CHAPTER 29

Invasive Species and Invertebrate Pests: Challenges in Conservation Biology

WARDA MUSTFA[1], MUHAMMAD TAHIR[1], NAZIA EHSAN[1*], SHAHABA TEHREEM[1], SYEDA EISHAH TU RAZIA[1], SADIA MAALIK[2], SAJIDA MUSHTAQ[2], IQRA BIBI[1]

[1]Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan
[2]Department of Zoology, Government College Women University, Sialkot, Pakistan
[*]Corresponding author: naziaeuaf@gmail.com

SUMMARY

Invasive species are widely recognized as a major threat to biodiversity. There has been no quantitative global assessment of their effects and routes of introduction. Invasions may have local impacts, but the drivers of biological invasion are increasing globally. Unfortunately, there is a lack of information on invasive species on a global scale. Managing invasive species necessitates directing limited resources toward the initiative-taking mitigation of those species that could have the most significant ecological impacts. This chapter will comprehensively explore the various aspects of invasive species, including their invasion mechanisms, ecological impacts on the environment, biodiversity loss and challenges associated with the identification, monitoring, and challenges in conservation of species. Based on the studies, it is recommended that Pakistan addresses this issue by increasing awareness, establishing a database on invasive species fostering international cooperation, conducting case studies, and implementing essential legislation, regulations, and monitoring measures. Human-induced disturbance is when natural vegetation is removed for mining, forestry, and farming purposes. Because of their altered soil structure, moisture, nutrient availability, and lack of competition, these create an open niche for alien invasiveness. Due to their enormous capacity for growth and proliferation, alien invasive species have a negative impact on the local environment. These effects include disturbance of habitat, biodiversity loss, economic loss, and ecological imbalance. Several types of pests have their impacts on the environment and the major ones are invertebrate pests. Insects, molluscs and arachnids are the main of them. So, to control them different conservation strategies should be used. Pesticides are being used at large scale to control pests, but these pose harmful impacts on the environment and these pesticides are also harmful to the non-targeted species. Biological control is the best way for ecological restoration in which living organisms are introduced to control pests.

INTRODUCTION

The biodiversity of the world is rapidly decreasing due to both direct and indirect human activities. A considerable number of species have already gone extinct, the number of others having declined to the point that they are vulnerable. Nowadays, to maintain their survival and better their management, many species need human assistance. The main causes of extinction are human caused factors such as pollution, over-exploitation, introduced species and habitat loss. One practical instrument for managing the environment and natural resources is biodiversity conservation. The biodiversity of the earth is impacted by humanity in a variety of intentional and unintentional ways. Up until now, human habitat modification to create space for farms or to gather natural resources has posed the greatest threat to biodiversity; however, as climate change gets worse, ecosystems will be increasingly impacted (Seymour et al., 2001).

Anthropogenic activities include mining, releasing industrial waste, smelting arsenic ore, burning fossil fuels, especially coal, using arsenic-loaded irrigation water, fertilizers, insecticides and herbicides using arsenic as an ingredient (Prakash and Verma, 2022). Human activity has had a substantial impact on the natural environment. The amount of land used for agriculture quadrupled between the 1700s and 2000s, while the amount of natural vegetation decreased by half worldwide. Furthermore, a large number of scientists contend that human activity is mostly to blame for the recent increase in CO_2 levels in the atmosphere. The primary source of elevated CO_2 is the combustion of fossil fuels such as coal and petroleum. The entire biota, including people, is facing an overwhelming challenge because of climate change and global warming. The primary source of global warming, which increases the greenhouse effect brought on by excessive human activity, is also what causes climate change. These negative alterations are mostly the result of non-systematic human activity. Many human actions, including habitat conversion and destruction, over-exploitation of species, fragmented areas of native vegetation, and pollution of the air and water, can lead to a loss of biodiversity (Verma et al., 2020).

Invasive species frequently outcompete or prey on native species, disrupt natural processes and may eventually lead to the extinction or decline of native plants and animals. Plants,

How to Cite: Mustfa W, M Tahir, N Ehsan, S Tehreem, SET Razia, S Maalik, S Mushtaq & I Bibi, 2024. Invasive species and invertebrate pests: challenges in conservation biology. In: Zoology: Advancements and Research Trends (Ijaz MU, N Ehsan, M Imran & S Yousaf, eds): FahumSci, Lahore, Pakistan, pp: 229-238. ISBN: 978-627-7745-02-8. https://doi.org/10.61748/Zool.2024/29

animals, fungi, and microorganisms are examples of invasive species (Simberloff et al., 2013). Various mammals, such as dogs, cats, horses, cattle, sheep, pigs, goats, and deer have been imported into the United States. However, some of these species have escaped or been released into the wild, where they have become pests by preying on native animals, consuming plants through grazing and accelerating soil erosion. For example, goats (*Capra hirus*) have caused the extinction of eight indigenous plant species and put another eight native plant species in endangerment on San Clemente Island, California (Pimentel et al., 2005).

Manny scholars have identified three to five distinct steps that make up the invasion process. A species is classified as an invasive species as it has been transported and introduced into a new ecosystem if it sustains a population through local reproduction and recruitment without the need for continuous introductions. The species is considered as invasive when it proliferates, achieves high population densities, and expands its range, all of which negatively impact the host ecosystem (Colautti & Isaac, 2004). Invasive species are organisms that are not native to a specific area and when introduced have the potential to harm human health, economy, and ecosystem.

Numerous invasive species exhibit high rates of reproduction, which facilitates population establishment in new areas (Simberloff et al., 2013). Many invasive species quickly reach maturity and exhibit faster growth than native species, providing them with a competitive edge in resource acquisition (Marchetti et al., 2004). Invasive organisms can survive in various habitats and outcompete with native species by adapting to a broad range of environmental conditions. Invasive species might experience a deficiency of natural predators and diseases that control their populations in native habitats Perkins et al., 2013). Invading species often have efficient means of dispersal, whether as a result of water, wind or human activity. This enables them to spread out and colonize new areas quickly. Invasive species may spread unchecked in a new area if there are no native predators, parasites, or diseases present. Invasive species have the potential to change the physical composition and structure of ecosystems, potentially affecting the services and functions these ecosystems provide (Mack et al., 2000).

INVERTEBRATE PESTS

Any organism or animal that people consider to be harmful to themselves, their property, their crops, or their animals is considered a pest. If an insect damages a crop or animals to the point where the farmer finds both the amount and the quality of the harvested product to be unsatisfactory, the insect may be considered a pest in farming. Because they can impair harvest-able items directly or indirectly through various means, insects may be categorized as pests. Insects can injure people in a variety of ways, and they have done so for thousands of years since humans have lived on Earth. Similar to this, there is a long and varied history of human attempts to manage or limit the harm caused by insects. Without question, damaging insects have brought significant difficulties to the subject of ecology, stimulated it, and supplied the motivation and resources for an extensive research program. A large portion of the study of insects and ecology in general has been motivated by the desire to comprehend the insects that pose a threat to our houses, crops, cattle, lumber supply, ornamental plants and health (Bade & Ghorpade, 2009).

There have been significant increases in the number of mealy bug species on ornamentals, fruits, vegetables and field crops. In reality, because of the gradual changes in climate that occurred between 2002 and 2005, mealy bugs have evolved as indicator insects for the current changes in ecosystems. Among these, *Paracoccus marginatus* and *Granara de* on papaya and *Phenacoccus solenopsis* on cotton have grown to be rather dangerous. In Tamil Nadu, the papaya mealy bug, *P. marginatus,* is posing a threat to IPM practices and insecticides (Rajendran, 2020).

The second-largest phylum in the animal kingdom is called Mollusca. Their name comes from the Latin word "mollus," which means "soft" and is typically shielded by a hard shell made of calcium (Zala et al., 2018). Six taxonomic classes, including Cephalopoda, Monoplacopoda, Amphineura, Scaphopoda, Bivalvia, and Gastropoda, make up this phylum. The Greek words gastros (stomach) and podos (foot) are the origin of the word gastropoda. These are asymmetrical, unsegmented, spirally coiled animals without backbones. Of the Mollusca phylum, 80% of its species are classified as gastropods. Molluscs like snails and slugs are hermaphrodites, but as they grow before developing eggs, spermatozoa exchange reciprocally (Das et al., 2020).

Raw, succulent vegetables, plant seeds, roots, seeds, and tuber crops are also targets for land mollusks, which also leave unsightly, slimy footprints on the damaged areas. In addition to other horticultural and agricultural crops, the land molluscs harm veggies, potatoes, cereal, lettuce, cabbage, carrots, maize and clover. This consumes all types of vegetables, oil plants, ornamental plants, field crops, and fruits from gardens and fields, as well as their roots, seedlings, seeds and tubers.

This vast class of arthropods, the majority of which are terrestrial, is distinguished by the division of its body into two primary sections: the anterior prosoma, also known as the cephalothorax and the posterior opisthosoma, which resembles the abdomen of an insect. Arachnid adults have four sets of legs. They have paired chelicerae in place of mandibles in their mouthparts for feeding. Numerous Acarina species are significant veterinary and clinical pests, and many of their phytophagous forms are known to be pests of developing plants. While certain predatory mite species target stored produce insects and other mites, while a small percentage of mites are significant pests in produce stores, there are many species known to target stored food items (Graham & Weinstein, 2018).

There have been reports of intestinal acariasis in the literature that link episodes of diarrhea to the presence of mites or mite eggs in stool samples. However, the relevance of mites in human excrement is now mostly questioned, and it is believed that microorganisms present in contaminated food are the source of diarrhea. However, dermatitis, or itchy grocery stores, is unquestionably linked to some mite infestations (Roslin & Majaneva, 2016).

Significance threats of invertebrate pests in conservation biology

As they provide the basis for understanding biological diversity's composition, distribution, ecological functions, and threats, biosystematics and conservation biology are essential for managing biodiversity. These fields provide essential knowledge to government and non-governmental organizations, enabling them to set conservation priorities and implement effective plans. They offer valuable insights into our natural heritage, helping us understand key processes that threaten biodiversity. This understanding enables the development of effective conservation policies (Braby & Williams, 2016).

The invasion of non-native insects poses a significant threat to ecosystems, often due to unintended consequences of international trade, Major threats to biodiversity are described in Fig 1. Common pathways for invasion include importing live plants, using solid wood packaging during shipping, 'hitchhiking' on various items and intentional introduction of biological control agents. Non-native herbivores, especially those that feed on sap and bore into wood, are major issues as they alter the ecological processes and composition of forests. Wasps and ants are two examples of invasive predators and parasitoids that greatly affect forest communities. Parasitoids also lead to a reduction in the native host populations (Brockerhoff & Liebhold, 2017).

Forest ecosystems serve as a host for a diverse range of insects, bacteria, viruses, fungi, and oomycetes. These organisms engage in various interactions with the trees and other plants in the area, exhibiting mutualistic, symbiotic, or parasitic relationships. These are commonly known as "pests and pathogens" due to the perceived negative impact on the economic value of trees to humans. In the last two decades, there has been a greater understanding of the effects of tree pests and diseases have on the environment, landscape and economy Santini *et al*. (2013).

The American chestnut (*Castanea dentata*) was exterminated due to chestnut blight (*Cryphonectria parasitica*), and the mountain pine beetle (*Dendroctonus ponderosae*) caused massive and unprecedented tree mortality in Canada and the Northern United States (Preisler et al., 2012). Pesticides are necessary in both non-agricultural and urban agricultural contexts to manage diseases and pests. High concentrations of herbicides, insecticides, fungicides, and rodenticides are frequently sprayed unintentionally on lawns, gardens and porous surfaces. Because of the widespread and heavy use of these pesticides in urban areas, there is a serious risk to ecosystems, living things and food safety. However, the ecological consequences of pesticides in agricultural soils are well-documented and information regarding their impacts in urban environments is limited and dispersed (Yadav, 2010).

EMERGENCE OF CONSERVATIVE STRATEGIES

The increasing adoption of conservation biology strategies, especially in addressing concerns related to invasive species, reflects a progression in comprehending and responding to the dynamic interactions within ecosystems. To address the influence of invasive species on biodiversity, ecosystem functioning and the overall ecological equilibrium, conservation biology has undergone development. The following are some key components of the conservative strategies that have emerged in response to invasive species from the perspective of conservation biology (Ackerly & David, 2003)

Conservation endeavors are increasingly concentrating on preventing the spread of invasive species to new locations. This involves imposing stricter restrictions on the import and transportation of invasive species. Conservation strategies highlight the importance of early discovery of invasive species in order to quick responses, including eradication or containment measures. Rapid response teams and citizen science activities aid in early detection efforts (Reaser et al., 2020).

Conservation biologists deal with risk assessments to scrutinize the potential invasiveness of species before introduction or to evaluate the potential impact of existing species. Prioritization is essential due to resource constraints. The objective of conservation strategies is to pinpoint and tackle the most threatening invasive species, and their effects on native biodiversity and ecosystems. Biological, chemical, and cultural techniques are used by conservation biologists in integrated pest management strategies to manage invasive species with the least amount of damage to non-target species (Radcliffe et al., 2009). Integrated pest management includes the safe and feasible introduction of natural predators or

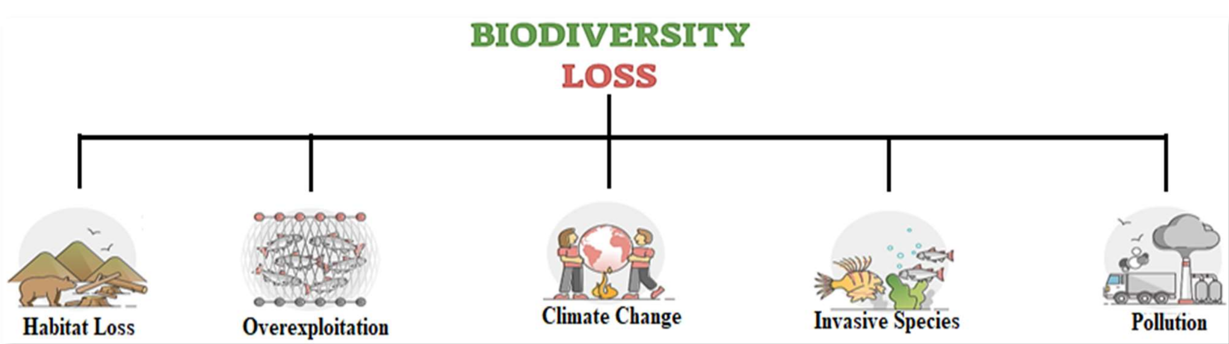

Fig 1. Major threats to biodiversity

pathogens related to invasive species. Conservation strategies incorporate adaptive management, recognizing the dynamic nature of ecosystems and the necessity for continuous learning. Adjustments can be made in response to new information and changing environmental conditions.

Case studies in conservation success and failure

Various research initiatives actively identify and define challenges within the area of conservation, where despite notable successes, biodiversity decline persists. The study conducts comprehensive interviews with 74 conservationists, predominantly based in Africa, to formulate a typology of barriers, highlight the threats that pose risks to conservation endeavors. This dynamic typology empowers conservationists to enhance decision-making and strategic planning, ultimately leading to more impactful project outcomes. Additionally, the framework supports the application of improved techniques to increase conservation success by giving the larger conservation community access to actionable information. Further attempts and revisions are warmly welcomed in light of this foundational work (Sanders et al., 2021). Numerous conservation case studies highlight both success stories and situations where conservation efforts faced challenges or fell short of achieving their intended objectives.

Due to habitat loss and fragmentation, the iconic giant panda has come dangerously close to extinction. China's conservation efforts were concentrated on community engagement, captive breeding, and habitat protection. The efforts resulted in the giant panda's lowered from "endangered" to "vulnerable" in the IUCN Red List (Buckingham & Jepson, 2013). In 1995, the reintroduction of gray wolves into Yellowstone National Park had a profound effect on the natural environment. Wolves assisted in the reduction of elk herds, which had a favorable cascading impact on vegetation and other wildlife populations. This is often cited as an illustration of a top-down ecological restoration strategy that works.

Conservation challenges and failure

The golden lion tamarin, a small sized monkey native to Brazil, faced imminent threats from habitat loss and fragmentation. Although conservation endeavors have contributed to stabilizing the population, challenges persist in the form of habitat destruction and insufficient genetic diversity. These issues cast uncertainty over the species' long-term survival prospects (Chrulew, 2017). One of the world's most endangered large mammals is the Java rhinoceros. Despite conservation efforts to maintain its habitat and prevent poaching, the population has dwindled to less than 80 individuals. The species remains under constant threat due to habitat loss and the impact of natural disasters.

Political boundaries are often crossed by invasive species. To tackle the global aspect of the invasive species issue, international cooperation is necessary for conservation efforts. Collaborations and agreements encourage research, information sharing and coordinated management initiatives. The introduction of invasive species into new habitats, anthropogenic alterations in land use and land cover, as well as an increase the scope and volume of international trade, significantly disrupt the composition, structure, function and dynamics of natural environments (Barfknecht & Gibson, 2023. Invasive species are those that pose a risk to human health and the environment as well as to other species, habitats and ecosystems through their introduction, establishment, and spread throughout a territory" (Gentili et al., 2021). Biological invasions are a major cause for concern due to their negative impact on native ecosystems, biodiversity, and the economy. Displacement events, integral to invasion biology, are increasing at an alarming rate, yet the underlying mechanisms and factors remain unknown (Gao & Reitz, 2017). Invasive species interact with native species through hybridization, predation and competitive displacement, Native species may become extinct as a result of these interactions (Mooney & Cleland, 2001).

Invasive species can outcompete the native species and cause disruptions in ecological processes and communities (Peh, 2010). These displacements have been linked with interspecific competition; a phenomenon called competitive displacement. Elimination of a species in a given habitat by another where one possesses the identical ecological niche of the other" (Boyero et al., 2014).

There are two categories of competition: interference competition and exploitation competition. In the realm of competition, exploitation competition occurs when one species demonstrates greater efficiency than its competitor in locating, harvesting, or utilizing a particular resource. When one species actively reduces the resources access to other species (Holway & Suarez, 2006). Various mechanisms exist through which a species can control resource access, leading to the displacement of another species. Direct aggressive interactions serve as a means for one species to monopolize resources, exemplified by the invasive *Linyphia* triangularis displacing native Linyphiidae spiders from both webs and websites (Bednarski et al., 2010). By eliminating their food sources, invasive species frequently pose a threat to native species' ability to feed. Between infected and uninsulated areas, there is a notable difference in the diversity of non-native ants and the foraging behavior of native ants (Zina et al., 2022).

Invasive species also cause displacement of native species through predation and herbivory. It has been shown that invasive predators negatively affect native communities by disturbing important native predator-prey dynamics (Kimbro et al., 2009). Sih *et al*. (2010), for example, have shown that these disturbances can result from the direct consumption of native species, but the direct consumer effect can also indirectly benefit both native and nonnative prey species (Rodriguez, 2006; Freeman et al., 2016). Non-native predators and pathogens pose a significantly higher risk of causing the extinction of native species (Gurevitch & Padilla, 2004). Predation contributes a significant portion of the biodiversity loss caused by invaders (Doherty et al., 2016), interference and exploitative competition with invaders have also led to the decline or displacement of native species (Kiesecker et al., 2001; Reitz & Trumble, 2002).

Predators can influence niche utilization, food availability, and the functioning of prey without immediately effecting their population structure (Miura & Ohgushi, 2011). Consequently, *S. frugiperda*, a highly voracious pest exhibiting cannibalism and predation behavior, has the potential to prey on and outcompete stem borers in a shared environment. Predation, therefore, may be considered a key mechanism influencing population dynamics in the communities of *S. frugiperda* and stem borers. Thus, it is necessary to clarify its pivotal role in shaping the *stemborer-S. frugiperda* community (Miura & Ohgushi, 2011).

Biologic invasions can significantly alter the composition, structure, functions, and dynamics of natural ecosystem (Barfknecht & Gibson, 2021). Invasive species are the major threat to native species and biodiversity (Rodriguez, 2006; Gentili et al., 2021). The fact that invasions cause massive and quick losses of biodiversity and community structure is supported by numerous studies (Kehoe et al., 2021). Around the world, a variety of human activities are altering environments, which is having a negative impact on the species that live there. Biological resource use, pollution, carbon emissions into the atmosphere that cause climate change, aquaculture and agriculture, and residential and commercial development are a few examples of these activities (Bellard et al., 2016).

Effects of native species differ greatly among species, geographic locations and ecosystems (Blackburn et al., 2014). Effects of nutrient recycling mainly depend on the abundance and trophic level of invasive species when compared with invasive species (Bradley et al., 2019). Decomposition, availability of nutrients, uptake of nutrients by plants and grazing, all are controlled by soil microbiota (Wardle et al., 2004; Bardgett & Wardle, 2010). Non-native species gain success by breaking down the interaction between native plant and soil communities (Reinhart & Callaway, 2006; Dawson & Schrama, 2016; Ricciardi et al., 2017).

There are many native plant species that significantly reshape the ecosystem to increase their persistence and decrease the native species' number at the same time through their feeding cycles that alter ecosystem structure and functions that cannot be reversed. However, these invasive species initiate the alteration in microbial communities (Bowen & Stevens, 2020). Invasive plants and animals have the potential to disturb nutrient cycling of the ecosystem and soil structure in many ways. Earthworms invade an area and cause nutrient deficiency in plants depicted in Fig 2.

Fig 2. Earthworm altering the nutrient cycling

Wild pig (*Sus scrofa*) serves as an example of an invasive species with the capability to cause considerable disruption to sustainable ecosystems. Indeed, wild pigs are recognized as ecosystem engineers due to their significant influence on and modification of the environments they inhabit (Crooks, 2002, Sandom et al., 2012). Disturbance by wild boars in Spanish alpine grasslands resulted in decreased soil moisture, alterations in carbon-to-nitrogen ratio (C: N), reductions in ammonium (NH4 +) and extractable Na, Mg, and Ca in soil solution, alongside an increase in bulk density, total nitrogen, and nitrate ($NO3^-$) levels (Bueno et al., 2013).

Challenges in identifying and monitoring Invasive species

The identification and monitoring of invasive species are challenging tasks requiring a well-thought-out plan. Accurate identification of invasive species is challenging due to mimicry and cryptic stages, necessitating the use of modern techniques like DNA barcoding and genetic analysis. Early detection and rapid response (EDRR) techniques include community engagement and routine surveys. The use of technology such as environmental DNA (eDNA) and remote sensing can further enhance efficacy. A wider monitoring network is expanded by citizen science initiatives and smartphone apps, and the spread of invasive species can be predicted with the use of prediction models based on ecological and climatic factors. The National Invasive Species Council and the Convention on Biological Diversity are two international organizations that work together and share information to boost the collective response. All things considered, multidisciplinary cooperation that integrates global cooperation, community involvement, and scientific advancements is necessary for efficient invasive species monitoring (Darling & Blum, 2007).

The utilization of satellite imaging and drones for collecting comprehensive, real-time data across vast geographical areas aids in detecting changes in vegetation patterns (Royimani et al., 2019). Through the application of eDNA techniques, it becomes feasible to identify genomes from invasive species in air, water, or soil samples, offering a non-intrusive and highly sensitive monitoring method (Larson et al., 2020).The use of different sensors, such as sonic or thermal sensors, to identify invasive species based on biological or environmental cues (Juanes, 2018). Utilizing UAVs for swift and adaptable surveillance in challenging terrains enables efficient coverage of difficult-to-access locations (Gonzalez et al., 2016).

The integration of advanced algorithms for analyzing vast datasets aims to improve the accuracy and efficiency of identifying and monitoring invasive species (Shivaprakash et al., 2022).Citizen science involves the active participation of individuals from the general public, often without formal scientific expertise, in scientific research projects. Citizen scientists collaborate with professional researchers to collect, analyze and interpret data, contributing valuable insights to various scientific fields. This collaborative approach expands the volume and scope of research, enabling scientists to collect data across extensive geographic areas or undertake projects that require a large number of people.

Citizen science projects play a significant role in enhancing the surveillance and monitoring of invasive species. They assist in tracking and recognizing the invasive species in the following ways:

Citizen science programs frequently involve community members in reporting invasive species occurrences via dedicated applications or internet platforms. This decentralized approach significantly broadens the spatial scope of monitoring activities (Johnson et al., 2020). Invasive species can be identified early by involving citizens in the monitoring process. Due to their local expertise, community members can detect changes in the ecosystem and quickly report any invasive species occurrences (Johnson et al., 2020). Citizen science activities function as educational tools, promoting awareness of invasive species and their environmental impact. More informed and proactive community participation in monitoring activities is often the outcome of this increased knowledge (Crall et al., 2013). Citizen science involves the public in collaborative research, using their contributions for data collection, analysis, and reporting (Gallo & Waitt, 2011).

Taxonomic and identification challenges

Cryptic species are organisms that share a striking morphological resemblance, or are nearly indistinguishable from one another, but actually belong to distinct biological species. Despite their visual similarities, these species exhibit genetic, ecological, or behavioral differences, enabling their differentiation at the molecular or functional level (Fiser et al., 2018). For traditional taxonomic identification based solely on morphological traits, cryptic species often pose challenges because these traits may not reveal the underlying genetic diversity. Due to their closely resembling physical features with native or non-invasive species, cryptic invasive species pose a challenge for taxonomists and field biologists who find it difficult to differentiate them using standard morphological markers (Jorger & Schrodl, 2013).

Although molecular techniques like DNA barcoding can assist in identifying cryptic species, not all places have established DNA databases for comparison, conducting genetic analysis may require specialized skills and equipment (Jorger & Schrodl, 2013). Cryptic intruders might have geographic ranges that overlap with those of native species, adding complexity to identification efforts. This overlapping increases the risk of invasive species being introduced and spreading unintentionally (Zhao et al., 2019). Taxonomic identification is crucial for advancing scientific knowledge, making well-informed conservation decisions, managing ecosystems, and addressing various challenges, including those posed by cryptic invasive species. It forms the basis of our comprehension/understanding of nature, guiding policies and practices aimed at preserving biodiversity and maintaining ecosystem health.

Accurate taxonomic identification is essential for various scientific, ecological, and practical reasons, especially when dealing with the challenges posed by cryptic invasive species. The importance of precise identification includes the following:

Accurate identification is crucial for comprehending and conserving biodiversity. Having accurate knowledge about the identity of organisms is essential for evaluating species distribution, abundance and conservation status. It also plays a vital role in identifying and managing invasive species that pose threats to native biodiversity (Creer et al., 2016). For management and control strategies to be successful, accurate identification of invasive species is essential. According to Pysek & Richardson (2010), misidentifying a species can result in inefficient management efforts or a delay in responding, which can allow invasive species to spread and cause harm to the environment and the economy.

CONSERVATION STRATEGIES AND MANAGEMENT APPROACHES

The process of using living things to control the proliferation of a particular pest is known as biological control (Rice et al., 2015). The glasshouse whitefly (*Trialeurodes vaporariorum*) and the parasitic wasp (*Encarsia formosa*) were involved in the first successful applications of seasonal inoculative biological control in protected agriculture. Whiteflies and other greenhouse pests, such as spider mites, thrips and aphids, prey on a variety of vegetable crops, including peppers, tomatoes, and cucumbers, as well as beautiful flowers. In addition to lowering yields and the market value of goods sold based solely on appearance, these pests also serve as a breeding ground for secondary illnesses like sooty mould [*Cladosporium sphaerospermum* (Barzman et al., 2014)].

Several Challenges and Ethical Consideration have dominated the discussions concerning commercial producers of arthropod biological control agents (Delfosse, 2005). The first is the accuracy with which commercially available arthropod natural enemies may be identified. It could be costly and ineffectual to release the wrong natural enemy against the intended pest. Thus, successful augmentation attempts require correct identifications. Even taxonomic experts find it extremely challenging to identify many beneficial species. Because many parasites and predators are small in size and raising operations are vast in scale, contamination of cultured may be widespread. Accurate taxonomic key identification and knowledge of specialized tools and preparation methods are prerequisites for the correct identification of numerous beneficial species. Plants, arthropod hosts as well as natural enemies are the three trophic levels that are frequently reared in large-scale arthropod natural enemy raising operations. There aren't many efficient artificial meals available for natural enemies or pest arthropods. Genetic alterations in the colony throughout the rearing process may lessen the natural enemy's efficacy after release. It takes a lot of work to maintain a high calibre natural enemy, and quality control plans for shipping, releasing, retaining, and rearing these enemies must be created on a species-by-species or case-by-case basis (Cappaert et al., 2005).

Following the acquisition of a beneficial species, the user needs to get precise instructions on how to store these extremely perishable organisms and how to release them. The user should be informed of how many to release, above anything else. When too few pests or predators are released, or when pest populations are abnormally high, it can cause severe crop damage and undermine the effectiveness of augmentation. The consumer should be informed that the releases are experimental in cases when commercial producers do not have precise information on suitable release rates and timing (Kaur, 2008).

The synthetic or natural chemicals used in diverse agricultural operations to manage weeds, pests and plant diseases are known as pesticides. A vast variety of herbicides, insecticides, fungicides, rodenticides, nematicides, etc. are classified as pesticides. As agriculture developed, pesticides became an essential tool for protecting plants and increasing crop productivity. Since insect infestations cause over 45% of the world's food output to be lost annually, effective pest management utilizing a variety of pesticides is necessary to combat pests and boost crop yields (Abhilash & Singh, 2009). The first insecticide to be manufactured in India was benzene hexachloride, which was followed by DDT in 1952. The production of insecticides skyrocketed. India produced more than 5000 metric tons of pesticides in 1958; by the mid-1990s, 145 pesticides had been registered, and the majority of the pesticides produced were insecticides. India ranks twelfth in the world for pesticide manufacture and is one of the major Asian producers, generating 90,000 tons of pesticides annually (Gupta, 2004).

Since the term "integrated control" was first used, which is described as "applied pest control which combines and integrates biological and chemical control," integrated pest management, or IPM, has greatly advanced. In response to insect epidemics brought on by the eradication of natural enemies and the rise of pesticide resistance, entomologists first devised the notion when confronted with the widespread use of broad-spectrum insecticides without a specific purpose or intention. All facets of plant protection are now covered by IPM. In an effort to mainstream it throughout the European Union, it is the focus of renewed attention in European policy, research and extension. This difficulty is addressed in the EU Framework Directive 2009/128/EC on sustainable utilization of pesticides (Barzman et al., 2014).

Despite the fact that different approaches have made it more difficult to quickly integrate restoration and conservation, ecological restoration which the Society for Ecological Restoration defines as the process of "assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" has grown to be a crucial part of contemporary conservation paradigms. Over the past five years, ecological restoration has also been incorporated into sustainable economic strategies and global and regional biodiversity policies. In the context of CBD and EU biodiversity policy, ecological restoration plays three distinct but concurrent roles: it is an aim, an objective, and a tool. This makes it difficult to genuinely improve the planet's biodiversity situation. Since the EU policy lists restoration as one of its objectives, achieving the goal by using a tool to hit a numerical target turns the goal into an accounting exercise. In order to reach the objective, parties are motivated to count as much territory as possible as restored (Suding, 2011).

In addition, restoration projects might need to consider potential invasive species (sometimes known as "sleepers") that are already present on a project site and incorporate eradication or control strategies into management plans. In situations where controlling them would be impractical, some IAS might theoretically have an acknowledged place in a restoration strategy. In addition, they might be beneficial to a newly forming novel ecosystem (Corlett, 2016).

FUTURE PERSPECTIVES

Innovative techniques for invasive species detection, identification, reporting and response recommendation for promoting additional developments in relevant technologies. Technologies are being used by federal agencies to increase programmatic effectiveness and cost-efficiency. The infrastructure of research facilities could be improved, data could be mobilized on a wide range of invasive species parameters (from genetic to landscape scales), important technological gaps could be supported and promoted (e.g., portable, field-ready devices with automated capacities), and more resources could be allocated to technology prizes and challenge competitions. In contrast to human and other animal intelligence, artificial intelligence (AI) refers to the capacity of robots to learn and use knowledge (Martinez et al., 2020).

Insect pest populations can be eliminated or replaced by species-specific genetic-control techniques, which add another useful toolkit for efficient integrative pest management. Dipteran and lepidopteran species have been the main focus of modern methods for the genetic control of disruptive insects. There are still many obstacles to overcome even if these genetic-control techniques are highly developed and, in many circumstances, practically ready for field use. Gene-editing technology is an emerging therapeutic approach with target-sequence- specific designed nucleases that manipulate the eukaryotic genome. Gene editing technology is proving to be extremely advantageous in enabling precise genome sequence correction, which is why gene editing-based therapy is rapidly being explored as a next-generation therapeutic method to treat many disorders (Shim et al., 2017).

Following decades of ecological and economic consequences from a growing list of non-indigenous and invasive species, government and management bodies are committing to systematic early- detection monitoring (EDM). EDM development has focused on two opposing strategies on answering the issue of what to monitor. The first method, known as target-species monitoring, looks for pre-identified species of concern. The second, known as broad-spectrum monitoring, looks for any new NIS within large taxonomic groups. Broad-spectrum monitoring yields biodiversity data important to assessing NIS impacts and other ecological concerns, while also facilitating the discovery of unanticipated

NIS. While target-species monitoring most directly and effectively integrates knowledge of impending NIS. Target-species monitoring and broad-spectrum monitoring, which are sometimes distinguished from passive versus active surveillance, are both important additions to a surveillance toolkit. Many studies have shown that shed DNA, sometimes known as environmental DNA or eDNA in literature, can recover biodiversity data important for broad-spectrum monitoring as well as disclose the presence of hard-to- find animals (Tzrebit et al., 2017).

By eradicating winter hypoxia and cold temperatures that currently hinder survival and by encouraging the creation of reservoirs that act as hotspots for invasive species, climate change will affect the likelihood of new species getting established. By strengthening their competitive and predatory effects on native species and by making some illnesses more pathogenic, climate change will alter the ecological implications of invading species. Invasive species that presently have only mild effects or are restricted by seasonally unfavorable conditions may require new prevention and control approaches, such as barrier construction or removal operations, as a result of climate change. The relationship between invasive species and climate change is complicated (Rahel & Olden, 2008).

Given the continuous worldwide change, a species, climatic niche, which can vary over time or across different geographic regions, has grown in significance (Guisan et al., 2014). The anisotropic nature of climatic space may produce significant (and to a large degree underestimated) non–evolutionary niche alterations. The ecological niche model's geographical transferability is primarily the context in which this can be observed. When ecological niche modelling indicates changes in the realized niche, the most economical theory is that environmental space is heterogeneous. It is not advisable to speculate on the evolution of niches or the involvement of competitors without taking into account variations in the structure of the surrounding environment. Predicting the possible ranges of invasive species is becoming more and more common with ecological niche modelling (ENM). Conservatism in the characteristics of the ecological niche basically, the notion that the position and form of the fundamental ecological niche change slowly in relation to the process of invasions, is a key premise that makes such exercises possible. If a species's basic niche is not preserved, it may be able to spread to new parts of the globe with drastically different environmental conditions than it did in its native habitat, making the phenomenon completely unpredictable (Soberon & Peterson, 2011).

Invasive alien species (IAS) are among the greatest dangers to biodiversity. Initiative-taking conservation programs should give priority to practical management measures that prioritize prevention, monitoring, and early control as they are the most effective means of mitigating the impacts of IAS. The situation of local populations can be significantly improved by IAS eradications and mitigation strategies, should IAS become established (Falaschi et al., 2020). Since invasive alien species pose a serious threat to local plants, they must be kept out of areas designated for plant conservation, particularly when those species are endangered or endemic. The coordination and operation of federal environmental agencies is essential to (1) designate priority areas for biological invasion prevention and management (2) manage invasive alien species and lessen their impacts (Dechoum et al., 2021).

CONCLUSION

The biodiversity of world is rapidly decreasing due to both direct and indirect human activities and the major causes are invasive species, pests (mainly invertebrate pests) and anthropogenic activities include mining, releasing industrial waste, smelting arsenic ore, burning fossil fuels, especially coal, using arsenic-loaded irrigation water, and creating fertilizers, insecticides, and herbicides using arsenic as an ingredient. It has been shown that invasive predators negatively affect native communities by disturbing important native predator-prey dynamics. So, Conservation biologists deal with risk assessments to scrutinize the potential invasiveness of species before introduction or to evaluate the potential impact of existing species. Biological, chemical and cultural techniques are used by conservation biologists in integrated pest management strategies to manage invasive species with the least amount of damage to non-target species. The Convention on Biological Diversity's worries about alien invasive species led to the creation of the Global Invasive Species Program (GISP). The World Conservation Union (IUCN), CAB International, and the Scientific Committee on Problems of the Environment (SCOPE) oversee the Global Index of Scientific Programmes. Its objective is to enhance biological invasion control and prevention.

REFERENCES

Abhilash PC & N Singh, 2009. Pesticide use and application: an Indian scenario. Journal of Hazardous Materials 165:1-12. https://doi.org/10.1016/j.jhazmat.2008.10.061

Ackerly D & David, 2003. Community assembly, niche conservatism, and adaptive evolution in changing environments. International Journal of Plant Sciences 164:165-84. https://doi.org/10.1086/368401

Bade BA & SA Ghorpade, 2009. Life fecundity tables of sugarcane woolly aphid, *Ceratovacuna lanigera* Zehntner. Journal of Insect Science (Ludhiana) 22:402-5.

Bardgett RD & DA Wardle, 2010. Aboveground-belowground linkages: Biotic interactions, ecosystem processes, and global change. Oxford University Press, UK.

Barfknecht DF & DJ Gibson, 2023. Are metapopulation species drivers of metacommunity structure in sandstone outcrop communities? Journal of Vegetation Science 34: e13167. https://doi.org/10.1111/jvs.13167

Barzman MS, L Bertschinge, S Dachbrodt-Saaydeh et al., 2014. Integrated pest management policy, research and implementation: European initiatives. In: Integrated Pest Management: Experiences with Implementation Global Overview Vol:4 (Peshin R & D Pimentel, eds) Springer, New York, USA pp:415-28. https://doi.org/10.1007/978-94-007-7802-3_17

Bednarski J, H Ginsberg & EM Jakob, 2010. Competitive interactions between a native spider (*Frontinella communis*, Araneae: Linyphiidae) and an invasive spider (*Linyphia triangularis*, Araneae: Linyphiidae). Biological Invasions 12:905-12. https://doi.org/10.1007/s10530-009-9511-7

Bellard C, P Cassey & TM Blackburn, 2016. Alien species as a driver of recent extinctions. Biology Letters 12:201-506. https://doi.org/10.1098/rsbl.2015.0623

Blackburn TM, F Essl, T Evans et al., 2014. A unified classification of alien species based on the magnitude of their environmental impacts. PLoS Biology 12:100-85. https://doi.org/10.1371/journal.pbio.1001850

Bowen AK & MH Stevens, 2020. Temperature, topography, soil characteristics, and NDVI drive habitat preferences of a shade-tolerant invasive grass. Ecology and Evolution 10:10785-97. https://doi.org/10.1002/ece3.6735

Boyero JR, JMV López, E Wong et al., 2014. Displacement of *Aphytis chrysomphali* by *Aphytis melinus*, parasitoids of the California red scale, in the Iberian Peninsula. Spanish Journal of Agricultural Research 12:244-51. https://doi.org/10.5424/sjar/2014121-5266
Braby MF & MR Williams, 2016. Biosystematics and conservation biology: critical scientific disciplines for the management of insect biological diversity. Austral Entomology 55:1-17. https://doi.org/10.1111/aen.12158
Bradley BA, BB Laginhas, R Whitlock et al., 2019. Disentangling the abundance-impact relationship for invasive species. Proceedings of the National Academy of Sciences 116:9919-24. https://doi.org/10.1073/pnas.1818081116
Brockerhoff E & A Liebhold, 2017. Ecology of forest insect invasions. Biological Invasions 19:3141-59. https://doi.org/10.1007/s10530-017-1514-1
Buckingham KC & P Jepson, 2013. Environmental reviews and case studies: Diplomats and refugees: Panda diplomacy, soft "cuddly" power, and the new trajectory in panda conservation. Environmental Practice 15:262-270. https://doi.org/10.1017/S1466046613000185
Bueno CG, J Azorín, DG García et al., 2013. Occurrence and intensity of wild boar disturbances, effects on the physical and chemical soil properties of alpine grasslands. Plant and Soil 373:243-56. https://doi.org/10.1007/s11104-013-1784-z
Cappaert D & DG McCullough, TM Poland et al., 2005. Emerald ash borer in North America: a research and regulatory challenge. American Entomologist 51:152-65. https://doi.org/10.1093/ae/51.3.152
Chrulew M, 2017. Saving the golden lion tamarin. In: Extinction Studies: Stories of Time, Death, and Generations (van Dooren T, DB Rose & M Chrulew, eds). Columbia University Press, USA, pp: 49-88. https://doi.org/10.7312/van-17880-004
Colautti RI & HJ Isaac, 2004. A neutral terminology to define 'invasive' species. Diversity and Distributions 10:135-41. https://doi.org/10.1111/j.1366-9516.2004.00061.x
Corlett RT, 2016. Restoration, reintroduction, and rewilding in a changing world. Trends in Ecology and Evolution 31:453-62. https://doi.org/10.1016/j.tree.2016.02.017
Crall AW, R Jordan, K Holfelder, et al., 2013. The impacts of an invasive species citizen science training program on participant attitudes, behavior, and science literacy. Public Understanding of Science 22:745-64. https://doi.org/10.1177/0963662511434894
Creer S, K Deiner, S Frey et al., 2016. The ecologist's field guide to sequence-based identification of biodiversity. Methods in Ecology and Evolution 7:1008-18. https://doi.org/10.1111/2041-210X.12574
Crooks JA, 2002. Characterizing ecosystem-level consequences of biological invasions: The role of ecosystem engineers. Oikos 97:153-66. https://doi.org/10.1034/j.1600-0706.2002.970201.x
Darling JA & MJ Blum, 2007. DNA-based methods for monitoring invasive species: a review and prospectus. Biological Invasions 9:751-65. https://doi.org/10.1007/s10530-006-9079-4
Das PPG, B Bhattacharyya, S Bhagawnti et al., 2020. Slug: An emerging menace in agriculture: A review. Journal of Entomology and Zoology Studies 8:1-6. https://doi.org/10.22271/j.ento.2020.v8.i6z.8105
Dawson W & M Schrama, 2016. Identifying the role of soil microbes in plant invasions. Journal of Ecology 104:1211-8. https://doi.org/10.1111/1365-2745.12619
Dechoum MDS, RB Sühs, SDM Futada et al., 2021. Distribution of invasive alien species in Brazilian ecoregions and protected areas. In: Invasive Alien Species (Pullaiah T & MR Ielmini, eds). Wiley, Hoboken, USA, pp:24-42. https://doi.org/10.1002/9781119607045.ch35
Delfosse ES, 2005. Risk and ethics in biological control. Biological Control 35:319-29. https://doi.org/10.1016/j.biocontrol.2005.09.009
Doherty TS, AS Glen, DG Nimmo et al., 2016. Invasive predators and global biodiversity loss. Proceedings of the National Academy of Sciences 113:11261-5. https://doi.org/10.1073/pnas.1602480113
Falaschi M, A Melotto, R Manenti et al., 2020. Invasive species and amphibian conservation. Herpetologica 76:216-27. https://doi.org/10.1655/0018-0831-76.2.216
Fiser C, CT Robinson & F Malard, 2018. Cryptic species as a window into the paradigm shift of the species concept. Molecular Ecology 27:613-35. https://doi.org/10.1111/mec.14486
Freeman AS, A Frischeisen & AM Blakeslee, 2016. Estuarine fouling communities are dominated by nonindigenous species in the presence of an invasive crab. Biological Invasions 18:1653-65. https://doi.org/10.1007/s10530-016-1108-3
Gallo T & D Waitt, 2011. Creating a successful citizen science model to detect and report invasive species. BioScience 61:459-65. https://doi.org/10.1525/bio.2011.61.6.8
Gao Y & SR Reitz, 2017. Emerging themes in our understanding of species displacements. Annual Review of Entomology 62:165-83. https://doi.org/10.1146/annurev-ento-031616-035425
Gentili R, U Schaffner, A Martinoli et al., 2021. Invasive alien species and biodiversity: Impacts and Management. Biodiversity 22:1-3. https://doi.org/10.1080/14888386.2021.1929484
Gonzalez LF, GA Montes, E Puig, et al., 2016. Unmanned aerial vehicles (UAVs) and artificial intelligence revolutionized wildlife monitoring and conservation. Sensors 16:97. https://doi.org/10.3390/s16010097
Graham CH & BG Weinstein, 2018. Towards a predictive model of species interaction beta diversity. Ecology Letters 21:1299-310. https://doi.org/10.1111/ele.13084
Guisan A, B Petitpierre, O Broennimann et al., 2014. Unifying niche shift studies: Insights from biological invasions. Trends in Ecology and Evolution 29:260-9. https://doi.org/10.1016/j.tree.2014.02.009
Gupta PK, 2004. Pesticide exposure, Indian scene. Toxicology 198:83-90. https://doi.org/10.1016/j.tox.2004.01.021
Gurevitch J & DK Padilla, 2004. Are invasive species a major cause of extinctions? Trends in Ecology and Evolution 19:470-4. https://doi.org/10.1016/j.tree.2004.07.005
Holway DA & AV Suarez, 2006. Homogenization of ant communities in mediterranean California: The effects of urbanization and invasion. Biological Conservation 127:319-26. https://doi.org/10.1016/j.biocon.2005.05.016
Johnson BA, AD Mader, R Dasgupta et al., 2020. Citizen science and invasive alien species: An analysis of citizen science initiatives using information and communications technology (ICT) to collect invasive alien species observations. Global Ecology and Conservation 21:8-12. https://doi.org/10.1016/j.gecco.2019.e00812
Jorger KM & M Schrodl, 2013. How to describe a cryptic species? Practical challenges of molecular taxonomy. Frontiers in Zoology 10:1-27. https://doi.org/10.1186/1742-9994-10-59
Juanes F, 2018. Visual and acoustic sensors for early detection of biological invasions: Current uses and future potential. Journal for Nature Conservation 42:7-11. https://doi.org/10.1016/j.jnc.2018.01.003
Kaur H, 2008. Field evaluation of two additives for improving the acceptance of some molluscicide baits by the slug, Filicaulis alte Ferussac in vegetable field at MalerKotla (Punjab). Environment and Ecology 26:1602-1606.
Kehoe R, E Frago & D Sanders, 2021. Cascading extinctions as a hidden driver of insect decline. Ecological Entomology 46:743-56. https://doi.org/10.1111/een.12985
Kiesecker JM, AR Blaustein & CL Miller, 2001. Potential mechanisms underlying the displacement of native red-legged frogs by introduced bullfrogs. Ecology 82:1964-70. https://doi.org/10.1890/0012-9658(2001)082[1964:PMUTDO]2.0.CO;2
Kimbro DL, ED Grosholz, AJ Baukus et al., 2009. Invasive species cause large-scale loss of native California oyster habitat by disrupting trophic cascades. Oecologia 160:563-75. https://doi.org/10.1007/s00442-009-1322-0
Larson ER, BM Graham, R Achury et al., 2020. From eDNA to citizen science: Etools for the early detection of invasive species. Frontiers in Ecology and the Environment 18:194-202. https://doi.org/10.1002/fee.2162
Mack RN, D Simberloff, WM Lonsdale et al., 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689-710. https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2
Marchetti MP, T Light, PB Moyle et al., 2004. Fish invasions in California watersheds: testing hypotheses using landscape patterns. Ecological Applications 14:1507-25. https://doi.org/10.1890/03-5173
Martinez B, JK Reaser, A Dehgan et al., 2020. Technology innovation: advancing capacities for the early detection of and rapid response to invasive species. Biological Invasions 22:75-100. https://doi.org/10.1007/s10530-019-02146-y
Miura K & T Ohgushi, 2011. A native predator affects the indirect interaction between exotic herbivorous insects on an invaded plant. Journal of Plant Interactions 6:175-176. https://doi.org/10.1080/17429145.2010.544411
Mooney HA & EE Cleland, 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences 98:5446-51. https://doi.org/10.1073/pnas.091093398
Peh KSH, 2010. Invasive species in Southeast Asia: The knowledge so far. Biodiversity and Conservation 19:1083-99. https://doi.org/10.1007/s10531-009-9755-7
Perkins T, BL Phillips, ML Baskett, et al., 2013. Evolution of dispersal and life history interact to drive accelerating spread of an invasive species. Ecology Letters 16:1079-87. https://doi.org/10.1111/ele.12136

Pimentel D, Zuniga & D Morrison, 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273-88. https://doi.org/10.1016/j.ecolecon.2004.10.002
Prakash S & AK Verma, 2022. Anthropogenic activities and biodiversity threats. International Journal of Biological Innovations 4:94-103. https://doi.org/10.46505/IJBI.2022.4110
Preisler HK, JA Hicke, AA Ager et al., 2012. Climate and weather influences on spatial temporal patterns of mountain pine beetle populations in Washington and Oregon. Ecology 93:2421-34. https://doi.org/10.1890/11-1412.1
Pysek P & DM Richardson, 2010. Invasive species, environmental change and management, and health. Annual Review of Environment and Resources 35:25-55. https://doi.org/10.1146/annurev-environ-033009-095548
Radcliffe EB, WD Hutchison & RE Cancelado (eds), 2009. Integrated pest management: concepts, tactics, strategies and case studies. Cambridge University Press, UK https://doi.org/10.1017/CBO9780511626463
Rahel FJ & JD Olden, 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521-33. https://doi.org/10.1111/j.1523-1739.2008.00950.x
Rajendran S, 2020. Insect pest management in stored products. Outlooks on Pest Management 1:24-35. https://doi.org/10.1564/v31_feb_05
Reaser JK, SW Burgiel, J Kirkey et al., 2020. The early detection of and rapid response (EDRR) to invasive species: A conceptual framework and federal capacities assessment. Biological Invasions 22:1-19. https://doi.org/10.1007/s10530-019-02156-w
Reinhart KO & RM Callaway, 2006. Soil biota and invasive plants. New Phytologist 170:445-57. https://doi.org/10.1111/j.1469-8137.2006.01715.x
Reitz SR & JT Trumble, 2002. Competitive displacement among insects and arachnids. Annual Review of Entomology 47:435-65. https://doi.org/10.1146/annurev.ento.47.091201.145227
Ricciardi A, TM Blackburn, JT Carlton et al., 2017. Invasion science: a horizon scan of emerging challenges and opportunities. Trends in Ecology and Evolution 32:464-74. https://doi.org/10.1016/j.tree.2017.03.007
Rice KB, SJ Fleischer, CMD Moraes et al., 2015. Handheld lasers allow efficient detection of fluorescent marked organisms in the field. PLOS ONE 10:129-75. https://doi.org/10.1371/journal.pone.0129175
Rodriguez LF, 2006. Can invasive species facilitate native species? Evidence of how, when, and why these impacts occur. Biological Invasions 8:927-39. https://doi.org/10.1007/s10530-005-5103-3
Roslin T & S Majaneva, 2016. The use of DNA barcodes in food web construction terrestrial and aquatic ecologists unite. Genome 59:603-28. https://doi.org/10.1139/gen-2015-0229
Royimani L, O Mutanga, TN Matongera et., 2019. Advancements in satellite remote sensing for mapping and monitoring of alien invasive plant species (AIPs). Physics and Chemistry of the Earth 112:237-45. https://doi.org/10.1016/j.pce.2018.12.004
Sanders MJ, L Miller, SA Bhagwat et al., 2021. Conservation conversations: A typology of barriers to conservation success. Oryx 55:245-54. https://doi.org/10.1017/S0030605319000012
Sandom C, J Bull, S Canney et al., 2012. Exploring the value of wolves (*Canis lupus*) in landscape-scale fenced reserves for ecological restoration in the Scottish Highlands. In: Fencing for Conservation (Hayward MM, ed). Springer, New York, USA, pp:245-76. https://doi.org/10.1007/978-1-4614-0902-1_14
Santini A, L Ghelardini, CD Pace et al., 2013. Biogeographical patterns and determinants of invasion by forest pathogens in Europe. New Phytologist 197:238-250. https://doi.org/10.1111/j.1469-8137.2012.04364.x
Seymour CL, HM Klerk, A Channing et al., 2001. The biogeography of the Anura of sub-equatorial Africa and the prioritisation of areas for their conservation. Biodiversity and Conservation, 10: 2045-76. https://doi.org/10.1023/A:1013137409896
Shim G, D Kim, GT Park et al., 2017. Therapeutic gene editing: delivery and regulatory perspectives. Acta Pharmacologica Sinica 38:738-53. https://doi.org/10.1038/aps.2017.2
Shivaprakash KN, N Swami, S Mysorekar et al., 2022. Potential for artificial intelligence (AI) and machine learning (ML) applications in biodiversity conservation, managing forests, and related services in India. Sustainability 14:7-154. https://doi.org/10.3390/su14127154
Sih A, DI Bolnick, B Luttbeg et al., 2010. Predator prey naïveté, antipredator behavior, and the ecology of predator invasions. Oikos 119:610-21. https://doi.org/10.1111/j.1600-0706.2009.18039.x
Simberloff D, JL Martin, P Genovesi et al., 2013. Impacts of biological invasions: What's what and the way forward. Trends in Ecology and Evolution 28:58-66. https://doi.org/10.1016/j.tree.2012.07.013
Soberon J & AT Peterson, 2011. Ecological niche shifts and environmental space anisotropy: A cautionary note. Revista mexicana de biodiversidad 82:1348-55.
Suding KN, 2011. Toward an era of restoration in ecology: successes, failures, and opportunities ahead. Annual Review of Ecology, Evolution, and Systematics 42:465-87. https://doi.org/10.1146/annurev-ecolsys-102710-145115
Tzrebit AS, JC Hoffman, JA Darling et al., 2017. Early detection monitoring for aquatic non-indigenous species: Optimizing surveillance, incorporating advanced technologies, and identifying research needs. Journal of Environmental Management 202:299-310. https://doi.org/10.1016/j.jenvman.2017.07.045
Verma AK, PR Rout, E Lee et al., 2020. Biodiversity and sustainability. Sustainability. Imn Fundamentals and Applications (Surampalli R, T Zhang, MK Goyal et al., eds) Wiley, Hoboken, USA, pp:255-75. https://doi.org/10.1002/9781119434016.ch12
Wardle DA, RD Bardgett, JN Klironomos et al., 2004. Ecological linkages between aboveground and belowground biota. Science 304:1629-33. https://doi.org/10.1126/science.1094875
Yadav S, 2010. Heavy metals toxicity in plants: An overview on the role of glutathione and phytochelatins in heavy metal stress tolerance of plants. South African Journal of Botany 76:167-79. https://doi.org/10.1016/j.sajb.2009.10.007
Zala MB, SA Sipai, TM Bharpoda et al., 2018. Molluscan pests and their management: A review. AGRES-An International EJ 7:126-132.
Zhao Q, H Zhang & J Wei, 2019. Climatic niche comparison across a cryptic species complex. PeerJ 7:7042. https://doi.org/10.7717/peerj.7042
Zina V, Duarte, G Stevens et al., 2022. Land use system, invasive species and shrub diversity of the riparian ecological infrastructure determine the specific and functional richness of ant communities in Mediterranean river valleys. Ecological Indicators 145:109-115. https://doi.org/10.1016/j.ecolind.2022.109613