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REVIEW ARTICLE

Impact of invasive ant species on native fauna across similar habitats under global environmental changes

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Abstract

Biotic invasions can predominantly alter the dynamics, composition, functions, and structure of natural ecosystems. Social insects, particularly ants, are among the most damaging invasive alien species. Invasive ant species are among the supreme threats to ecosystems. There are about 23 species of invasive ants recorded worldwide, according to the ant invasive databases. The ecological impacts of invasive ants comprise predation, hybridization, and competition with native species that changes the ecosystem processes with the biodiversity loss and upsurge of pests. The effects of invasion on native fauna in the same habitats might be catastrophic for the native community through various ecological mechanisms, e.g., habitat disturbance, resource competition, limiting the foraging activity of native species, and various other indirect mechanisms of invasive species. Invasive species may have harmful impacts on habitats and devastating effects on natural flora and fauna, and stopping these new species from being introduced is the most effective way to deter future invasions and maintain biodiversity. This paper reviews the literature to evaluate the effects of invasive ant species on the native species, including vertebrates, invertebrates, and plants sharing the same habitats as the non-native species under global environmental changes. We also highlighted the various management strategies that could be adopted in minimizing the adverse effects of these invasive ant species on the natural ecosystem. To this end, strategies that could regulate the mode and rate of invasion by these alien ant species are the most effective ways to deter future invasions and maintain biodiversity.

Keywords Alien species · Environmental impacts · Indigenous species · Intruders · Non-native species · Tramp species

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Introduction

Biotic invasions can predominantly modify the dynamics, composition, functions, and structure of natural environments (Barfknecht and Gibson 2021). The invasion of alien species into new habitats has been assisted by the anthropogenic revolution of land use and land cover and the cumulative volume and range of international trade (Hobbs 2000). An invasive alien species is elucidated as "a species whose introduction, establishment, and spread into a territory likely to cause economic and environmental threats to the humans, habitats, species, and ecosystems" (Mcneely 2001b; Gentili et al. 2021). These invasive species are among the highest threats to native communities and biodiversity (Mack et al. 2000; Rodriguez 2006; Gentili et al. 2021). It has been well documented that the invasion caused massive and rapid losses of community structure and biodiversity (Charles and Dukes 2007; Kehoe et al. 2020; Zina et al. 2020; Farahat et al. 2021).

Ecological impacts of invasive species comprise predation, hybridization, and competition with native species that change the ecosystem processes with the biodiversity loss and upsurge of pests (Bruno et al. 2005; Crooks 2002; Grosholz 2002; Mack et al. 2000; Peh 2010). Generalist non-native species may successfully become the ecologically dominant species resulting in trophic popularization (Kehoe et al. 2020). Invasive species may out-compete the native species, resulting in interruption to ecological processes and communities (Peh 2010). Certain alien species' direct and indirect impacts can be so pervasive and robust that they can reorganize entire communication networks and cause abrupt changes in bio networks (Maron et al. 2006; Linders et al. 2019). Invasive species naturally affect native species through competition for resources, predation, and habitat degradation (King and Tschinkel 2008).

Habitat disturbance or degradation plays a vital role in the intransigence and establishment of various dominant non-native species because it reduces the abundance and conscription of native species (MacDougall and Turkington 2005). The main threats to biodiversity are biotic invasion and habitat destruction (Sala et al. 2000), and they have various consequences. For instance, invasive ant species are most frequently established in disrupted places by humans (Hulme 2009). Disturbance forms the community assembly (Tilman 2004). The degradation of native habitats caused by alien species invasions and habitat destruction results from human activity and can be alleviated (Halpern et al. 2008; Leprieur et al. 2008; Taylor and Irwin 2004). The link between destruction triggered by humans and invasions of organisms has long been recognized (Gentili et al. 2021). It is now evident that the human intervention (Halpern et al. 2008; King et al. 2008; Leprieur et al. 2008), as opposed to natural processes (Fridley et al. 2007; Levine 2000), is the chief mediator of an immense and increasing number of alien species invasions (King and Tschinkel 2008).

The assembly of the population and biotic invasions are possibly regulated by particular processes (Tilman 2004). The capacity to compete with native species is an important mechanism suggested to understand the achievement and dynamics of invasive non-native species (Billen et al. 2005; MacDougall and Turkington 2005). Invasive species can be more successful than native species for various reasons, with their unique physical or functional features, superior capability to endure or expand in resource-constrained environments or escape from many natural enemies (Bruno et al. 2005). Invasive species, which thrive and attract more than native species in disturbed ecosystems, may profit from the conditions caused by anthropogenic disturbance (Seabloom et al. 2003). The main factor determining the success and abundance of the alien species is simply access to disturbed habitat, where invasive species are a "passenger" rather than a "driver" of ecologic change. However, both indigenous and exotic species' competitive abilities are much less important (King and Tschinkel 2008; MacDougall and Turkington 2005).

Social insects, predominantly ants, are among the most destructive invaders (Holway et al. 2002; Hoffmann et al. 2010). The features that distinguish them as incredibly successful intruders include a super-colonial assembly, high replicability, and a strong capacity to monopolize natural systems to overpower native species (Arnan et al. 2018; Bertelsmeier et al. 2017; Holway et al. 2002). Alien ants are among the supreme threats to ecosystems; many species have invaded the continents around the globe (Suarez et al. 2010). The generalist habits and their small size and frequent interactions with dwelling or ecological disruption (Fournier et al. 2019) make them easy to carriage by humans, allowing for their foundation and consequent dissemination (Bertelsmeier et al. 2018). As a result, over 200 non-native ant species colonies have been colonized beyond their local ranges (Bertelsmeier et al. 2018; Lach et al. 2010).

According to the International Union for Conservation of Nature (IUCN 2021) (http://www.iucngisd.org) and Global Invasive Species Database (GISD) (http://www.issg.org/database) lists of invasive ant species, around 23 species of invasive ants have been recorded (Table 1). Moreover, the red imported fire ant *(Solenopsis invicta)*, the Argentine ant (*Linepithema humile*), the yellow crazy ant (*Anoplolepis gracilipes*), the big-headed ant (*Pheidole megacephala*), and the little fire ant (*Wasmannia auropunctata*) are also on the list of the "100 of the world's most noxious invasive alien species" (Lowe et al. 2000). Subsequently, the invasive ant species numbers are steadily increasing with a substantial expansion in their dynamic range (Chifflet et al. 2018; Cordonnier et al. 2020) because of the increase in international trade and globalization (Seebens et al. 2021).

Invasive ants can affect the diversity, resources, conformation, and abundance of local fauna. Direct impacts of introduced alien species arise at the species level by mechanisms such as predation, competition, and transfer of diseases and parasites to distinct organisms, which eventually led to population decrease and species extinction (Loehle 2003). The number and type of species encounters are forecast to rise as invasive species integrate into recipient populations (Pearson and Callaway 2003; Gallardo et al. 2016). Introduced species are a significant aspect of the population decrease and loss of local fauna. Non-native species are the major factor of animal depopulation and extermination. For instance, approximately 400 of over 1300 species are recently protected under "the Endangered Species Act." Additionally, predation is threatening around 180 species. Around 42% of vulnerable or endangered species currently are in danger mainly because of alien species (Nikolovska 2016). About 8.7 million estimated animal species are reported on earth. Among them, around 97% of species are invertebrates and are an essential component of most food chains, either directly as prey or indirectly by

Table 1 List of invasive ant species

Scientific name	Common name	Reference
Acromyrmex octospinosus	Leaf-cutting ant	(Boulogne et al. 2018)
Anoplolepis gracilipes	Yellow crazy ant	(Wetterer 2005)
Brachyponera chinensis	Asian needle ant	(Guénard et al. 2018)
Lasius neglectus	Invasive garden ant	(Boase 2014)
Linepithema humile	Argentine ant	(Tsutsui et al. 2001)
Monomorium floricola	Flower ant	(MacGown and Hill 2010)
Monomorium destructor	Singapore ant	(Soto 2013)
Monomorium pharaonis	Pharaoh ant	(Krabbe et al. 2019)
Myrmica rubra	European fire ant	(Groden et al. 2005)
Nylanderia fulva	Tawny crazy ant	(Wang et al. 2016)
Nylanderia pubens	Hairy crazy ant	(Gotzek et al. 2012; Siddiqui et al. 2019a)
Paratrechina longicornis	Crazy ant	(Wetterer 2008)
Pheidole megacephala	Big-headed ant	(Pietrek *et al.,* 2021)
Solenopsis geminata	Tropical fire ant	(Wetterer 2011)
Solenopsis invicta	Red imported fire ant	(Wetterer 2013)
Solenopsis papuana	Papuan thief ant	(Ogura-Yamada and Krushelnycky 2020)
Solenopsis richteri	Black imported fire ant	(Peterson and Nakazawa 2008)
Solenopsis xyloni	Southern fire ant	(MacKay and Mackay 2002)
Tapinoma melanocephalum	Ghost ant	(Miric et al. 2021)
Tapinoma minutum	Dwarf pedicel ant	(McCormack 2007)
Technomyrmex albipes	White-footed ant	(Lach et al. 2010; Siddiqui et al. 2019a)
Triplaris americana	Tree ant	(Lalla and Ivey 2011)
Wasmannia auropunctata	Little fire ant	(Vonshak et al. 2010; Siddiqui et al. 2019a)

nutrient cycling (Salvador et al. 2021; Horenstein 2011). Economic risks associated with non-indigenous organisms are substantial, in addition to ecological costs. For instance, the predictable financial expenses of non-native species exceeded 314 billion US dollars a year for the USA (Pimentel et al. 2001). Moreover, the overall annual management cost only for the red imported fire ant was predicted to be 1 billion US dollars in the USA, 6 billion US dollars in New Zealand, and 1.65 billion AU dollars in Australia (Gutrich et al. 2007; Pimentel et al. 2005; Wylie and Janssen-May 2017).

Experimental trials related to invasion effects have been centered on direct viability: for example, the impacts of a novel invading predator on native prey mortality rates (Peck et al. 2008; Nunes et al. 2014). However, by altering the behavior of native species, outsiders may have more subtle consequences (Greenlees et al. 2010, 2007; Nelson et al. 2011, 2010). Such important ecosystem activities, including seed dispersal, decomposition, and pollination, are also carried out by invertebrates (Kehoe et al. 2020). Native invertebrate ecosystems can be decimated by introducing non-indigenous insects, resulting in the depletion of the diversity of native species and the destruction of critical ecological processes (Kapustka and Linder 2007). The effects of invasion on native fauna in the same habitats might be catastrophic for the native community via several ecological factors, e.g., habitat disturbance, resource competition, limiting foraging native species, and various other indirect mechanisms. The aim of this review is to provide an overview of the effect of alien ant species on native fauna and flora, which is linked to the disturbance of ecological function in the ecosystem. We made a general analysis of the literature presently available on the topic, finding the gaps in knowledge and proposed future prospects of impacts of invasive ant species on native communities.

Sources of invasion

Invasive species have been a concern since ancient times, when people began to travel rapidly using various modes of transport, such as horses, canoes, camels, carrying lice, rodents, bacteria, cows, dogs, cats, pigs, goats, and other livestock. During species invasions, the activities of other species, particularly people, play a growing role, as *Homo sapiens* have settled nearly all the earth's habitats and begin to turn natural areas into rural or urban land (Nikolovska 2016). Some invasive species are purposely introduced or released into the ecosystem carelessly (Table 2). The invasive species were introduced accidentally by animals, manufacturing goods, or by the transportation of the equipment such as packaging material or ballast water and ship hulls (Lovell et al. 2006). For instance, a study indicated that an increase in the influx of trade has resulted in the introduction of non-native species (Table 2).

Table 2 The means of dispersal of invasive ant species

Invasive ant species	Invasion pathway	Reference
Acromyrmex octospinosus (leaf-cutting ant)	Plants or parts of plants, cyclone or by wind	(Boulogne et al. 2018, 2014)
Anoplolepis gracilipes (yellow crazy ant)	Aircraft, cargo, containers and packaging wood or non-wood, land vehicles, Machinery and equipment, plants or parts of plants, ship structures above the water line, soil, sand, and gravel	(Harris et al. 2005; Wetterer 2005)
Brachyponera chinensis (Asian needle ant)	Imported plants, Plants or parts of plants, plants, and soil, bulk freight or cargo, ship structures above the waterline,	(Guénard et al. 2018; Nelder et al. 2006)
Lasius neglectus (invasive garden ant)	potted plants, turf peat, soil, cuttings of vegetation, human-mediated dispersal, plants or parts of plants, soil, sand and gravel, human transport	(Boase 2014; Espadaler et al. 2007)
Linepithema humile (Argentine ant)	Containers and packaging wood, debris and waste, vehicles, mulch, straw, baskets and sod, plants or parts of plants, soil, sand and gravel, infected trees, human-mediated dispersal	(Carpintero et al. 2005; Hee et al. 2000; Tsutsui et al. 2001)
Monomorium floricola (flower ant)	Plants or plant parts	(MacGown and Hill 2010; Wetterer 2010)
Monomorium destructor (Singapore ant)	Human-mediated dispersal via trade	(Harris et al. 2005; Soto 2013)
Monomorium pharaonis (Pharaoh ant)	Cargo	(Krabbe et al. 2019)
Myrmica rubra (European fire ant)	Infested potted plants, mulch	(Groden et al. 2005)
Nylanderia fulva (tawny crazy ant)	Infested plants or plant parts	(Wang et al. 2016)
Nylanderia pubens (hairy crazy ant)	Container or material, garbage, yard debris, bags or loads of compost, potted plants, bales of hay, truck, railroad, and airplane	(Gotzek et al. 2012; McDonald 2012; Wetterer and Keularts 2008)
Paratrechina longicornis (Crazy ant)	Large shipment, cargo (fresh produce, timber, empty sea containers, and personal baggage), potted plants	(Wetterer 2008)
Pheidole megacephala (big-headed ant)	Plants or parts of plants, soil, sand and gravel, seedlings, micro propagated plants, clothing, footwear and possessions, vehicles	(Pietrek *et al.,* 2021)
Solenopsis geminate (tropical fire ant)	Flowers, fruits, leaves, roots, seedlings, micro-propagated plants, true seeds, solid or lose wood packing material or non-wood	(Wetterer 2011)
Solenopsis invicta (red imported fire ant)	Float raft, electrical equipment or other equipment, vehicles, soil, and planting material	(Wetterer 2013)
Solenopsis papuana (Papuan thief ant)	Imported taro and coconut	(Harris and Berry 2005; Ogura-Yamada and Krushelnycky 2020)
Solenopsis richteri (black imported fire ant)	Wind (newly mated queens), floodwaters, floating colonies, turf, sod, hay and nursery containers, soil, potting media, straw, vehicles, ship ballast water and sediment, Soil, sand and gravel, human-mediated dispersal	(Peterson and Nakazawa 2008; Taber 2000; Weeks Jr and Drees 2002)
Solenopsis xyloni (southern fire ant)	Infested wood or plants or parts of plants	(MacKay and Mackay 2002)
Tapinoma melanocephalum (ghost ant)	Imported coconuts, wool, cut timber, cargo, non-wood containers and packaging, cut flowers, potted plants	(Appel et al. 2004; Miric et al. 2021; Harris et al. 2005)
Tapinoma minutum (dwarf pedicel ant)	Trade and transport of coconut tree leaf bases and infested plant or plant parts	(Clouse 2007; McCormack 2007)
Technomyrmex albipes (white-footed ant)	Cut flowers, infested plant or plant parts	(Lach et al. 2010)
Triplaris americana (tree ant)	Seed dispersal, wind, ornamental plant imports	(Chong et al. 2009; Lalla and Ivey 2011; Pires et al. 2015)
Wasmannia auropunctata (little fire ant)	Logs and lumber products, planting material, flooding, and other natural disasters, floating vegetation/logs/debris, food, garden waste disposal, camping equipment, nursery, timber trade, potted plants or parts of plants, soil, sand and gravel, cargo, wood containers and packaging, machinery and equipment, human-mediated dispersal	(Harris et al. 2005; Romanski 2001; Vonshak et al. 2010)

Moreover, the high to low diversity hotspots of non-native species across the 609 areas consisting of 186 islands and 423 inland regions are identified (Fig. 1). The database contained eight groups of different taxa (vascular plants, ants, spiders, amphibians, freshwater fishes, birds, reptiles, and mammals) (Dawson et al. 2017). Only ants covered about 64% of the land area consisting of the 402 regions, amounting to 4061 records. Most of the ant species spread when the global trade starts through merchant ships. Almost 51.8% of maritime shipments contain solid wood packaging materials, and there is significant infection with these materials (Lovell et al. 2006). Unintended species can also be harbored by military cargo transport. According to the Animal and Plant Health Inspection Service (APHIS) report, about 25 new or re-introduced species invade the USA in 2020 (APHIS 2020). Stimulated by the growth of global commodities and people transport, the invasive species and management costs are growing day by day at an alarming pace (Lovell et al. 2006; Anonymous 2021). According to the Global Ant Biodiversity Informatics project database, more than 237 alien ant species have been described globally (Guénard et al. 2017). Among them, 23 ant species were reported as highly invasive species spreading rapidly across the world (Tables 1 and 2).

Impacts on invertebrates

Invertebrates make up about 97% of all animal species which are an essential part of many food chains, whether indirectly through nutrient cycling or indirectly as predators or preys (Salvador et al. 2021). Invertebrates execute other essential roles in the ecosystem, including seed distribution, decomposition, and cross-pollination (Siddiqui et al. 2019a). Some introduced species can decimate the native invertebrates that cause the decline of the diversity among native species and disrupt critical ecological functions (Kapustka and Linder 2007). Invasion by introduced invasive ants can directly affect local invertebrates through predation or indirectly by manipulative competition for food sources (Holway et al. 2002).

Impacts of invasive species on the native ant fauna

The effects of invasive species on native species sharing their habitat are enhanced further by habitat loss and disturbance, competition for space and food sources, hybridization, fragmentation, and foraging behavior of vertebrates. Because of the important roles that ants play in ecosystems, many aspects of an ecosystem may be altered when invasive ant species reach high densities and local native ant species decrease. Ants are predators, scavengers, herbivores, detritivores, and granivores and are preyed on by a wide range of specialist predators and insect species (Holway et al. 2002). This study provides a representative insight into invasive species' effects on native species living in the same niche as invasive species in different ways.

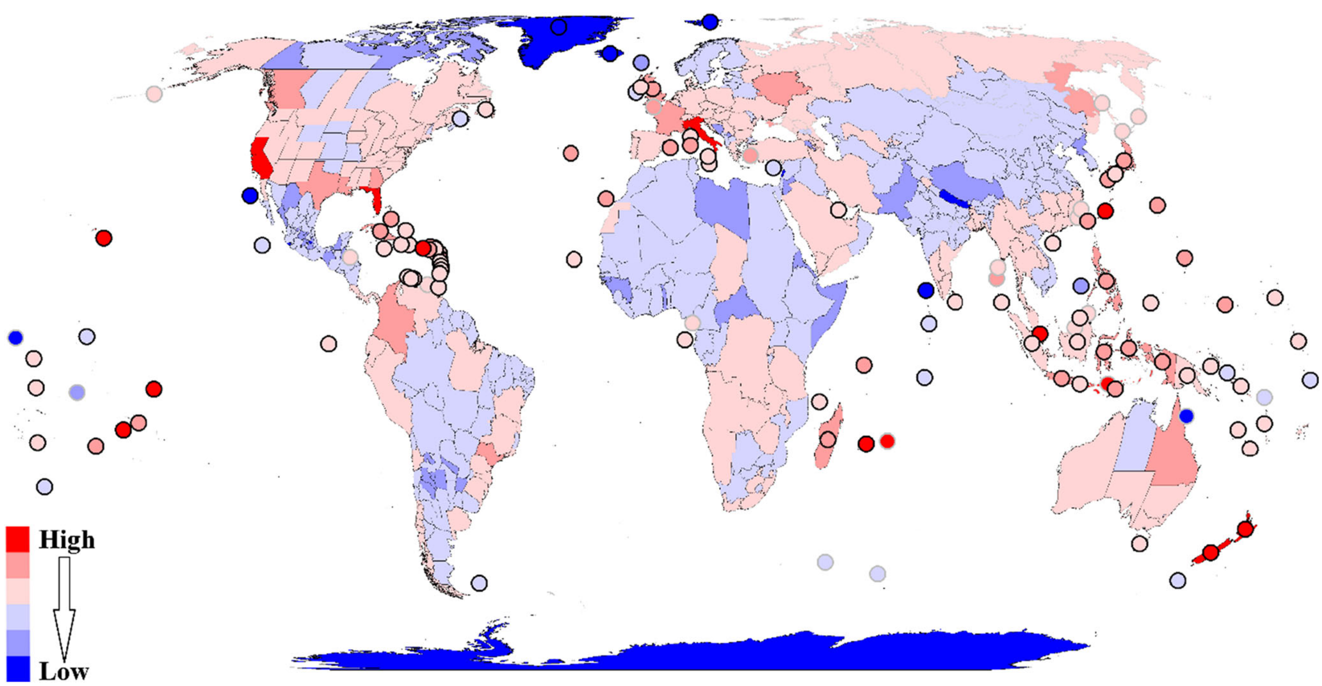

Fig. 1 The map shows the diversity of eight non-native taxonomic groups (ants, amphibians, birds, freshwater fishes, mammals, vascular plants, reptiles, and spiders) and their species hotspots. The red color indicated high diversity, and the blue color showed low diversity

Habitat disturbance

The indigenous species that share the same habitats with invasive species are possibly affected in various ways. For example, the Argentine ant negatively impacts the 16 native ant species in the citrus canopy by reducing their foraging activity. Some ant species were displaced from the invaded citrus canopy (Zina et al. 2020). Before the establishment of an invasive species, first, they have to find suitable habitats. Effective invaders are mostly human-altered species that inhabit human-reformed environments and are readily distributed by humans. Effective invader species are also habitat-generalists, meaning they are not limited by specific environmental criteria (Colautti and MacIsaac 2004). The introduction of non-native ants can cause significant changes to local ant population recipients (Goodman and Warren II 2019). In some instances, native species can be entirely excluded from their natural environments (Fig. 2) by invasive species (Naughton et al. 2020). At the same time, non-native and native ant species also concur to some degree on a regional scale (Arnan et al. 2018; Berman et al. 2013; Naughton et al. 2020; Stringer and Lester 2008). Spatial segmentation within their typical habitat and dietetic partitioning of food sources may be factors that potentially promote the co-occurrence of native and non-native ant species (Ward 2008). Fragmentation of habitat can also encourage the introduction of non-natives that either actively interacts with, prey on, parasitize or otherwise indirectly affect native species (Colautti and MacIsaac 2004). Many interdependent variables influence the invasive species success, particularly their characteristics, the population of recipients, abiotic conditions, and the link between these aspects (Gabriel et al. 2001; Holway 2005). For instance, strong evidence has been presented that *S. geminata*, the native ecological counterpart of *S. invicta*, has been replaced in the disturbed environments in the southern USA (King and Tschinkel 2006). The most concerning aspect is that habitat disruption could be the underlying cause of *S. invicta* dominance. Native species diversity and abundance are substantially lower in heavily degraded habitats than in controlled environments (King and Porter 2005; King and Tschinkel 2006; Lubertazzi and Tschinkel 2003).

Random connections between ant species were discovered, and substantially negative relationships between exotic *Ochetellus glaber* and both *Technomyrmex jocosus* and *Monomorium antarcticum* were identified, the last being native. In addition, *O. glaber* and *M. antarcticum* were found to feed at the same trophic stage, and in their isotopic niches, they had an 82% overlap. With the decreased probability of co-occurrence, this dietary overlap indicates competitive exclusion for the same niche (Probert et al. 2020). *Monomorium antarcticum* represents the most ubiquitous native ant species in New Zealand. However, it possibly means a complex species (Dann 2008; Wang and Lester 2004), occurring in a variety of habitats on the North and South Islands and several seaward islands. This species has been shown to display a violent behavior against different ant species and may be capable of suppressing small colonies of *Linepithema humile* in specific contexts; however, any competitive advantage tends to decrease as the colony of *L. humile* grows over a threshold (Probert et al. 2020; Sagata and Lester 2009).

The theoretical concept known as “niche opportunity” was developed by Shea and Chesson (Shea and Chesson 2002). The ability of invasive species to enhance population densities resulting from environmental circumstances in their introduced areas is a niche opportunity. It might be an “escape opportunity,” or a “resource opportunity,” or both. An escape opportunity occurs where species requirements are highly accessible and native species are not abundant or are not active with the non-native species. And when the resources that a species requires are readily available, this is referred to as a “resource opportunity.” Invaders’ success benefits from fewer attacks by enemies originating from invaded territories, thereby achieving much greater densities in exotic pests than its natural environment (Shea and Chesson 2002). For example, there is growing evidence that Argentina ant can invade uninterrupted territory (Tillberg et al. 2007). The Argentine ant has displaced native ant species and earlier ant invaders in areas where it has been introduced (Sunamura et al. 2007; Holway 2005). Non-ant arthropod communities can be altered or reduced by the Argentine ant, as evidenced by *S. invicta* in the Southeastern USA (LeBrun et al. 2007). So, it is evident that the invasive species can disrupt the habitat and possibly displace or extinct the native species from its native ecosystem (Fig 2).

Food source of native fauna

The ability of non-native species to monopolize resources and their ability to compete help them conquer native communities (Aslan and Rejmanek 2012). Invasive alien species are associated with higher levels of aggressive exploration and audacity than non-invasive alien species in general (Chapple et al. 2011; Monceau et al. 2015; Weis 2010). They may be more likely to scatter, and they may be more successful at foraging (Pintor et al. 2009; Rehage and Sih 2004; Short and Petren 2008). Foraging behavior most certainly facilitates species development and invasion success at various stages (Chapple et al. 2012). For instance, maximum levels of audacity and investigation will decide whether native species leave their community, join a human transportation vector, and transfer to a new place (Chapple et al. 2012, 2011). Once at a new location, species growth is sometimes correlated with advanced stages of boldness and discovery and minor levels of neophobia (Candler and Bernal 2015; Chapple et al. 2012; Griffin et al. 2016; Monceau et al. 2015). These characteristics

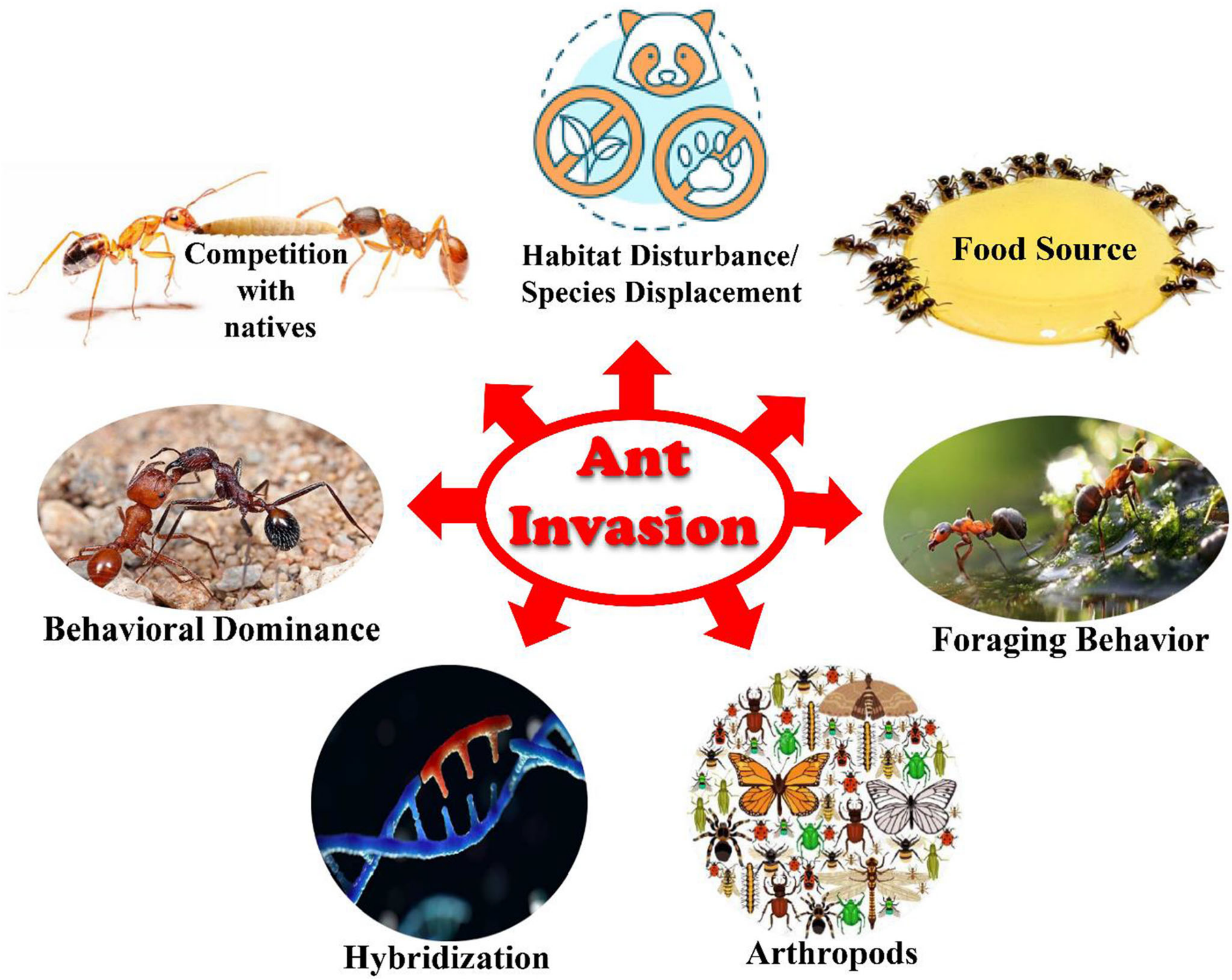

Fig. 2 Schematic diagram represents the effects of invasive ants on native species sharing the same habitat

may help manipulate resources and provide a benefit over invasive species (Fig. 2).

Increased antagonism and foraging can also provide alien species with a competitive advantage against local species during establishment, improving their successful growth (Downes and Bauwens 2002; Weis 2010). After the foundation, the increase of the range of a population may depend on the species attraction for dispersion, determination and investigative behavior, standards of aggression, and sociability (Cote et al. 2010; Damas-Moreira et al. 2019; Gruber et al. 2017; Michelangeli et al. 2017; Rehage and Sih 2004). Argentine ants, for example, can take advantage of resources that native ant species would otherwise use, which may minimize the effectiveness of native ant colonies in foraging. Invasive ant species compete for resources and interfere with each other, for instants, *Linepithema humile* and native ants. It can also encounter and relocate native ants from food sources (Cordonnier et al. 2020).

Mutualism between hemipterans and invasive ants can diversify and amplify the impacts on native vertebrate species (Siddiqui et al. 2019b; Styrsky and Eubanks 2007). Mutualistic associations between the *S. invicta* and honeydew-secreting hemipterans also harm the competitors, such as honeydew-secreting hemipterans and natural enemies. Honeydew provides almost 50% of food to fire ants (Helms and Vinson 2002). This food resource can fuel the foraging activity and adequately disturb the birds nesting on the ground (Allen et al. 2004). Mutualism between invasive ants and scale insects also enables the availability of resources correlated with elevated levels, altered the usage of substrates, increased foraging success, and modified foraging behavior.

There are large proportions of scale insects and honeydew supply chain in ant-invaded forests; both would have been significant foods for generalist customers (Davis et al. 2008). Changes in the habitat structure and access to resources produced by ants can indirectly affect the feeding and reproduction of birds. The *Wasmannia auropunctata* at the start of an invasion allows them to grow large populations with its unicoloniality (Le Breton et al. 2004). In addition, *W. auropunctata* encourages indigenous hemipterans' production, which provides valuable and continuous food supplies in return (Downes and Bauwens 2002). *Solenopsis invicta*, for example, defends the cowpea aphid (*Aphis craccivora*) and the cotton mealybug (*Phenacoccus solenopsis*) from natural predators such as *Menochilus sexmaculatus*, *Propylaea japonica*, and *Scymnus* (*Neopullus*) *hoffmanni* lady beetles and competitors like the poinsettia thrips *Echinothrips americanus* (Cheng et al. 2013; Huang et al. 2011). Consequently, these pests increase rapidly (Huang et al. 2010a; Zhou et al. 2012). The invasive species monopolizes existing resources and thus populates the habitat, resulting in the shift of various local species of New Caledonia (Le Breton et al. 2003); one of the worst ecological threats is a broadly diverse hotspot.

Indigenous ant populations are decreased in abundance and diversity mainly by competition for exploitation and interference with *S. invicta* (Epperson and Allen 2010). Fire ants are known to affect indigenous arthropods adversely (Wojcik et al. 2001). Predation by invasive red imported fire ants or exploitative competition for food supplies can directly impact native invertebrates (Holway et al. 2002). The invasion in central Texas of fire ants led to a 30% decrease in the richness of non-ant arthropods and a 75% decrease in the quantity of non-ant. They suggested that the native ant fauna was being wiped out due to competition with *S. invicta* for nesting locations or food (Epperson and Allen 2010; Lebrun et al. 2012).

There are a few instances of non-native species that cause damage to major crops in the native community. For instance, the mutual interactions of fire ants and honeydew-secreting insects indirectly influence crop production by encouraging the growth of aphids and restricting the natural enemies. Nevertheless, the invasive species intervene in the access of native species to the food source that affects the native community and indirectly disturbs the ecosystem functions.

Competition with native species

Competition's role in community structuring has been a controversial issue in ecology (Ellwood *et al.,* 2016), but there is substantial proof that interspecies competition correlates to abundance and distribution trends in ant communities (Chesson and Kuang 2008; Lach 2005). Numerous invasive species are believed to have succeeded primarily due to their superior competitive ability compared to native species (Bruno et al. 2005). Invasive species affect native fauna in several ways, including adverse effects through depletion of mutual resources (resource competition) (Sagata and Lester 2009), adverse effects through toxins, waste materials, or chemical or physical aggression (Sunahara and Mogi 2002), and negative effects through interspecific mating of depressive reproductive production (mating interference) (Gröning and Hochkirch 2008; Shuker and Burdfield-steel 2017).

Earlier studies have demonstrated a significant negative correlation between the abundance of the fire ant and co-existing ants (Epperson and Allen 2010). If these trends are driven by the mechanism of competitive suppression (Fig. 2), the abundance of co-occurring ants will increase by eliminating *S. invicta*. Therefore, a negative relationship exists between the abundance of fire ants and the abundance of other ants. During the displacement of native species by invading species, ecosystems undergo rapid flux, and native species often interact with invasive ones (Barfknecht and Gibson 2021; Gentili et al. 2021). The *S. invicta* Buren, the invasive fire ant, has a more robust competitive or disturbance capacity that could be the explanation for their success (King and Tschinkel 2008). Throughout its introduced and native areas, *S. invicta* is primarily confined to human-modified environments and reaches its maximum abundance in these regions (Deyrup et al. 2000; Tschinkel 2006). Thus, S. *invicta* is an ideal invasive ant for determining the competitive dominance, habitat disruption, or their interference which primarily restructures the native ant societies.

Similarly, the occurrence of Argentine ants decreases the activity of other ant species in foraging because of their highly aggressive behavior (Cerdá et al. 2013; Rowles and O'Dowd 2007). Aggressive encounters with Argentine ants decreased success in foraging can lead to eliminating native species of ants from areas where Argentine ants have invaded. Some indigenous species of ants often emigrate, such as the *Monomorium andrei*, *Pheidole californica*, and *Crematogaster coarctata*. The *M. andrei* and *C. coarctata* relocate after a series of aggressive encounters with the Argentine ants (Gordon and Heller 2014; Tillberg et al. 2007). The alien ant invasion decimated the indigenous ant fauna. The primary mechanism behind such an effect tends to be a competitive substitution. Another study recorded that the introduced fire ant has eliminated the local ant species in affected regions of the southeast of the USA, decreasing local ant abundance by 90% and species richness by 70%. Additionally, the other invertebrates sharing the same habitats are also significantly affected (Epperson and Allen 2010; Lebrun et al. 2012).

The Argentine ant (*L. humile*) has already driven native ants out of South Africa's Cape fynbos shrublands, disrupting ant-plant mutualisms and threatening numerous rare and endangered native flora (Botes et al. 2006). The little fire ant (*W. auropunctata*) is also an extremely competitive ant that takes over the litter habitat by eradicating the native ants. This intrusive performance can involve predation and competitive behaviors (exploitation and interference). *W. auropunctata's* invasive performance is like the tramp ants and supports the principle of general evolutionary characteristics that contribute to increased competition in a new habitat (Le Breton et al. 2003).

Foraging behavior

The invasive species often compete with the feeding of native species by destroying their food sources (Fig. 2). There is a significant variation in non-native ant diversity and native-ant foraging activity between infected and uninsulated spots (Zina et al. 2020). They proposed that local ants adjust their food searching behaviors to prevent competition against *S. invicta* (Wang et al. 2020). Soil temperature influences red imported fire ant foraging, though the fire ants can forage the whole year, making local arthropods susceptible throughout all periods (Lei et al. 2021). Maximum foraging activities occur on the ground, but the ants were found to forage up to 10 m in the tree shelter, possibly affecting shelter arthropods (Kaspari 2000). Interference competition is often essential in the displacement of one species of an ant by another in the form of aggressive behavior among worker ants (Cerdá et al. 2013; Chesson and Kuang 2008). For instance, in New Zealand, the Australian lycaenid butterfly *Zizina labradus* have reportedly decimated pervasive *Z. oxleyi* in many areas (Barlow and Goldson 2002).

Lubertazzi and Tschinkel (2003) explored that the fire ant is the dominant land-foraging ant species in the pine flatwood group. Fire ants are likely to have a detrimental effect on certain co-occurring ant species. In the laboratory, the foraging approaches of *S. invicta* and local ant species evaluated that the local ants were, by far, more successful foragers than *S. invicta*. They concluded that *S. invicta's* effectiveness as a competitor is due to its massive colony size (Tschinkel, 2011). There is an example of the Argentinian ant; a very efficient foragers. One factor contributing to Argentine ants' competitive potential can be the large nest size. While competition affects both Argentine ants and indigenous species' foraging success, it is indigenous species of ants that ultimately perish (Gordon and Heller 2014; Zina et al. 2020).

Behavioral dominance

Researchers have given significant attention to the behavioral processes involved in the proximate factors leading to the success of an ant invader; nevertheless, there is more yet to be discovered about the aspects that control the success of colonization. Currently, competitor capabilities of the invasive ants have been extensively evaluated (Holway et al. 2002) but poorly studied in their native habitat range. However, their impact on native species is vital to discover that leads to the native species dispersal or extinction. Therefore, the success of the Argentine ant and numerous other exotic ants are often assumed to derive mainly from behavioral dominance and liberation from natural opponents, allowing them to achieve numerical supremacy and aggressively eradicate co-occurring species (Zina et al. 2020; Sanders et al. 2003). For example, Argentine ant is behaviorally dominant in the invaded area due to their aggressive and rapid food searching behavior, which helps them to established faster in the introduced habitats, and consequently eliminate or displace the native ant species (Blight et al. 2017). The Argentine ant, the big-headed ant, the fire ants, the yellow crazy ant, and the electric ant are considered the behaviorally dominant invasive ant species in introduced habitats outside their native ranges (Fig. 2) (Arnan et al. 2018; Bertelsmeier et al. 2015; Garnas et al. 2016). According to the ecologists, these are the top five invasive ant species (Garnas et al. 2016).

It is assumed that behaviorally dominant ants with huge colonies can better gain access to limited resources and thus restrict or exclude native species (King and Tschinkel 2006). Simultaneously, through experimentation and observation, it is possible to detect the fire ants' indirect effects on the fauna of native insects. Indirect consequences may include behavioral changes, altered foraging patterns, habitat utilization, decreased survival and weight gain, and diminished food availability (Allen et al. 2004).

Hybridization with native species

Hybridization is the reproductive relationship between species whose lineages have been confirmed to have some level of evolutionary divergence (Arnold and Meyer 2006; Brennan et al. 2015; Mallet 2005). Due to increasing global changes and species translocations by humans, such interspecific genetic transfers are becoming considerably more frequent (Fig. 2) (Allendorf et al. 2001; Brennan et al. 2015). These progressions are also the products of human actions, offering an opportunity to dissect the mechanisms that underlie the formation of reproductive barriers. When introduced or spread into habitats with closely related species, alien species can interbreed with them, resulting in changes in the genetic makeup of either species (SCBD 2021). Many hybridization cases have been reported and recorded due to the un-intended introduction of alien species into new ecosystems (Ellstrand and Schierenbeck 2006; Mooney and Cleland 2001; Nolte et al. 2005). The potential negative effects of such modifications are the decrease of the viability of species or by creating a more successful invader, or by creating hybrids more sensitive to certain pests and pathogens.

Hybridization processes may have detrimental effects on organisms or habitats, resulting in biodiversity loss and ecosystem destruction, leading to the extinction of various species both directly and indirectly (Allendorf et al. 2001; Brennan et al. 2015). For individuals, sterility or inviability of hybrid progeny may be the most substantial negative impact of interspecies hybridization. Even though hybridization is a common phenomenon, hybrid individuals should be relatively rare

(Butler et al. 2018). However, hybrid offspring are fertile in certain instances, and hybridization may result in gene transfer from one species to another (Currat et al. 2008; Excoffier et al. 2009; Patten et al. 2015; Taylor et al. 2015). Gene flow could lead to new adaptive variations and even "hybrid speciation" on rare occasions (Brennan et al. 2015; Cordonnier et al. 2019; Dejaco et al. 2016; Kulmuni et al. 2010; Schumer et al. 2014).

Hybridization can therefore play a vital role in speciation (Allendorf et al. 2001; Arnold and Kunte 2017), even though maximum scholars agree on the adverse impacts of non-indigenous intrusions into the gene pools in native species (Allendorf and Luikart 2009). An example of two species of fire ants, *S. invicta* and *Solenopsis richteri*, both are from South America, and both species were mistakenly imported into North America in the early 1900s (Cohen and Privman 2019).

In addition, hybrid development is an influential engine of speciation, particularly in cases where hybrid lines differ environmentally or spatially from the maternal species (Purcell et al. 2016; Twyford and Ennos 2012). Earlier research on the hybrid field in ants has given insight into the speciation. For instance, Cahan and Vinson (2003) demonstrated that the *S. xyloni* developed social hybridization in the hybrid field of *S. geminata*, which leads to obligatory hybridization in the development of workers but avoids the presence of hybrids in the reproductive caste. Purcell *et al.* (2006) experimented on the hybrid gene of the *Formica selysi* and *Formica cinerea* to demonstrate the uneven distribution of distorted hybrids in the *F. cinerea* gene, which revealed a unidirectional pattern of nuclear gene transmission from *F. selysi* into *F. cinerea*. Feldhaar et al. (2008) projected that several additional cases of hybridization could be revealed in detail, particularly in the ant faunas represented by the recent influx of several invasive species. Furthermore, hybridization can play an essential role in introducing new species of invaders (Allendorf et al. 2007). The investigation of variances in the native and introduced species between communities and their niches may reveal the aspects responsible for genetic modifications that ultimately lead to speciation.

Impacts on the other arthropods

Invasive species, particularly non-native ants, frequently prey on or impede the reproduction of diverse arthropods, mammals, birds, and reptiles on the forest floor and canopy. One of their most surprising qualities is its ability to raise and defend the sap-sucking insects on Christmas Island, which affect the forest canopy. At the same time, less than 5% of the rainforest has been invaded by invasive ants on Christmas Island (Lowe et al. 2000).

The invasion had a less severe but significant impact on many other ground-active arthropods (Fig. 2). The numbers of isopods, Erythraeid mites, and tumblebug scarabs have substantially decreased, whereas the richness of crickets, brachypterous roach, and symbiotic scarab has amplified considerably. Overall, the richness of non-arthropod species in infested sites decreased by 30%, and individual numbers declined by 75%. The total richness of arthropod species (including ants) at infested locations was 40% lower (Epperson and Allen 2010; Lebrun et al. 2012; Zina et al. 2020). Such data suggest that polygynous fire ants pose a significant danger to the biodiversity of indigenous populations of arthropods (Porter and Savignano 2014), due to the competition with *S. invicta*, either for nesting sites or for food (Epperson and Allen 2010). Likewise, Garcia et al. (2011) indicated that the presence of fire ants decreased isopod densities.

Solenopsis invicta is a generalist invasive ant species that can consume several pest arthropods such as *Amblyomma americanum*, *Diatraea saccharalis*, and *Anthonomus grandis grandis* (Vogt et al. 2001; Rossi and Fowler 2002; Gleim et al. 2013). Red imported fire ants may also predate the valuable native arthropod species, minimizing the native arthropod abundance and diversity (Allen et al. 2004). The alien fire ants can limit species diversity and gain the status of the dominant species in the ecosystem but cannot replace the native species' functions (Holway et al. 2002). Local arthropods may serve as seed dispersers, decomposers, and pollinators, and these functions are hardly replaced by *S. invicta* (King and Tschinkel 2006; Zettler et al. 2001). Other examples of the native butterfly egg predator are invasive ant species S. geminata, M. floricola, and *T. minutum*, causing a significant reduction in the population of native butterflies (Lach et al. 2016). Moreover, *M. floricola* is recognized as a serious pest of silkworms and coconut in the Philippines. *M. floricola* is a widespread but insignificant agricultural and indoor pest in urban zones (Wetterer 2010; Harris et al. 2007).

Impacts on native vertebrates

Birds

Birds are ecologically essential but are declining globally, on islands in particular (Şekercioğlu et al. 2004). Birds also share and had their habitat affected by invasive species. The evidence for ant invasions having a detrimental effect on birds is, however, underreported (Allen et al. 2004). Invasive ants may have a better chance of succeeding on islands where there are fewer species and functional consistency, as well as a lack of functional groups (natural enemies) (Denslow 2003). Some invasive species threaten the entire island rainforest ecology. For example, the yellow crazy ant eliminated the dominant indigenous red crab (*Gecarcoidea natalis*) species of the Christmas Island (O'Dowd et al. 2003).

Fire ants have recorded direct and indirect impacts on birds and their hatchlings (Ligon et al. 2012). Prior to and following the invasion of fire ants in southeast parts of the USA, Allen et al. (2000) evaluated bobwhite abundance. They recorded that bobwhites' number decreased in the infestation of fire ants in Florida and South Carolina. The chicks of bobwhite birds were stung with red imported fire ants and decreased their survival rates and body mass (Fig. 3). There were significantly reduced survival rates for bobwhite hatchlings subjected to fire ant workers. At higher exposure levels, the decrease in weight gain of chicks was recorded (Allen et al. 2000; Myers et al. 2014). Scientists are worried that scarce birds, including Abbott's booby (*Sula abbotti*), who nest in no other part of the world, may eventually be extinguished by alteration in their habitats by ant attacks directly (Lowe et al. 2000).

Herpetofauna

Herpetofauna's global decline was related to six causes: habitat loss and destruction, contamination of the environment, world climate change, diseases, unjustifiable usage, and invasive species (Gibbons et al. 2000). Although several researchers believe that the most significant sole aspect leading to these degenerations is habitat loss, the consequences of alien species introduction might be significant. In addition, environmental invasion also indicates that invasive species in their environments negatively impact the vertebrates (Bos et al. 2008; Christian 2001; Rowles and O'Dowd 2007; Suarez et al. 2000). For instance, Argentine ants (*L. humile*) limit the accessibility of food for horned lizards (*Phrynosoma coronatum*) by disturbing the native ant populations in California (Suarez et al. 2000). Numerous life cycle traits, such as egg-laying and disturbance, as well as a delayed hatchling emergence, may render both reptiles and amphibians especially vulnerable to fire ants (Allen et al. 2000). The fire ants have been preying on the hatchlings of gopher tortoises (Fig. 3) (Epperson and Heise 2003).

More attention was given to impacts on snakes and lizards than herpetofauna (Tuberville et al. 2000). The decrease of the hognose snake (*Heterodon simus*) (Tuberville et al. 2000), horned lizard (*P. cornutum*), and peninsular kingsnake (*Lampropeltis getula floridanus*) (Wojcik et al. 2001) was attributed to the introduction of red fire ants (Allen et al. 2004). The invasion of fire ants corresponded with the extinction of each species (Allen et al. 2004). The horned lizard species is a dietary specialist that eats the harvester ants of the *Pogonomyrmex* genus as primary food, and it has been

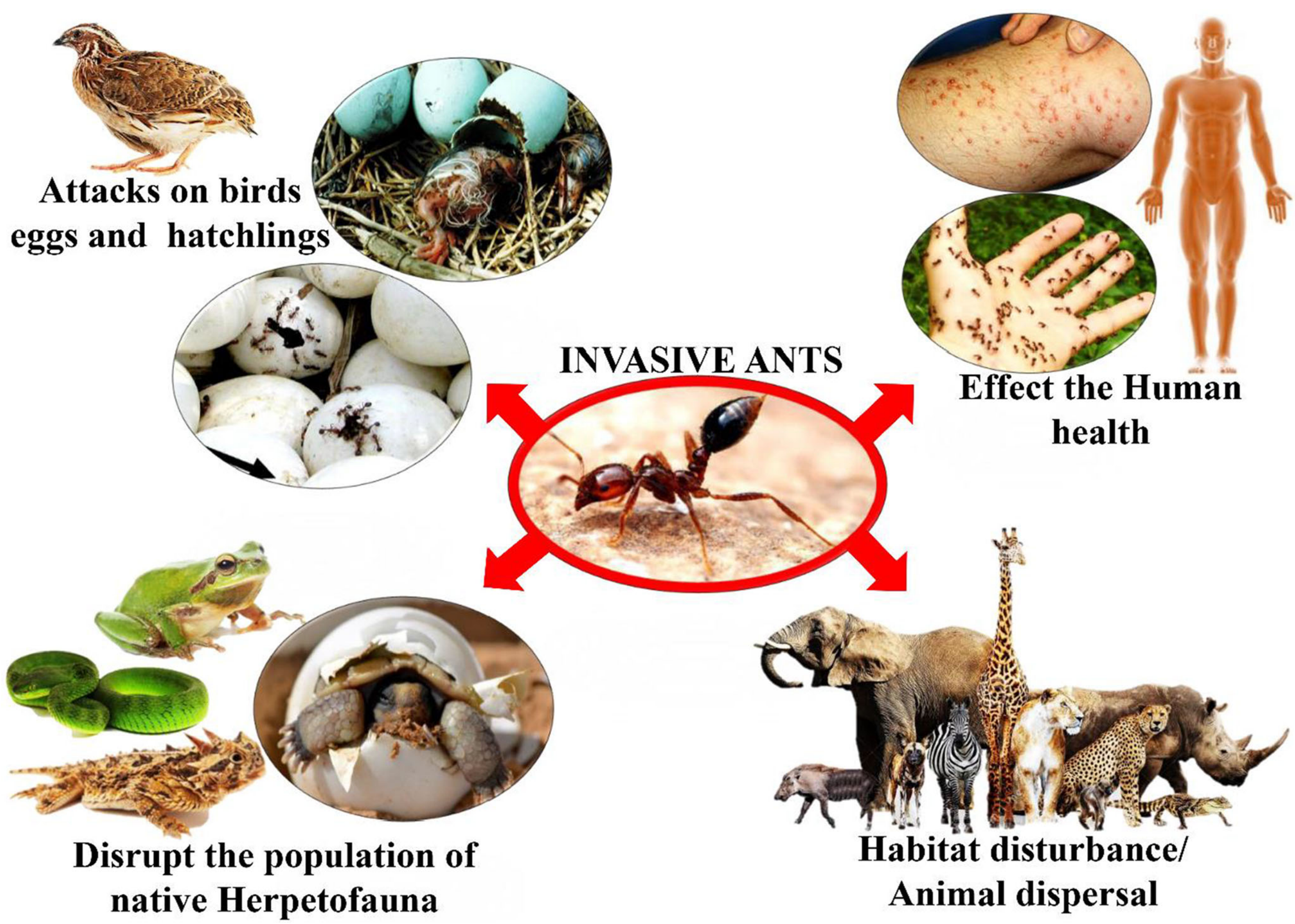

Fig. 3 Schematic diagram represents the impacts of invasive ants on animals sharing their habitat

reported in Texas. Its reduction has been attributed to both direct and indirect consequences of the fire ant invasion. These invasive fire ants can limit prey's availability and attack the hibernating individuals and the incubating eggs. A strongly fossorial, egg-laying species is the southern hognose snake, which might be prone to influences of red imported fire ants (Fig. 3) (Enge and Wood 2003). Tuberville et al. (2000) reported that the snake exclusion from several areas of its range correlates with fire ants range expansion. The *S. invicta* were far more probably responsible for destroying more than half of the batch of eggs of rough green snake (*Opheodrys aestivus*) observed to have exploded after ants had constructed a mound over their nest (Diffie et al. 2010).

Animals

All alien invasive fauna serves as a superior resource competitor and displaces native biota (Fig. 3). For instance, a study indicated a strong negative relationship among fire ants and pygmy mice (Allen et al. 2004). Orrock and Danielson (2004) discussed the effects on the abundance of small mammals sharing the fire ant habitat. Nevertheless, Pedersen et al. (2003) confirmed that the hispid cotton rat (*Sigmodon hispidus*) had transformed habitat usage in the warm climate, in the existence of red imported fire ants but not in the cold season. Wilkins and Broussard (2000) observed that about 80% of small mammal traps were "infested" with *S. invicta* in savannah ecosystems in central Texas. The richness of small species of mammals was inferior to predicted and formerly recorded in all ecosystems at two study sites. The success of traps was lower than the same habitats elsewhere. Many alien invasive species encourage the development and dissemination of another foreign invader or lead to other environmental catastrophes. For example, the introduced mammals, such as the coypu, the American mink, the muskrat, and the Canadian beaver, have strong associations with aquatic environments, where they contaminate water supplies with pathogens that cause salmonellosis, toxoplasmosis, and leptospirosis (Hulme 2012).

Human beings

Invasive ants pose a significant threat to human health and social amenity. Numerous invasive ant species, including *S. invicta*, *S. xyloni*, *S. geminate*, *S. richteri*, *S. papuana*, *B. chinensis*, *M. rubra*, and *W. auropunctata*, have excruciating stings that can result in anaphylactic shocks in individuals who are allergic to the ants' venom and cause blindness in animals when stung in the eyes. Symptoms include intense burning or itching, with a blister forming at the sting site within 5 h (GISD 2021; Osae et al. 2011; Wang et al. 2020). When these aggressive species come into contact with humans, they attack (Fig. 3). Humans stung by *S. invicta* may experience itching and redness, and in most cases, a white boil will be formed few hours after the sting. Additionally, few individuals face severe hypersensitivity, manifest as fever, urticaria, shocks, or even death (Qiao-li et al. 2006; Xu et al. 2012; Zhao and Xu 2015).

Numerous ant species can wreak havoc on infrastructure, particularly electrical equipment, by chewing through wires, resulting in short circuits and occasionally fires. Certain ant species develop synanthropic relationships with humans, which is familiar with tramp species, and thus cause a variety of problems in residential, commercial, and agricultural settings. The *N. fulva* and *N. pubens*, for example, accumulated in large numbers in electrical equipment in their infested areas, causing short circuits and equipment failure (Meyers and Gold 2008; Wetterer and Keularts 2008). In China, some scholars discovered fire ant mounds and nests around the, or in, power plants and transformer houses (Zhao et al. 2008; Zhong-dong 2005). Infestation of *S. invicta* in power facilities and transformer stations in Guangdong province, China, caused severe damage to cables, cabling boxes, power transformer boxes, and other power station infrastructure (Zhong-dong 2005). Because *S. invicta* is attracted to electric fields, there is concern that fire ants might cause a short circuit, resulting in a power system disaster (Xu et al. 2012). Mounds of *S. invicta* are primarily found near watercourses and dams. Another study discovered fire ant infestations in 28 of 64 waterways and dams in Guangdong province (Wang et al. 2020). The invasive ant species can destroy electrical infrastructure, sting employees, and jeopardize the stability of river banks.

Impacts on native plants

Plants are an essential part of all living beings in the ecosystem. The invasion of non-native species also poses a great danger to the native plant species. Several studies have demonstrated that loss of plant diversity can affect the importance of biomass production ecosystems (Hector and Bagchi 2007). These biomass-induced diversification changes can affect other ecological functioning. High plant biomass production rates may be associated with high insect population and diversity (Borer et al. 2012) or enhance soil carbon (Lange et al. 2015). As a result, variations in plant biomass output can mediate the impacts of plant diversity on a variety of activities. Additionally, it appears as though invading ant species indirectly affects plant biomass, as they can either enhance (Maron et al. 2014) or reduce plant biomass (Ndhlovu et al. 2011).

Invasive species might have an indirect effect on the functioning of ecosystems due to variations in the diversity of plants, plant biomass, or both. Invasive species can result in habitat destruction, disintegration, modification, and reconstruction due to their effects on species and ecosystem processes (Fig. 4), all of which have profound impacts on numerous species and ecological functions (Mcneely 2001b; Meyerson and Reaser 2003). Such as, over the past century, invasive alien diseases and pests have caused substantial variations in the structuring of the forests in the east of North America, including the extinction of species such as chestnuts, elm, and hemlock (Mcneely 2001a).

Non-native invasive species are concerned about endangering 762 forest species through direct impacts on species or changing habitats (IUCN, 2201). The extinction of such species contributes to a homogeneous environment, which is probably the greatest major threat to global biodiversity due to habitat loss (Mcneely 2001a; Perrings et al. 2000; Richardson and Rejmánek 2004). Invading ants can have a detrimental effect on agriculture and forestry. Many species can be damaging to plants by feeding on fruit and seeds or boring into stem structures, eating the emerging plant foliage, and cutting young seedlings. Seeds from plants are an essential food source for fire ants. In the mulberry plantations and on infertile land in Southern China, Zhang et al. (2015) discovered that the plant seeds made up 4.6–68% of compact searching materials for *S. invicta*. Xu et al. (2009) found that up to 12% of the waste created in Savannah included seeds in middens. It decreased germination rates by relocating and scarifying the plants. For instance, the plant species such as sesame (*Sesamum indicum*), goatweed (*Ageratum conyzoides*), and napier grass (*Pennisetum purpureum*) significantly affect the growth rate and seed formation by 63%, 56%, and 50% correspondingly (Huang et al. 2010b). Some leafcutter ant species can cause enormous damage to the plants by defoliation their leaves (Fig. 4). For instance, leaf-cutting ant species *Acromyrmex octospinosus* are considered to be significant crop pests. They pose a threat to numerous native plant species susceptible to defoliation in the wild (Boulogne et al. 2018). An evidenced considerable damage to crops and ecosystems caused due to foraging by foragers.

Certain ant species cultivate sap-feeding phytophagous insects, for instance, aphids, scale insects, and mealybugs, for the honeydew they produce. These interactions could lead to high densities of sap-feeding insects, reducing crop productivity and even causing host plant death (Fig. 4). For instance, these associations increased the population of associated aphids, which can harm host plants and decrease yield (Mcneely 2001a). Ants host various honeydew-producing hemipterans, comprising trees, shrubs, vines, fobs, and grasses (Moya-Ragoza and Nault 2000; Styrsky and Eubanks 2007). Some viral and bacterial pathogens can increase in a

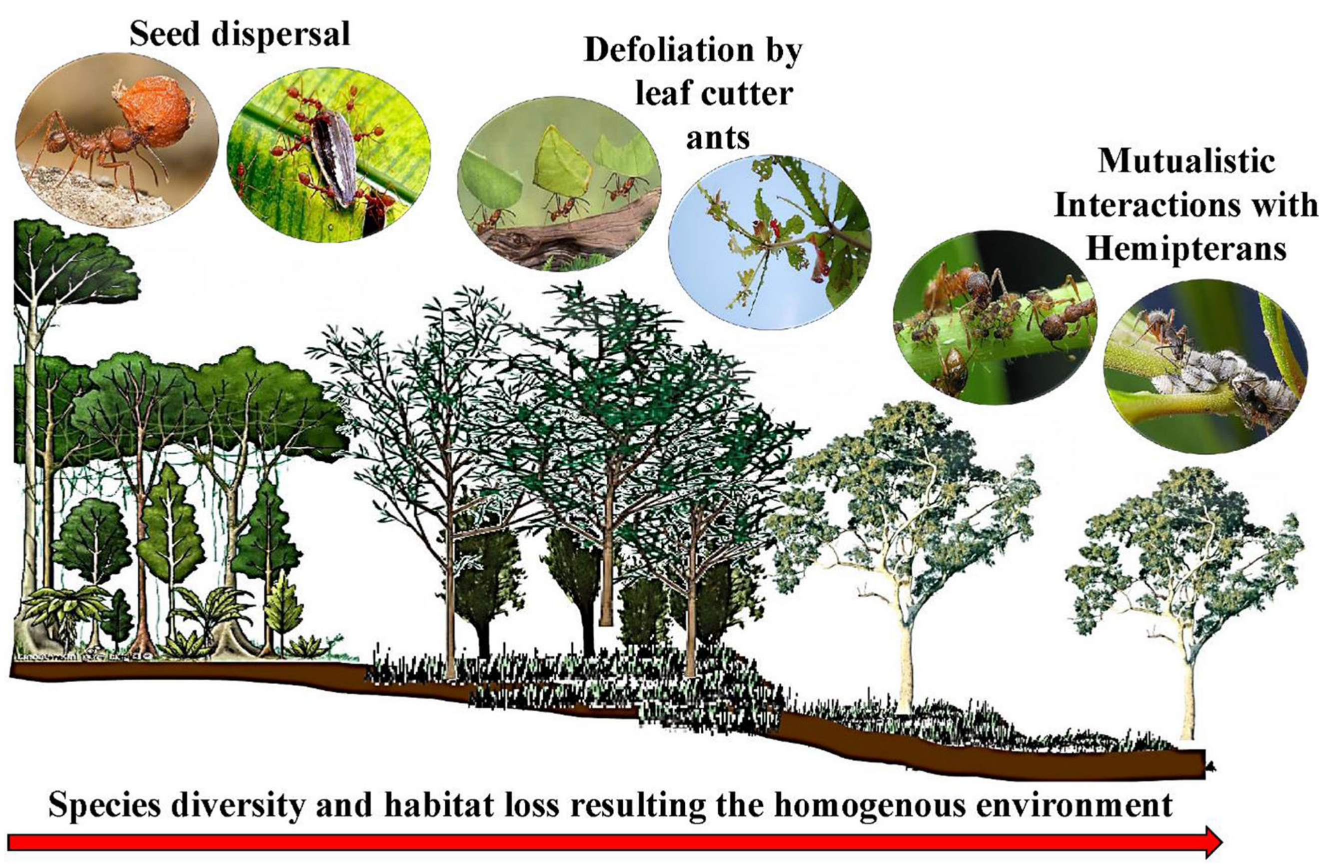

Fig. 4 The schematic diagram represents the destruction of habitat, reduction of species diversity that leads to the homogenous environment by invasive species

disproportionate number of ants than the plant populations because of the increase in the numbers of insects. These invasive ant species can cause the destruction of native flora in the ecosystem.

Management strategies

The aim of control is to maintain an invading organism's density and abundance below an appropriate threshold by reducing its density and abundance (Wittenberg and Cock 2001). A large number of techniques are present for the eradication of alien species. Numerous control methods are being used against invasive ant species. Early control strategies are the first step in the process, including comprehensive common prevention and control strategies, strengthening route prevention through human activity, defining prevention and control boundaries (infested ranges), and long-term surveillance of high-risk regions (Liu et al. 2020). Prevention is the most effective and least expensive way to deal with the introduction of invasive species. Interception of introduced non-indigenous species through ports following regulations enforced through inspections is crucial in the process (Epanchin-Niell 2017). Early discovery of an invasive species often decides whether eradication is possible. Early detection through surveys may target a particular species or site (Reaser et al. 2020). A species-specific survey is conducted, made, or designed for the particular needs of the target species. Site-specific surveys are conducted to detect invaders near high-risk entry points or in areas of high biodiversity value (Wittenberg and Cock 2001). For instance, the fire ant, *S. invicta*, was established in New Zealand three times before being successfully exterminated upon discovery. At the New Zealand border, another species of the fire ant, *Solenopsis papuana*, was discovered. However, the expansion of this species into wet forest ecosystems caused heavy impacts on the native species and ecology of the biota (Doddabasappa et al. 2010).

To date, the technology of monitoring systems, quarantine, emergency response, and eradication has been established to be safe and effective. These technological systems provide significant assistance in the supervision of invasive species. According to the previous experiences with fire ant supervision programs, the country may better respond to the threat of invasive ant invasion (Wang et al. 2020). First, plant quarantine is essential to restrict the invasive species introduction. For instance, one of the substantial reasons *S. invicta* continues expanding its area in China is the lack of plant quarantine for the seedlings (Zhang et al. 2007). Long-distance transport of potted flowers, garden plants, and tree debris is the primary tool to bring fire ants to a new location (Lu et al. 2008). Due to the increased global marine transportation, invasive species are expanding. Thus, the management of invasive and populations in seedling farms using an effective quarantine technology system can significantly decrease the spread of invasive ant species (Huang et al. 2007; Wang et al. 2020). The strict control and inspection procedures of biological materials should be employed when moving between districts (GISD 2021), filtering out materials most likely of a non-native origin. Specific goods should be screened and prohibited in compliance with international regulations.

Modern invasive ant management strategies are being developed with the aim of eradication or preventing further dispersal. Currently, eradication and control are mainly based on chemicals currently if other methods are not working (Hoffmann et al. 2010). Due to the rapid population growth and distribution of these species, the chemical application is the most effective in controlling their development. Insecticide applications such as liquid pesticides or baits, including powdered formulations or dust, are commonly used to deal with the highly toxic species of insects, such as *S. invicta* (Drees et al. 2013). Surface treatments for the quick removal of *S. invicta* are used as contact insecticides, but most are used to treat a single mound (Drees et al. 2013). Toxic bait works over a more extended period but is especially well-suited for spreading out and is safe in a large area (Vogt 2004). In the USA, annual bait treatments against fire ants minimize their colonies by 80 to 90% (Liu et al. 2020). Many chemicals including tralomethrin, tefluthrin, s-bioallethrin, permethrin, lambda-cyhalothrin, fluvalinate, fenvalerate, deltamethrin esfenvalerate, cyfluthrin, cypermethrin, carbaryl, bifenthrin, beta-cypermethrin, and acephate are being used effectively in China against fire ants (Wang et al. 2020).

Meanwhile, novel management approaches and biologically safe insecticides are required, particularly for aquaculture, drinking water regions, organic farms, and natural reserves, to condense both conservational and economic losses associated with the chemical use. According to Korzukhin et al. (2001), the range of *S. invicta* will spread from the Eastern USA to the Western USA due to climate change. There has been an increase in the average temperature of the planet's surface over the past 2 decades (Haiyan et al. 2011). As global weather changes, *S. invicta* can intrude on various ecological regions, and *S. invicta* will probably acclimatize to the new habitats and enhance its ecosystem impact.

Conclusion and future prospects

The impacts of invasive species on native fauna can have a devastating effect on indigenous communities and ecosystems, or whether anthropogenic effects, such as niche destruction, cause disruption in the community structure, disturbing ecosystem functions by replacing native species. For example, in native populations, some invasive ant species coexist through successful relationships like predation and competition at intra- and inter-specific levels. In comparison, unicolonial invasive species usually contain spatially expansive and competitively dominant super colonies without territorial boundaries. Because of their large numbers, they are among the most destructive invaders in the ecosystem, with significant implications for other animal species' structure and ecosystem functioning. However, there are concerns about non-native species, particularly as their ranges are rapidly expanding, and little is known about the majority of introduced species. Therefore, their role in novel habitats should be addressed, and the factors that encourage their occurrence that have a severe impact on native species should be explored. These factors and processes are essential to control the expansion of invasive ant species, enhance their management, and conserve native species in the future.

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