Evaluating The Effects of Invasive Species on Marine Food Webs and Ecosystem Services in Coastal Habitats

1 Mirkomil Gudalov, Jizzakh State Pedagogical University, Jizzakh, Uzbekistan.

Abstract: Marine food webs play a crucial role in sustaining marine ecosystems. Ecosystem services include the provision of fisheries as well as stability in the habitat. An invader species can be described as a species that enters the ecosystem through anthropogenic means and poses a risk to ecosystem services due to its disturbance of marine food webs. It is unclear what the specific impact of these invasive species is with respect to marine food webs and the services rendered by the ecosystem. The research focused on some of the most common invasive species, including Caulerpa taxifolia, Asterias amurensis, and Mnemiopsis leidyi, in estuaries, sandy beaches, and mangroves of the eastern seaboard of India. Sampling and data analysis lasted 12 months using stable isotope analysis and food web modeling techniques. Findings suggest that there is an observable disruption in the complexity of food webs due to the presence of alien species within different trophic levels, which contributed to the reduction in species diversity, biomass, and ecosystem resilience. There were impacts on ecosystem services in terms of fish production and nutrient cycling, according to the findings of the research. The findings of the current research emphasize the importance of implementing conservation policies and measures for detection and intervention in the early stages of ecosystem damage.

Keywords: Invasive Species; Marine Food Webs; Ecosystem Services; Coastal Ecosystems; Biodiversity Loss; Fisheries; Nutrient Cycling.

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I. Introduction

Marine food webs play a crucial role in maintaining the balance of coastal ecosystems (Glibert et al., 2011). They control the process of energy and nutrient transfer, promote diversity, and maintain the stability of coastal ecosystems. Marine food webs interact with coastal ecosystem services, which are beneficial to both ecosystems and humans (Giakoumi et al., 2015). Coastal ecosystem services, such as provision services (fisheries) and regulating services (nutrient cycling), are affected by marine food webs. Invasive species are considered to be non-native organisms that have a negative effect on ecosystems. Human activities, such as the transportation industry, aquaculture, and ballast water discharge, may introduce invasive species into coastal ecosystems. Invasive species may disrupt the food web balance, compete with native species, and affect ecosystem services (Calizza et al., 2021; Gallardo et al., 2019). As invasive species usually have no natural predators in the new ecosystem, they may dominate other species and adversely affect coastal ecosystems (Walsh et al., 2016; Ramus et al., 2017).

While the effects of invasive species on marine ecosystems have gained a lot of recognition, it appears that little attention has been given to the changes that invasive species cause in terms of trophic relationships in marine ecosystems (Salvaterra et al., 2013; Gallardo et al., 2016). Although there have been studies focusing on single invasive species, very few studies have analyzed the overall impacts of invasive species on the functioning of marine food webs and ecosystems (Deudero et al., 2011; McLaughlan et al., 2014). In addition, the invasion of new species may seriously affect critical ecosystem services, including fisheries, nutrient cycles, and habitat stabilization.

This information gap prevents one from accurately predicting the adverse consequences that invasive species will have on coastal ecosystems and the ecosystem services that they provide. An in-depth analysis is needed to design appropriate management actions.

The purpose of this research is to explore the impacts that particular invasive species have on the marine food web structure in coastal environments and how this will affect the ecosystem services provided. Research questions for this project include:

1. How does invasion affect the structure and function of marine food webs in native ecosystems?
2. How does the impact of invasion on food web structure affect provisioning, regulating, and cultural services in coastal areas?
3. What are the other ecological and socioeconomic implications of invasions on ecosystem services?

In this investigation, an attempt will be made to bridge the information gap in terms of understanding the complex interactions between invasive species and the functioning of marine food webs.

The paper is organized as follows: In the first section, there will be discussions on marine food chains/food webs and ecosystem services with emphasis on the threat caused by invasive species. The second section will cover the study area, habitat, invasive species, and sample collection methodology through stable isotopic analysis and food web modeling. Section three will cover major findings on changes in trophic structures, invasive species, and their impacts on ecosystem services through figures and tables. Section four will have interpretations of the results relative to other global studies.

II. Materials and Methods

Study Region and Habitat Description

The study was conducted in coastal areas where there are different marine biotic communities. These ecosystems comprise estuaries, sandy beaches, and mangroves, all of which play essential roles in ensuring biodiversity and ecosystem functioning. These ecosystems were selected due to their vulnerability to alien species invasion and their importance in offering critical ecosystem services like fishing, nutrient cycling, and carbon sequestration. The tropical and subtropical coastal regions under consideration guarantee the inclusion of different low latitude ecosystems in the study. The coastlines analyzed are 200 km long, mainly around the Bay of Bengal.

Target Invasive Species and Native Community Profile

The above species to be discussed in this research paper are *Caulerpa taxifolia*, *Asterias amurensis*, the ctenophore *Mnemiopsis leidyi*, and the lionfish *Pterois volitans* because they have shown interference with the tropical and subtropical reef environment, have high reproductive capabilities, and also do not have any natural enemies in the Bay of Bengal. The selected species were picked based on their interference with other ecosystems. Interference by these species is due to the fast reproduction ability, competition with the local species, and absence of any predators of these species. Local communities include several animal species like *Lutjanus argentimaculatus*, *Penaeus monodon*, and *Siganus canaliculatus*. These animals are important in the local food chain.

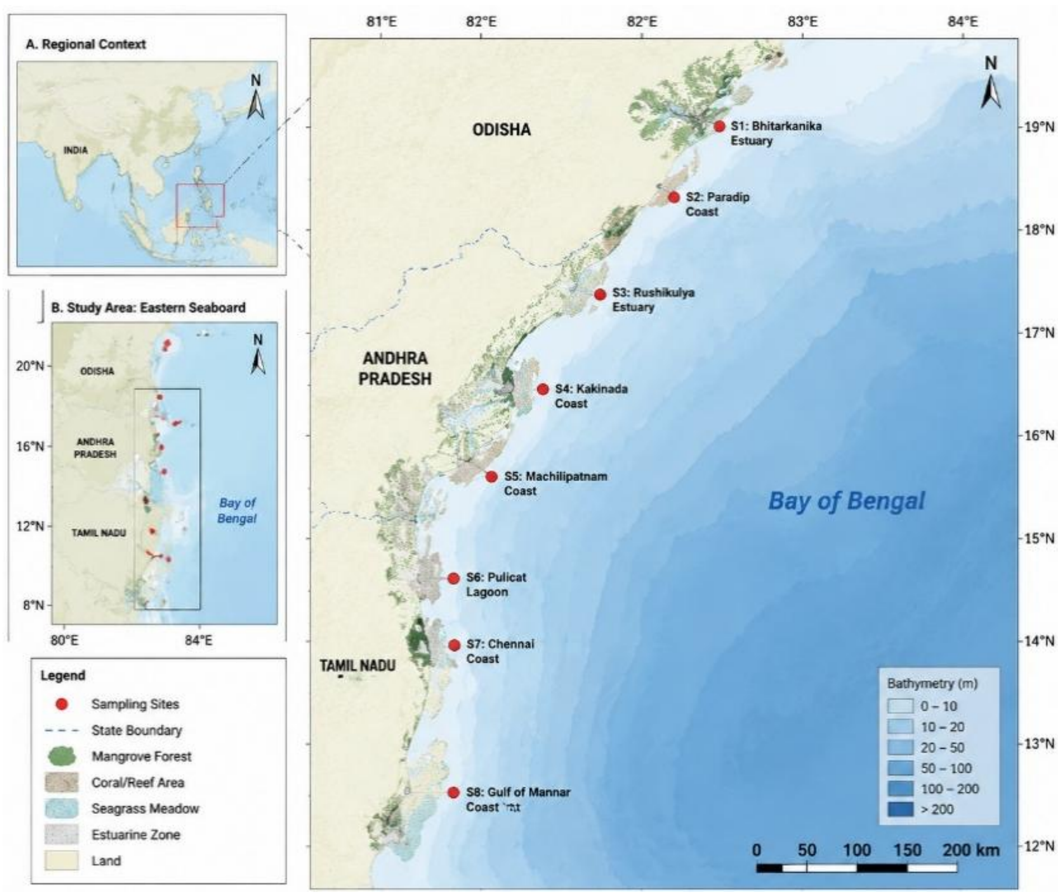

Figure 1: Study Region Map with Sampling Locations

The map of figure 1 displays the detailed study area along the east coast of India. In addition, this figure shows some inset maps that give a general picture of the location, where symbols have been added to illustrate various types of coastal ecosystems, including mangroves, coral reefs, sea grass beds, and estuaries. Depth shading on the map provides the readers with an idea about the water depth at different places, and boundaries for various states, along with sampling areas (S1-S8), have been labeled clearly.

Sampling Protocols

Through point surveys along transects set up in the study areas, sampling was done. A mixture of benthic and pelagic sampling approaches was utilized to get samples from bottom-dwelling and free-swimming species, respectively. Trophic information was gathered through stable isotope analysis in order to find out the trophic relationships between species in the food web. Water and sediment samples were collected to ascertain the nutrient content of the habitat. Information on species abundance and biomass was obtained through direct observation, quadrat sampling, and trap sampling. The duration of data collection was 12 months, taking into consideration seasonal variation due to invasion by the alien species.

Analytical Methods

The study of the trophic interactions in the marine food web was conducted using the method of stable isotope analysis. Isotopic signatures were used to determine the primary producers and consumers in the marine food web. In addition, they allowed for evaluating the trophic position of both invasive and native species. Ecological food web modeling, which involved the use of Ecopath with Ecosim software, was used to create an ecological model of the system, which simulates species interactions and the energy flow within the systems under study. The construction of such networks provided the opportunity to visualize the impact that invasions by alien species had on the structure of the food web. The network characteristics – the node degree, connectance, and trophic level were computed in order to assess the food web complexity and stability.

Statistical Analysis

All the data were used with R software (version 4.0.3) during Statistical analysis. Both descriptive statistics, such as means, standard deviations, and ranges, were computed for all quantitative data. Inferential statistics like ANOVA and regression analysis were applied to test if there is any significant difference between the invaded site and the non-invaded sites based on variables like species diversity, biomass, and functionality of the ecosystem. Correlation analysis was further done to determine if there was a relationship between invasion and modification of the food web. Statistical significance level (p-value) of less than 0.05 was used for all statistical tests.

Ecosystem Services Assessment Approach

The ecosystem services were analyzed employing both functional measures and methods of economic valuation. Some of the key functional measures included primary production rates, nutrient cycling efficiency, and habitat stability. The measures above were used to analyze the effect that invasive species have on ecological processes. Moreover, the measures were conducted in various habitats to examine the differences in the delivery of ecosystem services between those that are invaded and not invaded. Also, an economic valuation of provisioning services such as fisheries productivity was conducted using market approaches and ecosystem service models.

III. Results

Changes in Trophic Structure

Major changes in the trophic structure were noted after the invasion of exotic species in the coastal ecosystem. Comparing the food webs before and after the invasion indicated a disturbance in the equilibrium between species interactions, where the native species were displaced by the exotic species. The exotic species, like *Caulerpa taxifolia* and *Pterois volitans*, occupied different trophic levels, hence changing the energy flow in the ecosystem. Metrics, such as connectance, trophic level, and node degree, were computed to compare the food webs, revealing a decline in the complexity of the food webs and the stability of the ecosystem.

Table 1: Network Metrics Comparison Between Non-Invaded (Control) and Invaded Food Webs

Metric	Non-Invaded	Invaded	p-value
Connectance	0.45	0.35	0.001
Trophic Level	2.8	2.5	0.015
Node Degree	4.3	3.1	0.002
Species Richness	35	25	0.020

Table 1 presents important network parameters of the food webs before and after the invasion of invasive species. The reduction in connectance, trophic level, degree, and species richness is evident, suggesting that the food web is more simplistic as a result of the invasion.

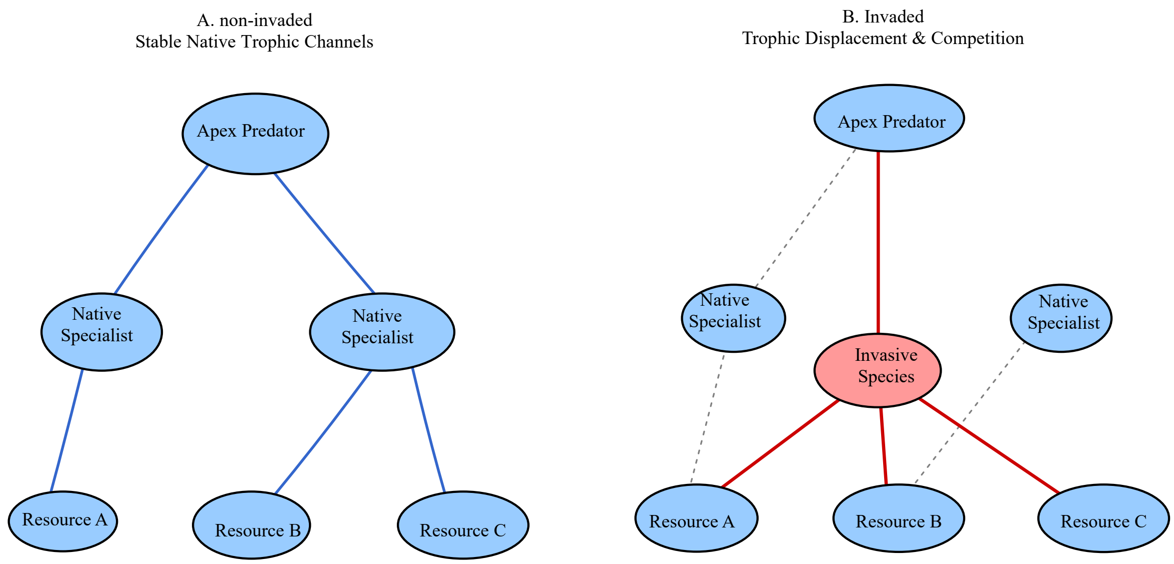

Figure 2: Comparative Food Web Diagrams Before and After Invasion

Figure 2 shows two models of the food webs: first, a model of the food web in the ecosystem prior to the invasion of alien species, and second, a model of the food web in the ecosystem following the invasion of alien species. The figures show that the alien species invaded different trophic levels, thereby reducing the complexity of the food web.

Species Abundance or Biomass Shifts

The invasion by alien species resulted in drastic changes in the abundances and biomass of the species. The native species *Lutjanus argentimaculatus* and *Penaeus monodon* showed reductions in their abundance and biomass in the invaded ecosystems, whereas the invasive species *Caulerpa taxifolia* and *Asterias amurensis* exhibited increases in their abundance and biomass. Biomass was calculated based on sampling data, and the findings revealed that the biomass of native species was gradually being substituted by invasive species.

Table 2: Biomass Changes of Native and Invasive Species

Species	Non-Invaded (g/m²)	Invaded (g/m²)	p-value
Lutjanus argentimaculatus	250	120	0.030
Penaeus monodon	300	150	0.040
Caulerpa taxifolia	10	75	0.005
Pterois volitans	15	90	0.002

Table 2 displays the biomass of the native and the invading species Non-Invaded and Invaded. This illustrates a sharp decline in the biomass of the native species and an equally remarkable increase in that of the invading species.

Influence on Ecosystem Functions

Invasive species had a considerable impact on the functioning of ecosystems, especially with regard to the process of primary production and nutrient cycling. Where the invasive species were dominant in the environment, the rate of primary production became low due to competition among the primary producers. Also, nutrient cycling in the ecosystem was greatly hindered since invasive species such as *Caulerpa taxifolia* interfered with the cycling of nutrients within the ecosystem.

Patterns Linking Invasives to Service Disruption

Invasive species increase was directly associated with disturbances in important ecosystem services, including fishery production, carbon capture, and water quality regulation. The invasion of *Pterois volitans* and *Caulerpa taxifolia* reduced fisheries production by competing for or preying on fish native to the area, while other species caused deterioration in water quality due to changes in nutrient composition. The impacts were measured using indicators of ecosystem services and revealed a significant reduction in the supply of ecosystem services in highly invaded areas.

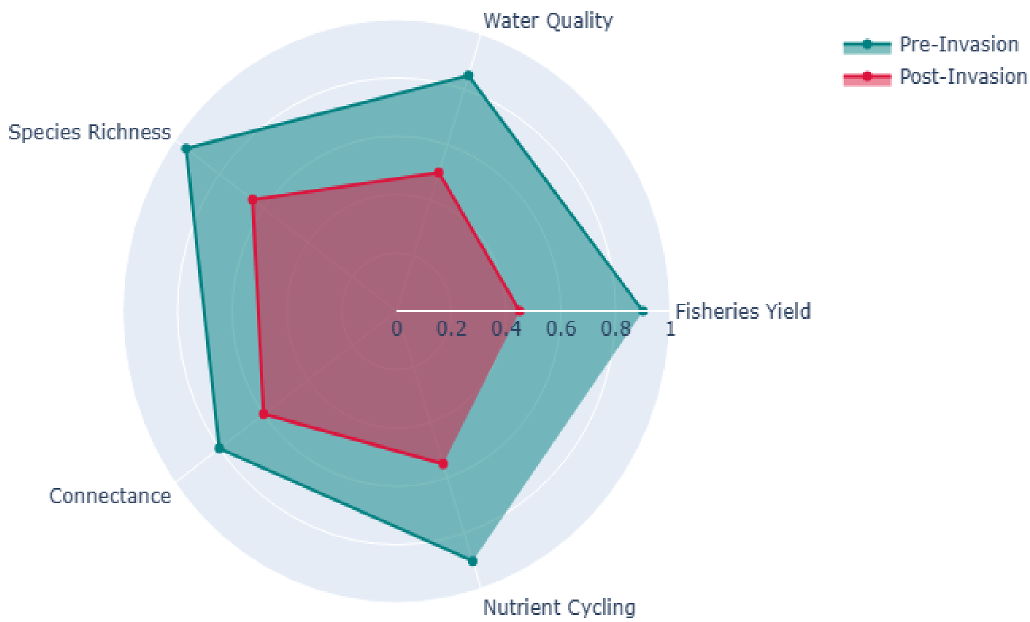

Figure 3: Changes in Ecosystem Service Indicators (Fisheries Yield and Water Quality)

Figure 3 shows that two important indices of ecosystem services, namely fisheries yield and water quality, have been plotted before and after the invasion by invasive species. It is evident from the figure that there has been a decrease in fisheries yield and water quality after the invasion.

IV. Discussion

The invasion of alien species such as *Caulerpa taxifolia* and *Pterois volitans* greatly impacted the structure of marine food webs in the studied ecosystems, resulting in a changed food chain and lower species diversity. Alien species, by inhabiting various trophic levels and competing with the indigenous species, brought about decreased food web complexity and diversity, thus undermining the stability of the ecosystem. Such changes negatively impacted the ecosystem functions, especially in terms of reduced fisheries production and nutrient cycling. The loss of fisheries, an important provisioning function, led to financial losses, while lowered efficiency in nutrient cycling affected the quality of the aquatic habitat. This is supported by other studies conducted regarding the effects of invasive species on marine food webs which exhibit negative effects, including the predatory effect of *Pterois volitans* on native fishes in the Caribbean Sea and alterations of primary producers caused by *Caulerpa taxifolia* in the Mediterranean Sea (Tsirintanis et al., 2022; Corriero et al., 2016). The study underscores the importance of implementing conservation measures that incorporate early warning and rapid response measures for containing the invasive species and restoration approaches intended to restore the damaged ecosystem. In order for a successful management of the coastline, consideration of both ecological and economic concerns is necessary for the purpose of ensuring that the local flora and fauna are preserved. The mitigation process involving the eradication of invasive species and restoration of the habitat could contribute to bringing back the stability of the food web.

V. Conclusion

This research observes the substantial ecological effects that the presence of invasive species causes to marine food webs in coastal areas. Such invasive species as *Caulerpa taxifolia*, *Asterias amurensis*, and *Mnemiopsis leidyi* have disrupted the normal functioning of the ecosystem in coastal areas. Invasive species have caused a change in the food web in terms of competition, which has resulted in a decrease in species diversity. This means that the resilience of these ecosystems has been weakened due to competition among species and changes in the normal functioning of marine food webs. Ecosystem services, such as fisheries yield, have been degraded because of competition, and the decrease in provisioning services and water quality has been observed. In this regard, it becomes clear why the importance of the study in terms of ecosystem services should be highlighted since the negative effects on marine food webs have serious consequences for coastal communities. The results of the research are consistent with global literature on the issue. The early detection of non-native species, along with rapid response policies and the elimination of non-natives, is imperative to reduce the threat from their proliferation. It is vital to restore habitats and conserve the native biodiversity to maintain the integrity of ecosystems and the ecosystem services provided. Decision-makers should ensure that all three factors are considered in coastal management strategies to preserve marine biodiversity and its services.

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