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The first national assessment of established non-native species in Türkiye

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47 **ABSTRACT**

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49 The ecological and socio-economic impacts of non-native species underscore the importance of
50 maintaining accurate national lists to support biosecurity and management strategies. Türkiye's
51 most recent national list highlights ongoing challenges in maintaining up-to-date records. To
52 advance Türkiye's national assessment of non-native species, we present the first comprehensive
53 list of established non-native species in the country, documenting 268 species from 157 families
54 across diverse taxonomic groups. Marine species ($n = 199$) dominated the list, with notable
55 contributions from Chordata, Mollusca, and Arthropoda, followed by Terrestrial (41), Freshwater
56 (24), Terrestrial/Freshwater (3) and Freshwater/Marine (1). Our spatial analysis revealed
57 considerable regional variation, with urban and coastal areas exhibiting higher rates of species
58 establishment likely facilitated by human-mediated pathways. We also identify Türkiye's role as a
59 crucial hub for the spread of non-native species across the country's borders. Further, we show
60 that 17% of non-native species have known ecological or economic impacts, emphasizing the
61 need for targeted impact assessments, monitoring, and proactive management. By providing a
62 detailed and up-to-date inventory of established non-native species and their impacts, this study
63 offers a critical foundation for strengthening biosecurity policies, guiding targeted monitoring
64 efforts, and fostering coordinated management responses at local, national, and international
65 scales to safeguard Türkiye's biodiversity.

66 **Key-words:** Biodiversity, Impacts, Species management, Human-mediated pathways, Trade
67 networks, Regional patterns

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70 Introduction

71
72 Non-native species pose significant ecological threats to biodiversity, and their socio-economic
73 impacts represent not only a burden on national economies but are also detrimental to human
74 well-being (Cucherousset and Olden 2011, Diagne et al. 2020). Despite the population-level
75 differences of invasion impacts (Haubrock et al. 2024), identifying and assessing non-native
76 species at the national level is essential for their effective management in view of legislation
77 measures. National lists of non-native species therefore serve multiple purposes: (i) they compile
78 species seen as relevant in terms of their potential or existing threats, (ii) they help prioritize
79 species for management actions, and (iii) they inform biosecurity measures by identifying those
80 species that may threaten neighbouring countries through trade and travel (Hulme 2009).
81 However, these lists, whenever available, are frequently inconsistent, reflecting the subjective
82 biases of assessors and differences in research fields (e.g. aquatic vs terrestrial, animals vs
83 plants), the status of non-native species (i.e. whether introduced, established, or invasive: *sensu*
84 Soto et al., 2024), and the criteria for determining a species as 'invasive' (i.e. spread vs impact:
85 (Cuthbert et al. 2022, Vilizzi et al. 2022a, Haubrock et al. 2024, Soto et al. 2024b). This can result
86 in misclassification of non-native species, with some being listed as established without clear
87 evidence, and some established being flagged as invasive without proper justification—although
88 we acknowledge that drawing a line to distinguish the different statuses of non-native species can
89 be obscure.

90
91 Several national lists of non-native species have emerged over the past two decades, providing
92 essential tools for guiding non-native species management, with most European Union countries
93 having compiled such lists even before formal regulations (Genovesi and Monaco 2013, Cerri et
94 al. 2022). Türkiye, however, exemplifies the challenges of maintaining accurate and updated
95 national lists. Given the country's significant economic position (ranked 18th globally: IMF, 2025),
96 coupled with its rich biodiversity (Şekercioğlu et al. 2011) and strategic location at the intersection
97 of the Middle East and Europe (Kahraman et al. 2012), such a national list is urgently needed to
98 mitigate the undesirable impacts of biological invasions. This is because non-native species in
99 Türkiye have been shown to pose substantial ecological and economic threats, adversely
100 affecting various sectors including agriculture, fisheries, tourism, and human health (Tarkan et al.
101 2012, 2024b). Their economic impact, while significant, is often underrepresented in national
102 financial assessments, despite the costs they impose on food production, biodiversity, and public
103 infrastructure (Shackelford et al. 2013, Bălăcenoiu et al. 2023). Incorporating these costs into

104 environmental policy and fiscal planning—such as through ‘green budgeting’—could improve
105 resource allocation and support more proactive management responses. Additionally, given
106 Türkiye's trade routes and the high volume of international travel, the risk of new non-native
107 species introductions in the country remains high (Kahraman and Altun 2016).

108
109 Although the first and only national list of non-native species in Türkiye dates back to 2020 and
110 includes 872 species (Uludag et al. 2020), questions remain about its accuracy and utility, as the
111 list includes all recorded occurrences of non-native species regardless of their establishment
112 status rather than focusing solely on those non-native species with self-sustaining populations,
113 i.e. established non-native species (hereafter, ‘established species’: see Soto et al., 2024). It is
114 therefore crucial to differentiate between those non-native species that are established, hence
115 likely to pose an immediate threat, and those that might be introduced, thereby presenting a
116 potential danger.

117
118 Updating existing national lists to guide future monitoring is essential for developing effective
119 early-warning systems and intervention strategies. In this respect, Türkiye exemplifies the
120 challenges of maintaining accurate and updated national lists, and the need for such updates is
121 critical in addressing the ecological and economic threats posed by non-native species. To fill this
122 gap, this study aims to provide a detailed overview of the established species in Türkiye by
123 compiling a new and up-to-date database. By analyzing the composition of these species, we
124 seek to understand the patterns and implications of their establishment in Türkiye. We
125 hypothesize that (1) the composition of established species will be dominated by terrestrial plants
126 and marine invertebrates, reflecting patterns observed in comparable regions, and (2) regions
127 within Türkiye with higher human activity, particularly those with dense populations, significant
128 trade and transportation infrastructure, and intensive land use, will exhibit higher rates of non-
129 native species establishment. In contrast, we hypothesize that (3) regions with less human activity
130 or more remote locations, such as certain inland or mountainous areas, will show lower rates of
131 invasion due to reduced opportunities for species introduction and less disturbance to native
132 ecosystems. We also anticipate that (4) the known ecological and economic impacts of these
133 established species are highly biased towards well-known invaders and taxonomic groups.
134 Finally, this study aims to assess known invasion impacts and, whenever possible, the level of
135 risk posed by the established species in Türkiye so as to provide targeted recommendations for
136 management and control.

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Material and methods

Data compilation

To compile a comprehensive and up-to-date database of established species in Türkiye, we used the recent global database of occurrences by Briski et al. (2024). This database gathers information from several sources, including the online database Standardising and Integrating Alien Species (SInAS: Seebens, 2021) and non-native species lists. We used the SInAS database as the base file for our study (see also Briski et al., 2024; Haubrock et al., 2025). We restricted usage to the spatial scale of species assigned only as CASUAL and ABSENT in the columns ‘degreeOfEstablishment’ and ‘occurrenceStatus’, respectively, which were removed due to their undetermined non-native establishment status (Groom et al. 2019). We emphasize that our dataset also contains taxonomically accepted subspecies as per the Global Biodiversity Information Facility (GBIF: <https://www.gbif.org/>). When a species was not found in GBIF, a manual search was done to verify its scientific name by consulting databases such as the World Register of Marine Species (WoRMS: <https://www.marinespecies.org/>), coupled with a general internet search in September 2024 (Briski et al. 2024). This process yielded a total of 1,092 established species in Türkiye. After a comprehensive review of each major species group by Turkish experts—based on the most up-to-date literature to filter out native, cryptogenic, and non-established species—a total of 268 species ($\approx 25\%$) remained classified as established in Türkiye.

Table 1. Breakdown of non-native organism habitat classifications (after Haubrock et al., 2025).

Habitat	Description
Freshwater	Species classified as freshwater inhabit environments such as rivers, lakes, and streams, with salinity $< 0.5 \text{ g kg}^{-1}$.
Marine	Species classified as marine occupy environments such as oceans, seas, coastal areas, and estuaries with salinity $\geq 0.5 \text{ g kg}^{-1}$.
Terrestrial	Species classified as terrestrial are found on land, including habitats such as forests, grasslands, deserts, and urban areas.
Semi-aquatic	Species associated with both terrestrial and aquatic habitats (e.g. freshwater-terrestrial), depend on both aquatic and terrestrial habitats to complete their life cycle or daily activities.

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Habitat and native range

161 For every species reported in the dataset, we identified the habitat it predominantly occupies (i.e.
162 terrestrial, freshwater, marine, or a mixture thereof) by consulting the
163 Step2_StandardTerms_GRIIS file (Seebens 2021) with habitat data originating from the Global
164 Register of Introduced and Invasive Species (GRIIS: (Pagad et al. 2018). We then assigned one
165 or more habitats (i.e. a combination of them, such as freshwater-marine) to each species. Where
166 habitat information was not available, we conducted an additional manual search of WoRMS and
167 a general internet search between July and September 2024. Of note, brackish habitats were
168 defined as marine based on the Venice System (1958)

169 We extracted the native range of each established species in Türkiye in two ways: (i) by employing
170 the web-scraping technique on several online databases, including Plants of the World Online
171 (<https://powo.science.kew.org/>) and GBIF, and (ii) by consulting targeted publications. We
172 identified the native range at the biogeographic realm (i.e. Nearctic, Neotropical, Palearctic,
173 Afrotropical, Indo-Malayan, Australasian, and Oceanian). Due to the low number of species from
174 the Oceanian realm, these were combined with the Australasian. Species associated with two
175 realms of equal weight were assigned to each realm (i.e. the taxon was distributed in both realms).
176 Species distribution across two or more realms (i.e. cosmopolitan) and species with unclear native
177 range were not considered in the analyses.

178 *Distribution of established species in Türkiye*

179 To unveil the spatial pattern of the established species, we extracted GBIF occurrences for each
180 of them in Türkiye. We restricted downloads to only those occurrences categorized as present,
181 with coordinates without geospatial issues and removal of fossil records. The download was done
182 by using the *occ_download* function from the *rgbif* R package (Chamberlain et al. 2017,
183 GBIF.org 2025). To identify the number of established species in each administrative area, we
184 overlapped the established non-native richness within the boundaries of each administrative area,
185 including marine areas. We downloaded the terrestrial administrative areas from the *geodata* R
186 package (Hijmans et al. 2024), whereas the marine areas (Exclusive Economic Zones) were
187 extracted from Marine Regions (<https://marineregions.org/>: Flanders Marine Institute, 2023).

188

189 *Compilation of impact and risk*

190 For each established species, we extracted all available information on its reported impacts (i.e.
191 environmental, economic, or social) at two levels: (i) reported in Türkiye and (ii) globally from

192 GRIIS. In the case of established species with a reported impact in Türkiye, we checked the
193 Centre for Agriculture and Biosciences International (CABI: <https://www.cabi.org/>) compendium
194 and the InvaCost database (v4.1: Diagne et al., 2020) for information on the type of impact. If the
195 data on the impact were not available in the CABI or InvaCost database, we used Google Scholar
196 to search for the information using the following search string: “species scientific name” and
197 “impact” or “invasive” in order to broaden the search, especially for less-studied species.
198 Comparison between regional (Türkiye) and global scale allowed us to identify potential gaps in
199 impact reporting.

200 For those established non-native species in the list for which published information was available
201 on the level of risk posed in risk assessment areas across Türkiye (including the country as a
202 whole), we included screening data from studies using the Aquatic Species Invasiveness
203 Screening Kit (AS-ISK: (Copp et al. 2016, Vilizzi et al. 2025). The AS-ISK (available in its v2.4.1
204 at <https://tinyurl.com/ISK-toolkits>) is a taxon-generic, multilingual decision-support tool that
205 complies with minimum standards for assessing non-native species (Copp et al. 2016). It consists
206 of 55 questions, 49 of which are for Basic Risk Assessment (BRA) and six are for Climate Change
207 Assessment (CCA). For each screened species, two scores are obtained: BRA, under current
208 climate conditions, and BRA+CCA, under predicted climate (change) conditions. Scores < 1
209 suggest a ‘low risk’ of the species being or becoming invasive in the risk assessment area, scores
210 ≥ 1 indicate a ‘medium risk’ or a ‘high risk’, which are distinguished using a calibrated threshold
211 (Vilizzi et al. 2022a). For those species classified as high risk, we also distinguished a ‘very high
212 risk’ category using an *ad hoc* threshold ≥ 45 based on the modular approach described by Britton
213 et al. (2011). Identification of very high-risk species helps to prioritize allocation of resources for
214 comprehensive (follow-up) risk assessment (Vilizzi et al. 2022a). In total, there were six AS-ISK
215 applications of relevance to this study (i.e. Bilge et al., 2019; Killi et al., 2020; Tarkan et al., 2021,
216 2017; Yapici, 2021), noting that the screenings by Tarkan et al. (2017) updated the previous ones
217 by Tarkan et al. (2014) using a predecessor toolkit to the AS-ISK.

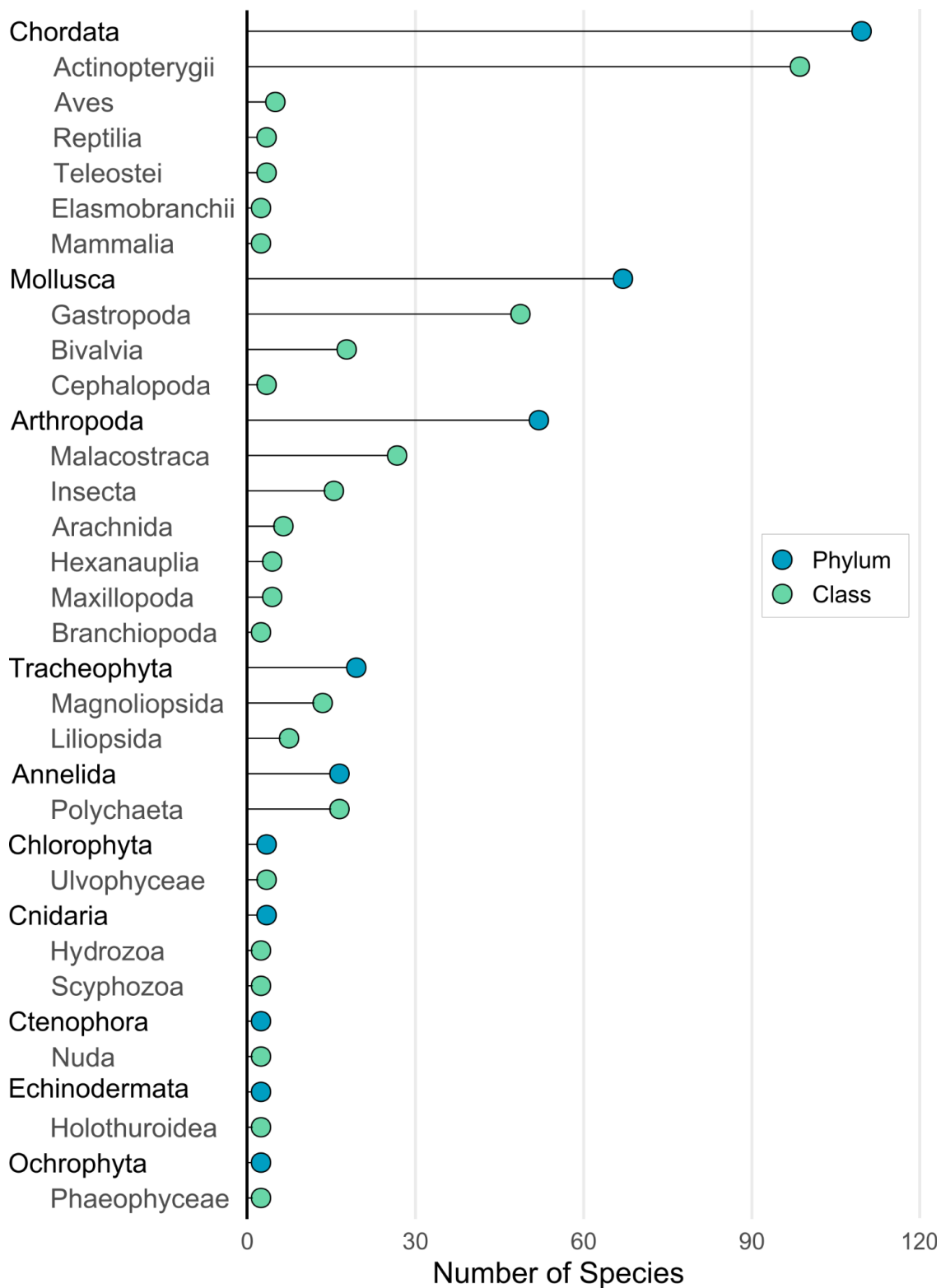
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219 **Results**

220

221 In the final dataset listing the 268 established species in Türkiye, we identified a total of 156
222 families from 24 classes and 10 phyla (Fig. 1; Supplementary Material 1). The families with the
223 highest number of established species were Formicidae ($n = 14$), followed by Pyramidellidae (9),
224 Penaeidae (8), and Tetraodontidae (7), with each of the remaining families containing fewer than
225 five species. In terms of classes, the most species rich was Actinopterygii (98), followed by

226 Gastropoda (48) and Malacostraca (26). Regarding phyla, Chordata was the most represented
227 (109 species), followed by Mollusca (67) and Arthropoda (52). The majority of species were strictly
228 marine (199), followed by terrestrial (41) and by those classified as strictly freshwater (24). Only
229 a few species were classified as freshwater-terrestrial (3) and freshwater-marine (1) (Fig. 2).

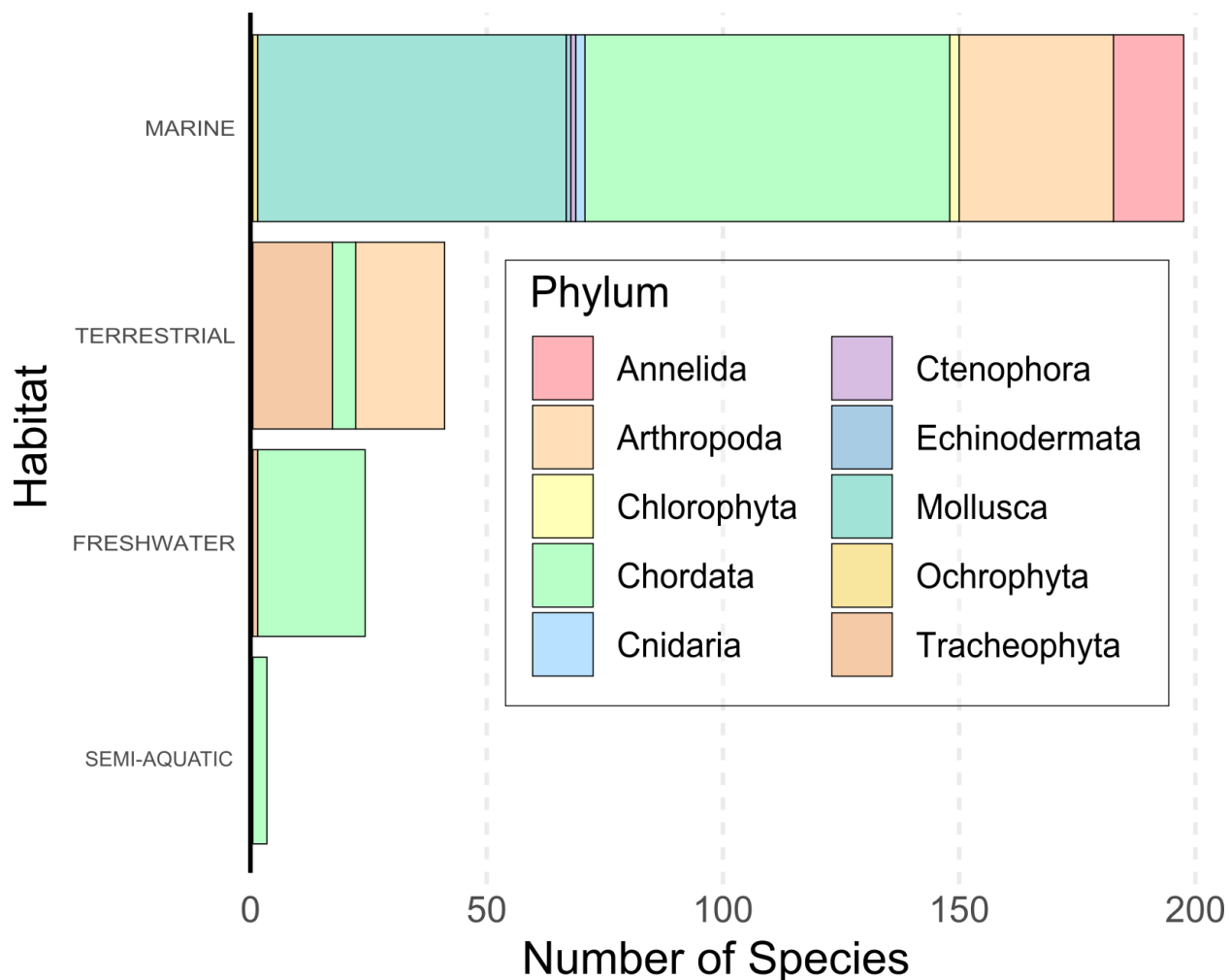


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231 **Figure 1.** Breakdown of Phyla and Classes with the highest number of established species in Türkiye.

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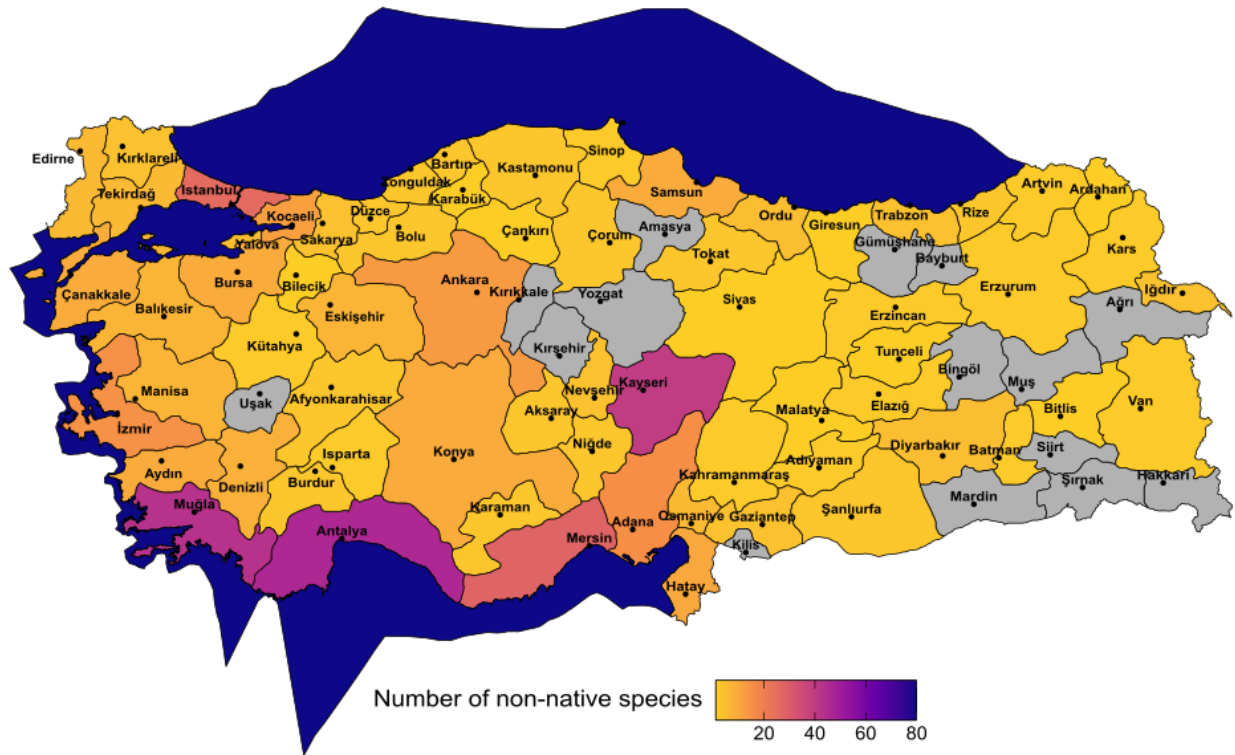


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235 **Figure 2.** Barplot of established species in Türkiye broken down by habitat.

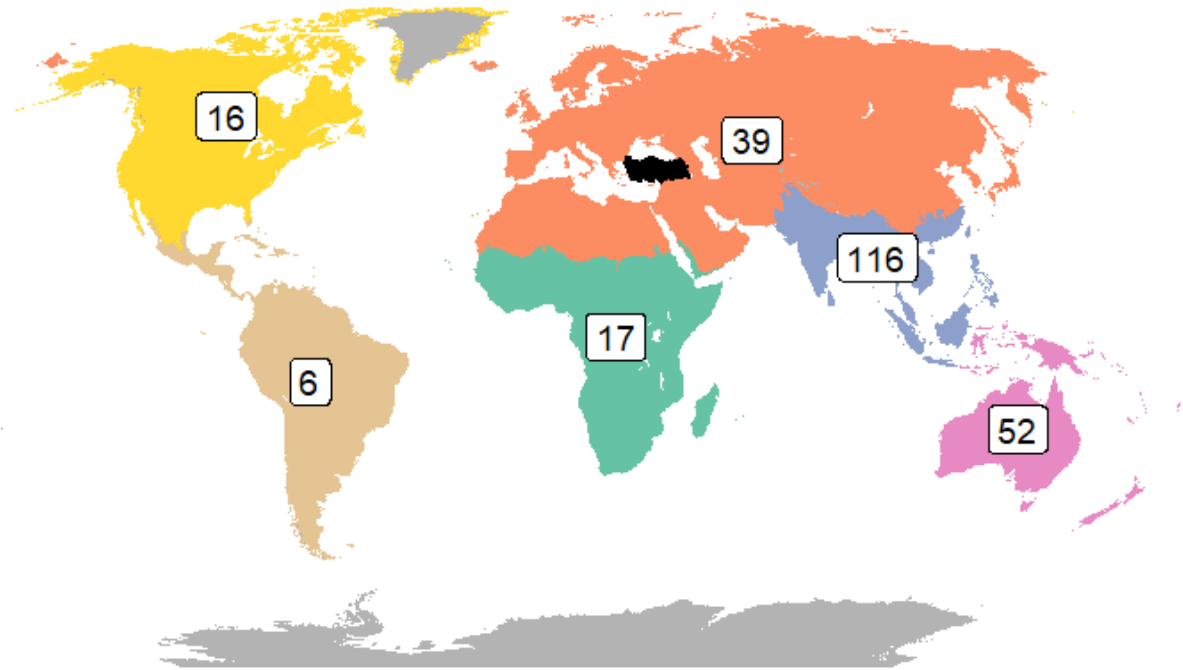
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237 From GBIF, we gathered a total of 16,160 records of the identified 268 established species in
 238 Türkiye. Most of the records came from three bird species, namely the rose-ringed parakeet
 239 *Psittacula krameri* ($n = 8,037$; 49.1%), the Alexandrine parakeet *Psittacula eupatria* (3,424;
 240 21.2%), and the common myna *Acridotheres tristis* (1,300; 8.0%). These species together
 241 constituted a total of 12,761 occurrences (78.3%). We observed a latitude gradient, with most of
 242 the species concentrated in the western part of the country and decreasing eastwards. The areas
 243 or zones with the highest numbers of reported species occurrences were Istanbul ($n = 184$),
 244 followed by Antalya (167) and Muğla (139) (Fig. 3).



245
 246 **Figure 3.** Number of established species in each administrative area of Türkiye based on GBIF records.
 247 Black areas represent administrative areas without non-native species based on GBIF. Marine areas
 248 represent the Exclusive Economic Zone.

249
 250 We identified the native range for 256 established species in Türkiye (84% of the total). The
 251 biogeographic realm where most established species originate was Indo-Malayan, with more than
 252 two times the number of species in Australasia (Fig. 4). Other realms with a lower number of
 253 established species were Palearctic, Afrotropical, Nearctic, and Neotropical.



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255 **Figure 4.** Biogeographic origin of established non-native species in Türkiye (highlighted in black).

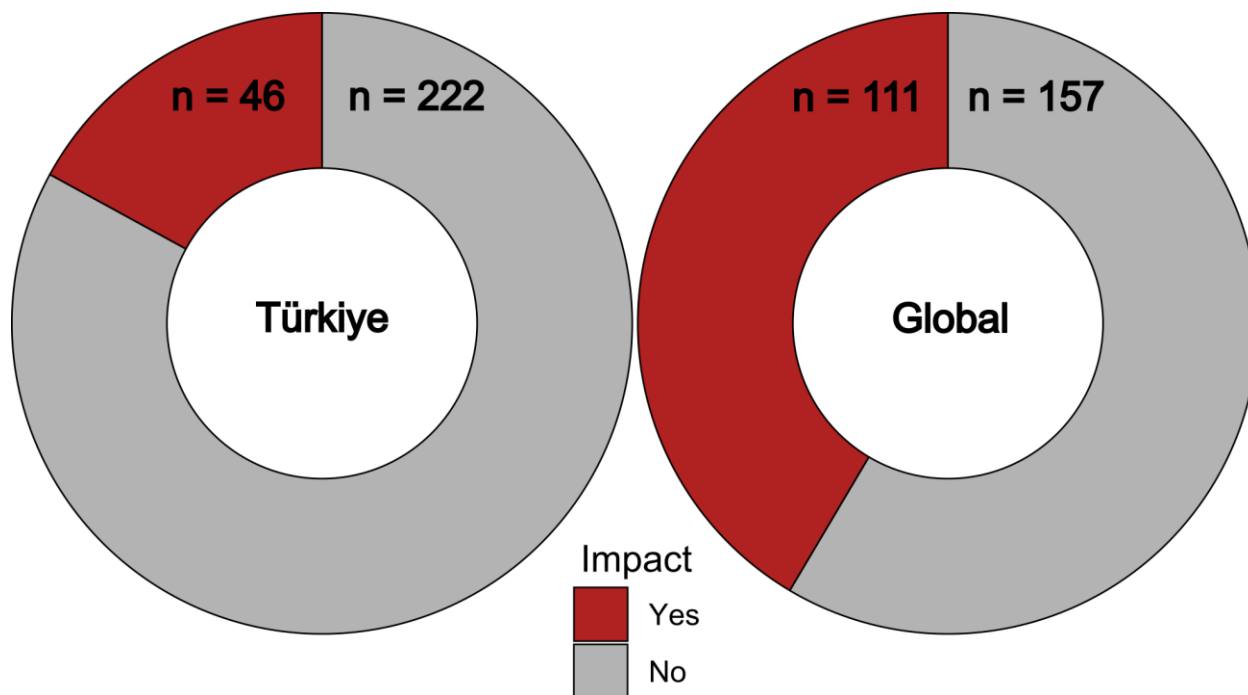
256 Numbers represent how many of the established species are native to their regions of origin.

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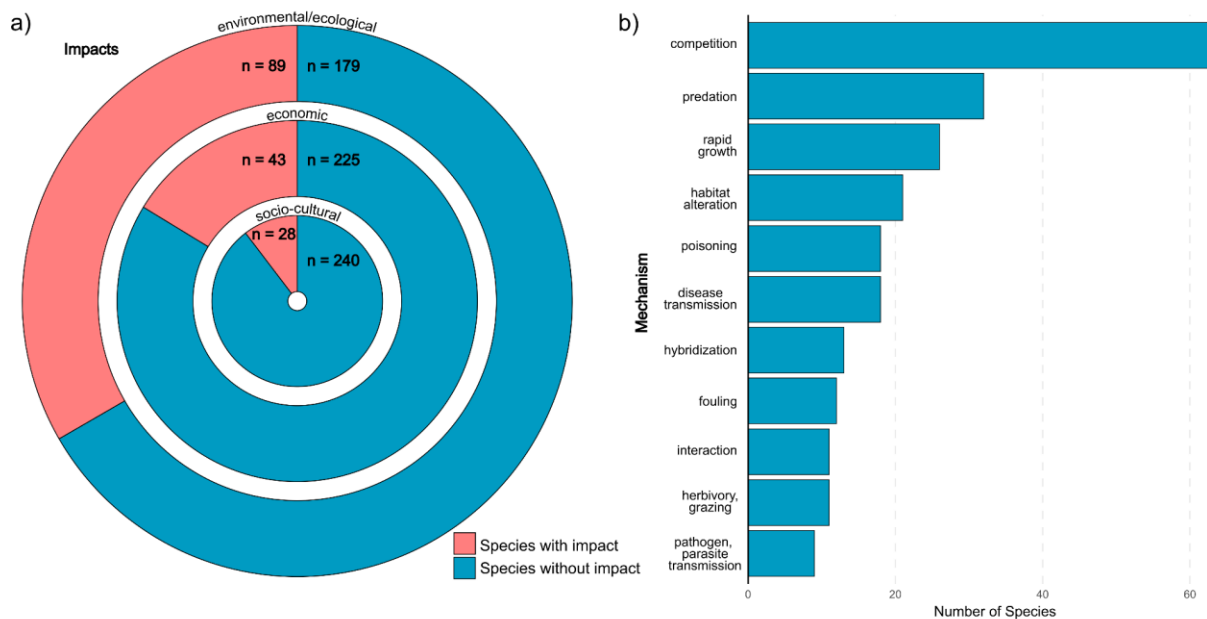
258 The majority of established species in Türkiye had no reported impacts ($n = 222$; 83%), although
 259 this number decreased to 157 (59%) at the global scale. Conversely, the 46 species with reported
 260 impacts in Türkiye (17%) increased to 111 (41%) at the global scale. The proportion of established
 261 species with documented impacts was generally lower than those without reported impacts,
 262 highlighting a considerable gap in impact assessment and reporting across taxa (Fig. 5). Among
 263 species with known impacts, ecological and environmental were the most frequently cited ($n =$
 264 89; 33%), followed by economic (43; 16%) and socio-cultural (28; 11%). In monetary terms, 87
 265 species (33%) recorded some form of economic costs in Türkiye, increasing to 133 (50%) with
 266 monetary terms at the global scale. Regarding ecological impact mechanisms (Fig. 6),
 267 competition was the most commonly reported (64), followed by predation (32) and hybridisation
 268 (13). Other recorded mechanisms included habitat alteration, disease transmission, and, among
 269 others, resource use, though these were reported less frequently.

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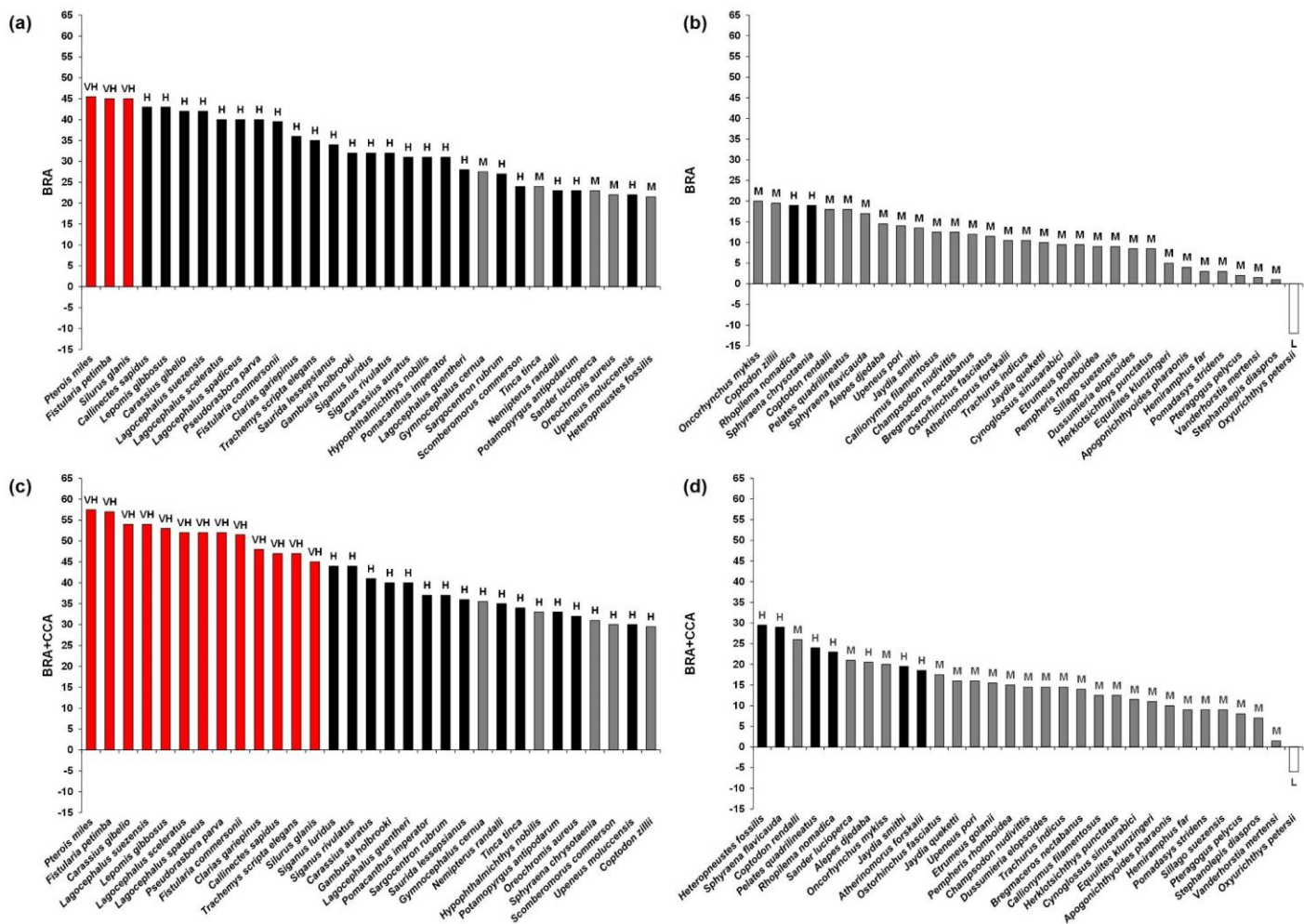
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274 **Figure 5.** Doughnut plot indicating established species with (red) and without (grey) known from Türkiye
275 (a) and (b) anywhere else
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280 **Figure 6.** (a) impacts and (b) impact mechanisms by species.
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283 The six AS-ISK applications of relevance to this study provided screenings for 62 established
 284 species, representing $\approx 23\%$ of the 268 species in total from the list (Supplementary Table 1). The
 285 risk assessment areas consisted of the inland waters of Türkiye (Tarkan et al. 2017, 2021, Aksu
 286 et al. 2024) and of the marine waters of the south-western coasts of Anatolia (Bilge et al. 2019)
 287 and of the Mediterranean Sea (Killi et al. 2020, Tarkan et al. 2021, Yapici 2021). Of the 62
 288 established species in total: (i) under current climate conditions (BRA scores), 3 (4.8%) posed a
 289 very high risk of invasiveness, 25 (40.3%) a high risk, 33 (53.2%) a medium risk, and 1 (1,6%) a
 290 low risk; (ii) under predicted climate (change) conditions (BRA+CCA scores), 13 (21.0%) posed
 291 a very high risk of invasiveness, 25 (40.3%) a high risk, 23 (37.1%) a medium risk, and 1 (1,6%)
 292 a low risk (Fig. 7). Overall, the number of very high-risk species substantially increased under
 293 predictions of climate change conditions for Türkiye and the risk assessment areas therein.

294



296 **Figure 7.** Risk outcome scores for 62 established species in Türkiye screened with the Aquatic Species
 297 Invasiveness Screening Kit. (a) Basic Risk Assessment (BRA) scores for the first 31 species; (b) BRA +
 298 Climate Change Assessment (BRA+CCA) scores for the first 31 species; (c) BRA scores for the last 31
 299 species; (d) BRA+CCA scores for the last 31 species. Red bars = very high-risk (VH) species (score ≥ 45);
 300 black bars = high-risk (H) species; grey bars = medium-risk (M) species; white bars = low-risk (L) species.
 301 Species-specific risk levels are based on the thresholds provided in Table S1.

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304 Discussion

305 Türkiye has a long-standing tradition of research in the natural sciences, yet national efforts to
 306 address the threats posed by biological invasions remain limited (Şekercioğlu et al. 2011). This
 307 study has offered the first comprehensive national assessment of established species in Türkiye,
 308 identifying 268 species that present substantial threats to the country's biodiversity and social
 309 well-being. Our compilation points to clear biases, with the majority of the identified species
 310 occupying marine environments in contrast to the less-represented freshwater species (Butchart
 311 et al. 2010), with the same being true for certain taxonomic groups such as insects and fishes.
 312 Even more notable is the lack of information on these species' impacts, raising concerns about
 313 biological invasions being a silently growing threat, especially in the case of understudied
 314 taxonomic groups and regions. In relation to our hypotheses, we did not find support for (1) the
 315 expectation that the composition of established species would be dominated by terrestrial plants
 316 but with marine fishes being more prevalent, and (2) confirmed that regions with greater human
 317 activity tend to host more established species, while (3) less accessible or remote areas
 318 experience lower invasion rates. However, (4) the anticipated regional variation in impact severity
 319 was only partially supported, suggesting that impact may not scale directly with establishment
 320 density.

321 Compared to the 268 established species we identified here, the national list of non-native species
 322 published by Uludag et al. (2020) reported 872 species—a number much higher than in the
 323 present study. The main reason for this difference is that the latter list included all non-native
 324 species ever recorded in Türkiye, without confirming whether they are actually established or still
 325 present today. While our focus was on species that are confirmed to be established, the 2020 list
 326 still represents an important resource. It provides a broader picture of potential non-native
 327 species, which could help identify future threats. In that sense, even though the two lists serve

328 different purposes, both are valuable for understanding and managing biological invasions in the
329 country.

330 *Taxonomic composition and biases*

331 The taxonomic profile of Türkiye's established species is shaped by a mix of ecological, economic,
332 and research-related factors. Our results show that Chordata, Mollusca, and Arthropoda are the
333 most represented Phyla, with a clear dominance of marine species. This is not surprising given
334 Türkiye's extensive coastline along three major seas, namely Black, Aegean, and Mediterranean,
335 which provide a broad range of habitats. These areas are also under intense pressure from
336 maritime traffic, aquaculture, and fisheries, all of which are known pathways for species
337 introductions (Çinar et al. 2005). Such conditions help explain the high number of marine species
338 in the national list.

339 The comparatively low numbers of terrestrial and freshwater species reflect a combination of
340 factors. In the case of terrestrial plants, the lower figures may be somewhat misleading. Türkiye
341 has a long history of plant introductions, especially for agriculture and horticulture, but not all
342 introduced species establish successfully or are monitored closely (Uludag et al. 2017). For
343 instance, the relatively small number of Tracheophyta in the dataset likely reflects gaps in
344 research and reporting rather than true absence. Therefore, there is still a need for more detailed
345 studies to fully understand the scale of non-native plant establishments.

346 Freshwater species were even less represented, which may be explained by both ecological and
347 research-related reasons. Many freshwater habitats in Türkiye, particularly those in regions of
348 high human impact, have been degraded by pollution, habitat destruction, and hydrological
349 changes (Pinarlik 2023). Such conditions can limit the success of new invasions (Rahel 2002). At
350 the same time, freshwater environments in more remote areas might be under-surveyed,
351 reflecting a lack of funding, institutional support, and research infrastructure in these regions.
352 Therefore, both real ecological constraints and a lack of data have likely contributed to the
353 observed pattern.

354 Regarding the role played by economic and industrial activities, marine ecosystems are heavily
355 exploited for fisheries and aquaculture, which increases the risk of species introductions and
356 establishment (Nunes et al. 2014). On the other hand, certain terrestrial sectors, such as
357 agriculture, may have stricter biosecurity protocols in place, which could explain the lower
358 representation of some groups (Pimentel et al. 2005). However, these patterns may also reflect

359 broader priorities, with more research and monitoring focused on economically important areas,
360 leaving others underexplored.

361 Overall, these taxonomic and environmental biases underline the need for a more balanced
362 research agenda. Without comprehensive assessments across all groups and environments,
363 gaps in knowledge will persist, increasing the risk of unforeseen ecological and economic
364 consequences. It is essential to strengthen research efforts, particularly in underrepresented
365 areas like freshwater systems and terrestrial flora, to ensure that management and policy
366 responses are based on a complete understanding of the country's non-native species landscape.

367 *Spatial heterogeneity and regional variability*

368 The distribution of non-native species across Türkiye displays marked spatial differences, with
369 the highest numbers recorded in urban and especially coastal regions. This pattern largely reflects
370 the role of human-mediated pathways, as areas with dense human populations, strong
371 economies, and well-developed trade networks—such as Istanbul, Antalya, and Muğla—offer
372 multiple routes for species introductions and establishment (Aikio et al. 2010). Key vectors in
373 these regions include maritime transport, aquaculture, the ornamental plant and pet trades, and
374 ballast water discharge, all of which are intensified by high volumes of trade and human activity.
375 In contrast, areas with lower population densities and limited economic activity, such as more
376 remote inland or mountainous regions, generally exhibit fewer invasions, which aligns with
377 patterns reported globally (Essl et al. 2015).

378 The underlying reasons for these differences are multifaceted. Urban and coastal centres are
379 hubs of international and domestic trade, dense infrastructure, and economic growth, which all
380 contribute to the introduction and establishment of non-native species (Hulme 2009). Increasingly,
381 global trade, tourism, and financial networks are recognized as key human-mediated pathways
382 for biological invasions, particularly in metropolitan settings (Seebens et al. 2021). In Türkiye,
383 rapid urbanisation and economic development have intensified these pathways, highlighting the
384 critical role of customs controls, ballast water regulations, and cross-border enforcement in
385 limiting new introductions. However, lax biosecurity enforcement, profit-driven trade in exotic
386 species, and limited institutional capacity continue to undermine prevention efforts (Tarkan et al.
387 2024b). Financial incentives often favour short-term economic gains over long-term ecological
388 health, placing additional pressure on regulatory systems that may lack political will or resources
389 to implement stringent controls (Early et al. 2016). In many cases, regions with fewer resources

390 and less institutional capacity also lack the funding, personnel, and infrastructure needed to
391 monitor and manage non-native species effectively (Pyšek et al. 2020). Local communities, often
392 burdened by more immediate socio-economic concerns, may have little opportunity to engage in
393 biodiversity monitoring or early detection programs. This disparity likely contributes not only to
394 lower actual introduction rates in remote regions but also to significant gaps in detection and
395 reporting (Pyšek et al. 2010).

396 Importantly, areas where non-native species have already established may also serve as stepping
397 stones for further spread within Türkiye. Once a species gains a foothold in a region, intentional
398 or accidental translocations—often linked to activities such as recreational angling, aquaculture,
399 and efforts to enhance local fisheries—can facilitate its movement to new areas (Tarkan et al.
400 2024a). These secondary introductions are often motivated by economic considerations or by the
401 aim of improving local food security, but they can have far-reaching ecological consequences if
402 left unchecked (Gaygusuz et al. 2015).

403 These observations highlight the need for management strategies that are tailored to the specific
404 risks and realities of different regions. Urban and coastal areas with high introduction pressure
405 require intensive monitoring and stricter biosecurity protocols, while less-affected regions would
406 benefit from investments in local capacity, training, and public awareness. Furthermore, policy
407 frameworks must account not only for initial introductions but also for the increasing risk of
408 secondary spread within the country, which remains a significant challenge for invasive species
409 management. Coordinated national efforts will be essential to mitigate the long-term impacts on
410 Türkiye's biodiversity and ecosystems (Early et al. 2016).

411 *Current and unknown impacts*

412 A clear pattern emerging from our analysis is the high proportion of non-native species for which
413 no impacts have been reported. This likely reflects two main issues: first, many species have not
414 yet been subject to formal impact assessment; second, some species—particularly those with
415 restricted distributions or narrow ecological niches—may indeed have limited or negligible
416 impacts. Initial impacts of biological invasions might seem benign or even positive, and while
417 being catastrophic in the long term (Soto et al. 2024a), this might create a lag in the reporting of
418 impacts. However, our results also indicate biases in which environments and taxonomic groups
419 are reported to have impacts. For instance, while marine species make up the largest portion of
420 the dataset, the ratio of reported impacts to non-impacts is around 19%, whereas freshwater

421 species show a notably higher ratio of 38%. Across taxonomic groups, Chordata has 14%,
422 Arthropoda 23%, and Mollusca 18%, with Annelida (20%) and Tracheophyta (28%) also showing
423 some level of recorded impacts. Many other groups have no reported impacts at all, underscoring
424 a significant gap in current knowledge.

425 This pattern likely stems from a focus on species already recognized as problematic—such as
426 large-bodied fishes or economically relevant invertebrates—while less conspicuous or poorly
427 studied taxa remain overlooked. Such gaps are concerning because they can result in delayed
428 responses to emerging threats, ultimately increasing biodiversity loss and the economic costs of
429 management. For Türkiye, with its rich biodiversity and reliance on ecosystems that are
430 vulnerable to invasive species (Tarkan et al. 2024b), the absence of robust impact data represents
431 a serious blind spot. Closing this gap requires systematic and ongoing assessments, particularly
432 targeting under-studied groups and habitats. Expanding monitoring and research to reflect the full
433 spectrum of Türkiye’s ecosystems will be crucial for strengthening biosecurity and ensuring timely,
434 evidence-based management actions.

435 *Invasiveness risk*

436 Having found more than 50% of established species in Türkiye—among those for which screening
437 data are available—to pose a high to very high risk of invasiveness, which increases to over 60%
438 under predicted future climate (change) conditions, is concerning. As a representative subset of
439 the whole list of 268 established species in Türkiye, a similar outcome may be expected should
440 the remaining species be eventually screened for their invasiveness. The limited number of
441 species screened so far is likely due to the unavailability of data for terrestrial species, as the
442 relevant tools for animals (Vilizzi et al. 2022b) and plants (Vilizzi et al. 2024)—have only recently
443 been developed (see also Vilizzi et al., 2025). Given the availability of our up-to-date list of
444 established species for Türkiye, future studies should therefore consider screening not only the
445 other aquatic species but also the terrestrial animals and plants in the list. This would provide a
446 comprehensive database of information based on which local legislation for the monitoring,
447 control, containment, and, if at all feasible, eradication of any established species in Türkiye could
448 be gauged accordingly. Moreover, given that nearly two-thirds of the screened species fall into
449 the high to very high risk categories under future climate conditions indicates the need to establish
450 a prioritization framework for their management. This could help allocate limited conservation and
451 management resources more effectively by targeting species and regions at the greatest risk.
452 Such a framework should consider both the risk scores (BRA and BRA+CCA) and ecological or

453 economic impact potential, especially for species expected to escalate in risk due to climate
454 change. Prioritization is also critical to guide early detection and rapid response measures.

455 **Conclusion**

456 Türkiye's strategic location at the intersection of Europe, Asia, and the Middle East makes it a
457 central hub for the spread of non-native species. Our findings show that Türkiye shares a
458 significant number of non-native species with neighbouring European countries (Güneralp et al.
459 2013, Uludag et al. 2020, Henry et al. 2023). Our findings also suggest that it not only receives
460 species from other regions but may also act as a source of invasions to nearby countries (Galil
461 2008). The observed spatial heterogeneity and regional variability highlight the need for tailored
462 management strategies that consider both local and international contexts. Moving forward,
463 addressing the identified biases, expanding research into underrepresented groups, and
464 strengthening biosecurity measures will be critical to preventing future invasions. A coordinated
465 approach, built on the insights from this comprehensive list, is essential for protecting Türkiye's
466 biodiversity and ensuring the sustainability of its ecosystems.

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473

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