Biological invasions and their potential economic costs in Morocco

Jazila El Jamaai
eljamaai.jazila@ucd.ac.ma

Chouaïb Doukkali University

Ahmed Taheri
Chouaïb Doukkali University

Liliana Ballesteros-Mejia
Muséum d'Histoire Naturelle, CNRS, Université des Antilles

Danish Ahmed
CAMB, Gulf University for Science and Technology

Alok Bang
Azim Premji University

Christophe Diagne
CBGP, IRD, Univ Montpellier, CIRAD, INRAE, Institut Agro

Franck Courchamp
CNRS, Université Paris-Saclay

Elena Angulo
Estación Biológica de Doñana (CSIC)

Article

Keywords: Invasive species, Economic impacts, Management strategies, Morocco, Biological invasions, InvaCost

Posted Date: September 9th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-4731421/v1

Additional Declarations: No competing interests reported.

Abstract

Biological invasions pose substantial economic threats globally, yet detailed cost assessments for many Global South nations, especially in Africa, remain scarce. This study presents the first comprehensive breakdown of the potential costs of biological invasions in Morocco. We identified 551 invasive alien species, comprising approximately 1.76% of Morocco's biodiversity. Using the *InvaCost* database, we gathered cost data for the 12 most frequent invasive species with available data. Calculating the mean annual cost for each species and extrapolating based on their prevalence in Morocco, we estimated the potential annual economic impact to be US$ 1.61 billion. Urban species management and damage, especially pigeons, accounted for a substantial portion of this impact. Invasive plant species also emerged as prevalent and costly. Annual management costs exceeded damage costs (US$ 1.50 billion vs. 856.80 million), driven mainly by pigeon management. Costs by authorities and stakeholders outweighed agricultural costs (US$ 1.49 billion vs. 859.10 million). Despite challenges in extrapolating cost data from other regions, this study underscores the urgent need for targeted management and policy interventions to minimize the spread of invasive species and reduce their economic toll. Morocco can implement proactive management measures and foster international collaborations to tackle this socio-ecological crisis, ensuring long-term sustainability and prosperity.

Introduction

Globalization has led to unprecedented growth in the number, reach, and impact of biological invasions, with adverse effects on ecological and socioeconomic systems worldwide [1, 2]. The increase in biological invasions is primarily due to the intensification of international trade and transport networks, resulting in the proliferation of pathways for the introduction and establishment of invasive alien species [3, 4, 5]. Biological invasions are considered as a major driver of global change, along with land-use and climate changes, which threaten ecosystems by altering biodiversity and functioning of ecosystems [6, 7], resulting in severe negative impacts on ecosystem services, human health, food security, and national economies [1]. Despite the substantial threat, the ability to prevent and effectively mitigate biological invasions has remained inadequate in numerous countries [8, 9]. For most taxonomic groups, the rate of first records has been steadily increasing annually, with no sign of saturation in the long term [10]. Future projections indicate that this upward trend will persist, and often accelerate, at least for the next three decades [11]. Countries with a high level of economic activity face increased vulnerability to harm from biological invasions, and more often document the presence of alien species [12, 13]. However, they also possess greater potential to mitigate such damage, rendering them at lower risk than nations with more limited resources and lower import levels. Consequently, a nation's economic capability partially determines the efficacy of investing in the detection, control and prevention of invasive species. Developing economies such as those in the Africa continent, with fewer resources directed towards tackling ecological crises, will likely experience more dire impacts of biological invasions [14, 15].

Intense research efforts in invasion science over the last few decades have provided a more comprehensive understanding of the environmental impacts of invasive alien species [16], but only recently have there been major developments in the evaluation of their economic impacts [17, 18]. Invasive species are estimated to have cost more than US $423 billion annually globally and have been increasing four-fold every decade since the 1970s [9]. With much progress in cost collection and standardization, economic analyses have provided cost assessments at various geographical scales, for different countries and taxonomic groups, various habitats, and several economic sectors [18, 19, 20, 21, 22, 23]. Moreover, numerous studies have shown that allocating greater investments toward prevention and other management measures during the initial stages of biological invasions increases the chances of attaining overall net benefits [24, 25, 26, 27, 28]. Given that prevention outweighs the efficacy of post-invasion mitigation and restoration, management strategies should prioritize early intervention in the invasion process [15, 27]. Such an intervention would involve rapid response, risk assessments, managing pathways and vectors, and early detection [1]. Building global collaborations and evidence-based innovations for effectively mitigating the ecological and economic impacts of invasive species is a necessity. To that end, resources for minimizing the negative effects of invasives should be allocated based on comprehensive assessments of their distribution and economic impact, a practice currently deficient in most countries worldwide [29]. However, to fully realize the benefits of effective management, more effort must be made to improve data availability, particularly in emerging countries integrated into global trade [26].

Morocco, situated in the northwest corner of Africa, is just 15 kilometers from Europe across the Strait of Gibraltar. It boasts a rich history as an international commercial hub and is one of Europe's largest trading partners in Africa. Indeed, it serves as a vital transportation node and commercial intermediary for numerous African nations, particularly those located in the hinterland. The country's geographical diversity is evident in its extensive coastline, stretching 3500 kilometers along the Atlantic and the Mediterranean oceans. Morocco features three major topographical zones, each with its unique characteristics. The verdant plains in the north thrive as agricultural centers, while the Rif region in the extreme north showcases a blend of plains and mountains. Dominating the landscape, the Atlas Mountains serve as the country's backbone. The climate across Morocco exhibits significant variation, transitioning from a Mediterranean climate in the northern coastal regions to mountainous areas with winter snow, and extending to extremely arid deserts in the south. This diversity in ecosystems, alongside high arrival rates of incoming alien species via trans-Mediterranean and trans-Atlantic routes of trade, as well as transport and tourism, makes the country increasingly susceptible to the introduction of many alien species, some of which may become invasive. However, there are currently no studies estimating the distribution and economic impacts of these species in Morocco, nor identifying the regions and sectors most adversely affected. From there, more research effort is required, given, for example, the presence of invasive species with considerable negative economic impacts [30], such as the tomato leafminer [31] and the silver nightshade, which pose a threat to various crops in Morocco [32]. Furthermore, the most recent evaluation of the cost of environmental degradation to Moroccan society, estimated at approximately US$ 3.9 billion or 3.5% of the country's GDP in 2014, did not include an assessment of biological invasions [33].

Currently, the management of biological invasions in Morocco and the wider Arab Maghreb region primarily revolves around implementing restrictive measures, preventing introductions, and controlling and combating harmful exotic species. However, these efforts are across various legal texts from different institutional structures and enforced by various competent services, often lacking comprehensive knowledge of invasive species. Better coordination among these services is required, leading to less fragmented governance and more effective collaboration. Additionally, the scarcity of data on invasive species, including inventories, prioritization, introduction pathways, propagation dynamics, and their responses to environmental pressures, hampers integrated research efforts. As a result, the effective management of these species remains challenging, making it difficult to accurately estimate the economic and biodiversity costs [34].

The *InvaCost* database provides the most current, comprehensive, and standardized compilation of global economic costs linked to biological invasions [17]. Through various analyses, this database has facilitated descriptive studies on the economic impacts of invasive species across different regions and countries [35, 36, 37, 38, 39]. In particular, the costs of invasive species in Africa have been examined [14], revealing lower costs than in other continents such as North America [39], Europe [36], or Asia [38]. Also, there is a notable geographic imbalance in research efforts and financial resources, with a significant portion of African costs originating from South Africa [40]. Despite concerted efforts, the availability of cost data specific to Morocco within the *InvaCost* database remains limited, even following thorough searches in non-English languages [19]. Such unavailability of data underscores the need for compiling comprehensive lists of invasive species and mapping their distribution across Morocco to understand their potential economic impacts better. Here, we provide a projected cost assessment, drawing upon a global analysis of invasive species currently established within the country.

Results

Observed invasive alien species in Morocco

After reviewing biodiversity databases, published papers, and other materials, we identified a total of 551 invasive species established in Morocco. Of these, 141 species were documented in the *InvaCost* database, whereas 410 lacked cost entries. Also, out of the total 551 species, only 188 had location data in the GBIF database (Table S1).

Among the 141 invasive species with recorded costs, 107 had documented occurrences. These occurrences were primarily associated with vertebrates (76.0%, 25 species), plants (23.5%, 68 species), and arthropods (0.4%, 11 species). In contrast, among the 410 invasive species with no recorded costs in *InvaCost*, 81 had documented occurrences in Morocco. These occurrences were mainly comprised of vertebrates (90.1%, ten species), followed by plants (9.3%, 56 species), red algae (0.3%, two species), and arthropods (0.2%, ten species). The taxonomic distribution of these species, ranked by the number of locations in Morocco across both lists, is illustrated in Fig. 1a.

Considering the invasive alien species established in Morocco with over 50 recorded locations, vertebrates emerged as the predominant taxonomic group (Fig. 2). Among these, three avian species, namely the Eurasian collared-dove (*Streptopelia decaocto*), the cattle egret (*Bubulcus ibis*), and the pigeon (*Columba livia*), were observed at over 8,000 locations collectively, making them notably the most extensively distributed invasive alien species in the country. Additionally, two other bird species, the mallard (*Anas platyrhynchos*) and the purple swamphen (*Porphyrio porphyrio*), each exceeded 500 occurrences. Among these species, only the pigeon had documented economic costs (Fig. 2a,b).

Among the invasive alien plants, the oleander (*Nerium oleander*), tree tobacco (*Nicotiana glauca*), castor bean (*Ricinus communis*) and common storksbill (*Erodium cicutarium*) were notably widespread, each ranging between 200 and 350 locations in Morocco, all with reported costs outside Morocco (Fig. 2c). Also, numerous other plant species had fewer than 200 locations, with most lacking reported costs in *InvaCost* (Fig. 2d).

Cost breakdowns by taxonomy, typology and impacted sector

Taxonomic distribution of the costs

Out of the 14 most widespread invasive species in Morocco that incur economic costs outside the country (Fig. 2a,c), two had reported costs not only for the target species but also for multiple species collectively. This was observed for the false yellowhead (*Dittrichia viscosa*) and the feral cat (*Felis catus*), whose management costs were documented alongside those of similar species (in the case of the former, with only two cost records), or alongside all invasive species in the region (in the case of the latter, with 26 cost records). Despite their inclusion at the bottom of Table 1, these two species were excluded from the subsequent calculations. Considering annual costs in *InvaCost*, the remaining 12 species accounted for 480 entries. The cumulative global economic cost for these species amounted to US$ 4.26 billion. The annual costs of these species in Morocco were estimated by multiplying the annual cost per site (or per country in the cases of country-level costs) by the number of locations in Morocco. Thus, we estimated a total economic impact of US$ 1.61 billion (Table 1).

Table 1

Cost estimates in InvaCost for the 14 invasive alien species in Morocco, using the expanded dataset. Species are ordered by their total economic impact reported in InvaCost (US$ in 2017), except for two species with costs that include other species (the false yellowhead, Dittrichia viscosa, and the feral cat, Felis catus). We also provide the number of cost entries in InvaCost for each species, the type of costs (D: damage, M: management, DM: both), the spatial scale of the costs reported and the countries in which these costs incurred, and the annual costs estimated for Morocco. Annual costs for species within Morocco were estimated by multiplying the annual costs by the number of sites, for all species except those with country as spatial scale. Labels for the spatial scale: C: country level, S: site, within country level, R: river basin, Ha: hectare, G: global. Labels for the countries: Sp: Spain, Po: Portugal, Fr: France, UK: United Kingdom; Mx: Mexico; SA: South Africa; US: United States of America; Au: Australia. Costs estimated in Morocco are annual costs in US$ 2017; b: billion, m: million, t: thousand.

Species	Annual cost in *InvaCost*	Number of entries	Cost type	Spatial Scale	Country	Cost in Morocco
Columba livia	1 106 745 250.67	3	DM	C	US, UK	1.107b
Solanum elaeagnifolium	456 122 075.40	2	D	C	Russia	456.12m
Erodium cicutarium	96 165.07	12	D	S	Au	20.58m
Arundo donax	65 126.88	229	M	S, R, Ha	Fr, Po, Mx, SA, Sp	4.77m
Ricinus communis	58 091.49	44	M	S	SA, Sp	10.90m
Arctotheca calendula	42 738.66	115	DM	C, S, R	Sp, Au	4.41m
Oxalis pes-caprae	35 085.28	12	M	S, G	Sp, Po	5.72m
Nicotiana glauca	1 105.68	28	M	S	Sp	323.96t
Gambusia holbrooki	918.90	10	M	S	Sp	51.46t
Nerium oleander	149.28	20	M	S	SA	50.16t
Solanum linnaeanum	128.60	4	M	S	Sp	14.27t
Schinus molle	29.37	1	M	S	Sp	3.64t
Subtotal	**4.256b**	**450**				**1.610b**
Felis catus	49 107.52	2	M	S	Sp	2.60m
Dittrichia viscosa	6 258.37	26	M	S	Sp	657.13t
Total	**4.257b**	**495**				**1.613b**

Species with only country-level cost estimates emerged as the most financially burdensome when annual costs were calculated across various spatial scales. Notably, the pigeon (*Columba livia*), which experienced a relatively large range expansion in Morocco, incurred the highest economic toll. The reported expenses of pigeon invasions included two instances from the United States (management) and one from the United Kingdom (damage), all documented in the early 2000s. Similarly, the silverleaf nightshade (*Solanum elaeagnifolium*), for which country-level cost estimates were available in Russia, were extrapolated to represent potential damages should the species invade the country, likely contributing to the considerable costs reported. Furthermore, costs associated with capeweed (*Arctotheca calendula*) were reported across various spatial scales, including country (e.g., natural areas in Spain), site, and river levels. While expenses were relatively modest at the country level, ranging around US$ 2,173.11 annually (N = 11), costs were substantially higher at lower spatial scales in Spain and South Africa, reaching US$ 47,439.19 at the site level (N = 103) and US$ 4,805.56 at the river scale (N = 1). As a result, capeweed was classified as having costs predominantly at the site level (all costs were averaged independently of the spatial scale).

While the pigeon and the silverleaf nightshade collectively incurred a projected annual cost exceeding US$ 1.5 billion in Morocco, the remaining invasive alien species accounted for an annual cost of US$ 49.91 million in the same region during the same period (Fig. 1b) The lower expenses associated with the remaining species can be due to costs primarily comprising management expenses rather than direct damages. The taxonomic breakdown of estimated annual costs for Morocco is as follows: US$ 20.58 million from 12 management costs reported for the common storksbill (*Erodium cicutarium*), across three different states in Australia; US$ 10.90 million from 44 management costs reported for the castor bean (*Ricinus communis*) across various villages in Spain and Kruger National Park in South Africa; US$ 5.72 million from 12 management costs reported for the Bermuda buttercup (*Oxalis pes-caprae*) with expenditures on research projects conducted in Spain and Portugal; US$ 4.76 million from 229 management costs reported for the giant reed (*Arundo donax*), covering various regions in Spain, Portugal, and France, as well as specific protected areas in Mexico and South Africa; and US$ 4.41 million from 71 management costs reported for the capeweed (*Arctotheca calendula*), across different sites in Spain and various states in Australia, along with 44 cost entries accounting for damage costs across different states in Australia.

The projected annual expenses for the remaining invasive species were less than US$ 1 million. Specifically, this included US$ 323.96 thousand coming from 28 management expenditures associated with the tree tobacco (*Nicotiana glauca*), across various locations in Spain; US$ 51.46 thousand from 10 management costs linked to the mosquitofish (*Gambusia holbrooki*), from different sites in Spain; and US$ 50.16 thousand from 20 management costs for the oleander (*Nerium oleander*), situated in the Kruger National Park in South Africa. The apple of Sodom (*Solanum linnaeanum*) with four management costs, and the false pepper tree (*Schinus molle*) with a single management cost reported, both at sites in Spain, represented the remaining cost entries totaling US$20.70 thousand and US$15.95 thousand.

Management and damage costs

In terms of cost type (either damage or management), only four species have reported damage costs: pigeons (*Columba livia*, N = 1), capeweed (*Arctotheca calendula*, N = 44), the silverleaf nightshade

(*Solanum elaeagnifolium*, N = 2) and the common storksbill (*Erodium cicutarium*, N = 12). By extrapolating, we estimate an annual damage cost of US$ 856.80 million in Morocco, presuming that all occurrences of pigeons and capeweed resulted in direct damages. Based on the annual management costs for pigeons and capeweed, we estimate a potential annual expenditure amounting to US$ 1.5 billion (Fig. 3). Notably, projected management expenses surpass damage costs, and this difference is mainly influenced by the reported costs associated with pigeons. If we remove pigeons, damage costs surpass management costs (US$ 483.03m vs US$ 27.09m).

Sectoral distribution of cost

All damage costs were reported for agriculture, except for pigeons, where agriculture and public/social welfare were jointly reported. Regarding management costs, the majority were borne by the authorities and/or stakeholders, including governmental services and official organizations such as conservation agencies, forest services, or associations involved in the broad management of biological invasions, e.g., control programs, eradication campaigns, research funding (Table S2). Two exceptions were noted, capeweed (*Arctotheca calendula*) and giant reed (*Arundo donax*), which also reported management costs in agriculture (Fig. 3b). On assessing the annual costs per site for the five invasive species affecting the agricultural sector outside of Morocco, and extrapolating these figures based on occurrences in Morocco, the estimated annual cost impacting agriculture totaled US$ 859.10 million. Similarly, in this context, the economic impact on authorities and stakeholders amounted to US$ 1.49 billion annually.

Geographic distribution of cost

The geographic distribution of costs is dependent on the locations of the occurrences of the twelve invasive alien species considered (Fig. 4). Besides, it is also dependent on the scale of the cost that these species have.

Summing the extrapolated annual costs per site for all the species, we observe that the potential economic costs in Morocco are unevenly distributed across the country. Higher costs are concentrated in more densely populated regions, such as Casablanca, Rabat, and Marrakech, as well as along the Atlantic coast, including Casablanca and Rabat.

Discussion

This study presents the first comprehensive global analysis of invasive species in Morocco, offering insights into the potential economic costs associated with biological invasions in the country and the geographic distribution of the estimated costs. Urgent research was prompted by the necessity to identify invasive alien species and map their distribution across Morocco, an essential step for assessing their economic impacts. A total of 551 invasive alien species were identified, representing 1.76% of the nation's plant and animal biodiversity. The absence of cost data for Morocco in the *InvaCost* database highlighted the need for promoting cost reporting, and based on extrapolation of costs from other countries, we estimated a potential annual cost amounting to at least US$ 1.61 billion.

Compared to the estimated annual mean cost for the entire African continent, estimated between US$2.6 and US$ 8.6 billion in 2019 [1, 2], the potential economic toll of invasive species in Morocco is, therefore, substantial. However, this estimate is likely conservative, as they were predominantly based on data from a single country, with South Africa accounting for approximately 86% of the total number of cost entries [14]. Besides, Eschen et al. [43] projected the annual cost of invasive alien species in the Moroccan agricultural sector alone to be US$ 1.66 billion, drawn from literature data and stakeholder interviews. Another example of the underestimation of the costs from Africa generally, is the descriptions of the costs caused by biological invasions in the Mediterranean basin, which were available for only 15 out of 26 countries, with most reports arising from Western European nations, i.e., France, Spain, and Italy, and only 11 records from African countries such as Libya (US$ 593,04 million, N = 8) and Egypt (US$ 147.16 million, N = 3) [35]. While both studies relied on the *InvaCost* database, note that none of them incorporated cost data for Morocco. Thus, using known cost estimates for documented species appears to be the only practical and straightforward approach for estimating missing costs in other countries affected by invasions [44].

We estimated a potential annual cost of US$ 1.61 billion in Morocco, and as a first assessment for the country, it should help develop effective national policies and global management initiatives to tackle this issue. Our assessment is essential for informed decision-making at both national and international levels. Birds are the most prevalent invasive alien species nationwide; however, only the pigeon (*C. livia*) has recorded economic costs. The lack of cost data for most exotic bird species may stem from their occurrence in regions with limited resources for researching their impacts or in remote areas where tracking their effects proves challenging [29]. Alternatively, it could be attributed to research prioritizing well-known taxa [1, 2] or the most threatening alien species [36, 46], given that exotic birds often have minimal environmental and socioeconomic impacts [47, 48]. Despite this, pigeons accounted for over half of all exotic bird costs globally [49], reflecting their significant economic burden - with an estimated cost of US$ 1.11 billion in Morocco.

In contrast, invasive alien plants such as the oleander (*N. oleander*), tree tobacco (*N. glauca*), castor bean (*R. communis*), and common storksbill (*E. cicutarium*), were the most widespread, each observed ranging between 200 and 350 locations across Morocco. While some authors consider oleander and the common storksbill to be native to Morocco [50], projected costs for those species are still very conservative. The tree tobacco is native to northwest Bolivia and Argentina, and is recognized as an invasive plant in Morocco [51], whereas the castor bean is native to Northeastern Africa; both probably introduced before 1931 [52]. Notably, the silverleaf nightshade, a global threat and the second most expensive plant species in Morocco, is estimated to cost approximately US$ 456.12 million. This plant, introduced unintentionally around 1949, profoundly impacts agriculture, biodiversity, and the environment. For example, losses of up to 64% in maize production have been recorded in Morocco [53]. While costs for the silverleaf nightshade were not directly assessed in Morocco, estimates were derived from economic costs reported in Russia, with extrapolations made to predict potential damages if the species spreads there [54]. Even though it is challenging to standardize costs across different economies, using exchange rates provides a practical method, albeit with limitations due to the lack of data on Purchasing Power Parity (PPP).

While the pigeon and silverleaf nightshade incurred a combined annual cost surpassing US$ 1.5 billion, the other invasive alien species accrued an estimated annual cost of US$ 49.91 million. The comparatively lower costs associated with the remaining species can be attributed to the fact that most of these expenses are primarily related to management rather than direct damages. This aligns with earlier findings regarding the costs of invasive alien species, where reported management expenses typically fall well below reported damages [28]. It must be considered that the costs for Morocco are estimated costs using the costs from other countries. Thus, whether costs are typified as management or damage corresponds to the availability of costs in *InvaCost* for the species invading Morocco. Thus, as many of the costs come from Spain (many of the invasive species are the same, very likely because of the proximity), where management costs surpass damages [19], this could be one of the reasons why most invasive species have management costs available for Morocco. Given that at the global scale, management costs are about ten times lower than damage costs [28, 29], the actual costs for Morocco might be much higher than estimated here.

The uneven geographic distribution of potential economic costs from invasive species in Morocco can be attributed to several factors. Firstly, more densely populated regions like Casablanca, Rabat, and Marrakech have higher economic activity, infrastructure, and assets at risk, leading to greater potential costs when invasive species cause damage. These urban centers serve as major hubs of human and commercial activity, facilitating the introduction and proliferation of invasive species through increased transportation, trade, and tourism. Secondly, the Atlantic coast, where Casablanca and Rabat are located, features ecosystems that are particularly vulnerable to certain invasive species (Fig. 4), which can thrive in these environments and cause significant economic harm. For example, *Solanum elaeagnifolium* was introduced to Morocco in the mid-20th century, first establishing itself in the Tadla region (Beni Mellal-Khenifra region) [55] and spreading widely by the 1990s. The estimated potential cost incurred thus far stands at US$ 0.45 billion annually (Fig. 4), emphasising the significant economic consequences of its spread. Currently, all six geographical zones in Morocco are infested, with the least impact in the Saharan and mountainous areas. Around 70% of infestation sites are in major agricultural districts, and more than 15% along the Rabat-Casablanca axis. Moreover, this species is rapidly adapting and spreading to new regions [56, 57, 58]. Coastal regions often host diverse and economically significant industries such as fisheries, tourism, and agriculture that can be severely impacted by invasive species, thereby driving up the costs, such as the Marrakech-Safi region, with an estimated potential cost of US$ 361.62 million (Fig. 5). As the primary tourist destination in the kingdom, Marrakech is home to Morocco’s busiest airport, which served over 6.3 million passengers in 2019, and includes Safı, the country’s oldest port. Additionally, the region accounts for 22% of Morocco’s useful agricultural area. Lastly, urban areas and economically vibrant regions tend to have more comprehensive monitoring and reporting systems in place, which can result in better documentation and more frequent records of invasive species presence, compared to less populated and economically active areas.

Given that the failure to act on invasive species management can lead to substantial avoidable costs [27], Morocco must establish proactive measures aimed at preventing the introduction of new invasive alien species. To achieve this, future studies should focus on identifying and cataloging these potential invasive species. With a better understanding of which species pose a threat and early detection of possible introduction pathways, the country will be better positioned to enable policymakers and environmental managers to develop targeted strategies for interception and control. By taking timely action, Morocco can effectively reduce the economic costs linked to the impacts of invasive species in the future.

On synthesis, although the estimated annual economic impact of invasive species in Morocco is US$ 1.61 billion, this figure likely underestimates the actual economic burden for several reasons: it is derived from data on only 2% of the invasive species present in Morocco, there is a lack of Morocco-specific cost data, and many invasive species worldwide have relatively low reported costs, including the 12 invasive alien species for which we found cost data. The disproportionate focus on specific taxa, such as pigeons, highlights the need for a more comprehensive approach to invasive species management that considers the full spectrum of ecological and economic impacts. Improved cost reporting, early detection, and effective management strategies are essential for minimizing the economic and environmental consequences of biological invasions. Enhanced collaboration between researchers, policymakers, and stakeholders is necessary to develop targeted laws and interventions, and allocate resources efficiently. By addressing these challenges, we can better protect ecosystems, safeguard biodiversity, and mitigate the economic risks of invasive species in Morocco and the wider region.

Methods

Data collection, compilation and filtering

To assess the economic costs associated with invasive alien species in Morocco, we first identified existing species within the country using comprehensive databases such as GISD, GRIIS, and the ‘Standardising and Integrating Alien Species workflow’ [41]. Additionally, we utilized resource lists such as ‘Terrestrial Invasive Alien Species in the Arab Maghreb’ and ‘Elements for Reflection on Primary Invasive Alien Species in Morocco’. Supplementary systematic searches in online repositories (Web of Science, Google Scholar and Google search engine), and gray literature were performed. We further engaged with national experts and stakeholders to gather additional information, e.g., official national managers or researchers that could provide cost data. We removed duplicates and considered only those that were taxonomically ranked at the species level (i.e., discarding cases with only genus information).

We then cross-checked the *InvaCost* v4.1 database [17] (https://doi.org/10.6084/m9.figshare.12668570.v5) to determine whether any of these species incurred economic costs somewhere in the world. Although *InvaCost* compiles cost information obtained from non-English sources, including French and Arabic [19], the database still did not feature any reported costs for Morocco. Comparing the list of invasive alien species detected in Morocco with the invasive species having costs in *InvaCost*, we separated this information into two categories: invasive alien species detected in Morocco lacking cost information in *InvaCost*, and species observed in Morocco with documented costs in *InvaCost*, but arising from cost occurrences outside of Morocco (Table S1).

Occurrence records detailing their current invasive distribution in the country were retrieved from the Global Biodiversity Information Facility (GBIF; https://www.gbif.org) for all species listed in both datasets. In order to have a reliable dataset, we removed duplicated geographic coordinates, occurrences without GPS coordinates, and those with erroneous coordinates falling outside terrestrial borders that could not be georeferenced from the information provided. Taxonomic descriptions were provided for species in both lists, and those with more than 50 occurrences (N = 14 species) were selected.

Estimating costs of invasive alien species in Morocco

By filtering the 'Species' column in the *InvaCost* database, we obtained the reported costs for the 14 invasive alien species. We considered only high-reliability cost entries from the 'Reliability' column, i.e., cost estimates sourced from official peer-reviewed material and/or material with reproducible methods [17]. Costs were extracted from the 'Cost_estimate_per_year_2017_USD_exchange_rate' column, such that all cost entries were adjusted to a common currency and year for comparability, i.e., in 2017 US dollars. This adjustment also factored in inflation, referencing the Consumer Price Index of 2017 in relation to the year of the cost estimation. Each entry also includes the timespan linked with the recorded costs, facilitated by the *expandYearlyCosts* function from the *invacost* R package [42]. This function distributes the total reported cost evenly across probable start and end years, generating an expanded dataset where each entry represents a cost estimate for a specific year. Within the *InvaCost* database, each publication served as a distinct point of reference for reported costs, although the duration over which costs were estimated differed among references. Complete details regarding the compilation and standardization of data stored in *InvaCost* are provided in Diagne et al. [17].

First, we calculated the total economic cost reported in *InvaCost* for each of these 14 IAS. Then, to ascertain a relative annual cost per species, we calculated the annual amount per spatial unit, whether it be as large as a country or as small as a local site, utilizing the 'Spatial_scale' column. A site refers to an area at the intra-country level, while a unit denotes a well-defined surface area or entity, such as a hectare or a river basin. This adjustment was necessary due to the non-uniformity in the number of reported costs and the spatial scale of these costs in *InvaCost* across various species. We took into account the costs incurred by different impacted sectors, as indicated in the 'Impacted_sector' column, and the cost typology (i.e., management and damages), as specified in the 'Type_of_cost_merged' column.

We then extrapolated the economic costs accounting for the distribution of each species, by multiplying the annual cost per site, obtained from the reported data in *InvaCost*, by the number of occurrences sourced from GBIF. An estimate of the total cost incurred by invasive species within Morocco was computed as the sum of extrapolated annual costs per site for all species. Finally, we created a map that included the sum of the extrapolated annual costs per site for all the species in order to understand the spatial distribution of potential economic costs in Morocco and highlight the places in the country that are predicted to cause the highest economic costs of invasive alien species. For the two species that have costs at the country level (*C. livia* and *S. elaeagnifolium*), we first calculated a cost per site by dividing the country cost by the number of occurrences in Morocco.

Declarations

Data availability Statement

Data supporting the results reported in this article can be found in:

- Global Invasive Species Database (GISD) https://www.iucngisd.org/gisd/
- Global Register of Introduced and Invasive Species (GRIIS) https://griis.org/
- Standardising and Integrating Alien Species workflow (SInAS) https://doi.org/10.3897/neobiota.59.53578
- Terrestrial Invasive Alien Species in the Arab Maghreb https://www.cbd.int/invasive/doc/arab-maghreb-eee-fr.pdf
- Elements for Reflection on Primary Invasive Alien Species in Morocco https://doi.org/10.1002/9781119607045.ch7
- *InvaCost* database https://doi.org/10.6084/m9.figshare.12668570.v5
- Global Biodiversity Information Facility (GBIF) https://www.gbif.org/fr/

Acknowledgments

We would like to thank the Direction of Climate and the Biological Diversity, Ministry of Energy Transition and Sustainable Development, Morocco

Author contributions:

EA and AT contributed to the study conception and design. Data collection was performed by CD, EA, FC, and LBM, the methodology was agreed by JEJ, LBM, EA and AT and analysis were performed by JEJ, CD, EA and LBM. Supervision was carried out by EA and AT and funding was spent by FC, EA and DA. The first draft of the manuscript was written by JEJ and visualization items were created by JEJ, AT and EA. All authors commented on previous versions of the manuscript and all authors read and approved the final manuscript.

Additional Information

Funding

Funding was partially given to Elena Angulo by Junta de Andalucía, Consejería de Universidad, Investigación e Innovación, PROYEXCEL_00688 within the PAIDI 2020. The InvaCost project was funded by the French National Research Agency (ANR-14-CE02-0021), the BNP-Paribas Foundation Climate Initiative, the AXA Research Fund Chair of Invasion Biology of University Paris Saclay and by the BiodivERsA and Belmont-Forum call 2018 on biodiversity scenarios (AlienScenarios; BMBF/PT DLR 01LC1807C).

Competing Interests

The authors have no conflicts of interest to disclose.

References

1. Pyšek, P., Richardson, D. M. Invasive Species, Environmental Change and Management, and Health. *Annual Review of Environment and Resources*. **35**(1), 25-55 https://doi.org/10.1146/annurev-environ-033009-095548 (2010)
2. Laginhas, B.B., Bradley, B.A. Global plant invaders: A compendium of invasive plant taxa documented by the peer-reviewed literature. *Ecology***103**(2): e03569. 10.1002/ecy.3569. (s. d.) https://doi.org/10.1002/ecy.3569 (2022)
3. Hulme, P. Unwelcome exchange: International trade as a direct and indirect driver of biological invasions worldwide. *One Earth*. **4**. 666-679 https://doi.org/10.1016/j.oneear.2021.04.015 (2021).
4. Epanchin-Niell, R., McAusland, C., Liebhold, A., Mwebaze, P., Springborn, M.R. Biological Invasions and International Trade: Managing a Moving Target. *Review of Environmental Economics and Policy*. **15**(1), 180-190 https://doi.org/10.1086/713025 (2021)
5. Turbelin, A. J., Cuthbert, R. N., Essl, F., Haubrock, P. J., Ricciardi, A., Courchamp, F. Biological invasions are as costly as natural hazards. *Perspectives in Ecology and Conservation*, **21**(2), 143-150, ISSN 2530-0644 https://doi.org/10.1016/j.pecon.2023.03.002 (2023)
6. Sala, O. E. *et al.* Biodiversity: global biodiversity scenarios for the year 2100. *Science*. **287**. 1770-1774 (2000)
7. Pyšek, P. *et al.* Scientists' warning on invasive alien species. *Biological Reviews*, **95**(6), 1511-1534 https://doi.org/10.1111/brv.12627 (2020).
8. Early, R. *et al.* Global threats from invasive alien species in the twenty-first century and national response capacities. *Nat Commun.***7**, 12485 https://doi.org/10.1038/ncomms12485 (2016)
9. I. P. B. E. S. Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.7430692 (2023).
10. Seebens, H. et al. No saturation in the accumulation of alien species worldwide. *Nature Communications*, **8**(1), 14435 (2017) https://doi.org/10.1038/ncomms14435

11. Seebens, H. *et al.* Projecting the continental accumulation of alien species through to 2050. *Global Change Biology*, **27**(5), 970-982 https://doi.org/10.1111/gcb.15333 (2021)
12. Chapman, D., Purse, B., Roy, H., Bullock, J. Global trade networks determine the distribution of invasive non-native species: CHAPMAN et al. *Global Ecology and Biogeography.***26** https://doi.org/10.1111/geb.12599 (2017)
13. Capinha, C., Essl, F., Porto, M., Seebens, H. The worldwide networks of spread of recorded alien species. *Proceedings of the National Academy of Sciences*, **120**(1), e2201911120 https://doi.org/10.1073/pnas.2201911120 (2023).
14. Diagne, C., *et al.* The economic costs of biological invasions in Africa: a growing but neglected threat? In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota***67**: 11-51 https://doi.org/10.3897/neobiota.67.59132 (2021)
15. Bradshaw, C.J.A. *et al.* Damage costs from invasive species exceed management expenditure in nations experiencing lower economic activity. *Ecological Economics*, **220**, 108166, ISSN 0921-8009 https://doi.org/10.1016/j.ecolecon.2024.108166 (2024)
16. Crystal-Ornelas, R., Lockwood, J. L. Cumulative meta-analysis identifies declining but negative impacts of invasive species on richness after 20 yr. *Ecology*, **101**(8) https://doi.org/10.1002/ecy.3082 (2020)
17. Diagne, C. *et al.* InvaCost, a public database of the economic costs of biological invasions worldwide. *Scientific Data*, **7**(1), 277 https://doi.org/10.1038/s41597-020-00586-z (2020)
18. Ahmed, D. A. *et al.* Recent advances in availability and synthesis of the economic costs of biological invasions. *BioScience*, **73**(8), August 2023, 560–574 https://doi.org/10.1093/biosci/biad060 (2023)
19. Angulo, E. *et al*. Non-English languages enrich scientific knowledge : The example of economic costs of biological invasions. *Science of The Total Environment*, **775**, 144441 https://doi.org/10.1016/j.scitotenv.2020.14444 (2021)
20. Moodley, D. *et al.* Economic costs of biological invasions in protected areas worldwide-where do we stand?. *Biological Invasions***24**:1995-2016 https://doi.org/10.21203/rs.3.rs-289130/v1 (2021)
21. Bang, A. *et al.* Massive economic costs of biological invasions despite widespread knowledge gaps: a dual setback for India. *Biological Invasions*https://doi.org/10.1007/s10530-022-02780-z (2022)
22. Bodey, T. W. *et al.* Economic costs of protecting islands from invasive alien species. *Conservation Biology*, **37**, e14034 https://doi.org/10.1111/cobi.14034 (2023)
23. Heringer, G. *et al.* Economic costs of invasive non-native species in urban areas: An underexplored financial drain. *Science of The Total Environment*https://doi.org/10.1016/j.scitotenv.2024.170336 (2024)
24. Finnoff, D., Shogren, J. F., Leung, B., Lodge, D. Take a risk : Preferring prevention over control of biological invaders. *Ecological Economics*, **62**(2), 216-222 https://doi.org/10.1016/j.ecolecon.2006.03.025 (2007)
25. Davidson, A. D., Hewitt, C. L., Kashian, D. R. Understanding Acceptable Level of Risk : Incorporating the Economic Cost of Under-Managing Invasive Species. *PLOS ONE*, **10**(11), e0141958

https://doi.org/10.1371/journal.pone.0141958 (2015)

26. Lodge, D. M. *et al.* Risk Analysis and Bioeconomics of Invasive Species to Inform Policy and Management. *Annu. Rev. Environ. Resour.* **41**:453-488 https://doi.org/10.1146/annurev-environ-110615-085532 (2016)
27. Ahmed, D. A. *et al*. Managing biological invasions: the cost of inaction. *Biol. Invasions* **24** (7), 1927–1946 https://doi.org/10.1007/s10530-022-02755-0 (2022)
28. Cuthbert, R. N. *et al.* Biological invasion costs reveal insufficient proactive management worldwide. *Science of the Total Environment*, **819**, 153404 (2022).
29. Diagne, C. *et al.* High and rising economic costs of biological invasions worldwide. *Nature*, **592**(7855), 571-576 https://doi.org/10.1038/s41586-021-03405-6 (2021)
30. Ghabrit, S.B., Bouhache, M., Birouk, A., Bon, M-C. Quand les plantes exotiques envahissantes menacent l'agriculture et les écosystèmes. *Onzième Congrès de l'Association Marocaine de Protection des plantes* : 26-27 (2018)
31. Ouardi, K., Chouibani, M., Rahel, M. A., El Akel, M. Stratégie Nationale de lutte contre la mineuse de la tomate Tuta absoluta Meyrick. *EPPO Bulletin*, **42**(2), 281-290 https://doi.org/10.1111/epp.2568 (2012)
32. Menioui, M. Elements for Reflection on Primary Invasive Alien Species (IAS) in Morocco : Actual and Potential Impacts. In T. Pullaiah & M. R. Ielmini (Éds.). *Invasive Alien Species* **1**:196-241. Wiley https://doi.org/10.1002/9781119607045.ch7 (2021)
33. Croitoru, L., Sarraf, M. The Cost of Environmental Degradation in Morocco. Environment and Natural Resources Global Practice Discussion Paper #5. World Bank Group Report Number 105633-MA. Washington DC (2017)
34. O. S. S. *Espèces exotiques envahissantes (EEE) terrestres au Maghreb arabe: Etat des lieux et perspectives pour une stratégie sous régionale (Algérie, Libye, Mauritanie, Maroc et Tunisie)*, 148 p. (2020)
35. Kourantidou, M. *et al.* Economic costs of invasive alien species in the Mediterranean basin. In: Zenni RD, McDermott S, Garcia-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota* **67**: 427–458 https://doi.org/10.3897/neobiota.67.58926 (2021)
36. Haubrock, P. J. *et al.* Economic costs of invasive alien species across Europe. In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota* **67**: 153-190 https://doi.org/10.3897/neobiota.67.58196 (2021)
37. Heringer, G. *et al.* The economic costs of biological invasions in Central and South America: a first regional assessment. In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota* **67**: 401–426 https://doi.org/10.3897/neobiota.67.59193 (2021)
38. Liu, C. *et al.* Economic costs of biological invasions in Asia. In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota* **67**: 53 78 https://doi.org/10.3897/neobiota.67.58147 (2021)

39. Crystal-Ornelas, R. *et al.* Economic costs of biological invasions within North America. In: Zenni RD, McDermott S, García-Berthou E, Essl F (Eds) The economic costs of biological invasions around the world. *NeoBiota* **67**: 485-510 https://doi.org/10.3897/neobiota.67.58038 (2021)
40. Van Wilgen, B. W., Measey, J., Richardson, D. M., Wilson, J. R., Zengeya, T. A. Biological Invasions in South Africa. *Springer Nature*. 975 (2020)
41. Seebens, H. *et al.* A workflow for standardising and integrating alien species distribution data. *NeoBiota* **59**: 39-59 https://doi.org/10.3897/neobiota.59.53578 (2020)
42. Leroy, B., Kramer, A. M., Vaissière, A. C., Kourantidou, M., Courchamp, F., Diagne, C. Analysing economic costs of invasive alien species with the invacost R package. *Methods in Ecology and Evolution*, **13**(9), 1930-1937 https://doi.org/10.1111/2041-210X.13929 (2022)
43. Eschen, R. *et al.* Towards estimating the economic cost of invasive alien species to African crop and livestock production. *CABI Agric Biosci* **2**, 18 https://doi.org/10.1186/s43170-021-00038-7 (2021)
44. Henry, M. *et al.* Unveiling the hidden economic toll of biological invasions in the European Union. *Environ Sci Eur* 35, 43 https://doi.org/10.1186/s12302-023-00750-3 (2023)
45. Soto, I. *et al.* Global economic costs of herpetofauna invasions. *Scientific Reports*, **12**, pp.10829 https://doi.org/10.1038/s41598-022-15079-9 (2022)
46. Wang, S., Deng, T., Zhang, J., Li, Y. Global economic costs of mammal invasions. *Science of The Total Environment*, **857**(2), 159479, ISSN 0048-9697 https://doi.org/10.1016/j.scitotenv.2022.159479 (2023)
47. Evans, T., Kumschick, S., Blackburn, T. M. Application of the Environmental Impact Classification for Alien Taxa (eicat) to a global assessment of alien bird impacts. *Diversity and Distributions*, **22**(9), 919-931 https://doi.org/10.1111/ddi.12464 (2016)
48. Evans, T. *et al.* Identifying links between the biodiversity impacts and monetary costs of alien birds. *People and Nature*, **5**(5), 1561-1576 https://doi.org/10.1002/pan3.10521 (2023)
49. Evans, T., Angulo, E., Bradshaw, C. J. A., Turbelin, A., Courchamp, F. Global economic costs of alien birds. *PLoS ONE* **18**(10): e0292854 https://doi.org/10.1371/journal.pone.0292854 (2023)
50. U. S. D. A. Agricultural Research Service, National Plant Germplasm System. Germplasm Resources Information Network (GRIN Taxonomy). National Germplasm Resources Laboratory, Beltsville, Maryland. https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomydetail?id=15670 . (Accessed 17 April 2024).
51. Assaeed, A. M., Alharthi, A. S., Abd-ElGawad, A. M. Impacts of Nicotiana glauca Graham Invasion on the Vegetation Composition and Soil: A Case Study of Taif, Western Saudi Arabia. *Plants* (Basel). **10**(12):2587 https://doi.org/10.3390/plants10122587 (2021)
52. E. P. P. O. Global Database, European and Mediterranean Plant Protection Organisation. https://gd.eppo.int/reporting/article-974 (2023)
53. Uludag, A. *et al.* Review of the current situation for Solanum elaeagnifolium in the Mediterranean Basin. *EPPO Bulletin*, **46**(1), 139–147 https://doi.org/10.1111/epp.12266 (2016)

54. Kirichenko, N. et al. Economic costs of biological invasions in terrestrial ecosystems in Russia. *NeoBiota*, **67**, 103-130 https://doi.org/10.3897/neobiota.67.58529 (2021)
55. Tanji, A., Boulet, C., Hammoumi, M. Etat actuel de l'infestation par Solanum elaeagnifolium Cav. pour les differentes cultures du perimetre du Tadla (Maroc). *Weed Research*, **25**(1), 1–9 https://doi.org/10.1111/j.1365-3180.1985.tb00610.x (1985)
56. Ben-Ghabrit, S., Bouhache, M., Birouk, A., Bon, M. C. History and characterization of the invasion of silverleaf nightshade (Solanum elaeagnifolium Cav.# SOLEL) in Morocco. *Revue Marocaine de Protection des Plantes*. **10**: 37-56 (2016)
57. Ben-Ghabrit, S., Bouhache, M., Birouk, A., Bon, M. C. Macromorphological variation of the invasive Silverleaf nightshade (Solanum elaeagnifolium Cav.) and its relation to climate and altitude in Morocco. *Revue Marocaine des Sciences Agronomiques et Véterinaires***7** (2):243-251 (2019)
58. Chafik, Z., Bouhache, M., Berrichi, A., Taleb, A. Infestation by Silverleaf Nightshade Solanum elaeagnifolium (Cav.) in the eastern region of Morocco. *Revue Marocaine de Protection des Plantes*, **4**:59-66 (2013)

Figures

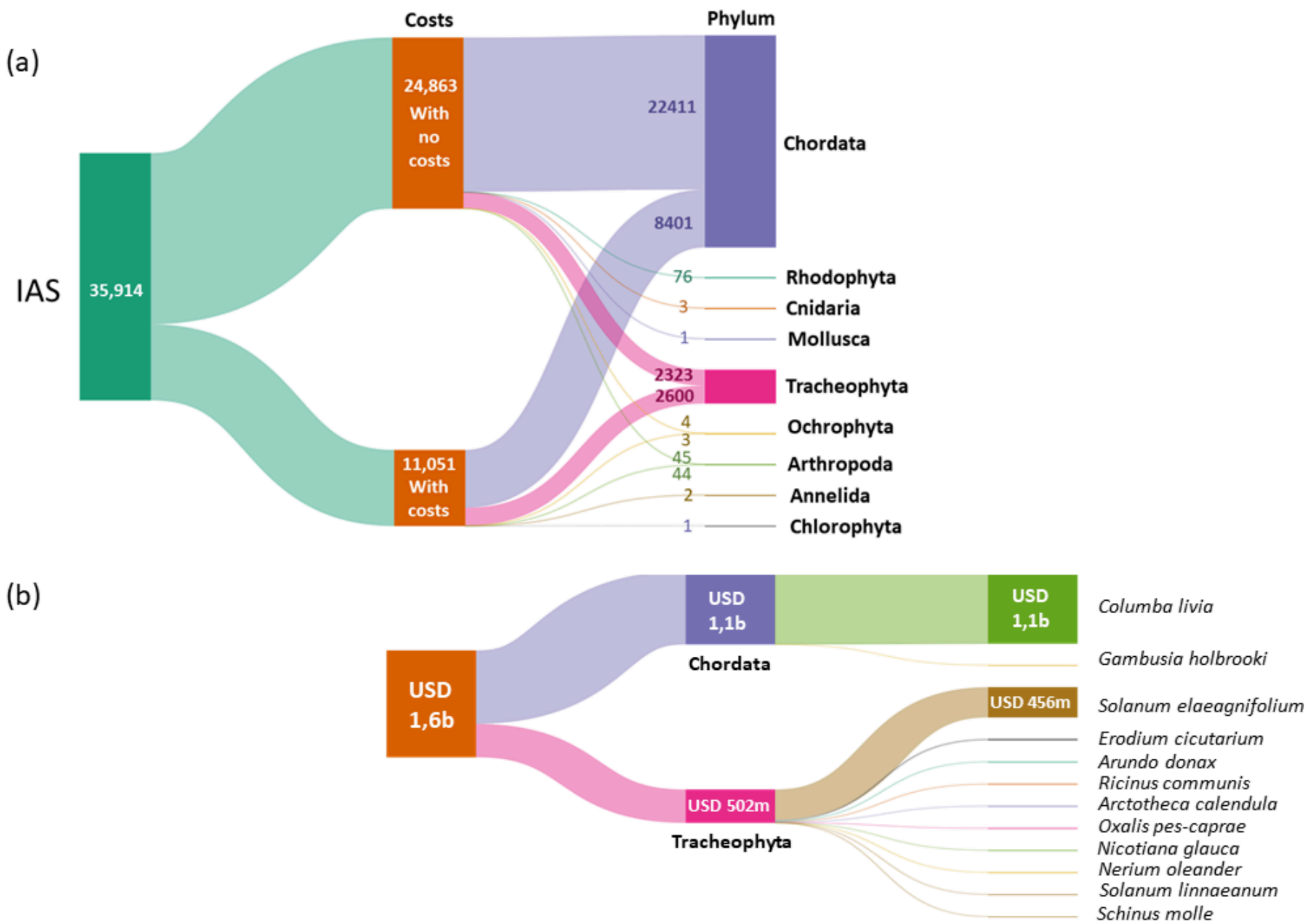

Figure 1

The number of locations of invasive alien species in Morocco is classified based on whether they have costs listed in InvaCost outside Morocco or lack such costs. The distribution of these locations is categorized taxonomically by their phylum (a), and, the distribution of estimated costs of invasive alien species in Morocco classified taxonomically by phylum and species (b)

Diagram created using SankeyMATIC (https://sankeymatic.com/)

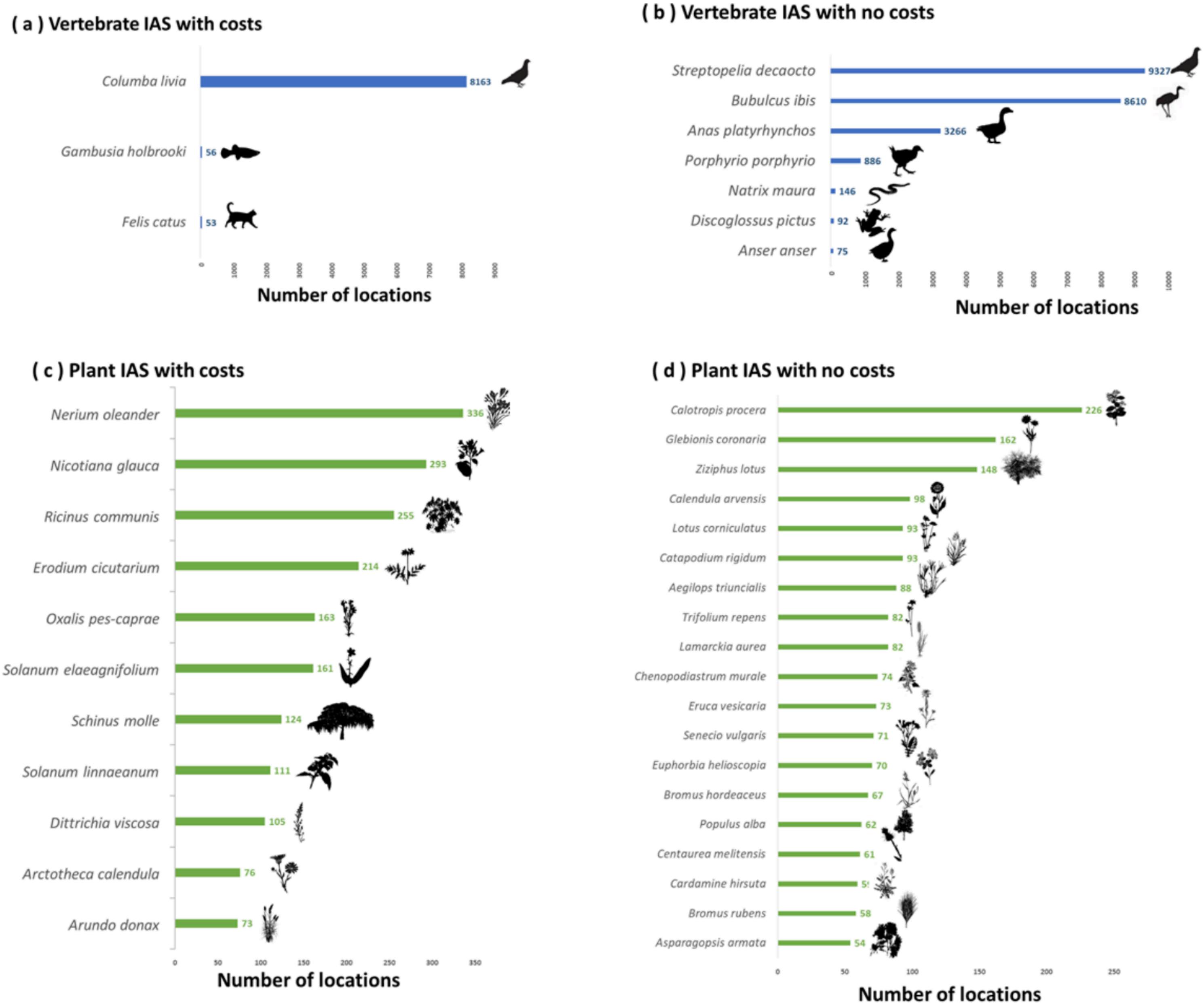

Figure 2

The number of locations for the invasive alien vertebrate species with more than 50 occurrences in Morocco categorized by whether they incur costs in InvaCost (a) or not (b), alongside the count of locations for invasive alien plant species with over 50 occurrences in Morocco, incurring costs (c) or not (d)

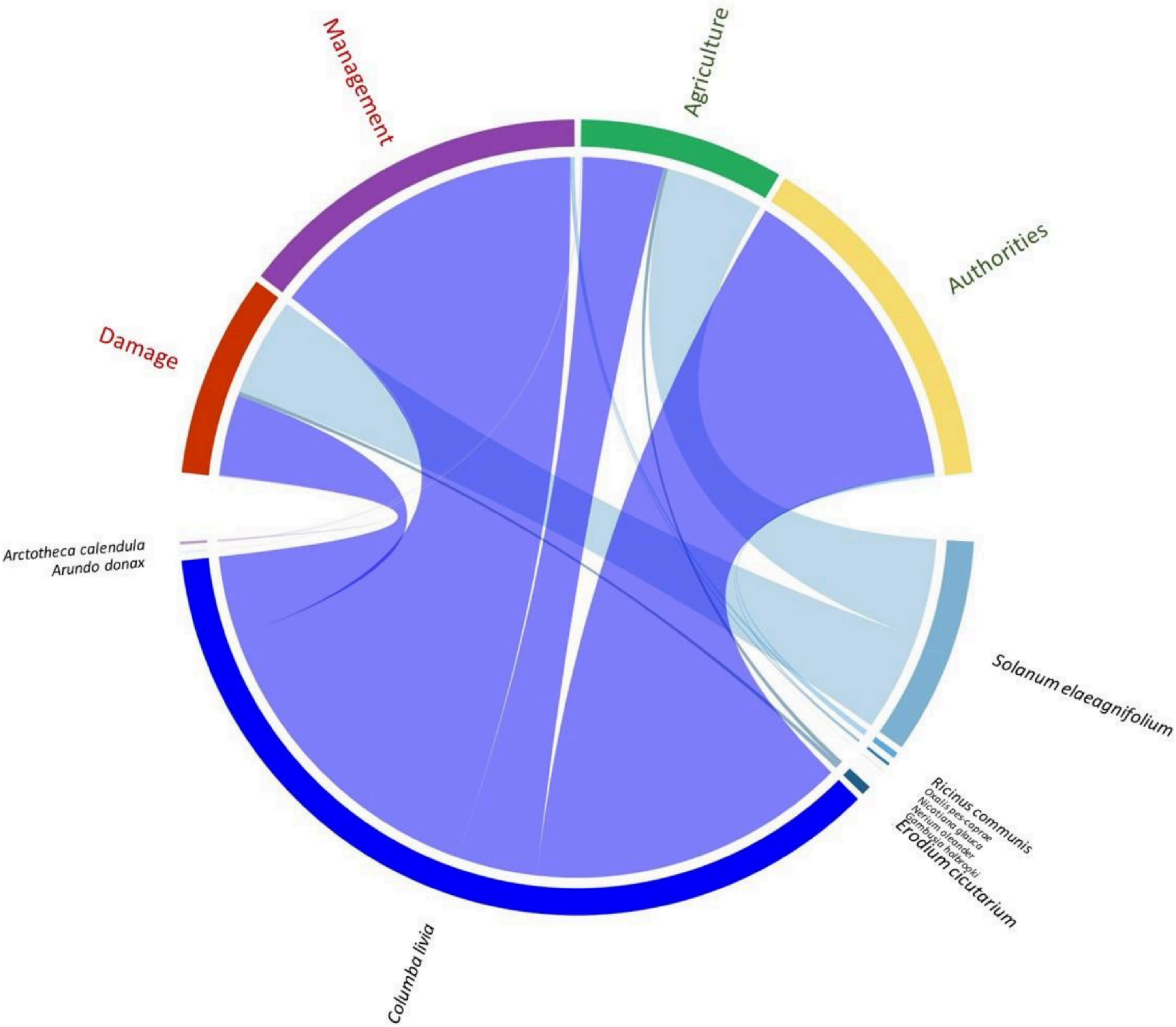

Figure 3

Estimated costs associated with the 12 identified invasive alien species in Morocco, categorized by type of cost (red and purple) and affected economic sector (green and yellow)

Diagram created using R version 4.4.0 (https://cran.r-project.org/bin/windows/base/)

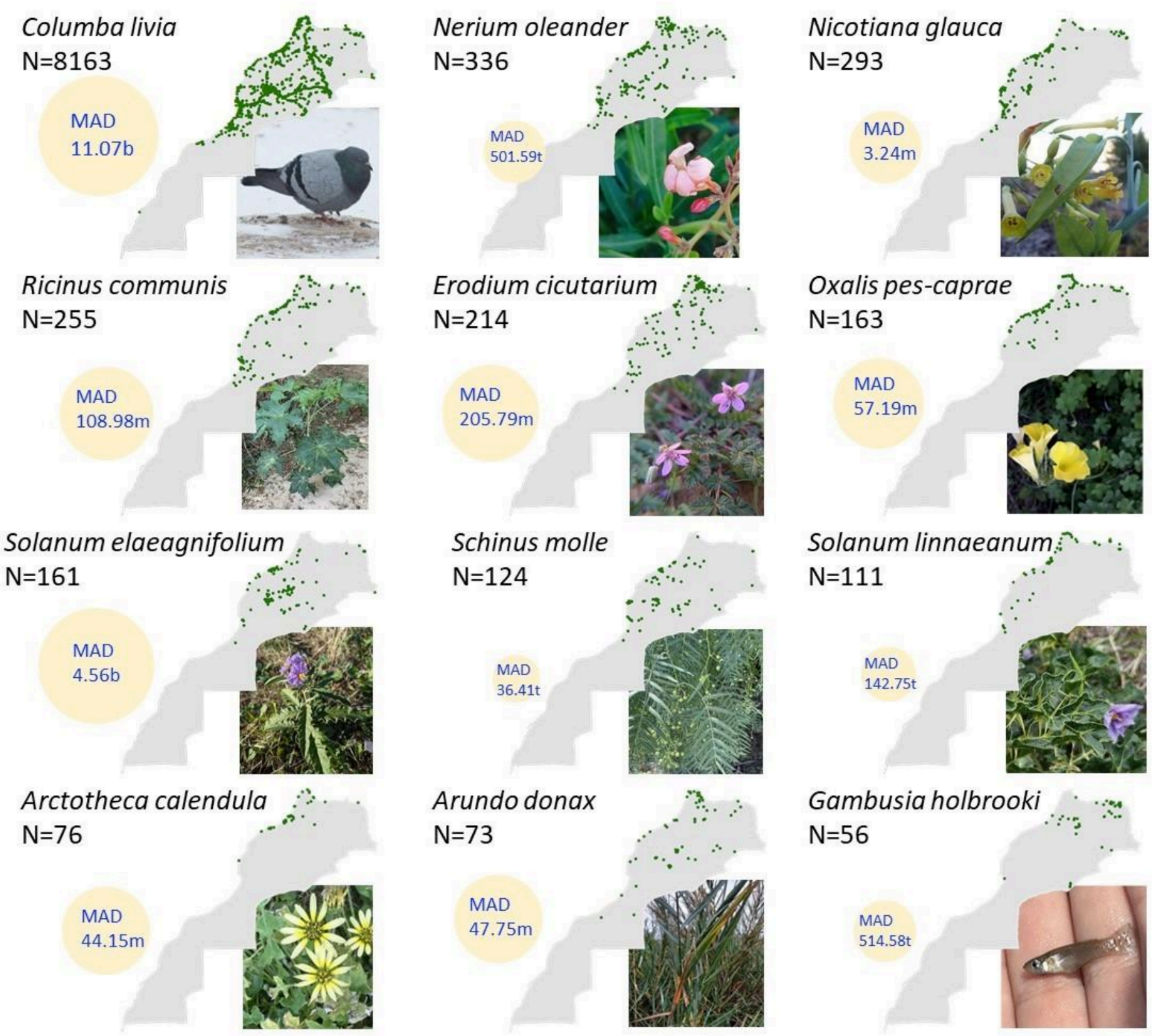

Figure 4

Occurrences of the twelve invasive alien species having reported economic costs and their costs in Dírham (MAD). The volume of the yellow circle represents the relative amount of their costs on a log scale. The species are ordered by the number of occurrences retrieved from the Global Biodiversity Information Facility (https://www.gbif.org). Photos obtained in iNaturalist with creative commons license.

Maps created using Arcgis 10.8 (https://desktop.arcgis.com)

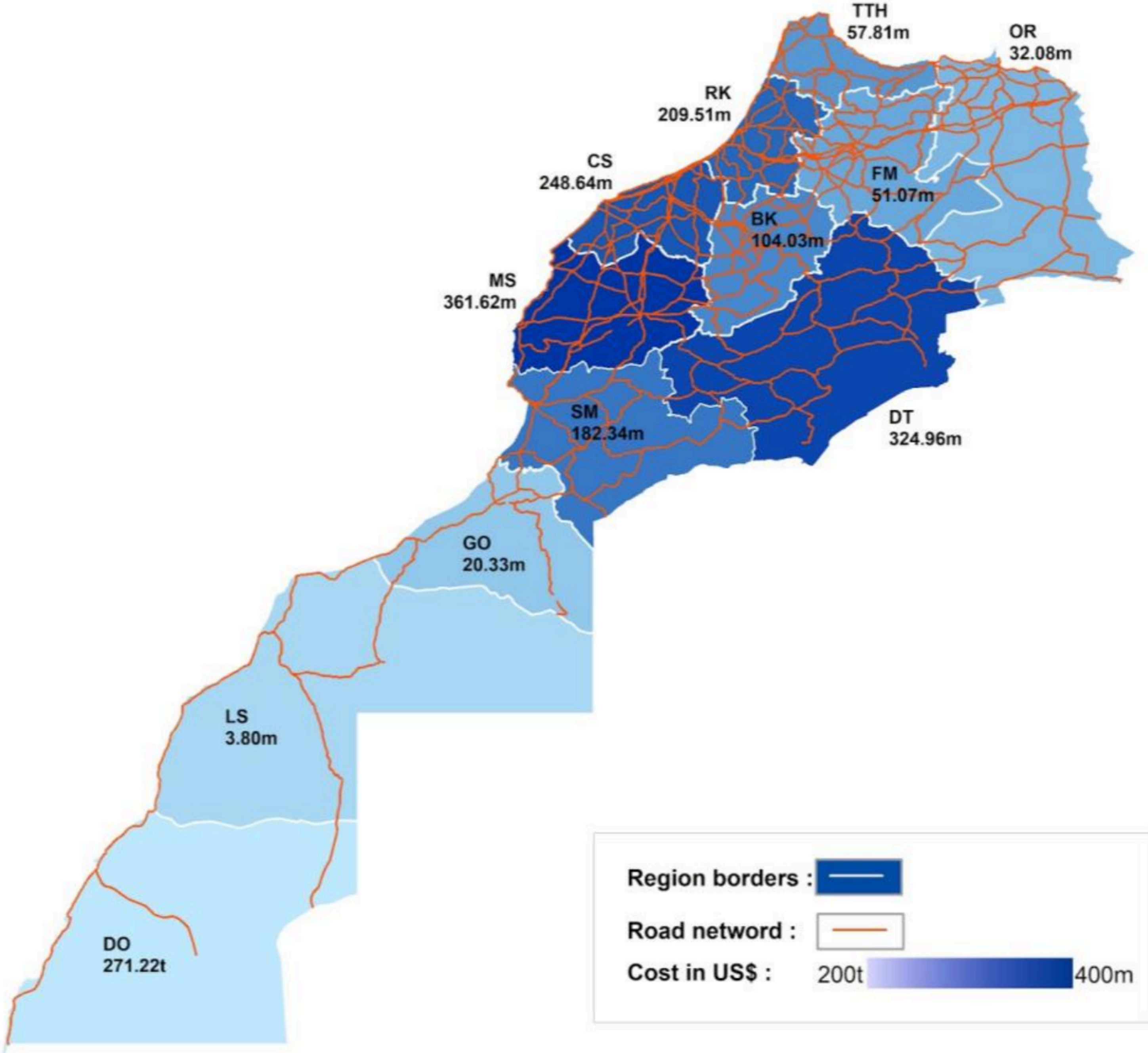

Figure 5

Geographic distribution of estimated costs in Morocco. Abbreviations of the regions on the map are: BK Beni Mellal-Khenifra; CS Casablanca-Settat; DO Dakhla-Oued Eddahab; DT Draa-Tafilalet; FM Fez-Meknes; GO Guelmim-Oued Noun; LS Laayoune-Sakia El Hamra; MS Marrakech-Safi; OR Oriental; RK Rabat-Sale-Kenitra; SM Souss-Massa; TTA Tangier-Tetouan-Al Hoceima

Maps created using Arcgis Desktop 10.8 (https://desktop.arcgis.com)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarymaterial.docx