Journal of Environmental Management 358 (2024) 120779

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Economic costs of non-native species in Türkiye: A first national synthesis

Ali Serhan Tarkan [a,b,c,*], Esra Bayçelebi [d], Daniela Giannetto [e], Emine Demir Özden [f], Ayşe Yazlık [f], Özgür Emiroğlu [g], Sadi Aksu [h], Ahmet Uludağ [i], Necmi Aksoy [j], Hazel Baytaşoğlu [d], Cüneyt Kaya [d], Tanju Mutlu [k], Şerife Gülsün Kırankaya [l], Deniz Ergüden [m], Esra Per [n], İlhan Üremiş [o], Onur Candan [p], Aysel Kekillioğlu [q], Baran Yoğurtçuoğlu [r], F. Güler Ekmekçi [r], Esra Başak [s], Hatice Özkan [t], Irmak Kurtul [c,u], Deniz Innal [v], Nurçin Killi [b], Sercan Yapıcı [b], Dinçer Ayaz [w], Kerim Çiçek [w,x], Oğuzcan Mol [g], Emre Çınar [g], Vedat Yeğen [y], Elena Angulo [z], Ross N. Cuthbert [aa], Ismael Soto [ab], Franck Courchamp [ac,1], Phillip J. Haubrock [ab,ad,ae,1,**]

[a] Department of Ecology and Vertebrate Zoology, Faculty of Biology and Environmental Protection, University of Lodz, Lodz, Poland
[b] Department of Aquatic Basic Science, Faculty of Fisheries, Muğla Sıtkı Koçman University, Muğla, Türkiye
[c] Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, Poole, Dorset, United Kingdom
[d] Faculty of Fisheries, Recep Tayyip Erdogan University, Rize, Türkiye
[e] Department of Biology, Faculty of Sciences, Muğla Sıtkı Koçman University, Muğla, Türkiye
[f] Department of Plant Protection, Faculty of Agriculture, Düzce University, Düzce, Türkiye
[g] Department of Biology, Faculty of Science, Eskişehir Osmangazi University, Eskişehir, Türkiye
[h] Vocational School of Health Services, Eskişehir Osmangazi University, Eskişehir, Türkiye
[i] Plant Protection Department, Faculty of Agriculture, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
[j] Department of Forest Botany, Faculty of Forestry, Düzce University, Düzce, Türkiye
[k] Vocational School of Technical Sciences, Environmental Protection Technologies Department, Recep Tayyip Erdoğan University, Türkiye
[l] Department of Biology, Faculty of Arts and Science, Düzce University, Düzce, Türkiye
[m] Department of Marine Sciences, Faculty of Marine Sciences and Technology, İskenderun Technical University, İskenderun, Türkiye
[n] Department of Biology, Faculty of Science, Gazi University, Ankara, Türkiye
[o] Plant Protection Department, Faculty of Agriculture, Hatay Mustafa Kemal University, Antakya, Hatay, Türkiye
[p] Department of Molecular Biology and Genetics, Faculty of Arts and Sciences, Ordu University, Ordu, Türkiye
[q] Department of Biology, Faculty of Science and Literature, Nevşehir HBV University, Nevşehir, Türkiye
[r] Department of Biology, Faculty of Science, Hacettepe University, Beytepe Campus, Ankara, Türkiye
[s] Project House Cooperative, Moda Caddesi Borucu Han No:20/204 Kadıköy, Istanbul, Türkiye
[t] Department of Biology, Faculty of Science, Karadeniz Technical University, Trabzon, Türkiye
[u] Marine and Inland Waters Sciences and Technology Department, Faculty of Fisheries, Ege University, İzmir, Türkiye
[v] Department of Biology, Faculty of Sciences and Literature, Burdur Mehmet Akif Ersoy University, Burdur, Türkiye
[w] Department of Biology, Faculty of Science, Ege University, Izmir, Türkiye
[x] Natural History Application and Research Centre, Ege University, Izmir, Türkiye
[y] Fisheries Research Institute, Eğirdir, Isparta, Türkiye
[z] Estación Biológica de Doñana, CSIC, Avda. Americo Vespucio 26, 41092, Seville, Spain
[aa] Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, Belfast, BT9 5DL, United Kingdom
[ab] Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of Hydrocenoses, University of South Bohemia in České Budějovice, Vodňany, Czech Republic
[ac] Université Paris-Saclay, CNRS, AgroParisTech, Ecologie Systématique Evolution, Gif sur Yvette, France
[ad] Department of River Ecology and Conservation, Senckenberg Research Institute and Natural History Museum Frankfurt, Gelnhausen, Germany
[ae] CAMB, Center for Applied Mathematics and Bioinformatics, Gulf University for Science and Technology, Kuwait

* Corresponding author. Department of Aquatic Basic Science, Faculty of Fisheries, Muğla Sıtkı Koçman University, Muğla, Turkiye.
** Corresponding author. Department of River Ecology and Conservation, Senckenberg Research Institute and Natural History Museum Frankfurt, Gelnhausen, Germany.

E-mail addresses: serhantarkan@gmail.com (A.S. Tarkan), phillip.haubrock@senckenberg.de (P.J. Haubrock).
[1] Senior authors: Franck Courchamp; Phillip J. Haubrock.

https://doi.org/10.1016/j.jenvman.2024.120779
Received 6 November 2023; Received in revised form 1 March 2024; Accepted 27 March 2024
Available online 10 April 2024

ARTICLE INFO

Keywords:
Damages and losses
Economic impact
InvaCost
Invasive species
Conservation policy
Turkey

ABSTRACT

Biological invasions are increasingly recognised as a major global change that erodes ecosystems, societal well-being, and economies. However, comprehensive analyses of their economic ramifications are missing for most national economies, despite rapidly escalating costs globally. Türkiye is highly vulnerable to biological invasions owing to its extensive transport network and trade connections as well as its unique transcontinental position at the interface of Europe and Asia. This study presents the first analysis of the reported economic costs caused by biological invasions in Türkiye. The *InvaCost* database which compiles invasive non-native species' monetary costs was used, complemented with cost searches specific to Türkiye, to describe the spatial and taxonomic attributes of costly invasive non-native species, the types of costs, and their temporal trends. The total economic cost attributed to invasive non-native species in Türkiye (from 202 cost reporting documents) amounted to US$ 4.1 billion from 1960 to 2022. However, cost data were only available for 87 out of 872 (10%) non-native species known for Türkiye. Costs were biased towards a few hyper-costly non-native taxa, such as jellyfish, stink bugs, and locusts. Among impacted sectors, agriculture bore the highest total cost, reaching US$ 2.85 billion, followed by the fishery sector with a total cost of US$ 1.20 billion. Management (i.e., control and eradication) costs were, against expectations, substantially higher than reported damage costs (US$ 2.89 billion vs. US$ 28.4 million). Yearly costs incurred by non-native species rose exponentially over time, reaching US$ 504 million per year in 2020–2022 and are predicted to increase further in the next 10 years. A large deficit of cost records compared to other countries was also shown, suggesting a larger monetary underestimate than is typically observed. These findings underscore the need for improved cost recording as well as preventative management strategies to reduce future post-invasion management costs and help inform decisions to manage the economic burdens posed by invasive non-native species. These insights further emphasise the crucial role of standardised data in accurately estimating the costs associated with invasive non-native species for prioritisation and communication purposes.

1. Introduction

Biological invasions are a widespread ecological phenomenon that has garnered increasing attention due to their potential to disrupt ecosystems and economies on a global scale (Hulme et al., 2008; Simberloff et al., 2013; Sutcliffe et al., 2018; Hudgins et al., 2023; Soto et al., 2024). These invasions, fuelled by human activities such as trade and travel (Anderson et al., 2014; Essl et al., 2015), often result in ecological disruptions and socio-economic challenges (Pranovi et al., 2006; Bacher et al., 2018). While extensive research has documented the ecological consequences of these invasions (Ricciardi et al., 2013; Lima et al., 2018), understandings of their monetary impacts remain a critical yet underexplored aspect that requires comprehensive assessment at the scale of national economies where decision-making occurs (Aukema et al., 2011; Turbelin et al., 2023).

Understanding the economic consequences of biological invasions is essential (Cuthbert et al., 2021a), especially for making informed policy decisions and implementing effective management strategies with monitoring (Wilson et al., 2018), risk and prioritisation analyses (Brunel et al., 2010) as well as horizon scanning (Peyton et al., 2020). Globally, monetary impacts from biological invasions have been estimated to reach staggering figures, with assessments indicating a minimum of US$ 1.28 trillion (2017 US dollars) over the past few decades (1970–2017) (Diagne et al., 2021). On a continental scale, Europe, North America, and Africa have each incurred substantial economic burdens — US$ 4.7 billion (2017 value), US$ 1.26 trillion (between 1960 and 2017), and US $ 78.9 billion (between 1970 and 2020) in monetary damages and losses, respectively (Crystal-Ornelas et al., 2021; Diagne et al., 2021; Henry et al., 2023). Closer examination of individual countries further reveals the magnitude of these costs: for example, the United States has so far faced US$ 1.22 trillion (between 1960 and 1920) (Fantle-Lepczyk et al., 2022) from a broad variety of taxa (Warziniack et al., 2021). France has incurred up to US$ 11.50 billion since 1993 (Renault et al., 2021), the UK with US$ 17.6 billion since 1976 (Cuthbert et al., 2021b), and Japan with US$ 725 million (between 1965 and 2017) (Watari et al., 2021). Invasion and impact risks also differ between origin and recipient countries, according to factors such as trade relationships and shared environments which are subject to change with environmental and socio-political contexts (Countryman et al., 2018; Yazlık et al., 2018; Hudgins et al., 2023). Aside from these cases, however, the majority of countries are yet to undergo comprehensive economic cost assessments of biological invasions (Ahmed et al., 2023).

Türkiye is a country that stands out as a unique case in biological invasions, due to its historical and geopolitical position bridging the European and Asian continents, while also having strong trade relationships with numerous countries globally. This unique positioning places Türkiye at the convergence of three of the world's 36 biodiversity hotspots (Caucasus, Irano-Anatolian, and Mediterranean basin hotspots), which host many endemic species (Kahraman et al., 2012). Moreover, Türkiye's geography, climate, and terrain create a suitable environment for invasive species to take hold and propagate across the area (Şekercioğlu et al., 2011). With its pivotal location at the intersection of three continents, Türkiye has historically served as a vital centre for trade, migration, and cultural interchange over centuries (Siddiq, 2016). However, while promoting economic activity and cultural diversity, this role also designates Türkiye as a significant conduit for the entry and proliferation of invasive species from various origins (Uludag et al., 2017). Moreover, Türkiye's substantial urbanisation and intensified agricultural practices heighten the risk of non-native species' introduction and their spread through human disturbances (Çoban et al., 2021). The intricacies of Türkiye's trade, encompassing both imports and exports (Parlar-Dal and Dipama, 2020), also contribute to its vulnerability to biological invasions (Emiroğlu et al., 2020; Aksu et al., 2021); meanwhile, several intentional introductions (e.g. common carp *Cyprinus carpio*, striped catfish *Pangasianodon hypophthalmus*). were due to the perceived economic benefit to locals paired with the often fast and easy cultivation of non-native species (Tarkan et al., 2015, 2020). Although the number of non-native species differs according to the source (see for instance *GRIIS* (Pagad et al., 2018): 968 vs. the *Global Alien First Record Database* (Seebens et al., 2017): 493), the majority of non-native species in Türkiye according to the *Global Alien First Record Database* (Seebens et al., 2017) are molluscs with 107 reported species, followed by fishes (n = 96), algae (n = 90), crustaceans (n = 74), and vertebrates (n = 63), while other groups such as insects, birds or plants were each represented by less than 50 species (Fig. 1). While there are likely more species in Türkiye considering that e.g. the *Global Naturalized Alien Flora* database GloNAF (van Kleunen et al., 2019) lists 340 non-native plants for Türkiye, there are also some highly well-known invasive species, such as gibel carp *Carassius gibelio* (Tarkan et al., 2012) and the warty comb jelly *Mnemiopsis leidyi* (Shiganova et al., 2019), which have also been proven to be the most costly. However, certain others, like the pond slider turtle *Trachemys scripta*, although not considered costly, have been extensively documented for their widespread occurrence and successful breeding in the wild (Yakin et al., 2023). These, however, lack comprehensive impact or cost assessments, as well as assessments pertaining to their invasiveness (Yoğurtçuoğlu et al., 2021). Previous studies on groups of invasive species' impacts in Türkiye were disparate or had terminological shortcomings, such as studies on weed control which did not separate native and non-native species according to invasion status, despite many important weeds in such studies being non-natives (Erturk et al., 2012). With its diverse ecosystems and dynamic economy (Kaya and Raynal, 2001; Pata and Balsalobre-Lorente, 2022), but also the fact that the reported number of non-native and invasive species has been steadily rising (Kaya, 2020; Kırankaya and Ekmekçi, 2021), economic impact assessments are urgently needed in Türkiye.

Here, the *InvaCost* database, a recently compiled and extensive resource documenting the economic costs of biological invasions (Diagne et al., 2020), is used to quantify the economic burden that invasive non-native species impose on Türkiye's economy across taxonomic, typological, and temporal scales. By shedding light on the costs associated with biological invasions across environmental and economic contexts, valuable insights for policymakers and managers are provided, aiming to empower them to make informed decisions and design effective strategies to mitigate the economic challenges posed by invasive species in Türkiye.

2. Material and methods

2.1. Data collection

To quantify the monetary cost of biological invasions in Türkiye, the latest version of the *InvaCost* database (v.4.1) is used, which is the most comprehensive database of the economic costs of invasive species worldwide (https://doi.org/10.6084/m9.figshare.12668570). The *InvaCost* database aggregates data from series of literature searches in the *Web of Science* (webofknowledge.com), *Google Scholar* (scholar.google.com), and the *Google search engine* (google.com) and opportunistic targeted searches (i.e. expert consultations for which data gaps were identified, (see Diagne et al., 2020). Additionally, each cost data entry is categorised with 65 bibliographical, taxonomic, temporal, geographical, and typological descriptors detailing variables such as the type of costs (e.g., damage or management), sectors affected, or the taxonomy of the invasive species (Diagne et al., 2020).

InvaCost is regularly updated through the incorporation of new data or cost descriptors and checking for potential errors (e.g., duplicate entries). To control for inflation and enable direct comparison among cost entries, each row of data is standardised to a common currency (US $) and a specific year (2017). Given the significance of non-English languages, *InvaCost* aggregates information from over 20 languages (Angulo et al., 2021b). This was advanced further, following the same approach detailed by Angulo et al. (2021b), by gathering additional cost data in the Turkish language. This approach involved thoroughly exploring governmental agencies' websites, particularly within ministries responsible for invasive species management, such as the Turkish Ministry of Environment, Urbanization, and Climate Change. Furthermore, environmental managers were contacted by sending e-mail inquiries and administrative forms to request economic data pertaining to the costs associated with invasive species. Lastly, data from municipal authorities in major cities, including İstanbul, Ankara, İzmir, Trabzon, and Rize, were acquired and reviewed for available information, alongside through contact with city officials who could provide further contact details of environmental managers.

We filtered *InvaCost* to include only entries from Türkiye (Turkey) in the "Official_country" column. Prior to analysing these data, the dataset was refined to retain only entries with complete temporal information. Cost entries prior to 1960 were also removed due to the inability to correct for inflation.

In order to obtain comparable invasion costs, all costs considered for a period of less than one year were deemed as annual costs. To annualise the data costs spanning several years, costs expanding over several years were divided equally among the years of the respective study period. This was done using the *expandYearlyCosts* function of the *InvaCost* R package version 0.3–4 (Leroy et al., 2022). This function divides the total cost estimated by the respective duration of the cost entry. For example, an estimate of $1000 over ten years would be transformed into ten cost entries with a cost of $100 per year. After filtering and refinement of the database, 278 entries were retained (1656 after the aforementioned temporal expansion) for Türkiye for the purpose of the analyses that were described by several descriptors (Supplementary note 1).

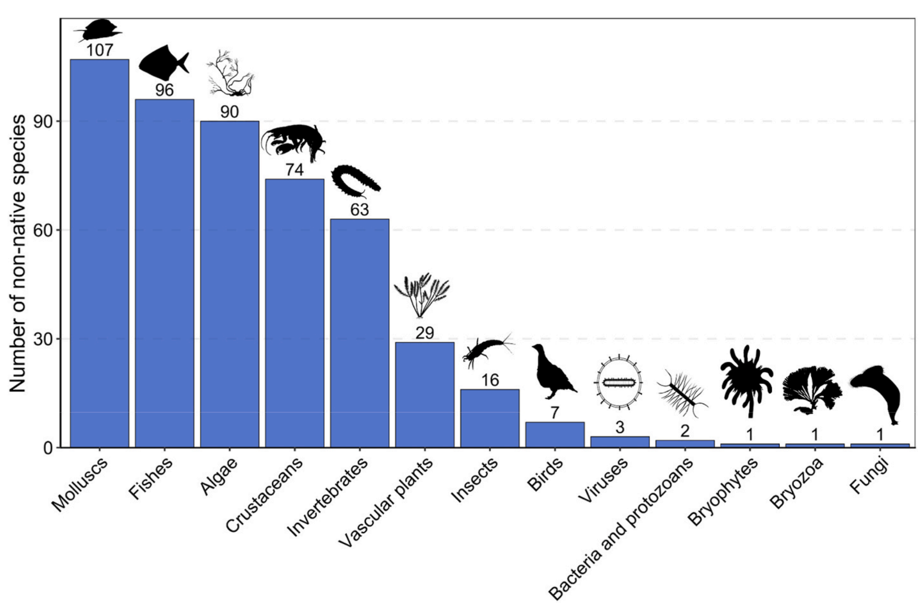

Fig. 1. Breakdown of reported non-native species in Türkiye across various life forms according to Seebens et al. (2017).

2.2. Temporal dynamics

Firstly, the average cost for each decade in the period of the study (1960–2022) was estimated using the *summarizeCosts* function implemented in the *invacost* R package (Leroy et al., 2022). Secondly, temporal modelling forecasted future costs. Due to the significant effect of outliers that can distort statistical analyses and violate model assumptions in the study of temporal dynamics, "extreme" cost entries were identified as any cost value exceeding the third quartile +1.5 times the interquartile range annually (Cuthbert et al., 2021a). Accordingly, 164 cost entries were identified as outliers and subsequently removed. The final dataset used for this analysis contained 1492 cost entries.

We then identified the temporal dynamics of the monetary impacts in Türkiye caused by biological invasions. For this, the data were restricted to the period 1990–2022, excluding all years prior to 1990 as these were repeated measures (Henry et al., 2023). The annual total of this subset over time (using the 'Impact_year' column of each cost entry as the year of occurrence) was modelled using linear and quadratic robust regressions via the *lmrob* function of the *robustbase* R package (Maechler et al., 2022), with maximum iterations set to n = 1000 to optimize the balance between computational efficiency and the precision of results.

Ultimately, to project the temporal dynamics of the monetary impacts until 2030, the highly reliable and observed data subset was used (Diagne et al., 2020; Henry et al., 2023). Outliers were excluded as before. To project the direction costs invasive species may incur in Türkiye in the future based on currently available information, we then modelled the annual total of this subset over time using the 'Impact_year' of each cost entry as the year of occurrence using both linear and quadratic robust regressions on the highly reliable, observed data. For this, we used the *lmrob* function, with maximum iterations set to n = 1000. This model was selected because of its resilience against data outliers and its capability to yield reliable estimations, even in the presence of non-normative data points. Overall, the trend in total costs until 2030 was projected, by using the *predict* function in the forecast R package (Hyndman et al., 2023), which calculated the expected costs and their confidence intervals based on the robust linear regression model.

3. Results

All 1656 entries between 1960 and 2022 were observed costs (the ones incurred already), totalling US$ 4.1 billion (Fig. S1). Of these, the vast majority (1583 entries; US$ 4.08 billion, 99.4%) were considered highly reliable (Fig. S1). These costs were incurred by 87 species from 57 families, encompassing costs from the aquatic (US$ 1.21 billion; 29.37%), semi-aquatic (US$ 5 million; 0.001%), and terrestrial realms (US$ 2.89 billion; 70.48%), with the remainder being diverse/unspecified (US$ 0.4 million; 0.0001%) (Fig. 2) (<1%).

Among the top ten species with reported costs, the warty comb jelly *Mnemiopsis leidyi* had the highest reported impacts at US$ 1.18 billion (n = 2 entries), followed by the brown marmorated stink bug *Halyomorpha halys* (US$ 0.94 billion; n = 10 entries) and desert locust *Schistocerca gregaria*, which incurred US$ 40.2 million (n = 54 entries). Therefore, the costliest species were not those with the most entries. The costs incurred by these three non-native species were found to be the costliest (52.86% of the overall cost) and these costs mostly affected the fishery (*M. leidyi*) and agriculture (*H. halys* and *S. gregaria*) sectors.

All other species, including the gibel carp *Carassius gibelio*, the silver-cheeked toadfish *Lagocephalus sceleratus*, the bur cucumber *Sicyos angulatus*, mosquitoes from the genus *Aedes* sp., the nutria *Myocastor coypus*, and the citrus longhorned beetle *Anoplophora chinensis*, incurred costs below US$ 10 million (<1%). The 290 entries classified as "diverse/unspecified" for species had the highest total cost of US$ 1.88 billion (Table 1). Aside from *M. leidyi,* which incurred costs classified as mixed type, the majority of costs inferred by the other costliest species were classified as management or damage costs (Fig. 3). In terms of damage costs, the costliest species were *C. gibelio*, (US$ 8 million, n = 707), followed by *L. sceleratus* (US$ 8 million, n = 2), and *S. angulatus*, (US$ 6 million, n = 1). *M. coypus*, caused an economic burden of US$ 4.8 million (n = 1) and lastly, *Rhopilema nomadica* with US$ 0.2 million (n = 6). For management costs, the costliest species were *H. halys* with US$ 0.95 billion (n = 2), followed by *S. gregaria*, (US$ 40 million, n = 54), the genera *Aedes* (US$ 60 million n = 7) and *Eurygaster* (US$ 4 million, n = 1), and finally *A. chinensis* (US$ 3 million n = 7). The remaining (16) species belonging to both Animalia and Plantae accounted for ~0.01 billion in costs (0.32%) (Fig. S2).

Regarding types of costs associated with biological invasions, management costs were the highest at US$ 2.89 billion (n = 542 entries). Of these, costs were mostly split into post-invasion management (US$ 1.93 billion, n = 131, 66.73%) followed by knowledge/funding (US$ 0.96 billion, n = 407, 33.26%) and lastly mixed costs with less than US$ 0.01 billion (n = 4, <0.01%). Mixed costs (damage + management) followed with US$ 1.19 billion (n = 263 entries), while damage costs totalled US$ 28.4 million (n = 841 entries). Unspecified costs were notably low, at US $ 33,400 (n = 9 entries). Among the relevant sectors impacted by

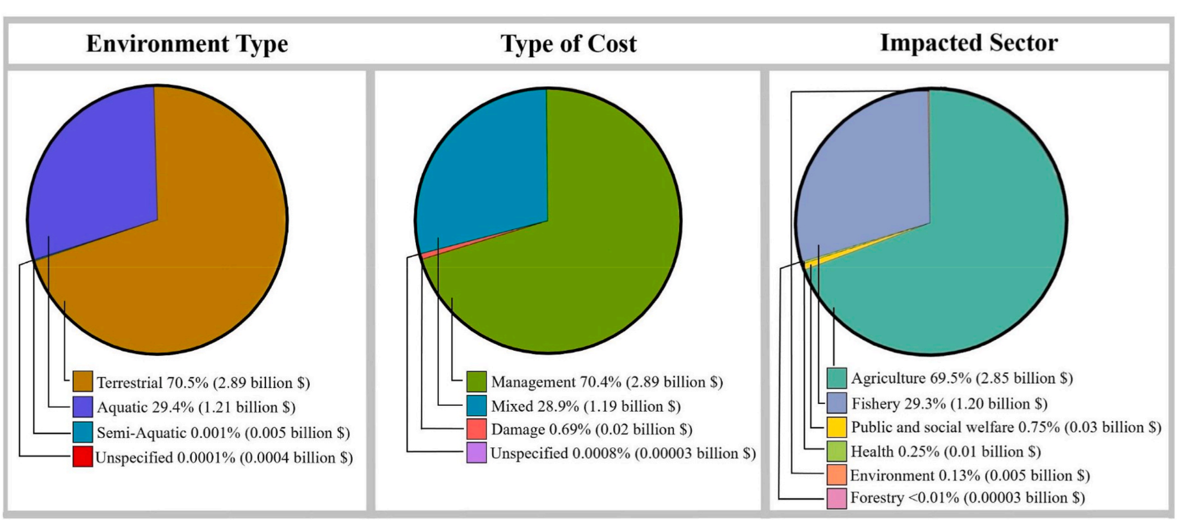

Fig. 2. Distributions of the economic costs caused by biological invasions in Türkiye, based on available information found in *InvaCost* v.4.1, categorised by environment type, type of cost, and impacted sector.

Table 1
Top ten costliest species in Türkiye, their costs, number of database entries, percentage contribution of the total, and main sector impacted by each invasive species. Presented information is based on available data for Türkiye found in *InvaCost* v.4.1.

Family/Species	Total cost (in US$ billion)	n (number of entries)	Percentage of total	Main sector impacted
Diverse/Unspecified	1.88	290	45.9	Agriculture
Bolinopsidae/ *Mnemiopsis leidyi*	1.18	2	28.8	Fishery
Pentatomidae/ *Halyomorpha halys*	0.947	10	23.1	Agriculture
Acrididae/ *Schistocerca gregaria*	0.0402	54	0.979	Agriculture
Cyprinidae/ *Carassius gibelio*	0.00942	742	0.229	Fishery
Tetraodontidae/ *Lagocephalus sceleratus*	0.00871	8	0.212	Fishery
Cucurbitaceae/ *Sicyos angulatus*	0.00645	6	0.157	Agriculture
Culicidae/*Aedes* sp.	0.00614	7	0.150	Public and Social Welfare
Myocastoridae/ *Myocastor coypus*	0.00517	6	0.126	Agriculture
Soutelleridae/ *Anoplophora chinensis*	0.00501	12	0.122	Agriculture

biological invasions, agriculture bore the highest total cost, amounting to US$ 2.85 billion (n = 512 entries). Impacts on the fishery sector followed, with a total cost of US$ 1.20 billion (n = 835 entries). Public and Social Welfare incurred a cost of US$ 31.1 million (n = 42 entries), while both the Health and Environment sectors had considerably lower costs with US$ 10.6 million (n = 20 entries) and US$ 5.40 million (n = 233 entries), respectively. Forestry incurred the smallest amount (US$ 30,600; n = 14 entries).

Decadal costs of biological invasions in Türkiye increased rapidly after the 1990s, increasing to on average US$ 120.34 million per year (between 2000 and 2009 and totalling US$ 1.2 billion in the period) and US$ 135.18 million per year (between 2010 and 2019 and US$ 1.35 billion in the whole period) (Fig. 4a). Based on the available annual totals, both extrapolation methods (i.e., linear and quadratic) identified an increase in the trajectory of annual costs observed between 1990 and 2022 (Fig. 4a), and up to 2030, totalling almost US$ 359 million (linear) and US$ 503 million (quadratic) (Fig. 4b).

4. Discussion

We report the first detailed national-scale invasive species' cost assessment for Türkiye, at US$ 4.1 billion between 1960 and 2022. This accounts for approximately 0.45% of the country's annual Gross Domestic Product, which stood at US$ 905.5 billion in 2022. This impact intensity is even more noteworthy when compared to annual expenditures, such as 5% of GDP allocated to healthcare, 6.5% to agriculture, and 3.5% to education. Moreover, these costs are expected to rise massively (approximately nine times) in 2030.

The literature concerning the national costs of invasive species in Türkiye is very scarce and primarily based on specific, small-scale cases of a few highly costly species, such as the silver-cheeked toadfish (Ünal et al., 2015) and the warty comb jelly (Özdemir and Ceylan, 2007). This cost data scarcity further highlights a lack of coordinated national efforts to gather cost related information. The data for Türkiye spanning 278 entries revealed that others, such as Spain (2384 entries, Angulo et al., 2021a), France (595 entries, Renault et al., 2021), and the UK (353 entries, Cuthbert et al., 2021b), had compiled comparably more research and/or had greater cost reporting capacities, while probably not as many more invasive species.

The Global Register of Introduced and Invasive Species (Uludag et al., 2020) for Türkiye currently lists 872 introduced and invasive non-native species, but only for 87 species an economic impact was recorded (9.98%) with this study. These numbers highlight a significant discrepancy between the species present and the sources reporting their economic costs. Notably, invasive species in Türkiye are reportedly costlier than other regions, such as Japan (Watari et al., 2021). Similar patterns nevertheless emerge when examining regional studies within the *InvaCost* database. These studies consistently reveal that the number of species with recorded costs constitutes only a small fraction of the total known non-native species. For instance, cost evaluations were absent for over 90% of invasive species in the UK (Cuthbert et al., 2021b), 97% of invasive species in France (Renault et al., 2021), and 96% of all invasive species in both Asia (Liu et al., 2021) and Argentina

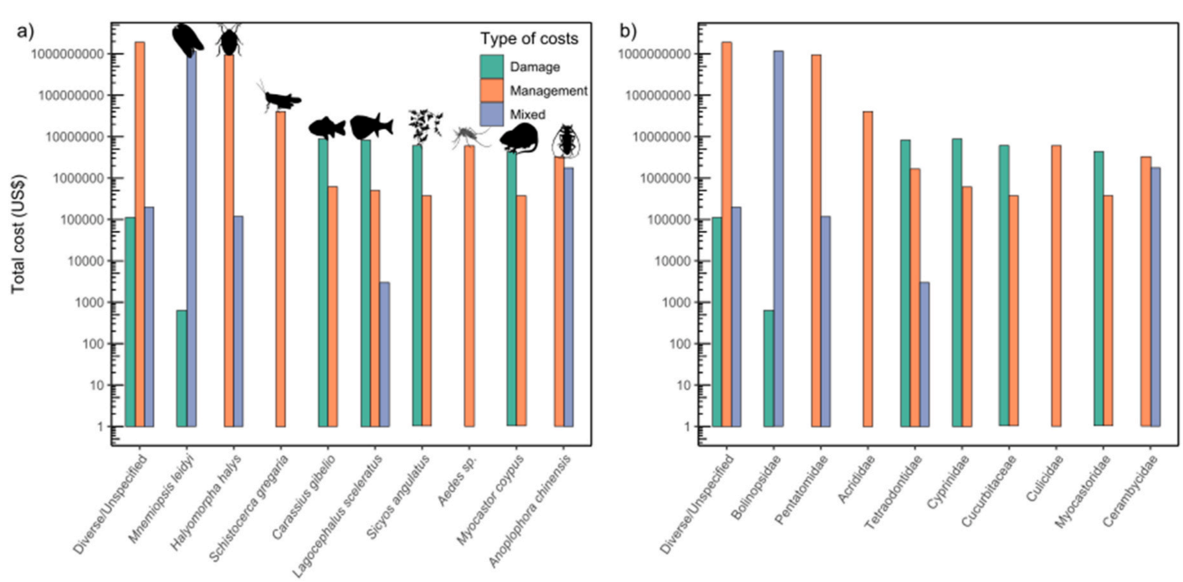

Fig. 3. Total economic costs (log scale) of biological invasions in Türkiye (a) across species and type of costs and (b) families, filled according to types of costs for the top ten categories. Presented information is based on available data for Türkiye found in *InvaCost* v.4.1.

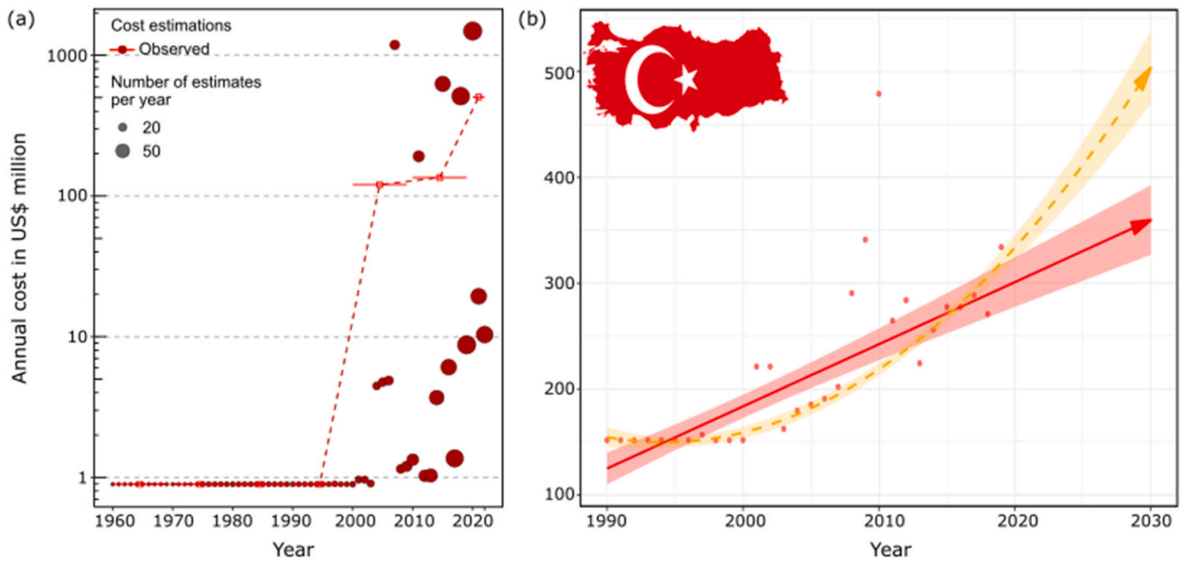

Fig. 4. (a) Annual temporal costs of invasive species in Türkiye. Bars and squares reflect annual average costs per 10-year period, whereas circles are annual totals and the dashed line connects the periods. Note the y-axis is on a log scale. (b) Temporal projection of total cost from robust regression until 2030. The dashed line refers to the quadratic model fit while the solid line refers to the linear model fit and the shaded area is the 95% confidence interval. Dots represent annual total costs after the removal of outliers.

(Duboscq-Carra et al., 2021). In Australia, where an estimated 2700 non-native plant species are established, recorded costs existed for only about 1% of these plant species (Bradshaw et al., 2021). Conversely, research efforts in other regions appear to be more extensive, with costs documented for approximately 50% of all invasive species in North America (Crystal-Ornelas et al., 2021). This suggests that these knowledge gaps are not uniformly low across countries with greater research capacities or reporting efforts. While not all invasive species have direct monetary costs, the gaps both for entire species and within currently reported species suggest that, in reality, costs may be several orders of magnitude higher than reported here. Some invasive species may indeed have relatively benign impacts or be characterised by indirect effects that are challenging to monetize. In certain cases, they might even be associated with economic benefits alongside their negative impacts (Haubrock et al., 2021a; Kourantidou et al., 2022), often yielding an equivocal message regarding their problematic effects.

Across Europe, research has shown that invasion costs, encompassing both management and damage, tend to correlate positively with parameters such as the size of the human population, geographical area, and the level of tourism activity (Haubrock et al., 2021a). Considering Türkiye's substantial population of 85 million and its allocation of approximately 1.5% of GDP to research and development, it becomes evident that the national representation of invasion costs may be inadequate due to a deficit in cost reportings (Haubrock et al., 2021a). This suggests the pressing need for improved scientific infrastructure to facilitate the reporting and tracking of invasion costs in Türkiye, especially in light of predictions indicating that biological invasions are likely to substantially increase in the coming decades across various habitat types and geographic regions (Seebens et al., 2021).

When considering the high fraction of observed costs, it becomes evident that aquatic invasive species and agriculturally relevant invasive species (i.e. pests) caused the most recorded impacts, followed by a diverse array of invertebrates and other taxonomic groups. A substantial portion, albeit not the majority, of the reported costs falls under the 'Diverse/Unspecified' category. These costs were primarily attributed to post-invasion management efforts involving multiple or unspecified species. In this category, many municipalities across Türkiye employ control measures such as spraying common invasive species such as mosquitoes. The major contributors to observed costs were however isolated studies reporting expenses that could arise during the potential spread of specific species. For instance, the warty comb jelly *M. leidyi*, an aquatic invader suspected of causing substantial ecological damage during its widespread invasion of the Black Sea in the past (Knowler, 2005; Özdemir and Ceylan, 2007; Shiganova et al., 2019), and the brown marmorated stink bug *H. halys*, a known agricultural pest present in Türkiye (Ozdemir and Tuncer, 2021), were prominent.

While it is not surprising that fishery or agricultural impacts would contribute significantly to costs, the fact that only a few studies (n = 115) address these costs in Türkiye underscores a deficiency in cost reporting. In comparison, similar national studies conducted in Argentina (Duboscq-Carra et al., 2021), Brazil (Adelino et al., 2021), the UK (Cuthbert et al., 2021b), Australia (Bradshaw et al., 2021), and the USA (Crystal-Ornelas et al., 2021) have consistently revealed a notable dominance of reported agricultural costs over cost reporting studies for other sectors. This discrepancy in cost reporting suggests that invasion costs in Türkiye may be substantially underrepresented owing to the disparity between known invasive species and those with reported costs. A comparable case would be Singapore, where reported costs exist only for two out of >100 known established invasive species (Haubrock et al., 2021b), suggesting that the relatively low number of cost reports recorded for non-native species in Türkiye may be attributed to a lack of comprehensive data in this regard.

A striking illustration of data scarcity can be found in the case of the desert locust, *S. gregaria* (Yıldırım, 2014). In Türkiye, significant post-management costs, totalling around 86 million Turkish Lira (TRY) (equivalent to approximately 3.30 million 2017 US$), were incurred from 1950 to 2013 due to locust outbreaks (www.tarimorman.gov.tr). However, historical records reveal even more ancient occurrences of these devastating plagues in Western Anatolia during the 1850s, 1860s, 1880s, and 1910s, inflicting financial and moral distress on the government, local authorities, and the populace (Gökmen, 2010). During the First World War, this invasion of locust species was dubbed the 'fifth enemy of the Ottoman Empire' affecting regions in West and South Anatolia, as well as areas in Aleppo and Syria (Yıldırım, 2014). To combat these outbreaks, the government enacted stringent laws and regulations in 1912, diverting considerable time and resources toward the prevention and management of locust infestations. Following the collapse of the Ottoman Empire and the establishment of the Turkish Republic, the nation grappled with severe socio-economic challenges. Despite these difficulties, Türkiye continued to allocate significant human and economic resources to combat the impacts of orthopteran invasions, totalling approximately 4 million US dollars (not adjusted for inflation) between the 1930s and 1980s (Balamir, 1973). However, despite well-documented historical evidence of damage caused by orthopterans and both observed and potential impacts, there has been a noticeable paucity of research into their invasion ecology and potential distribution patterns (Kulessa et al., 2023). Numerous countries have reported substantial economic losses resulting from locust species. For example, the locust plague in West Africa from 2003 to 2005 caused an estimated economic loss of US$ 2.5 billion in crop and livestock damage, severely impacting local economies and leading to food shortages and resource scarcity (Showler et al., 2022). Similarly, in 2019 and 2020, the Moroccan locust migrated to Sardinia, where it devastated thousands of hectares of agricultural land, resulting in significant economic losses for farmers (Bauer et al., 2022).

Economic and recreational activities pertaining to aquatic systems, such as angling (Cooke and Cowx, 2004), have long been associated with aquatic invasive species introductions in Türkiye (Tarkan et al., 2015). These species have gained a lot of attention that resulted in numerous research activities. *C. gibelio* and *L. sceleratus*, a freshwater and a marine fish species, respectively, are among the costliest invasive species in Türkiye. The Turkish government allocates substantial annual budgets for management efforts related to these two species. This includes separate EU-based projects for each species, providing governmental support for puffer fish catch by fishermen. This utilisation of these species, however, contributes major economic gains that should be considered in parallel with economic costs (Steffens and Winkel, 2002).

Concomitant to these and other anthropogenic activities, communities and the hydro-morphology of aquatic ecosystems have long been transformed (Arlinghaus, 2005), while at the same time remaining under the management of fishing associations. Even though fisheries was the second most impacted sector in Türkiye, the costs were reported for the coastal fisheries, and thus, there were no/few reported costs for the inland fisheries. This lack of economic impact estimation, positive or negative, of invasions into inland fisheries in Türkiye may thus result from a lack of governmental regulations or public and scientific perception. Another example of a costly invasive species in Türkiye is the nutria *Myocastor coypus*, also known as the coypu, a large, herbivorous, semiaquatic rodent. Interestingly, this species has invaded two significant watersheds, one in the west and another in the east of Türkiye (Pamukoğlu and Türkoğlu, 2021). Remarkably, there has been extensive research and funding allocated to this species, including resources for post-invasion management, suggesting that the actual economic costs of this, but also other invasive species in Türkiye, whether unreported or inadequately evaluated, are likely to be significantly higher than what is reported here. For instance, despite the likely existence of substantial costs associated with invasive species transmitting fish diseases in Turkish aquaculture, these costs are often overlooked or inadequately reported (Ercan et al., 2015). As a matter of fact, a similar situation also applies to invasive non-native plant species, as one of Türkiye's main shortcomings highlighted in this study is measuring the socio-economic costs of invasive non-native plants. For example, *Robinia pseudoacacia* and *Ailanthus altissima*, which are among the most invasive non-native plants in Türkiye (Yazlık and Ambarlı, 2022), provide socio-economic benefits through exploitation in the timber industry, as well as for landscaping and erosion control in Türkiye (Vítková et al., 2020; Yazlık and Ambarlı, 2022). The spread of these invasive species to different habitats may cause problems that require management (i.e. controlled and/or eradicated), which are costs that are not adequately represented in *InvaCost*. For instance, instead of a special control cost for *Ailanthus altissima* in agricultural habitats (Yazlık and Ambarlı, 2022), a cost expense (e.g. labour expense, herbicide) is calculated within the framework of the control of all target weeds in the relevant habitat. This highlights the need for a comprehensive and accurate assessment of the economic impact of invasive species in different regions, considering all relevant sectors, environments, and species.

Management costs in Türkiye were found to be substantial, but less reported than damages (in terms of cost entries in *InvaCost*). Management costs in Türkiye were found to be substantial, but less reported than damages (in terms of cost entries in InvaCost). This is similar to the cost evaluation conducted for Spain (Angulo et al., 2021a), only two out of 174 species incurred costs related to damage, suggesting that the ability to report damages or management costs may differ across countries. Certain damage costs are, however, frequently intertwined with management costs, implying that there might be reporting issues and gaps in the data. It is therefore crucial to recognize that the conspicuous absence of comprehensive cost quantifications on a national scale can hinder decision-making for policymakers and stakeholders. This deficiency results in a lack of economic justification for prioritising actions to address invasive species. Investments in prevention and control have the potential to mitigate the impacts and consequently reduce the costs associated with invasive species (Cuthbert et al., 2022). Many costly management reports were incurred post-invasion in this study, with no information on pre-invasion (i.e. prevention) costs, making it reasonable to assume that without sufficient future investments in control and prevention (i.e., within the "Management" cost category), damage-related costs are likely to increase. Given the evident scarcity of information regarding various known invasive species in Türkiye, there is currently no governmental body actively responsible for tracking and accounting for the costs associated with invasive species. Despite the existence of specific departments dedicated solely to the management of invasive species within some ministry branches, little to no scientific effort has been focused on this issue on a national level. This is remarkable considering the substantial research costs reported for Türkiye (2.086 million Euros, http://teriasturk.org/), which is unique among recent national cost assessments for invasive species (Crystal-Ornelas et al., 2021; Diagne et al., 2021). The availability of cost estimates is anticipated to provide valuable support for such governmental initiatives. Considering that costs remain undisclosed for numerous species and affected sectors, it is plausible that the current reported cost figures may be at least two orders of magnitude lower than the actual economic impact.

5. Conclusions

The significant economic costs associated with biological invasions in Türkiye should help to move the issue up the policy agenda and inform decision-making at the national level. Most of the costs were spent in post-invasion management, providing a compelling economic incentive for taking measures to prevent and control the introduction and spread of invasive species. Moreover, these staggering costs affecting the Turkish economy underline the importance of conducting invasive species screenings and impact assessments to inform national deny lists (i.e. black lists) for non-native species. This is especially important as the expenses related to pre-invasion biosecurity protocols (i.e. border checks, surveillance) are generally significantly lower, averaging at least one magnitude lower, than the costs of active management (Leung et al., 2002; Cuthbert et al., 2022). It is evident that there are major knowledge gaps, as reflected in the limited number of species with economic costs compared to the known number of invasive species in Türkiye. Therefore, the sparsity of costs presented in this study should be considered and filled further when planning prospective prevention and surveillance efforts, while underlining how significant the actual costs of all invasions could be. Additionally, the present study underscores the necessity for national and regional authorities to implement more structured reporting of costs, which would aid in refining future management cost planifications (Diagne et al., 2020). Future projections indicate urgent needs for increased national budgets to effectively address the threat posed by alien species (Silva et al., 2014; OECD, 2019), and for better-coordinated international actions and policy changes, including risk assessments, monitoring, and rapid responses, which would lead to mitigation of the economic costs associated with invasive species.

CRediT authorship contribution statement

Ali Serhan Tarkan: Writing – review & editing, Writing – original draft, Investigation, Data curation, Conceptualization. **Esra Bayçelebi:** Writing – review & editing, Investigation, Data curation. **Daniela Giannetto:** Writing – review & editing, Validation, Investigation, Data curation. **Emine Demir Özden:** Investigation, Data curation. **Ayşe Yazlık:** Writing – review & editing, Resources, Investigation, Data curation. **Özgür Emiroğlu:** Investigation, Data curation. **Sadi Aksu:** Investigation, Data curation. **Ahmet Uludağ:** Writing – review & editing, Investigation, Data curation. **Necmi Aksoy:** Investigation, Data curation. **Hazel Baytaşoğlu:** Investigation, Data curation. **Cüneyt Kaya:** Writing – review & editing, Investigation, Data curation. **Tanju Mutlu:** Investigation, Data curation. **Şerife Gülsün Kırankaya:** Investigation, Data curation. **Deniz Ergüden:** Writing – review & editing, Investigation, Data curation. **Esra Per:** Investigation, Data curation. **İlhan Üremiş:** Investigation, Data curation. **Onur Candan:** Writing – review & editing, Visualization, Investigation, Data curation. **Aysel Kekillioğlu:** Investigation, Data curation. **Baran Yoğurtçuoğlu:** Writing – review & editing, Investigation, Data curation. **F. Güler Ekmekçi:** Investigation, Data curation. **Esra Başak:** Writing – review & editing, Investigation, Data curation. **Hatice Özkan:** Writing – review & editing, Investigation, Data curation. **Irmak Kurtul:** Investigation, Data curation. **Deniz Innal:** Investigation, Data curation. **Nurçin Killi:** Investigation, Data curation. **Sercan Yapıcı:** Investigation, Data curation. **Dinçer Ayaz:** Investigation, Data curation. **Kerim Çiçek:** Investigation, Data curation. **Oğuzcan Mol:** Investigation, Data curation. **Emre Çınar:** Investigation, Data curation. **Vedat Yeğen:** Investigation, Data curation. **Elena Angulo:** Writing – review & editing, Validation, Supervision, Methodology. **Ross N. Cuthbert:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Ismael Soto:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Methodology, Formal analysis. **Franck Courchamp:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Phillip J. Haubrock:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Resources, Project administration, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

We thank TÜBİTAK-BİDEB (2219 Program), which supported Ali Serhan Tarkan and Irmak Kurtul with one-year scholarships during their post-doctoral research in the United Kingdom. We thank Christophe Diagne for helping with the sighting and correction of the underlying data.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2024.120779. Reproducible R code can be found at github.com/IsmaSA/InvaCost_Turkey.

References

Adelino, J.R.P., Heringer, G., Diagne, C., Courchamp, F., Faria, L.D.B., Zenni, R.D., 2021. The economic costs of biological invasions in Brazil: a first assessment. NeoBiota 67, 349–374. https://doi.org/10.3897/neobiota.67.59185.

Ahmed, D.A., Haubrock, P.J., Cuthbert, R.N., Bang, A., Soto, I., Balzani, P., Courchamp, F., 2023. Recent advances in availability and synthesis of the economic costs of biological invasions. Bioscience 73, 560–574. https://doi.org/10.1093/biosci/biad060.

Aksu, S., Başkurt, S., Emiroğlu, Ö., Tarkan, A.S., 2021. Establishment and range expansion of non-native fish species facilitated by hot springs: the case study from the Upper Sakarya Basin (NW, Turkey). Oceanol. Hydrobiol. Stud. 50, 247–258. https://doi.org/10.2478/oandhs-2021-0021.

Anderson, L.G., White, P.C.L., Stebbing, P.D., Stentiford, G.D., Dunn, A.M., 2014. Biosecurity and vector behaviour: evaluating the potential threat posed by anglers and canoeists as pathways for the spread of invasive non-native species and pathogens. PLoS One 9, 1–10. https://doi.org/10.1371/journal.pone.0092788.

Angulo, E., Ballesteros-Mejia, E., Novoa, A., Duboscq-Carra, V.G., Diagne, C., Courchamp, F., 2021a. Economic costs of invasive alien species in Spain. NeoBiota 67, 267–297.

Angulo, E., Diagne, C., Ballesteros-Mejia, L., Adamjy, T., Ahmed, D.A., Akulov, E., Courchamp, F., 2021b. Non-English languages enrich scientific knowledge: the example of economic costs of biological invasions. Sci. Total Environ. 775, 144441 https://doi.org/10.1016/j.scitotenv.2020.144441.

Arlinghaus, R., 2005. A conceptual framework to identify and understand conflicts in recreational fisheries systems, with implications for sustainable management. Aquatic Resources,. Culture and Development 1, 145–174. https://doi.org/10.1079/aqres20063050513.

Aukema, J.E., Leung, B., Kovacs, K., Chivers, C., Britton, K.O., Englin, J., von Holle, B., 2011. Economic impacts of non-native forest insects in the continental United States. PLoS One 6, e24587. https://doi.org/10.1371/journal.pone.0024587.

Bacher, S., Blackburn, T.M., Essl, F., Genovesi, P., Heikkilä, J., Jeschke, J.M., Kumschick, S., 2018. Socio-economic impact classification of alien taxa (SEICAT). Methods Ecol. Evol. 9, 159–168. https://doi.org/10.1111/2041-210X.12844.

Balamir, S., 1973. Türkiye'de Çöl çekirgesi (Schistocerca gregaria forsk.) salgınları [desert locust (Schistocerca gregaria fors.) outbreaks in Turkey]. Şark Matbaası, Ankara, Turkey, pp. 1–94.

Bauer, C., Fekete, A., Kühne, S., Baufeld, P., 2022. Abschätzung des Klimawandel induzierten Gefahrenpotentials von Feldheuschrecken (Acrididae) als Schädlinge für die zukünftige deutsche Landwirtschaft. Journal für Kulturpflanzen 74, 153–165.

Bradshaw, C.J., Hoskins, A.J., Haubrock, P.J., Cuthbert, R.N., Diagne, C., Leroy, B., Courchamp, F., 2021. Detailed assessment of the reported economic costs of invasive species in Australia. NeoBiota 67, 511–550. https://doi.org/10.3897/neobiota.67.58834.

Brunel, S., Branquart, E., Fried, G., Van Valkenburg, J., Brundu, G., Starfinger, U., Baker, R., 2010. The EPPO prioritisation process for invasive alien plants. EPPO Bull. 40, 407–422.

Çoban, S., Yener, Ş.D., Bayraktar, S., 2021. Woody plant composition and diversity of urban green spaces in Istanbul, Turkey. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology 155, 83–91. https://doi.org/10.1080/11263504.2020.1727980.

Cooke, S.J., Cowx, I.G., 2004. The role of recreational fishing in globalfish cruises. Bioscience 54, 857–859.

Countryman, A.M., Warziniack, T., Grey, E., 2018. Implications for U.S. Trade and nonindigenous species risk resulting from increased economic integration of the Asia-Pacific region. Soc. Nat. Resour. 31, 942–959. https://doi.org/10.1080/08941920.2018.1447713.

Crystal-Ornelas, R., Hudgins, E.J., Cuthbert, R.N., Haubrock, P.J., Fantle-Lepczyk, J., Angulo, E., Courchamp, F., 2021. Economic costs of biological invasions within North America. NeoBiota 67, 485–510. https://doi.org/10.3897/neobiota.67.58038.

Cuthbert, R.N., Pattison, Z., Taylor, N.G., Verbrugge, L., Diagne, C., Ahmed, D.A., Courchamp, F., 2021a. Global economic costs of aquatic invasive alien species. Sci. Total Environ. 775, 145238 https://doi.org/10.1016/j.scitotenv.2021.145238.

Cuthbert, R.N., Bartlett, A.C., Turbelin, A.J., Haubrock, P.J., Diagne, C., Pattison, Z., Courchamp, F., Catford, J.A., 2021b. Economic costs of biological invasions in the United Kingdom. The economic costs of biological invasions around the world. NeoBiota 67, 299–328. https://doi.org/10.3897/neobiota.67.58834.

Cuthbert, R.N., Diagne, C., Hudgins, E.C., Turbelin, A., Ahmed, D.A., Albert, C., Courchamp, F., 2022. Biological invasion costs reveal insufficient proactive management worldwide. Sci. Total Environ. 819 (153404) https://doi.org/10.1016/j.scitotenv.2022.153404.

Diagne, C., Leroy, B., Gozlan, R.E., Vaissiere, A.-C., Assailly, C., Nuninger, L., Roiz, D., Jourdain, F., Jaric, I., Courchamp, F., 2020. InvaCost, a public database of the economic costs of biological invasions worldwide. Sci. Data 7, 1–12. https://doi.org/10.1038/s41597-020-00586-z.

Diagne, C., Turbelin, A.J., Moodley, D., Novoa, A., Leroy, B., Angulo, E., Courchamp, F., 2021. The economic costs of biological invasions in Africa: a growing but neglected threat? NeoBiota 67, 11–51. https://doi.org/10.3897/neobiota.67.59132.

Duboscq-Carra, V.G., Fernandez, R.D., Haubrock, P.J., Dimarco, R.D., Angulo, E., Ballesteros-Mejia, L., Nuñez, M.A., 2021. Economic impact of invasive alien species in Argentina: a first national synthesis. NeoBiota 67, 329–348. https://doi.org/10.3897/neobiota.67.63208.

Emiroğlu, Ö., Atalay, M., Ekmekçi, F., Aksu, S., Başkurt, S., Keskin, E., Tarkan, A.S., 2020. One of the world's worst invasive species, *Clarias batrachus* (Actinopterygii:

Siluriformes: Clariidae), has arrived and established a population in Turkey. Acta Ichthyol. Piscatoria 50, 391–400. https://doi.org/10.3750/aiep/03028.
Ercan, E., Agrali, N., Tarkan, A.S., 2015. The effects of salinity, temperature and feed ratio on growth performance of European sea bass (*Dicentrarchus labrax* L., 1758) in the water obtained through reverse osmosis system and a natural river. Pakistan J. Zool. 47 (3), 625–633.
Erturk, Y.E., Uremis, I., Uludag, A., 2012. The economic impact of weeds and their control in Turkey. In: Proceedings of the International Symposium on Current Trends in Plant Protection. Institute for Plant Protection and Environment, Belgrade, Serbia, pp. 79–85, 25-28th September, 2012.
Essl, F., Bacher, S., Blackburn, T.M., Booy, O., Brundu, G., Brunel, S., García-Berthou, E., 2015. Crossing frontiers in tackling pathways of biological invasions. Bioscience 65, 769–782. https://doi.org/10.1093/biosci/biv082.
Fantle-Lepczyk, J.E., Haubrock, P.J., Kramer, A.M., Cuthbert, R.N., Turbelin, A.J., Crystal-Ornelas, R., Courchamp, F., 2022. Economic costs of biological invasions in the United States. Sci. Total Environ. 806 (151318) https://doi.org/10.1016/j.scitotenv.2021.151318.
Haubrock, P.J., Turbelin, A.J., Cuthbert, R.N., Novoa, A., Taylor, N.G., Angulo, E., Courchamp, F., 2021a. Economic costs of invasive alien species across Europe. NeoBiota 67, 153–190. https://doi.org/10.3897/neobiota.67.58196.
Haubrock, P.J., Cuthbert, R.N., Yeo, D.C., Banerjee, A.K., Liu, C., Diagne, C., Courchamp, F., 2021b. Biological invasions in Singapore and Southeast Asia: data gaps fail to mask potentially massive economic costs. NeoBiota 67, 131–152. https://doi.org/10.3897/neobiota.67.64560.
Henry, M., Leung, B., Cuthbert, R.N., Bodey, T.W., Ahmed, D.A., Angulo, E., Haubrock, P. J., 2023. Unveiling the hidden economic toll of biological invasions in the European Union. Environmental Science Europe 35 (43). https://doi.org/10.1186/s12302-023-00750-3.
Hudgins, E.J., Cuthbert, R.N., Haubrock, P.J., Taylor, N.G., Kourantidou, M., Nguyen, D., Courchamp, F., 2023. Unevenly distributed biological invasion costs among origin and recipient regions. Nat. Sustain. 6, 1113–1124. https://doi.org/10.1038/s41893-023-01124-6.
Hulme, P.E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., Vilà, M., 2008. Grasping atthe routes of biological invasions: a framework for integrating pathways into policy. J. Appl. Ecol. 45, 403–414. https://doi.org/10.1111/j.1365-2664.2007.01442.x.
Hyndman, R., Athanasopoulos, G., Bergmeir, C., Caceres, G., Chhay, L., O'Hara-Wild, M., Yasmeen, F., 2023. forecast: forecasting functions for time series and linear models. R package 20 version 8.
Kahraman, A., Onder, M., Ceyhan, E., 2012. The importance of bioconservation and biodiversity in Turkey. International Journal of Bioscience,. Biochemistry and Bioinformatics 2, 95. https://doi.org/10.7763/IJBBB.2012. V2.79.
Kaya, C., 2020. The first record and origin of *Salmo trutta* populations established in the upper tigris river and lake van basin, eastern Anatolia (teleostei: salmonidae). Journal of Anatolian Environmental and Animal Sciences 5, 366–372. https://doi.org/10.35229/jaes.777575.
Kaya, Z., Raynal, D.J., 2001. Biodiversity and conservation of Turkish forests. Biol. Conserv. 97, 131–141. https://doi.org/10.1016/S0006-3207(00)00069-0.
Kırankaya, Ş.G., Ekmekçi, F.G., 2021. First record of a feral population of Exotic Green Swordtail (*Xiphophorus hellerii*) with an additional record of guppy (*Poecilia reticulata*) in Turkish freshwaters. Hacettepe Journal of Biology and Chemistry 49, 433–441. https://doi.org/10.15671/hjbc.961220.
Knowler, D., 2005. Reassessing the costs of biological invasion: *Mnemiopsis leidyi* in the Black Sea. Ecol. Econ. 52, 187–199. https://doi.org/10.1016/j.ecolecon.2004.06.013.
Kourantidou, M., Haubrock, P.J., Cuthbert, R.N., Bodey, T.W., Lenzner, B., Gozlan, R.E., Courchamp, F., 2022. Invasive alien species as simultaneous benefits and burdens: trends, stakeholder perceptions and management. Biol. Invasions 24, 1905–1926.
Kulessa, A.K., Kouba, A., Renault, D., Soto, I., Haubrock, P.J., 2023. Assessing non-native invasive orthoptera in Europe. https://doi.org/10.21203/rs.3.rs-2828952/ v1.
Leroy, B., Kramer, A.M., Vaissière, A.C., Kourantidou, M., Courchamp, F., Diagne, C., 2022. Analysing economic costs of invasive alien species with the invacost R package. Methods Ecol. Evol. 13, 1930–1937. https://doi.org/10.1111/2041-210X.13929.
Leung, B., Lodge, D.M., Finnoff, D., Shogren, J.F., Lewis, M.A., Lamberti, G., 2002. An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. In: Proceedings of the Royal Society of London Series B: Biological Sciences, vol. 269, pp. 2407–2413. https://doi.org/10.1098/rspb.2002.2179.
Lima, L.B., Oliveira, F.J.M., Giacomini, H.C., Lima-Junior, D.P., 2018. Expansion of aquaculture parks and the increasing risk of non-native species invasions in Brazil. Rev. Aquacult. 10, 111–122. https://doi.org/10.1111/raq.12150.
Liu, C., Diagne, C., Angulo, E., Banerjee, A.-K., Chen, Y., Cuthbert, R.N., Courchamp, F., 2021. Economic costs of biological invasions in Asia. The economic costs of biological invasions around the world. NeoBiota 67, 53–78. https://doi.org/10.3897/neobiota.67.58147.
Maechler, M., Rousseeuw, P., Croux, C., Todorov, V., Ruckstuhl, A., Salibian-Barrera, M., Anna di Palma, M.. Robustbase: basic robust statistics. R package version 0.95–0. http://robustbase.r-forge.r-project.org/.
Oecd, 2019. Biodiversity: Finance and the Economic and Business Case for Action Report Prepared for the G7 Environment Ministers' Meeting, pp. 5–6. May 2019.
Özdemir, G., Ceylan, B., 2007. Biyolojik istila ve karadeniz'deki istilacı türler. SÜMAE Yunus Araştırma Bülteni 7, 3.
Ozdemir, I.O., Tuncer, C., 2021. Turkiye'de Yeni bir istilaci polifag zararli, kahverengi kokarca [Halyomorpha halys (stal, 1855) (Hemiptera: pentatomidae)]: tanimi, benzer turler ve mevcut durum. Black Sea Journal of Engineering and Science 4, 58–67.
Pagad, S., Genovesi, P., Carnevali, L., Schigel, D., McGeoch, M.A., 2018. Introducing the global register of introduced and invasive species. Sci. Data 5, 1–12.
Pamukoğlu, N., Türkoğlu, M., 2021. İstilacı bir tür, su maymunu (*Myocastor coypus*). Doğanın Sesi 3, 3–13.
Parlar-Dal, E., Dipama, S., 2020. Assessing the Turkish "trading state" in sub-Saharan Africa. Turkey's political economy in the 21st century 239–270. https://doi.org/10.1007/978-3-030-27632-4_10.
Pata, U.K., Balsalobre-Lorente, D., 2022. Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach. Environ. Sci. Pollut. Control Ser. 29, 13491–13503. https://doi.org/10.1007/s11356-021-16675-4.
Peyton, J.M., Martinou, A.F., Adriaens, T., Chartosia, N., Karachle, P.K., Rabitsch, W., Roy, H.E., 2020. Horizon scanning to predict and prioritise invasive alien species with the potential to threaten human health and economies on Cyprus. Frontiers in Ecology and Evolution 8, 566281. https://doi.org/10.3389/fevo.2020.566281.
Pranovi, F., Franceschini, G., Casale, M., Zucchetta, M., Torricelli, P., Giovanardi, O., 2006. An ecological imbalance induced by a non-native species: the Manila clam in the Venice Lagoon. Biol. Invasions 8, 595–609. https://doi.org/10.1007/s10530-005-1602-5.
Renault, D., Manfrini, E., Leroy, B., Diagne, C., Ballesteros-Mejia, L., Angulo, E., Courchamp, F., 2021. Biological invasions in France: alarming costs and even more alarming knowledge gaps. NeoBiota 67, 191–224. https://doi.org/10.3897/neobiota.67.59134.
Ricciardi, A., Hoopes, M.F., Marchetti, M.P., Lockwood, J.L., 2013. Progress toward understanding the ecological impacts of nonnative species. Ecol. Monogr. 83, 263–282. https://doi.org/10.1890/13-0183.1.
Seebens, H., Bacher, S., Blackburn, T.M., Capinha, C., Dawson, W., Dullinger, S., Essl, F., 2021. Projecting the continental accumulation of alien species through to 2050. Global Change Biol. 27 (5), 970–982.
Seebens, H., Blackburn, T.M., Dyer, E.E., Genovesi, P., Hulme, P.E., Jeschke, J.M., Essl, F., 2017. No saturation in the accumulation of alien species worldwide. Nat. Commun. 8 (14435) https://doi.org/10.1038/ncomms14435.
Şekercioğlu, Ç.H., Anderson, S., Akçay, E., Bilgin, R., Can, Ö.E., Semiz, G., Dalfes, H.N., 2011. Turkey's globally important biodiversity in crisis. Biol. Conserv. 144, 2752–2769. https://doi.org/10.1016/j.biocon.2011.06.025.
Shiganova, T.A., Mikaelyan, A.S., Moncheva, S., Stefanova, K., Chasovnikov, V.K., Mosharov, S.A., Dzhurova, B., 2019. Effect of invasive ctenophores *Mnemiopsis leidyi* and *Beroe ovata* on low trophic webs of the Black Sea ecosystem. Marine Pollution Bullettin 141, 434–447.
Showler, A.T., Shah, S., Khan, S., Ullah, S., Degola, F., 2022. Desert locust episode in Pakistan, 2018–2021, and the current status of integrated desert locust management. Journal of Integrated Pest Management 13, 1–11.
Siddiq, A.B., 2016. Anatolian farmers in Europe: migrations and cultural transformation in the early Neolithic period. In: The Proceedings of 1st International Symposium on Migration and Culture, vol. 2. Amasya: Amasya University Press, pp. 519–532.
Silva, J.P., Sopeña, A., Sliva, J., Toland, J., Nottingham, S., Jones, W., Eldridge, J., Thorpe, E., Thévignot, C., Salsi, A., 2014. LIFE and Invasive Alien Species. Publications Office of the European Union Luxembourg.
Simberloff, D., Martin, J.L., Genovesi, P., Maris, V., Wardle, D.A., Aronson, J., Vilà, M., 2013. Impacts of biological invasions: what's what and the way forward. Trends Ecol. Evol. 28, 58–66. https://doi.org/10.1016/j.tree.2012.07.013.
Soto, I., Balzani, P., Carneiro, L., Cuthbert, R.N., Macêdo, R., Tarkan, A.S., Haubrock, P. J., 2024. Taming the terminological tempest in invasion science. Biol. Rev. 1–34.
Steffens, W., Winkel, M., 2002. Evaluating recreational fishing in Germany. Recreational fisheries: ecological, economic and social evaluation, pp. 130–136.
Sutcliffe, C., Quinn, C.H., Shannon, C., et al., 2018. Exploring the attitudes to and uptake of biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in UK natural environments. Biol. Invasions 20, 399–411. https://doi.org/10.1007/s10530-017-1541-y.
Tarkan, A.S., Copp, G.H., Top, N., Özdemir, N., Önsoy, B., Bilge, G., Filiz, H., Yapıcı, S., Ekmekçi, G., Kırankaya, Ş., Emiroğlu, Ö., Gaygusuz, Ö., Gürsoy Gaygusuz, Ç., Oymak, A., Özcan, G., Saç, G., 2012. Are introduced gibel carp *Carassius gibelio* in Turkey more invasive in artificial than in natural waters? Fish. Manag. Ecol. 19, 178–187.
Tarkan, A.S., Marr, S.M., Ekmekçi, F.G., 2015. Non-native and translocated freshwater fish. FiSHMED Fishes in Mediterranean Environments 3, 1–28.
Tarkan, A.S., Yoğurtçuoğlu, B., Ekmekçi, F.G., Stacey, A.C., Louisa, E.W., Vilizzi, L., Copp, G., 2020. First application in Turkey of the European Non-native species in Aquaculture Risk Analysis Scheme to evaluate the farmed non-native fish, striped catfish *Pangasianodon hypophthalmus*. Fish. Manag. Ecol. 27, 123–131.
Turbelin, A.J., Cuthbert, R.N., Essl, F., Haubrock, P.J., Ricciardi, A., Courchamp, F., 2023. Biological invasions are as costly as natural hazards. Perspectives in Ecology and Conservation 21, 143–150. https://doi.org/10.1016/j.pecon.2023.03.002.
Uludag, A., Aksoy, N., Yazlık, A., Arslan, Z.F., Yazmış, E., Uremis, I., Brundu, G., 2017. Alien flora of Turkey: checklist, taxonomic composition and ecological attributes. NeoBiota 35, 61–85.
Uludag, A., Aksoy, N., Uremis, I., Yazlik, A., Arslan, Z.F., Demir Ozden, E., Kırankaya, S. G., Ekmekçi, F.G., Wong, L.J., Pagad, S., 2020. Global register of introduced and invasive species - Turkey. Invasive Species Specialist Group ISSG Version 1.2. https://doi.org/10.15468/r88y8n.
Ünal, V., Göncüoğlu, H., Durgun, D., Tosunoğlu, Z., Deval, M.C., Turan, C., 2015. Silver-Cheeked Toadfish, *Lagocephalus sceleratus* (Actinopterygii: tetraodontiformes: Tetraodontidae), causes a substantial economic losses in the Turkish Mediterranean coast: a call for decision makers. Acta Ichthyol. Piscatoria 45, 231–237.
van Kleunen, M., Pyšek, P., Dawson, W., Kreft, H., Pergl, J., Weigelt, P., Winter, M., 2019. The global naturalized alien flora (GloNAF) database. Ecology 100, 1.

Vítková, M., Sádlo, J., Roleček, J., Petřík, P., Sitzia, T., Müllerová, J., Pyšek, P., 2020. *Robinia pseudoacacia*-dominated vegetation types of Southern Europe: species composition, history, distribution and management. Sci. Total Environ. 707 (134857) https://doi.org/10.1016/j.scitotenv.2019.134857.
Warziniack, T., Haight, R.G., Yemshanov, D., Apriesnig, J.L., Holmes, T.P., Countryman, A.M., Haberland, C., 2021. Economics of invasive species. In: Poland, T.M., Patel-Weynand, T., Finch, D.M., et al. (Eds.), Invasive Species in Forests and Rangelands of the United States. Springer International Publishing, Cham, pp. 305–320.
Watari, Y., Komine, H., Angulo, E., Diagne, C., Ballesteros-Mejia, L., Courchamp, F., 2021. First synthesis of the economic costs of biological invasions in Japan. NeoBiota 67, 79–101. https://doi.org/10.3897/neobiota.67.59186.
Wilson, J.R., Faulkner, K.T., Rahlao, S.J., Richardson, D.M., Zengeya, T.A., Van Wilgen, B.W., 2018. Indicators for monitoring biological invasions at a national level. J. Appl. Ecol. 55, 2612–2620. https://doi.org/10.1111/1365-2664.13251.
Yakin, B.Y., Çiçek, K., Bayrakci, Y., Günay, U.K., Afsar, M., Ayaz, D., Tok, C.V., 2023. On the occurrence of the pond slider turtle *Trachemys scripta* (thunberg in schoepff, 1792) (Testudines: emydidae) from southwestern Turkey. Journal of Wildlife and Biodiversity 8, 89–98. https://doi.org/10.5281/zenodo.7701167.
Yazlık, A., Ambarlı, D., 2022. Do non-native and dominant native species carry a similar risk of invasiveness? A case study for plants in Turkey. NeoBiota 76, 53–72. https://doi.org/10.3897/neobiota.76.85973.
Yazlık, A., Pergl, J., Pyšek, P., 2018. Impact of alien plants in Turkey assessed by the generic impact scoring system. NeoBiota 39, 31–51. https://doi.org/10.3897/neobiota.39.23598.
Yıldırım, M.A., 2014. The Fifth Enemy of the Ottoman Empire during World War I: Grasshoppers, vol. 13. Gaziantep University Journal of Social Sciences, pp. 1017–1042.
Yoğurtçuoğlu, B., Bucak, T., Ekmekçi, F.G., Kaya, C., Tarkan, A.S., 2021. Mapping the establishment and invasiveness potential of rainbow trout (*Oncorhynchus mykiss*) in Turkey: with special emphasis on the conservation of native salmonids. Frontiers in Ecology and Evolution 8, 599881. https://doi.org/10.3389/fevo.2020.599881.
Gökmen, E., 2010. The locust disaster In Western Anatolia (1850-1915). Belleten 74 (269), 127.