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Rethinking Biological Invasion as a Balance Between Ecological Risk and Adaptive Opportunity

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Abstract: ***Biological invasion is regarded as the most challenging ecological problem of this present scenario. invasion whether accidental or intentional imposes a number of detrimental effects like destruction of biodiversity, homogenization of community, disruption of food web structure, economic loss and different health hazards. Example like*** **Parthenium hysterophorus** ***in India, zebra mussels in North America, and the Nile perch in Lake Victoria buttresses the ill-effects of invasive alien species. On the contrary, invasive species in several instances serves as source of food, fodder and different ecosystem services like removal of different heavy metals, purification of water, phytoremediation and cultural integration etc. For instances,*** **Prosopis juliflora** ***supporting rural livelihoods, water hyacinth helps in phytoremediation, and tilapia supporting fishery industry. Invasion causes phenotypic plasticity and accumulation of variation which ultimately causes species more resistant and adapted to the environment. So, the invasion can neither be addressed as curse nor boon completely as there is a trade off between these two types of roles. Whether it is boon or curse depends on the ecological context and management strategy. Acoordingly, invasion is a multifaceted eco-evolutionay phenomenon which needs to be understood thoroughly with respective to the current ecological context when framing conservation priorities and strategy.***

Keywords: Biological invasion, Invasive species, Ecosystem disruption, Biodiversity loss, Ecological homogenization

1. Introduction

Biological invasion has long been studied as a matter of serious concern in ecology. In *The Ecology of Invasions by Animals and Plants,* 1958 Charles Elton emphasized invasion as a potential disruptors of our ecosystem. Accordingly biological invasion is designated as a subject of serious ecological concern of multidisciplinary field, integrating ecology, evolution, economics, and social sciences.

Long ago, invasion was regarded as means of population expansion. Europeans reshaped different types of ecosystem by introducing various live stocks, crops, different rodents and weed species and such types of invasions were regarded as beneficial and integrated to our agriculture and other ecosystem services. So, discrimination of this ecological phenomenon as a major cause of ecosystem disruption came later due to its persistent effects on the biodiversity in the long run.

Invasion challenges the boundaries between the concept of indigenous and alien. In this recent scenario, when due to different anthropological disturbances climate changes and invasion is facilitated (Sarkar et al. 2026) in different types of ecosystem, there is a trade-off between harmful invasive species and beneficial introduced species. Conceptually, invasions challenge traditional boundaries between “native” and “alien.” In a rapidly changing world, where climate shifts and human activity blur ecological lines, the distinction between harmful invaders and beneficial newcomers is increasingly contested. This distinction foments the “curse or boon” debate.

In this 21st century, the concept invasion can be addressed as an ecological phenomenon having dual perspectives. Invasion can be said both as an ecological threat for the survival of ecosystem. In the 21st century, invasion is recognized both as ecological threat as well as ecosystem service provider (Sarkar et al. 2016). Invasive species is regarded as a nuisance to the ecosystem concerned causing destruction of biodiversity, economical loss, and degradation of the ecosystem. On the contrary, aquatic invasive species has been reported to serve as refuge for a number of mcroinvertebrates and as ecosystem service provider (Sarkar et al. 2016) and a means of cultural integration. For instance, the Nile perch has been documented to have devastating effects on the native fish populations but at the same time it harbours another type of fish population assemblage serving local peoples and thus local economical improvement. In another example, water hyacinth has been found to transform water bodies eutrophic, clogs water ways, and destroys native hydrophytes but can also be used as biofuel, materials of handicrafts and remover of heavy metals in water bodies (Villamagna and Murphy 2010). Such case studies nullifies our decade-long ideas of invasive species rather qualifies its beneficial role in an ecosystem. Form evolutionary perspective, invasion can be featured as positive interaction in addition to its harmful effects as it inculcates different adaptive features in native species while introduced species evolve phenotypic plasticity to overcome the adverse situation. This dynamic dual play enriches our understanding about different manifestations of evolution in real time.

Thus biological invasion is not any isolated phenomenon but an emerging problem in this modern era where pollution facilitates invasion. It encompasses the complex interaction of animal kingdom with the nature which compels us to reconsider the conservation priorities while framing and implementing conservation strategies. This review sets the stage for exploring invasions as both curse and boon, highlighting their multifaceted impacts across ecological, economic, and cultural dimensions.

2. Harmful Effects

1) Loss of biodiversity: Invasive species causes different native species to decline due to their low resilience thus causing significant devastating effects on diversity worldwide (Clavero and García-Berthou 2005). The communities are affected from local to global scale leading to global homogenization of ecosystems. In Indian context as evidenced by Hiremath & Sundaram 2005, *Lantana camara* causes frequent forest fires destroying local species assemblage and degrading the forests area. In another example, the diversity of crops and indigenous species are destructed by *Parthenium hysterophorus* which exerts cascading effects on pollinators (Nawaz et al. 2025; kaur et al. 2014; Masum et al. 2013). As reported in Australia, destruction of native vegetation and soil erosion was caused by an invasive rabbit population *(Oryctolagus cuniculus*) (Lees and Bell 2008; Courchamp et al. 2003). Australian native predator population viz. monitor lizards and snakes were declined due to introduction of invasive *Cane Toad (Rhinella marina*) in Queensland (Shine, 2010). In Guam of pacific Islands, introduction of *Brown Tree Snake (Boiga irregularis*) killed nearly all native forest birds showing a good example of predator driven extinction (Savidge 1987). An invasive goat species (*Capra hircus*) when introduced into Galapogos Island causes severe destruction of indigenous plant communities due to extensive overgrazing of indigenous plant communities thus exerting community top-down effect of food web (Campbell et al. 2004). In South Africa, introduction of black wattle plant species *Acacia mearnsii* caused severe reduction of grass cover due to which live stocks decline and also altered forest fire regime (Richardson & van Wilgen 2004). Introduction of Nile perch (*Lates niloticus)* in Lake Victoria caused around 200 endemic cichlid species to become extinct (Ogutu-Ohwayo 1990). In North America, introduction of *Zebra Mussels (Dreissena polymorpha*) was found to reduce native mussel population thus causing homogenization of habitat reshaping the structure of food web. (Strayer 2009). In America, another invasive bird species *European Starlings (Sturnus vulgaris*) was found to out compete the native cavity-nesting birds, causing rapid decline of their population (**Linz 2007; Koenig 2003)** In sum up, invasion has been recognized as an obvious natural phenomenon which causes extinction of certain low-resistant native population leading to simplification of food web and alteration of community dynamics (Mooney and Cleland 2001, Sax et al. 2007; Early et al. 2016).

2) Disruption of ecosystem dynamics and economy: In India, invasion of water hyacinth into different water bodies whether accidental or intentional has showed tremendous reproductive potential degrading the quality of water like depletion of dissolved oxygen level, decrease of pH, increase in nitrate and phosphate content of water (Sarkar et al. 2016). This noxious weed has also been reported to block the water ways and thus affects the fisheries, transport and irrigation of that area. Above all, this invasive weed population causes native hydrophytes and associated animals to die out due to low resistance in such highly competitive, hostile environment and disrupts the ecosystem balance. In North America, Golden and Zebra mussel population has been found as invasive and remains attached to the hard surfaces. They block the water channels and take over the control of the entire ecosystem thereby restructuring the ecosystem (Petsch et al. 2021; Strayer 2009; Ricciardi et al. 2003). In India, *Parthenium hysterophorus* is a potent, highly prolific invasive weed which reduces crop production by releasing different allelochemicals like parthenin, hysterin, hymenin, and ambrosin (Kaur et al. 2014). The allelopathy has been reported to inhibit the germination and growth of a different variety of monocot and dicot plants. Due to severe destruction of crops, huge amount of money is to be invested in agriculture to ensure food security and rural economy. The weed also interferes with the nitrogen fixation process of nitrifying bacteria, viz. *Rhizobium, Actinomycetes, Azotobacter, and Azospirillum.* This notorious weed also acts as a host of different viruses of crop plants (Kaur et al. 2014).

3) Severe health hazards: *Parthenium hysterophorus* (India) is one of the noxious weed in India (Gnanavel and Natarajan 2013) to cause dermatitis, hay fever, asthma, bronchitis and respiratory allergies due to the presence of few common allergens parthenin, coronopilin, tetraneuris, and ambrosin (Kaur et al. 2014). Few invasive mosquitoes like Aedes *albopictus* (Asian Tiger Mosquito) are found to spread different diseases like , chikungunya, and Zika. Water has been has been found to harbor a planorbid snail *Indoplanorbis exustus* species which transmits schistosomiasis**,** and human cercarial dermatitis (Sarkar et al. 2023)

Ultimately, biological invasions remind us of the interconnectedness of human and ecological systems. They are both a warning of the unintended consequences of globalization and a testament to nature's capacity for adaptation. By embracing a nuanced view, societies can transform invasions from ecological crises into opportunities for resilience, sustainability, and innovation.

Beneficial effects: Biological invasions, though often destructive, can also be harnessed for human and ecological benefit. Case studies from India and all around the world demonstrates that invasive species provides resources like food, fodder, ecosystem services, evolutionary opportunities, and cultural enrichment. The challenge lies in adaptive governance—knowing when to harness these invasive aliens responsibly and when to control them. By recognizing invasions as potential boons, societies can develop nuanced strategies that balance ecological integrity with socio-economic needs.

4) Agriculture and Livelihoods

a) **Food and Fodder:** Invasive species can serve as alternative source of food and fodder where biodiversity cannot meet the food crisis due to degradation of habitat. In sterile habitats of India and Africa *Prosopis juliflora* acts as fuelwood, fodder, and thus a source of earning livelihood for local people. (Shackleton et al. 2014; Mwangi and Swallow 2005).

b) **Fisheries:** Tilapia (*Oreochromis spp.*) is easily available aquaculture species across Africa and Asia thus minimizing food crisis (Canonico et al. 2005; De Silva 2004). In Asian countries, invasive carp has rejuvenated fishery industries and rural economy (Lorenzen 2000). In Lake Victoria, Nile Perch has fomented the

establishment of fishery industries although it has been a notorious fish of ruining the biodiversity of local community (Pringle 2005).

5) Ecosystem Services

Despite several ill-effects, invasive species has been found to serve different ecosystem services especially when the native species diversity fails to support due to degradation of habitats. Invasive species prevents soil erosion stabilizing soil structure, eutrophication, and purify water at a certain percentage of coverage in water body. *Acacia mearnsii* helps stabilization of soil and carbon storage in South Africa (Richardson and van Wilgen 2004). *Eichhornia crassipes* (water hyacinth) can be utilized in the purification of waste water and thus phytoremediation (Malik 2007; Lu and Zhu 2011; Gopal 1987). *Parthenium hysterophorus* has been documented as green solution for the treatment of degraded soil. Several species of algae has been utilized in bioremediation as well as maintaining biogeochemical cycles (Shanab et al. 2010).

6) Economic and Industrial Uses

There are plenty of examples where aliens are utilized commercially to serve different purposes for ecosystem sustenance. The Kudzu *Pueraria Montana can be used as* biofuel crop and also has medicinal values (Forseth and Innis 2004; Duke 1992). For production of bio-gas and bioactive substance, *Parthenium hysterophorus* is used widely (Kaur et al. 2014). *Eichhornia* sp. can be used for the production of bioethanol and animal feed supplement (Shanab et al. 2010). *Prosopis* charcoal has been reported to serve as critical source of rural energy needs (Mwangi and Swallow 2005). Golden Mussel (*Limnoperna fortunei*) has the potential to filter water thus purifying water (Boltovskoy et al. 2006).

7) Human Health and Medicinal Potential

Various invasive alien species have medicinal or pharmaceutical uses. For instance, *Parthenium hysterophorus, Eichhornia crassipes* have antimicrobial and antioxidant properties (Kaur et al. 2014; Lu and Zhu 2011; Shanab et al. 2010). Due to having isoflavones, Kudzu is known a traditionl medicine having cardiovascular benefits (Duke 1992).

In sum up, it can be asserted that invasive species plays a dual role when considering maintenance of diversity and balance of ecosystem as well as providing ecosystem services. Pejchar and Mooney (2009) emphasized the positive impacts of invasion while Vilà and Hulme (2017) explained the dual impacts of these invasive aliens in ecosystem. Many authors have highlighted its positive impacts to utilize these alien species for balancing ecosystem, deriving ecosystem services thus minimizing its disruptive potential (Simberloff et al. 2013; Pyšek and Richardson 2010). Despite different ecosystem services and cultural practices it causes homozenisation and ultimately extinction of an ecosystem by destruction of native species, loss of biodiversity, simplification of food web, degradation of habitat. Considering different explanations regarding potential harmful and positive impacts in an ecosystem as evidenced by different eminent authors, it can be excerpted that, this obvious natural or man-made phenomenon can be best utilized for the sustenance of ecosystem because of different ecosystem services that it provides if these invasive aliens can be maintained at e certain density level or percentage coverage (Sarkar et al. 2016).

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