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REVIEW

The neglect of nonnative orthopterans as potential invaders: A call for awareness

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Abstract Despite the potential ecological and economic impacts of invasive species, there is a dearth of data on the presence, impacts, and management implications of potentially invasive Orthoptera species. This lack of research and inconsistent data, including risk screenings and impact assessments, is especially evident in Europe. Consequently, assessing the status, distribution, and potential threats of nonnative Orthoptera in Europe remains challenging, impeding the development of effective management strategies. To address this gap, we call for increased efforts to collect and curate data on non-native and possibly invasive Orthoptera in Europe. Such efforts will improve our understanding of this order's invasion dynamics, facilitate the identification of priority areas for conservation, and support the development of effective management policies and preventive measures.

Key words costs; cricket; damages; grasshopper; impact; research

Introduction

While biological invasions are known as a major driver of global change, the diverse impacts or spread of numerous non-native species often go unnoticed or have not yet been considered, in particular for insect species (McNeely, 2006; Diagne *et al.*, 2021). This is because assessments can be difficult, as they depend on various factors, such as the non-native species' origin, dispersal pathways and vectors, ecology, and physiology (Jeschke *et al.*, 2014). Orthoptera, which include grasshoppers, containing locusts (Acridoidea), crickets (Grylloidea), mole- and ant-crickets (Gryllotalpoidea), bush-crickets or katydids (Tettigonioidea), and camel-crickets (Rhaphidophoridae) (Song, 2018), play important ecological roles for nutrient cycles and food chains in their native ecosystems (Samways & Lockwood, 1998). Their non-native populations can become invasive, concomitantly causing significant damage to crops, grasslands, and forests when spreading, with cascading effects on ecosystem health, community composition and human well-being (Samways & Lockwood, 1998; Jucker & Lupi, 2011; Hill *et al.*, 2016; Cavaletto *et al.*, 2018; Saha, 2020; Fortuna *et al.*, 2022), yet have been largely neglected by

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invasion scientists (Jago, 1998; Popova *et al.*, 2022). This has resulted in a lack of research on their invasion ecology, distribution patterns, and potential impacts on invaded ecosystems (Kulessa *et al.*, 2023).

Orthopterans have a long history of causing significant damages worldwide (Nevo, 1996), even in their native range where they can act as common pests (Samways & Lockwood, 1998; Çiplak, 2021). Locust plagues have been documented since biblical times, with swarms of locusts mentioned in both the Old and New Testaments (Lomer *et al.*, 2001). The Quran also references to locusts as a plague "sent by God" (Simpson & Sword, 2008), and ancient Chinese and Roman texts describe the devastating effects of locust plagues on crops and vegetation (Nevo, 1996; Chen & Zhang, 1999; Wang *et al.*, 2023). More recent examples of these plagues are the "Moroccan locust disasters" (caused by *Dociostaurus maroccanus* Thunberg, 1815) that occurred in Western Anatolia during the 1850s, 1860s, 1880s, and 1910s, putting the government, local administrators, and people in financial and moral distress (Gökmen, 2010). The desert locust (*Schistocerca gregaria* Forsskål, 1775) invasion was also known as the "fifth enemy of the Ottoman Empire" during the First World War, impacting West and South Anatolia along with regions in Aleppo and Syria (Yildirim, 2014). The government responded to these outbreaks with strict laws and regulations enacted in 1912, spending a considerable amount of time and money for preventing and managing outbreaks, at the expense of infrastructure and transportation, which were insufficiently developed in the Empire at that time (Yıldırım, 2014). After the collapse of the Empire and during the establishment of the Turkish Republic, the country faced extreme poor socioeconomic conditions. Yet, despite these challenges, the Turkish Republic continued to allocate considerable amounts of human and economic resources toward combating the impacts of orthopteran invasions (Balamir, 1973), totaling ∼4 million US$ between the 1930s and 1980s (Tarkan *et al.*, unpublished). In the year 2006 and now again in 2023, the Mormon cricket (*Anabrus simplex* Haldeman, 1852) had infested approximately 10 million hectares of the state of Nevada with so far unquantified damages (Schell, 2023).

Only few studies have however considered the ecological and socioeconomic impacts of nonnative orthopterans. In this work, we amalgamate the current knowledge on their potential impacts and invasiveness, and emphasize the need for collecting novel information on potentially invasive Orthoptera species. This commentary note evidenced the current lack of research and inconsistent data, thus preventing risk screenings and impact assessments for those species.

Impact and invasiveness

In recent times, the desert locust has caused significant damages to agricultural crops across the globe, for example, in Africa, the Middle East, and South Asia (Peng *et al.*, 2020). These outbreaks of locust swarms led to millions of individuals swarming fields and devouring entire crops in a matter of hours (Showler *et al.*, 2022). Impacts of orthopterans can vary significantly due to their diverse ecological preferences and geographical origins. Some exhibit a remarkable ability to adapt and thrive in human-altered environments, such as greenhouses and urban areas, while others prefer specific natural habitats. Understanding the differences among non-native species is essential for effective management and mitigation strategies in larger politicial entities like the European Union, especially when considering that certain species known for their impacts have their origins in Asia (Anonymous, 2013; www.tarimorman.gov.tr), whereas others are native to e.g. the southern regions of Europe (Bauer *et al.*, 2022). This is, because the spread of these species across e.g. continental Europe may be closely associated with human activities, while in some cases, natural dispersal mechanisms might also play a role.

Non-native orthopterans not only cause large-scale crop failures or reduce yields, but can also have negative impacts on biodiversity by causing population declines (Preuss *et al.*, 2015) and even local extinctions (Simberloff, 2010), indirectly altering ecosystem functioning, reducing biodiversity by changing plant community composition, and suppressing native vegetation (Samways & Lockwood, 1998; Showler *et al.*, 2022). Non-native species also often have a high adaptability and wide temperature tolerances, which give them a competitive advantage over other coexisting native species (Lenz *et al.*, 2011). While for instance the southern oak bush-cricket (*Meconema meridionale* Costa, 1860) is expected to negatively impact the native oak bush-cricket (*Meconema thalassinum* De Geer, 1773) in some parts of Europe (Hochkirch *et al.*, 2016; Essl & Zuna-Kratky, 2021), the Roesel's bush-cricket (*Roeseliana roeselii* Hagenbach, 1822) has possibly already outcompeted at least one native Orthoptera species in Sweden (McAlpine, 2009). Their spread to new regions is also facilitated by rising temperatures, but also anthropogenic effects. The house cricket (*Acheta domesticus* Linnaeus, 1758) is native to Southeast Asia but has a broad distribution in large parts of northern, western, southern, and central Europe, being mostly established in urban areas and may continue to expand its range further (Szelei *et al.*, 2011). However, not all introduced Orthoptera species will establish. Non-native locust swarms for instance,

while capable of invading new regions and crossing vast distances when forming swarms, may not always lead to persistent populations in those areas. Nevertheless, these migrations can cause significant damage to agricultural fields and rangelands, impacting local ecosystems and livelihoods. The recurrent nature of locust migrations underscores their significance as a persistent problem, and the potential for further spread is always present. It is essential to recognize that even temporary or failed invasions can have far-reaching consequences, warranting appropriate management efforts. While swarms of non-native locusts may not conform to the classic definition of an invasive species (i.e., spreading following the establishment of stable populations), their transient invasions demand attention and response from policymakers and environmental managers. Neglecting to address the ecological impacts of such migratory events may lead to inadequate preparedness for potential future invasions or exacerbate the challenges faced by affected regions.

Considering the utilization of Orthoptera as a novel food and source of protein—with numerous species already commercially produced (Fernandez-Cassi *et al.*, 2019)—emphasizes the critical need for more information and underline a severe neglect of research on orthopterans. This is a worrying concern given their potential to cause significant damage to crops and natural vegetation, leading to disastrous ecological and economic losses (Showler *et al.*, 2022).

Neglect

While some invasive species, such as those listed among the 100 worst invasives (Lowe *et al.*, 2000) are well-studied and recognized as threats to human health and ecosystems (Lourenço *et al.*, 2022), other groups such as non-native orthopterans have received much less attention. Indeed, despite historically documented damages caused by orthopterans and both observed and potential impacts, there has been a lack of research on their invasion ecology and (potential) distribution patterns (Kulessa *et al.*, 2023). A recent study by Kulessa *et al.* (2023) indicated that out of the 37 non-native Orthoptera species recorded in Europe, 23 were established in at least 1 European country where they are not native. From these, only 4 species are listed as invasive based on their ability to spread, despite reported negative impacts. Another 6 species are potentially invasive, and negative impacts have been described for them as well. One possible reason for this disparity is that the damages caused by orthopterans are often seasonal and not constantly recurring due to their life cycle and migration (Tanaka, 1994) and may therefore not be as apparent to researchers studying invasive species over longer periods (Crooks, 2005). Certain conditions must be met for an outbreak to occur, namely specific weather patterns, habitat availability, and sufficient food sources (Dempster, 1963). Orthopterans are also often perceived as less charismatic and less appealing to by study compared to other insect groups such as butterflies or beetles (Nash, 2004). While possible reasons are manifold, one is likely the perception that orthopterans are believed not to be as significant a threat as other invasive species, such as invasive mammals, fish, or plants (Kapitza *et al.*, 2019), but also other insects such as ants or mosquitoes (Juliano & Philip Lounibos, 2005; Angulo *et al.*, 2022). The few existing studies, however, suggest that orthopterans can be highly disruptive to native ecosystems (Fashing *et al.*, 2010; Sultana *et al.*, 2021), especially when they occur in large numbers (even without forming swarms; Lecoq & Cease, 2022). The impacts of most orthopterans are furthermore predominantly observed in underdeveloped countries or regions, which may not have the resources to study or report on the economic impacts of these species, or are recorded in non-English languages (Angulo *et al.*, 2021). The 2003–2005 locust plague in West Africa, for instance, caused an estimated economic loss of US$2.5 billion in damages to crops and livestock, which severely affected local economies and resulted in a scarcity of food and resource shortages (Showler *et al.*, 2022). Similarly, Turkey faced significant postmanagement costs of approximately 86 million TRY for the period between 1950 and 2013 due to locust outbreaks (Anonymous, 2013; www.tarimorman.gov.tr). Significant outbreaks also occurred within Europe. Although the island of Sardinia is within the native range of the Moroccan locust, its nativeness to this island is debated (Bauer *et al.*, 2022; Klein *et al.*, 2022). However, in 2019 and 2020, the Moroccan locust destroyed thousands of hectares of agricultural land, causing massive economic losses to farmers (Bauer *et al.*, 2022). In Europe, where the agricultural sector is of great importance (Bindi & Olesen, 2011), the impacts of non-native species are estimated to have cost billions of euros (Haubrock *et al.*, 2021), seemingly increasing (Henry *et al.*, 2023), yet do not list any cost inferred to orthopterans (as of InvaCost v4.1).

Climate change effect

Studying non-native orthopterans is particularly important given that their impacts could be aggravated by climate change, which is expected to have significant

effects on the development, distribution, and spread of non-native species (Salih *et al.*, 2020). As global temperatures continue to rise, many species are shifting their historical ranges (Panagiotopoulou *et al.*, 2016), enabling non-native species to establish themselves in new areas more easily (Hellmann *et al.*, 2008). In addition, climate change may alter weather patterns and affect the phenology of seasonal events, affecting reproduction or the emergence of different life stages, possibly impacting the success of particular species (Lecoq & Cease, 2022), including orthopterans. One example of climate change facilitating the expansion of a non-native Orthoptera species is the two-spotted cricket (*Gryllus bimaculatus* De Geer, 1773). This species can be found in Africa and Asia, and it has a widespread presence throughout the Mediterranean, extending its range into northern Europe where it competes with native species (Mito & Noji, 2008; Panagiotopoulou *et al.*, 2016). Despite being widely distributed across continental Europe, the range of the cone-headed grasshopper *Conocephalus fuscus* (Fabricius, 1793) has also been expanding through Europe and temperate Asia due to global warming (Sutton *et al.*, 2017; Myagmar & Gantigmaa, 2023).

Climate change may also affect the behavior of nonnative orthopterans, with warming altering the metabolism of the individuals, and thus affecting the timing, duration, and amount of feeding. This could, in turn, lead to changes in the likelihood and intensity of swarming behavior (Wang *et al.*, 2019; Meynard *et al.*, 2020; Lecoq & Cease, 2022), potentially exacerbating impacts on crops and other vegetation (Youngblood *et al.*, 2023). However, the response of many orthopterans to climate change has not yet been adequately studied (Lecoq & Cease, 2022). Warmer temperatures may affect the timing and frequency of mating, which could impact population growth and, thus, further facilitate ongoing range expansion. Finally, climate change could affect the movements of migratory species, resulting in shifts in the areas affected by these species.

Management and mitigation

Studying non-native species is crucial to minimize their potential impacts. The European Union has implemented strict measures to regulate the introduction of non-native species (Genovesi *et al.*, 2015), but the effectiveness of such measures depends on a thorough understanding of the risks and impacts posed by these species. Moreover, without adopting a clear definition what an invasive species is (Soto *et al*., 2023b), the scarcity of research limits the ability to develop effective mitigation measures for non-native Orthoptera species (Piou & Marescot, 2023).

Neglecting the study of non-native orthopterans could lead to significant ecological and economic damages through an increased risk of crop damage and loss of biodiversity, ultimately negatively impacting human well-being. Addressing the impacts of these species is already challenging, as several species can swarm under certain (also stable) conditions (Topaz *et al.*, 2012), and quickly spread over large areas, which is further exacerbated by a lack of understanding of their invasion dynamics and ecology (Kulessa *et al.*, 2023). Preventive measures, such as biosecurity protocols (Coughlan *et al.*, 2020), can be effective in preventing the introduction of non-native orthopterans into new areas. This may involve implementing measures such as quarantine procedures, inspections of imported goods, and restrictions on the trade of live animals, but also insect farms that are expanding in Europe (Żuk-Gołaszewska *et al.*, 2022). Monitoring and implementing early detection can be effective in preventing the establishment and spread of non-native orthopterans with this being related to many species-specific factors. This can involve setting up surveillance programs in high-risk areas to detect the presence of non-native orthopterans and developing rapid response plans to control their spread if detected. The Food and Agriculture Organization of the United Nations, for instance, is implementing preventive control strategies to limit pesticide use and control local outbreaks of desert locusts. They are incorporating the latest technologies and monitoring weather and ecological conditions to determine breeding, gregarization, and migration 6 weeks ahead. However, if non-native orthopterans do establish and become invasive, control measures may be limited to the use of chemical or biological control methods. While chemical control methods, such as the use of insecticides, can effectively reduce populations of non-native orthopterans (Yildirim, 2014), they may interfere with European regulation (Genovesi *et al.*, 2015), as they may also have negative impacts on non-target species and the environment. Biological control methods, such as the introduction of natural predators or parasites, can also be effective in controlling nonnative orthopterans (Cunningham & Sampson, 2000), but may have unforeseeable impacts on the environment (Carruthers & Onsager, 1993).

The current understanding of all aspects pertaining to the invasion dynamics (Soto *et al.*, 2023a), impacts (Haubrock *et al.*, 2022), invasion history (Kulhanek *et al.*, 2011), and management actions for invasive Orthoptera are limited (Kulessa *et al.*, 2023), revealing an unknown but potentially significant risk and threat not only to

the European Union, but for the worldwide population. For instance, interception data, information on climatic niches, the risks accompanying their use as edible insects with limited regulation (not to mention absence), and biosecurity protocols will ultimately result in high risks of invasion of surrounding environments. Therefore, there is an urgent need to explore this important area of research in the future to underpin management strategies needed in the future.

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