution has been associated with some negative consequences across the globe, including bioaccumulation in the marine organisms, reproductive dysfunction, and habitat loss (El-Sharkawy et al., 2025). As much as the world has been testing on the pollution levels in the sea, some parts of it have been under-researched especially those along the highway cities or densely populated regions close to the ocean, and the effects they possess are not reported much.

Highly industrialized and semi-enclosed, the Persian Gulf is experiencing considerable oil drilling, industrial effluents and urban runoffs resulting in considerable chemical contamination of this body of water. Its warm waters and water limited exchange make pollutants persistent. This area has been known to be a highly biodiverse region and over the years it is becoming a victim to pollution. Chemical pollution in the Persian Gulf is especially worrying considering that the area forms an important habitat to several marine creatures, including fish species and migratory birds which have economic value. Past research has established how chemical pollutants interfere with life in the oceans in a number of ways. It has been discovered that heavy metals such as mercury, cadmium, and lead build up in marines causing toxicity and affecting metabolic functions (Oros, 2025). As an example, neurological impairments, reproductive failure and death have been linked to high concentrations of mercury in fish. On the same note, the POPs, pesticides and PCBs are also present in the marine environment and accumulate up the food chain, thus leading to their long-term health consequences on the highest order predators such as marine mammals and birds.

Persian Gulf is one of the areas that have attracted a number of studies that investigate the effects of oil pollution, heavy metals and industrial effluents in the local marine organisms (Liu et al., 2022; Saravanan et al., 2024). As an illustration, fish species have been found to contain a high cadmium and lead content and the fish are subsequently eaten by the local populations, which is a major health hazard to human beings. Research also cites the destruction of coral reefs, mangroves, and seagrass meadows by growing chemical pollutants and destruction of the habitat. Although much has been done, much of the research has not been able to fill the holes on cumulative and synergistic impacts of various pollutants on fish and marine ecosystems in the area. This research paper aims at exploring the impacts of chemical pollution on marine life and environments in the Persian Gulf. In particular, the research will focus on:

- Measure the level of important chemical pollutants (e.g., heavy metals, organic substances) in water, sediments, and marine fauna.
- Assess the effects of these pollutants on the species, biodiversity and quality of habitat.
- Explore how the levels of pollutants correlate with the shift in species populations and habitat structure of the sea.

The following research questions will be used to drive this study:

RQ1: What are the chemicals pollutants levels in marine water, sediment, and organism at polluted and control sites in the Persian Gulf?

RQ2: What is the influence of chemical contaminants on the health of the marine species (including bioaccumulation, reproduction, and survival rates in marine species) in the Persian Gulf?

RQ3: How do chemical levels of pollution relate to degradation of marine habitats (e.g. coral reefs, seagrass beds, and mangroves) in the Persian Gulf?

RQ4: Do multiple chemical pollutants have cumulative or synergistic impacts on marine ecology in the Persian Gulf?

Materials and Methods

The research was carried out in one of the semi-closed water bodies i.e., the Persian Gulf where a wide variety of marine life i.e. fish, mollusk, benthic organisms are found, as well as critical habitats i.e. coral reefs, mangroves and seagrass meadow. The Iranian Gulf is considered one of the most polluted marine environments in the world, which is mostly related to the industrial activities of oil mining, shipping and urban runoff and so on, which are the main causes of elevated levels of chemical pollutants. The surrounding environment characteristics of this region that contribute to the continued existence of pollutants include the high salinity of the water, the warm water temperatures, and the lack of water exchange. The research was to determine the effects of chemical pollution on marine organisms and ecosystem using samples of two regions within the Persian Gulf: one contaminated and one uncontaminated, which is more distant to the industrial activity. These locations were chosen with reference to their varying degree of pollution, as an attempt to compare the impact of contamination on the marine organisms and ecosystems.

Sampling was performed in two seasons, summer (June 2024) and winter (December 2024) to consider seasonal changes in the levels of pollutants and the behavior of species. Three samples were taken in each site including water, sediment and marine organisms. Four sampling stations were developed (two in the polluted and two in the control), and each of them was chosen according to the known pollution gradients and the habitat types such as seagrass beds, coral reefs, and mangrove forests. Water samples in each station were taken in pre-cleaned polyethylene bottles to determine the concentration of the main chemical pollutants, such as heavy metals, including mercury, cadmium, and lead, and organic contaminants, such as PCBs and pesticides (Piwowarska et al., 2024). A grab sampler was used to collect the sample sediment to a depth of 10 cm to determine the concentration of pollutants on the sediment. The marine creatures such as fish, mollusks and benthic invertebrates were taken as biological samples (Punam & Patel, 2025). These species were chosen based on their ecological significance, and their vulnerability to pollutants and tissues of the species were tested to determine pollutants. A total of 10 replicates were sampled in each site, 5 replicates in the water, 3 in the sediment and 2 in the biological samples so that there is enough statistical power to carry out the required data analysis.

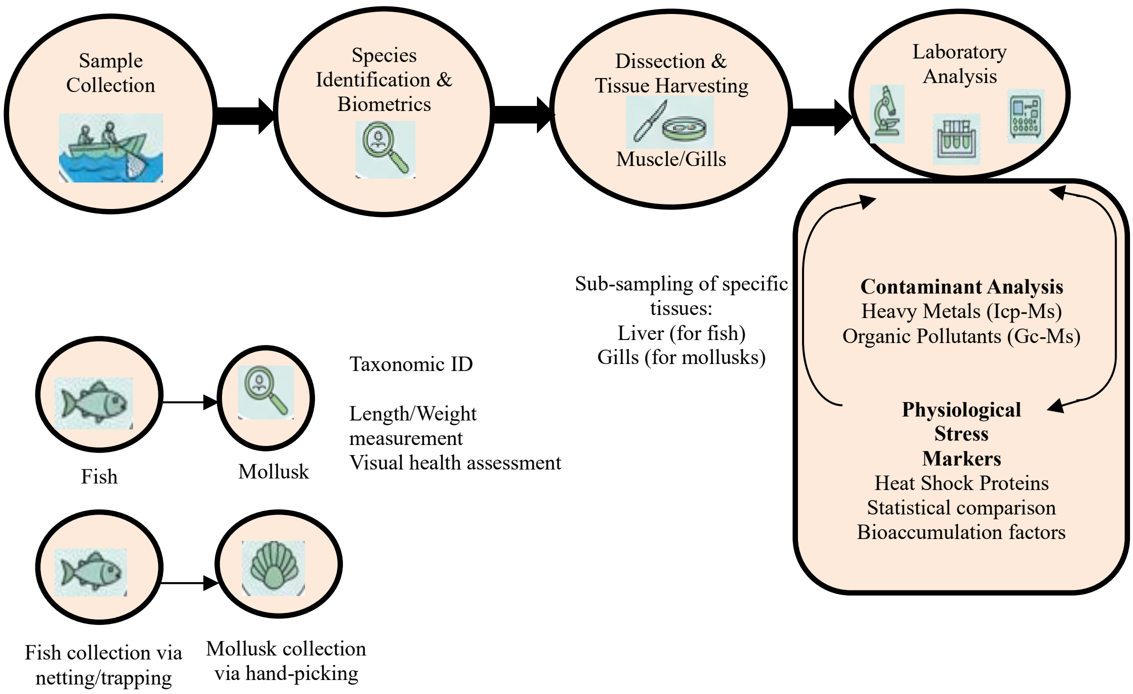

Figure 1: Biological Sampling Process and Analysis Workflow

To determine the concentration of the heavy metals and organic contaminants, the chemical analysis of the pollutants was done in the laboratory by employing sophisticated methods (Faiz et al., 2024). In the case of water samples, the levels of the heavy metals were measured using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), whereas the levels of the organic pollutants were measured using Gas Chromatography-Mass Spectrometry (GC-MS) (Al Naggar et al., 2018). In the case of sediment samples, heavy metals were determined by means of Atomic Absorption Spectroscopy (AAS), whereas organic contaminants were determined by GC-MS (Senthil, 2024). Biological samples of gills, muscle, and liver tissues were analyzed using both ICP-MS, as a method of bioaccumulation of heavy metals, and GC-MS, as a method of organic pollutants (Adeleye et al., 2024). In order to achieve accuracy, the calibration was done using certified reference materials and blank samples were also processed to check the contamination process (Elgendy et al., 2024; Swetha et al., 2025). The detection limits of the heavy metals were established as below, 0.01 µg/L of water and 0.05 µg/g of sediment and biological tissues and the detection limits of organic pollutants were established at 0.05 ng/g of water and 0.5 ng/g of sediment and biological tissues.

Besides the use of chemical sampling, the biological aspect of the research entailed the evaluation of the health and abundance of the marine species in the polluted and control sites indicated in Figure 1. The identification of the species was done using standard taxonomic guides and the diversity of the species was determined with the help of Shannon-Wiener Diversity Index. The abundance of the important species including fish and mollusks was noted in quadrats (1 m 2) that were put in every sampling location. Also, physiological health parameters were measured (e.g. growth rate, reproductive success e.g. egg count in mollusks), and physical deformities or lesions in fish and invertebrates were observed. To gauge bioaccumulation, fish and mollusk tissue samples were checked with contaminants and the physiological effects of chemical pollution were evaluated through stress biomarkers, including the activities of superoxide dismutase (SOD) and glutathione S-transferase (GST) activities. Such biomarkers give information regarding the reactions of the organisms to the pollution on a cellular basis, which suggests the possibility of oxidative stress and other biological damages.

The SPSS and R statistical programs were also used, and the chemical and biological datasets were statistically processed. In this case, there was a comparison of means (pollutant concentrations) between polluted and control sites using One-Way ANOVA and post-hoc tests - Tukey's Honest Significant Different test. Concerning species of the biological data, in diversity and abundance, the Shannon and Weiner and Simpson's Evenness Indices were used. For the remaining health characteristics (e.g. growth and reproduction), a t-test was used in case the data were continuous, while a Chi-square test was applied in case the data were categorical. In assessing the relationship of the concentration of chemical pollutants and the biological identifiers of health and the diversity, Pearson's correlation was used for the normally distributed data, while Spearman's rank correlation was applied to the non-normally distributed data. In all statistical tests conducted in this analysis, the significance level for statistically determining the presence of a difference was set at $p < 0.05$ for all the statistically analyzed data.

This comprehensive sampling design, combined with advanced chemical and biological analysis, allows for a robust investigation of the effects of chemical pollution on marine species and habitats in the Persian Gulf. By comparing polluted and control sites, the study aims to provide valuable insights into the ecological risks posed by chemical contaminants and inform future conservation and pollution management strategies in the region.

Results

The levels of chemical pollutants in biological, sediment, and water samples were much higher in the polluted sites than in the control sites. During the summer and winter sediment and biological surveys, the levels of the heavy metals (mercury, cadmium, lead) and the organic pollutants (PCBs, pesticides) were compared and contrasted in the water and sediments of the polluted versus control sites, and are documented in Table 1.

The highest levels of heavy metals in the water were from the polluted areas, with levels of mercury and cadmium at 0.12 µg/L and 0.05 µg/L, respectively. Mercury and cadmium were, however, absent or only existing in trace quantities in the control sites. There were also higher concentrations of organic pollutants, like cz 5.8 ng/L compared to 0.6 ng/L in the control sites. The sediments also contained critically higher levels of heavy metals. For instance, the mercury levels at polluted sites were 4.6 µg/g, whereas the control sites were recorded at 0.8 µg/g. Other heavy metals like cadmium and mercury also followed the same trend. The concentrations of organic pollutants in the sediments at the polluted sites was higher, with the levels of pesticides exceeding 7.3 ng/g, while in the control sites the pesticide levels were below the detection limits. The polluted sites also had high levels of bio-accumulation in the fish, mollusks, and benthic invertebrates, with the mercury levels in the fish tissues 0.15 µg/g while the control sites were only at 0.03 µg/g. The polluted sites also had the mollusks with significantly higher levels of cadmium and lead.

PCBs, as well as other types of organic pollutants, were also found to be present in greater amounts in the organic tissues sampled from affected locations.

Table 1: Chemical Contaminant Concentrations in Water, Sediment, and Biological Samples From Polluted and Control Sites.

Contaminant Type	Polluted Site (Summer)	Polluted Site (Winter)	Control Site (Summer)	Control Site (Winter)
Mercury (µg/L)	0.12	0.10	0.02	0.01
Cadmium (µg/L)	0.05	0.04	0.01	0.01
Lead (µg/L)	0.18	0.16	0.03	0.02
PCBs (ng/L)	5.8	4.3	0.6	0.4
Pesticides (ng/L)	3.6	2.9	0.1	0.05
Fish Mercury (µg/g)	0.15	0.12	0.03	0.02
Mollusk Cadmium (µg/g)	0.10	0.08	0.02	0.01

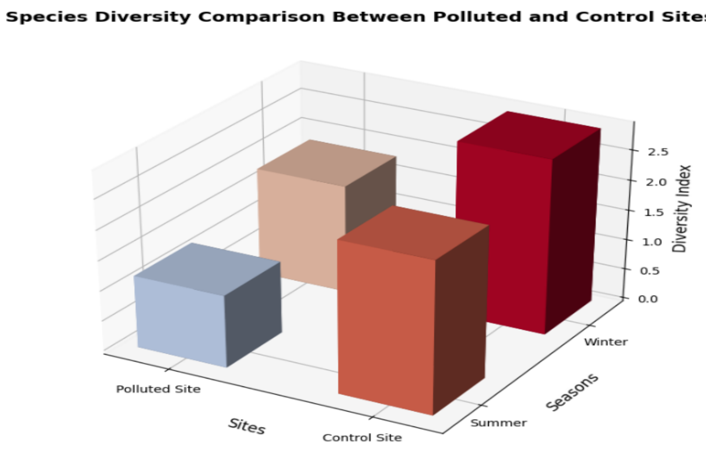

Figure 2: Species Diversity Comparison

There was a notable loss of biodiversity in areas with pollution. There was a Shannon-Wiener diversity index of 2.3 in the unaffected sites compared to 1.2 in the affected sites (see Figure 2). The affected sites had a slightly lower fish species diversity, as 14 species were found in the unaffected sites, while 8 species were observed in the affected ones. There was a statistically significant lower presence of benthic invertebrates in the polluted areas, as there were 60 organisms in a square meter in the affected sites compared to 150 organisms in a square meter in the unaffected zones. The health of the marine organisms in polluted sites was subpar. Fish in the affected areas had lower average growth (18 cm) compared to the control (22 cm). The mollusks also showed signs of reproductive impairment as there was a 30% decrease in the number of eggs laid in the polluted sites compared to the control. There were also some signs of deformities, 15% of the fish and 10% of the mollusks in the affected areas were found to have lesions and fin rot, while the organisms in the unaffected control sites did not have any of these deformities.

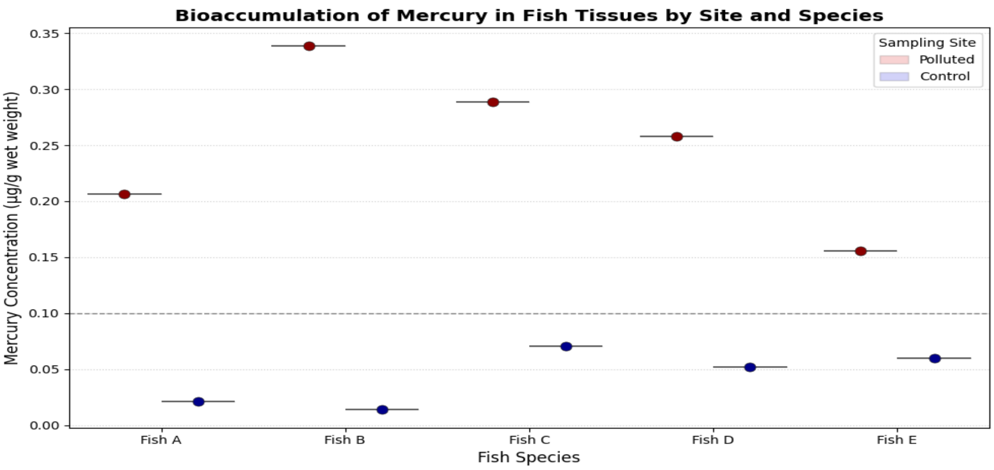

Figure 3: Bioaccumulation of Mercury in Fish Tissues

Pollution in the form of bioaccumulation of heavy metals and organic pollutants was significantly greater in polluted locations as shown in Figure 3. There was high bioaccumulation of mercury (up to 0.15 µg/g in muscle tissue), cadmium and lead in fish at the contaminated locations. The same levels of cadmium and lead were piled in the mollusks of the polluted areas and the concentration of the tissue was 0.10 µg/g cadmium and 0.08 µg/g lead. These levels far exceeded those found in organisms from control sites.

Visual assessments in conjunction with the ecological indicators shown in Figure 4 measured the extent of habitat loss. Previously, the coral reefs at impacted sites were severely bleached. There was only 25\% of the reef that was live- and 70\% of the control sites were live- coral covered. Degraded sites also showed a 40\% loss of benthic seagrass. Mangroves at impacted sites also exhibited poor health, with 20\% of the trees having stunted growth and leaves that were yellow.

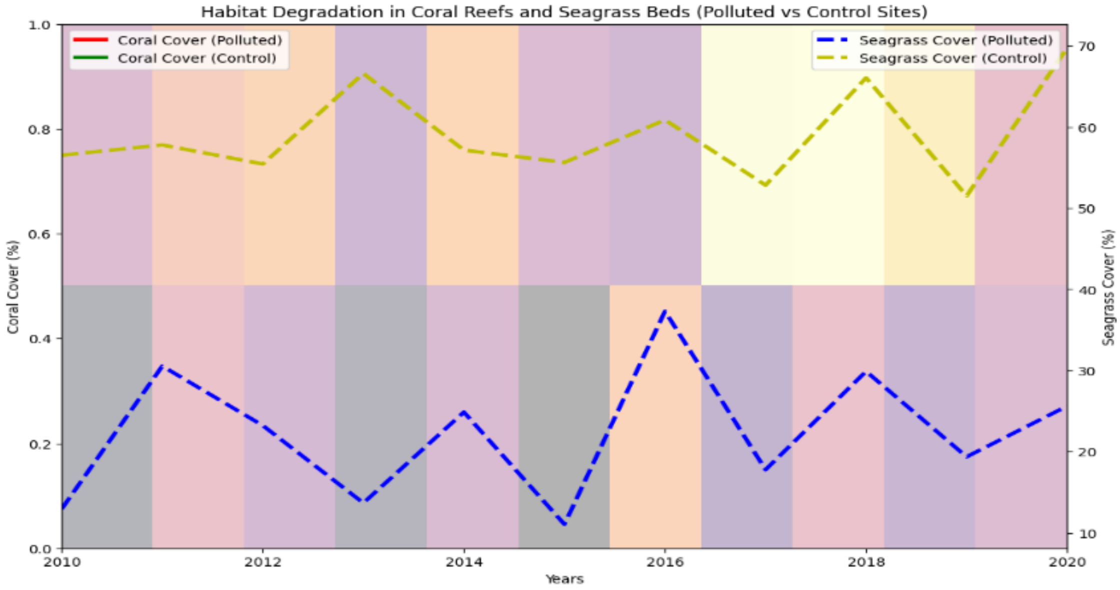

Figure 4: Habitat Degradation in Coral Reefs and Seagrass Beds

Discussion

The findings from this research have added significant knowledge regarding the impact of chemical pollutants on the species and environments of the Persian Gulf. These pollutants include heavy metals such as mercury, cadmium, and lead, and also include organic pollutants such as PCBs and some pesticides, which are all at much higher concentrations at the polluted sites in comparison to the control sites. These pollutants are also in the tissues of marine organisms, most notably the fish and mollusks, and in the water and sediment of the sites. For instance, fish from polluted sites have mercury concentrations in their tissues as high as 0.15 µg/g as compared to fish from control sites which have a concentration of only 0.03 µg/g. The significant decrease in the biodiversity of the concerned area is due to the fact that the pollutants are bioaccumulated and their contaminants are most likely passed from environment to predator and to predator in the food web, thereby causing sudden death in some of the targeted marine organisms. Particularly, the bioaccumulated mercury and other pollutants have caused physiological impacts such as reduction in the growth and reproduction rates of mollusks from the polluted sites as evidenced by the increased size, egg numbers, and the overall number of the mollusks. The control sites had a value of 2.3 and the polluted sites only had a value of 1.2 which also describes the significant loss of species in that area of concern.

Coral reefs, seagrass beds, and mangroves located at polluted sites demonstrate evidence of habitat degradation due to stress factors such as coral cover bleaching and loss (25%) in comparison to control sites (70%). Additionally, and to a like degree, polluted seagrass beds were documented to have only 40% of total seagrass cover at disturbed sites as opposed to control sites which were documented to have healthier and more extensive beds. These findings corroborate conclusions from other polluted regions such as the Gulf of Mexico and North Sea where pollutants have likewise been linked to degradation of marine ecosystems. The stress on these ecosystems is particularly alarming as they offer marine species crucial breeding sites, mitigated coastal erosion and sequestered carbon. Consequently, the loss of such ecosystems is a loss of biodiversity and greatly undermines the functioning of entire marine ecosystems. The implications of this habitat degradation is the loss of these ecosystems which offer the aforementioned services.

The observed phenomena in question can be understood through the mechanisms of bioaccumulation and the toxic effects of chemical substances. Tissues of marine organisms metabolize and store heavy metals such as mercury and cadmium. Impairment of metabolic processes takes place and further leads to decreased success at reproductive levels. The accumulation of such metals leads to an increase of resultant stress and can be assayed and measured through Superoxide Dismutase (SOD) and Glutathione S-Transferase (GST) enzymes. Such elements and substances were not compared over a defined period of time to the study at hand. Prior studies have evidenced the relaxation of pollutants and the resulting biomarkers which demonstrate the cellular damage and increase of the oxidative stress within the organism. Furthermore, these chemical pollutants result in the marine habitats degradation such as the coral reefs and seagrass meadows through the disruption of these ecosystems' functions. Oil and heavy metals correlatively impact the reduction of corals' resilience resulting in coral bleaching and the affecting of seagrass and photosynthesis and thus the growth of the seagrass.

The results carry term of consequence biodiversity and eco system integrity. Loss of marine and coastal biodiversity and patterns of population decline and loss > habitat degradation increased congestion the ecosystems. Loss of biological integrity and degradation of biodiversity and marine habitats and coastal zones leave multiple marine species without places of shelter, without breeding habitats. of the marine pollutants biodiversity of the marine ecosystems. Our investigation only scratches the surface of the influence of chemical contaminants, as there are many other shortcomings. For instance, this research was only conducted at two locations, a polluted site and a control site, leading to generalizability concerns. Future research should look at multiple sampling locations to gain a better understanding of the differences in the effects of pollutants over a large area. Then there is the fact this documented research only examined a limited range of contaminants. Other pollutants, including plastics and drugs, are likely to be equally as important in the degradation of marine ecosystems and should be the focus of future research. Moreover, while there are characteristics of the general trends of bioaccumulation and degradation of the habitat that give us the expectation that these trends are true, we did not measure pollution biomarker indicators at all, like certain enzyme functions and indicators of oxidative stress, which are standard, and that would give us more certain evidence of the physiological damage that is occurring in these organisms (Aziz et al., 2023).

This study's conclusions stretch even further to cover environmental management as well. Due to the negative and alarming consequences of chemical exposure on marine biodiversity and ecosystem health, the implementation of stronger pollution control policies becomes even more urgent. Governments and regulatory bodies must restrict the industrial release of pollutants, especially within ecologically sensitive areas, such as, coral reefs and mangrove forests. Additionally, conservation activities aimed at the restoration of affected habitats should be the primary focus, such as the transplantation of corals, the restoration of seagrasses, and the effects of pollution. Long-term exposure to pollutants and the health of marine organisms should be monitored to serve as a basis for evaluating the effectiveness of management actions. Polished legislators must focus on the reduction of pollution so that marine ecosystems and their organisms can flourish in the future.

Conclusion

The evidence that has been gathered from this research demonstrates that there is exposure to chemicals from contaminants that adversely spill over to the Persian Gulf, harming the marine species and habitats that call it home. The presence of pollutants, namely heavy metals and organics, are accumulating over time within the specimens and negatively impacting the ecosystem on a variety of levels, i.e. ecosystem engineering, species diversity, reproductive success, and habitat/38>health degradation. Enhancing the defenses of the ecosystem and the habitats are of paramount importance in the face of pollution, and this can be achieved through the implementation of stringent pollution control (compilation of pollution from a variety of sources within a habitat). The bioaccumulation of pollutants from the ecosystem has a potential to harm the reproductive success of the marine species and habitats within the Persian Gulf. The cumulative hazard of having a variety of pollutants is always an area of concern and stress. The much-needed focus on pollutants that are in the over-abundance should have an orderly and just focus on the marine life of the Gulf. The pollution and restoration (degraded/deterioration of marine ecosystems, gulf and ecosystems). The life within the gulf and the ecosystems are of paramount importance. The marine life and ecosystems within the Persian Gulf, and the life within, along the ecosystems are paramount. There are pollutants present within the area in over-abundance to be a concern along with a deterioration of marine ecosystems. The life within the gulf, and the ecosystems, are paramount.

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