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Preventing Invasive Non-Native Species: A Horizon Scanning for the Canary Islands

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ABSTRACT

Aim: Oceanic islands host exceptional biodiversity and endemism but are highly vulnerable to biological invasions. We aimed to identify non-native species with high potential to invade the Canary Islands within the next decade and to prioritise them based on their environmental and socioeconomic risks.

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Location: The Canary Islands, Macaronesia, northeastern Atlantic Ocean.
Methods: We applied a structured horizon scanning protocol with a global scope. A panel of 37 experts assessed 823 species across five thematic groups (marine species, freshwater animals, terrestrial vertebrates, terrestrial invertebrates and plants) by scoring their likelihood of arrival, establishment and impacts. Impacts were evaluated separately as environmental and socio-economic. Agreement and consistency among experts were quantified, and two consensus-based ranked lists were developed.
Results: Although agreement in expert scores was relatively low, species rankings showed high consistency. A total of 94 species were identified as priorities for prevention based on environmental impacts (12 very high risk, 82 high risk), while 49 species were prioritized for socioeconomic impacts (2 very high, 47 high). Environmental risks were dominated by lizards, snakes and freshwater fish, whereas socioeconomic risks were mainly concentrated on insects. Environmental and socioeconomic impact scores were only weakly related, underscoring the value of independent evaluation.
Main Conclusions: This study provides a horizon scanning explicitly focused on the Canary Islands, with separate assessments of environmental and socioeconomic risks. Our results highlight taxonomic groups that warrant urgent attention, show that invasion risk patterns vary depending on the spatial and contextual scale of assessment and provide a proactive tool to support surveillance, early warning systems and biosecurity measures. By anticipating future threats, this work contributes methodological and applied advances with broad relevance for conservation biogeography and invasive species management in island ecosystems.

1 | Introduction

Oceanic islands are those that have formed over oceanic plates and have never been connected to continental landmasses (Whittaker and Fernández-Palacios 2007). They are shaped by long-term isolation and often pronounced environmental heterogeneity and have long served as natural laboratories for evolutionary studies, given their exceptionally high levels of endemism (Losos and Ricklefs 2009). Despite covering only 6.7% of the world's surface, islands contribute disproportionately to global biodiversity, hosting around 20% of all known species (Whittaker and Fernández-Palacios 2007). Although multiple human-driven pressures (i.e., habitat destruction, overexploitation of resources, climate change) have contributed to species loss in islands (Fernández-Palacios et al. 2021), the introduction of non-native species stands out as one of the most severe threats (Bellard et al. 2017; Moser et al. 2018; Lenzner et al. 2020; Orihuela-Rivero et al. 2025; Haubrock et al. 2026). Currently, global trade and human mobility, coupled with accelerated habitat destruction, continue to accelerate the arrival of non-native species, with islands remaining particularly exposed to biological invasions (Kueffer et al. 2010; Seebens et al. 2017; Sardain et al. 2019; Morente-López et al. 2023). The ecological uniqueness and high endemicity of island biotas make them particularly vulnerable to the impacts of introduced predators, competitors and pathogens (Leclerc et al. 2018). Indeed, around 75% of documented extinctions since the onset of European expansion in the late 15th century have occurred on islands and, among the remaining species, roughly 50% are now severely endangered (Fernández-Palacios et al. 2021).

Given the ongoing increases in the trend of biological invasions (Seebens et al. 2017; Haubrock et al. 2023; Morente-López et al. 2023), predictive tools are essential for early detection and risk management, especially in vulnerable oceanic islands, such as the Canary Islands. The archipelago's diverse climates, complex topography and ecological isolation have made it a biodiversity hotspot of endemic species with significant global ecological importance. The Canary Islands host over 14,300 native terrestrial species, including approximately 4600 endemic species, along with almost 7500 native marine species (BIOTA 2025). This remarkable biodiversity is reflected in the establishment of four National Parks and a large network of 146 protected natural areas, collectively covering roughly 44% of the total land area (Hästbacka et al. 2024). However, this ecological richness is extremely vulnerable to biological invasions, largely driven by intense tourism and commercial activity that position the archipelago as a major hub among different regions (Morente-López et al. 2023; Hästbacka et al. 2024). At least 2400 non-native species have been recorded in the archipelago (BIOTA 2025), with remarkable impacts, including predation and competition by invasive mammals (e.g., *Rattus* spp., *Felis catus*), reptiles (e.g., *Lampropeltis californiae*), plants (e.g., *Opuntia* spp., *Cenchrus* spp.) and terrestrial arthropods (e.g., *Rhynchophorus ferrugineus*, *Reticulitermes flavipes*) (Traveset et al. 2009; Padrón et al. 2011; Medina et al. 2014; Pajuelo et al. 2016; Fajardo et al. 2021; Morente-López et al. 2023; López-Darias et al. 2024; Hernández-Teixidor et al. 2024). In addition to ecological consequences, biological invasions have generated substantial economic costs in the Canary Islands. The region accounts for the highest reported invasion-related costs in Spain (Angulo et al. 2021), such as the control of the invasive ring-necked parakeet (*Psittacula krameri*) which accounted for expenditure of over 40,000€ in the La Palma Island Biosphere Reserve (Saavedra and Medina 2020), reflecting concerns over its impacts on native biodiversity, agriculture and urban infrastructure (Medina and Saavedra Cruz 2018). Therefore, anticipating which species are likely to invade the Canary Islands and cause major impacts in the near future is not only timely but critical to preserving their unique biodiversity and to inform biosecurity measures in a rapidly changing world.

Assessments of the economic costs of biological invasions have shown that management actions are more effective and cheaper if they focus on preventing novel invasions (Cuthbert et al. 2022). In this context, biological invasions in the EU are addressed through the EU Regulation on Invasive Alien Species (Regulation (EU) No 1143/2014). In Spain, this is complemented by the national Catalogue of Invasive Alien Species (Royal Decree 630/2013), which provides an official list of regulated taxa and associated management obligations. However, these regulatory instruments primarily target already established invasive species and may not fully account for emerging risks. Horizon scanning (hereafter termed as HS) is therefore

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a useful tool to inform rapid response systems and to support mitigation measures towards reducing the probability of arrival of non-native species (Roy et al. 2014; Reaser et al. 2020). A HS approach generally involves compiling a list of potential non-native species, independently assessing their risks by a group of experts and preparing a ranked list through expert consensus (Roy et al. 2014; Cano-Barbacil et al. 2023; Oficialdegui et al. 2023). Horizon scanning is not a formal risk assessment, but rather a rapid prioritization approach based on a reduced set of criteria. By contrasts, full risk assessments require a detailed bibliographic review for each species, and the application of more comprehensive frameworks to assess the potential of non-native species to arrive, establish, spread and cause impact (e.g., González-Moreno et al. 2019; Vilà et al. 2019; Vilizzi et al. 2022). While limited in scope, information provided by HS can serve as a foundation for prioritizing species that warrant invasion risk assessments or should be included in watch lists (i.e., a list of invasive species that should be prioritized for surveillance, reporting and action) and citizen science initiatives (Roy et al. 2014; Reaser et al. 2020).

Despite the increased use of HS to assess non-native species with the potential to arrive and become invasive, it has been scarcely applied in tropical and subtropical regions (e.g., Dawson et al. 2022; Kenis et al. 2022; Mulema et al. 2022), particularly in regions with high endemism such as oceanic islands. The primary goal of this study was to identify non-native species most likely to invade the Canary Islands and their surrounding marine delimitation within the next decade, and to cause significant ecological and or socioeconomic impacts if established. Specifically, we developed a prioritized list of species not yet present in the Canarian archipelago but considered likely to arrive, establish and exert negative impacts, based on expert knowledge. Even though Cano-Barbacil et al. (2023) considered the Canary Islands in their assessment of the invasion risk of the Spanish territory, the unique and local context of the archipelago was not considered, which is particularly important in this region, taken into account its endemism and high species richness. Uniquely, our HS exercise also evaluated, in parallel, the potential for both environmental and socioeconomic impacts, allowing for comparisons across impact types and the identification of taxonomic groups more closely associated with each. We also analysed the consistency and agreement among expert assessments across impact categories and thematic groups. This HS is intended to serve as a scientifically robust and up-to-date reference framework to support evidence-informed policy-making, foster effective communication and knowledge exchange among social actors and facilitate the implementation of the EU Invasive Alien Species Regulation.

2 | Methods

2.1 | Study Area

The Canary Islands are formed by eight main oceanic volcanic islands and several islets (27°–29° N and 13°–18° W; 7500 km^2) in the north-eastern Atlantic Ocean, located about 96 km from the African mainland and 940 km from continental Europe. The archipelago shows notable altitudinal variation, reaching over 3000 m on Tenerife (El Teide, 3715 m) and over 2000 m on various peaks in La Palma and Tenerife (Walter and Schmincke 2002). The Canary marine demarcation (Figure 1) is the marine environment under Spanish sovereignty or jurisdiction around the Canary Islands and is the unit for implementing the Marine Strategy Framework Directive (Directive 2008/56/EC). This area largely corresponds to the Exclusive economic zone (i.e., up to 200 nautical miles from the territorial sea baseline), where Spain has special rights for activities like resource exploitation (e.g., energy production from water and wind). This demarcation does not include the nearby Selvagens Islands, which are part of Portugal.

Freshwater systems in the archipelago are highly fragmented and mainly consist of small, intermittent streams, ravines, isolated water bodies and artificial reservoirs (Malmqvist et al. 1995). Despite their limited extent and strong hydrological seasonality, these systems support a notable proportion of particular, endemic species, especially among aquatic invertebrates, although many populations are highly localized and vulnerable to extinction due to water abstraction and habitat loss (Malmqvist et al. 1995; Lüderitz et al. 2016). These systems are among the most altered habitats in the archipelago, with many historical streams now reduced or completely lost (Malmqvist et al. 1995; Lüderitz et al. 2016).

The climate in the Canary Islands is very diverse and varies markedly with altitude (Figure 1; del Arco-Aguilar and Rodríguez-Delgado 2018). According to the Köppen-Geiger classification, many low-elevation areas, particularly in Fuerteventura and Lanzarote, have a hot desert climate (BWh), with average annual temperatures above 18°C and very low precipitation (less than 300 mm). By contrast, higher altitudes, such as those in Tenerife and La Palma, have a warm-summer Mediterranean climate (Csb), with monthly average temperatures between 10°C and 22°C, dry summers (< 40 mm) and rainy winters (AEMET, IM—Agencia Estatal de Meteorología 2012). There is also a marked west-to-east precipitation gradient, with the western islands being much wetter than the eastern ones (Sánchez-Benítez et al. 2017; del Arco-Aguilar and Rodríguez-Delgado 2018). Annual precipitation ranges from 50 to 500 mm in lowlands (with prolonged dry periods in southern areas from mid-February to October), 300–800 mm at mid-elevations (with large differences between north and south slopes and maxima of 1300 mm in cloud zones) and 500–600 mm at higher elevations (Marzol Jaén and Máyer Suárez 2012). Snowfall can occur above 1800 m, typically between December and May.

In agreement with the climatic variation, the vegetation of the Canary Islands also shows strong altitudinal and directional zonation, including desert-like habitats in the eastern-most islands under the influence of the dry winds from the Sahara Desert and more humid and forested habitats in other areas (see Figure S1.1) (del Arco-Aguilar et al. 2010; del Arco-Aguilar and Rodríguez-Delgado 2018). On northern slopes, particularly in Tenerife, five primary vegetation belts follow an elevational sequence: (1) xerophytic lowland scrubs; (2) thermo-sclerophyllous woodlands; (3) evergreen laurel forests; (4) Canarian pine forests; and (5) high mountain scrubs.

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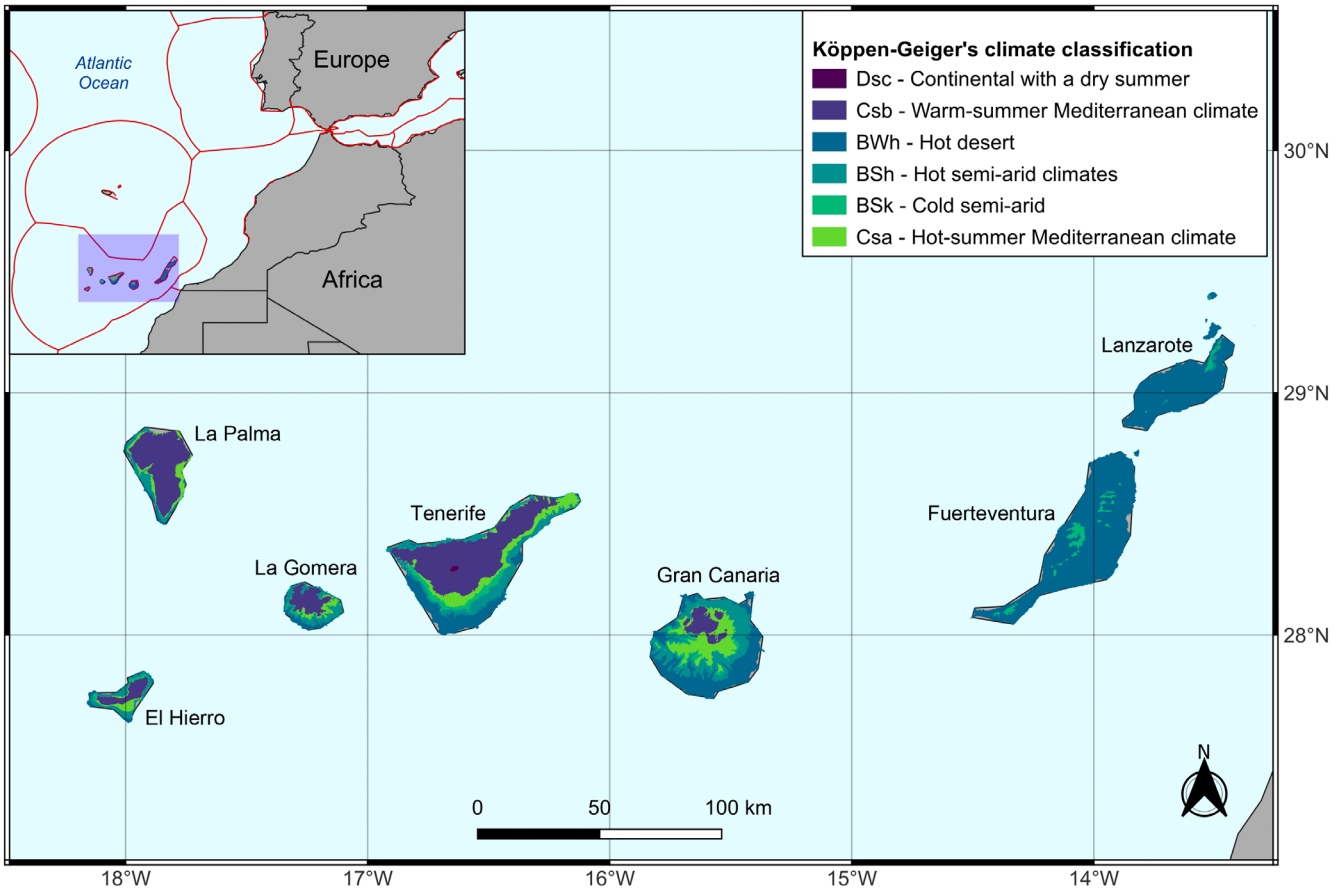


FIGURE 1 | Map of the study area in the Canary Islands archipelago with a detail of the Köppen-Geiger climate classification. Red lines in the small map delineate the exclusive economic zones. SITCAN—Sistema de Información Territorial de Canarias (2023).

Southern slopes experience more arid conditions, leading to compressed zonation, with *Euphorbia* scrub extending to higher elevations. The laurel forests persist in humid cloud montane zones as a relict forest ecosystem, while the endemic *Pinus canariensis* woodlands demonstrate remarkable adaptability across wide altitudinal ranges. This vegetation structure reflects both the archipelago's complex bioclimatic gradients and its evolutionary history as a refuge for ancient Mediterranean flora (del Arco-Aguilar et al. 2010; del Arco-Aguilar and Rodríguez-Delgado 2018).

The marine environment surrounding the islands includes a wide diversity of habitats such as volcanic rocky reefs, sandy bottoms, seagrass meadows (*Cymodocea nodosa*) and submarine lava systems, all shaped by the narrow insular shelf and deep bathymetry (Francisco-Ortega et al. 2019). Although marine endemism is generally low due to high connectivity driven by the Canary Current and planktonic dispersal, isolated systems such as caves and anchialine habitats can exhibit high levels of local endemism (Riera et al. 2014). Across both marine and freshwater systems, biological invasions are increasingly relevant, particularly in highly disturbed coastal zones and artificial freshwater bodies. Marine invasions are strongly associated with heavy maritime traffic and port infrastructure, while freshwater invasions are facilitated by habitat simplification, reservoirs and human-mediated species introductions (Pajuelo et al. 2016; Castro et al. 2022).

2.2 | Horizon Scanning Protocol

We applied a HS protocol adapted from Roy et al. (2019) and Cano-Barbacil et al. (2023) to generate a ranked list of potential invasive non-native species likely to arrive in the Canary Islands in the next 10 years and cause significant environmental or socioeconomic impacts. The process involved three stages: (1) defining thematic working groups, (2) compiling and screening preliminary species within each thematic group and (3) reaching a cross-group consensus to prioritise a final list. We established five thematic expert groups: marine species (including all marine animals and algae), freshwater animals (including inland aquatic invertebrates and fishes), terrestrial vertebrates (including amphibians, mammals, reptiles and birds), terrestrial invertebrates and plants (including terrestrial and freshwater aquatic plants). We did not consider subspecies, microorganisms, bryophytes, lichens or fungi. We compiled species lists using the CABI Horizon Scanning tool (CABI 2023), which draws on information from the CABI Invasive Species Compendium (https://www.cabidigitallibrary.org/journal/cabicompendium) and integrates standardised global species distribution records, invasion history, habitat associations, pathways of introduction and documented impacts.

This tool allows users to define an 'area at risk' (the Canary Islands in this study) and to identify 'source areas' where

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species are currently present, including neighbouring regions, trade partners and regions with climatically similar conditions. Climate matching is based on the Köppen–Geiger classification, enabling the identification of species occurring in regions with analogous current climate zones to those of the Canary Islands and thereby supporting inference of potential establishment under similar environmental conditions. The Horizon Scanning Tool also provides information on the number of occurrences in climatically matched regions, which we used as a proxy for environmental suitability and establishment potential. In addition, it optionally incorporates filters related to organism type, habitat (marine, freshwater, terrestrial, brackish), pathways of introduction (e.g., stowaway, contaminant) and impact categories.

This list was complemented with species from previous HS carried out in Spain and Europe (Bayón and Vilà 2019; Oliva-Paterna et al. 2021; Peyton et al. 2019; Roy et al. 2014, 2019; Cano-Barbacil et al. 2023; Oficialdegui et al. 2023) and with species extracted from relevant Spanish and European regulations on non-native species (e.g., RD 630/2013—the Spanish Catalogue of Invasive Alien Species). We removed species already established on at least one of the islands from the list, mostly based on BIOTA (2025) and EXOS (2025) databases.

The geographical scope of the search for potential non-native species to evaluate was global. General criteria used to establish the preliminary list followed Roy et al. (2019) and were as follows: (i) non-native species not currently established on any of the Canary islands (based on the Canary Islands' BIOTA and EXOS databases and experts' evaluations); (ii) species present in areas near the Canary Islands (including native species from mainland Spain that are not present in the islands); (iii) species present in areas with climatic characteristics compatible with the Canary Islands (using the Köppen-Geiger classification; Figure 1); (iv) species with a documented invasion history in other areas of the planet; and (v) species that are already traded or present (but not naturalized/established) within the Canary Islands, or are present in areas that have trade or travel connections with the archipelago. We ranked species based on their occurrence across climatically similar regions as identified by the CABI Horizon Scanning tool, using Köppen–Geiger climate matching as implemented in the CABI Compendium framework. This metric reflects the extent of a species' distribution across environmentally analogous regions and was used as a proxy for establishment likelihood. We then selected the top 200 taxa per group for further evaluation. Each thematic group consisted of 5–7 experts, with the number adjusted to the number of species involved (Table S1.1). Expert selection ensured representation across different taxa, comprising researchers and managers with expertise in biological invasions, including experts based in the Canary Islands, while promoting gender (12 female and 19 male scientists) and both early-career and senior researchers balances. All experts are co-authors of this study.

We distributed the agreed preliminary list among experts of each thematic group, who reviewed and refined it, adding or removing species when appropriate, then proceeding to species scoring. We asked experts to evaluate and score (from 1 as very unlikely to 5 as very likely) the likelihood of arrival, establishment and potential impacts of the species listed. Impacts were assessed separately for the environmental (based on the Environmental Impact Classification for Alien Taxa, EICAT; Hawkins et al. 2015) and socioeconomic domains (using SEICAT, which focuses on effects on human well-being, safety, livelihoods and cultural assets; Bacher et al. 2018) (see Appendix S2 for the template provided and the precise scoring criteria used). Each expert also assigned a confidence level (low, medium, or high) to each score (see Appendix S2 for precise definitions). Each species was scored by 2–3 experts (with a minimum of 50 species per expert). The scores provided by each expert for each species were, then, averaged to produce a mean value per category (e.g., arrival). Following Roy et al. (2014), we calculated the total impact score for each species as the product of its mean arrival, establishment and impact scores. Since we evaluated two impact domains (environmental and socioeconomic), all species had two total scores, one involving the product of arrival, establishment and environmental impact, and the other as the product of the two former categories and socioeconomic impact, each total score achieving a maximum possible value of 125.

Following Cano-Barbacil et al. (2023) and in accordance with proposals to improve the quality of HS assessments (Vanderhoeven et al. 2017), we evaluated agreement and consistency of experts' preliminary scores using Krippendorff's α and Kendall's coefficient of concordance, respectively. The former (Krippendorff 2004) is a standard measure of reliability (Hayes and Krippendorff 2007) that ranges from −1 to 1, where values of 1 indicate perfect agreement, 0 indicates no agreement beyond chance and −1 indicates inverse agreement (Krippendorff 2004). Both the bootstrapped Krippendorff's α and its 95% confidence interval were obtained using the *kripp.boot* R package (Proutskova and Gruszczynski 2017). To formally test whether expert agreement varied among thematic groups and across the different scoring categories (i.e., likelihood of arrival, establishment and impacts), we fitted beta regression models (*betareg* package; Cribari-Neto and Zeileis 2010), as this approach is appropriate for modelling bounded response variables, such as Krippendorff's α. We also assessed the goodness-of-fit of the models with McFadden's pseudo-R^2, which ranges between 0 and 1, with higher values indicating better fit. We finally calculated Kendall's coefficient of concordance (W) (Legendre 2005), which is a non-parametric method that informs about the correlation among experts' scores (i.e., consistency), with the *kendallNA* function of the *irrNA* package (Brueckl et al. 2022). Krippendorff's α and Kendall's W were used as complementary measures, as they capture different aspects of expert elicitation: absolute agreement (Krippendorff's α) versus consistency in ranking among experts (Kendall's W). Note that reliability is used with various meanings in literature and that the differences between agreement and consistency can be subtle (Table S8 of Cano-Barbacil et al. (2023) illustrates the difference). All statistical analyses were carried out using R software environment 4.4.2 (R Core Team 2025).

The final consensus list was developed during an in-person workshop attended by experts from all thematic groups, through a process of identification and expert judgement carried out within a continuous consensus-building framework. Each group presented the species that had received the highest scores for environmental and socioeconomic impacts separately, and we collectively discussed criteria to reach cross-group standards, explicitly framing all evaluations

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TABLE 1 | Results of the beta regression model assessing expert agreement (Krippendorff's α) on species scores as a function of thematic group and the variable (likelihood of arrival and establishment, and environmental and socioeconomic impacts).

	Estimate	Standard error	*Z* value	*p*
Intercept	−0.233	0.011	−20.16	**<0.001**
Group—Terrestrial invertebrates	0.005	0.013	0.40	0.688
Group—Marine species	0.114	0.012	9.34	**<0.001**
Group—Plants	0.136	0.012	11.11	**<0.001**
Group—Terrestrial vertebrates	−0.038	0.011	−3.35	**<0.001**
Variable—Establishment	−0.371	0.013	−27.60	**<0.001**
Variable—Environmental impacts	−0.079	0.011	−7.02	**<0.001**
Variable—Socioeconomic impacts	−0.206	0.012	−15.90	**<0.001**

Note: The intercept corresponds to the coefficient for arrival and the freshwater group. All other coefficients show differences in agreement relative to this reference level. McFadden's pseudo-$R^2 = 0.47$. Significant variables are shown in bold.

within the biogeographical and socio-ecological context of the Canary Islands. The workshop included experts from all thematic groups, allowing for cross-taxa comparison and calibration of scoring criteria among participants. The thematic groups then reconvened to review and refine the scores, reaching a consensus. We merged the refined lists to produce two ranked consensus lists of potential non-native species, categorized by threat levels based on their total scores, one for environmental impacts and another for socio-economic impacts. Species scoring 100–125 were classified as very high risk, 60–80 as high risk, 27–50 as moderate risk and below 26 as low risk. These class limits mostly corresponded to dividing the total score range into four equal groups; note that only a few discrete total scores are possible (e.g., 75, 80, 100, 125) and that three partial scores (i.e., arrival, establishment and impact) of 5 correspond to very high risk, three 4 s correspond to high risk, three 3 s to moderate. Finally, the final consensus list (i.e., after merging all revised scores of each group and accounting for each species total score) was revisited during a virtual meeting with the participation of all experts where final adjustments in species ranking were discussed and implemented. The environmental impact consensus list was then compared to the consensus list of a previous HS at the national level (Cano-Barbacil et al. 2023) through a contingency table and tested through a Chi-squared test.

3 | Results

3.1 | Reliability Analysis

Agreement values varied across thematic groups (Table 1), with the lowest average Krippendorff's alpha observed for freshwater organisms (mean $\alpha = 0.23$), intermediate values for terrestrial vertebrates (mean $\alpha = 0.26$) and invertebrates (mean $\alpha = 0.25$) and higher agreement for plants (mean $\alpha = 0.32$) and marine organisms (mean $\alpha = 0.35$) (Figure 2). We also found significant differences among the evaluated variables (Table 1), with higher expert agreement on the probability of arrival (mean $\alpha = 0.39$) and environmental impacts (mean $\alpha = 0.31$) and lower agreement on establishment (mean $\alpha = 0.21$) and socioeconomic impacts (mean $\alpha = 0.21$). We observed the weakest consensus for the establishment potential of terrestrial invertebrates and the socioeconomic impacts of freshwater organisms and terrestrial vertebrates. Conversely, we recorded the highest agreement for species arrival, except for freshwater species (Figure 2).

Despite relatively low agreement values (i.e., the scores did not fully coincide), Kendall's coefficients indicated considerable consistency (i.e., concordance in the most/least risky species) in species rankings across experts (Figure 2, Table S1.2). This consistency was generally higher for species arrival (except for freshwater organisms) and slightly lower for socioeconomic impacts (except for marine species and terrestrial invertebrates). We found the highest consistency in species ranking for the arrival of marine organisms and plants, while we detected the lowest values for the socioeconomic impacts and establishment of terrestrial vertebrates (Table S1.2). Overall, agreement and consistency were only weakly correlated (Figure S1.2) and that pre- and consensus comparisons showed considerable changes in species scoring (Figure S1.3).

3.2 | Consensus List

The consensus list included 823 non-native species, 12 with very high risk for environmental impacts, due to their potential to arrive, establish and significantly impact the biodiversity of the Canary Islands, 82 as high risk, 283 as moderate and the remaining 446 as low risk (Table S1.1 and Appendix S3). The group with the highest number of species posing very high environmental risks was terrestrial vertebrates ($n = 8$): the wild boar *Sus scrofa*, the red fox *Vulpes vulpes*, the common myna *Acridotheres tristis*, the crested myna *Acridotheres cristatellus*, the common house gecko *Hemidactylus frenatus*, the horseshoe whip snake *Hemorrhois hippocrepis*, the ladder snake *Zamenis scalaris* and the corn snake *Pantherophis guttatus*. Freshwater species were the second largest group of very high risk species ($n = 3$) with the Nile tilapia *Oreochromis niloticus*, the guppy *Poecilia latipinna* and the mosquitofish *Gambusia affinis*. The red palm weevil *Rhynchophorus ferrugineus*, an introduced invertebrate successfully eradicated from the Archipelago in 2016 (EPPO Global Database online 2025), was the only terrestrial invertebrate included in this very high risk

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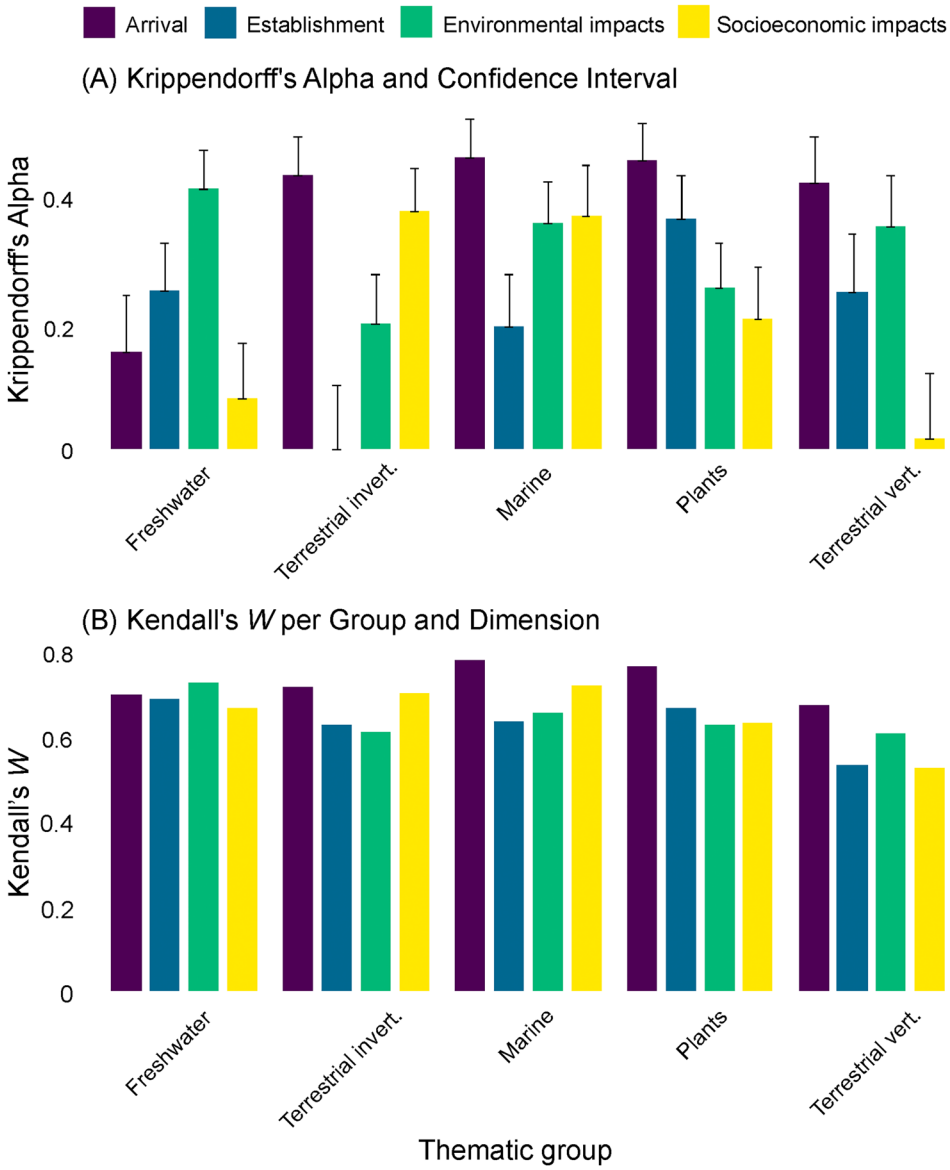


FIGURE 2 | Expert agreement on species scores across the four variables of the Horizon Scanning exercise for each thematic group, showing (A) Krippendorff's α (with upper 95% confidence limits) and (B) Kendall's coefficients of concordance (W).

category (Figure 3 and Table S1.3). For the high risk category, the group with the highest number of species was freshwater ($n = 26$), followed by plants ($n = 19$), marine species ($n = 17$), terrestrial vertebrates ($n = 11$) and terrestrial invertebrates ($n = 9$) (Figure 3).

In terms of socioeconomic impacts, only two species scored as very high risk, 47 as high risk, 218 as moderate and 556 as low risk (Figure 3). The two very high risk species were the red palm weevil *Rhynchophorus ferrugineus* and the yellow fever mosquito *Aedes aegypti*. Terrestrial invertebrates had the highest number of species with high risk for socioeconomic impacts ($n = 16$), including the other palm weevil *Rhynchophorus phoenicis*, the pine wood nematode *Bursaphelenchus xylophilus* and the oriental fruit fly *Bactrocera dorsalis*. A total of 14 marine species were included in the high risk category for socioeconomic impacts, such as the lionfish *Pterois volitans* and *P. miles* and the gladiator swimcrab *Callinectes pallidus*. The other groups had a smaller number of species: plants ($n = 10$), terrestrial vertebrates ($n = 6$) and freshwater (only *Culex quinquefasciatus*).

The total species scores obtained for environmental and socioeconomic impacts were only moderately related ($p < 0.01$, Figure 4), despite sharing two out of three variables, because the individual scores for environmental and socioeconomic impacts were weakly related ($p < 0.01$) (Figure 4). Although some species had simultaneously high impact scores on environmental and socioeconomic impacts (e.g., the palm weevils *R. ferrugineus* and *R. phoenicis* both scoring 5 for both criteria), there were other species with high socioeconomic impacts (scores 4–5) but low environmental impacts (scores 1–2) ($n = 9$; e.g., the Asian citrus psyllid *Diaphorina citri*) or low socioeconomic impacts and high environmental impacts ($n = 84$; e.g., the corn snake *Pantherophis guttatus*). However, most species had low scores on both impact categories ($n = 316$). It is important to highlight that all the variables evaluated (i.e., arrival, establishment) are

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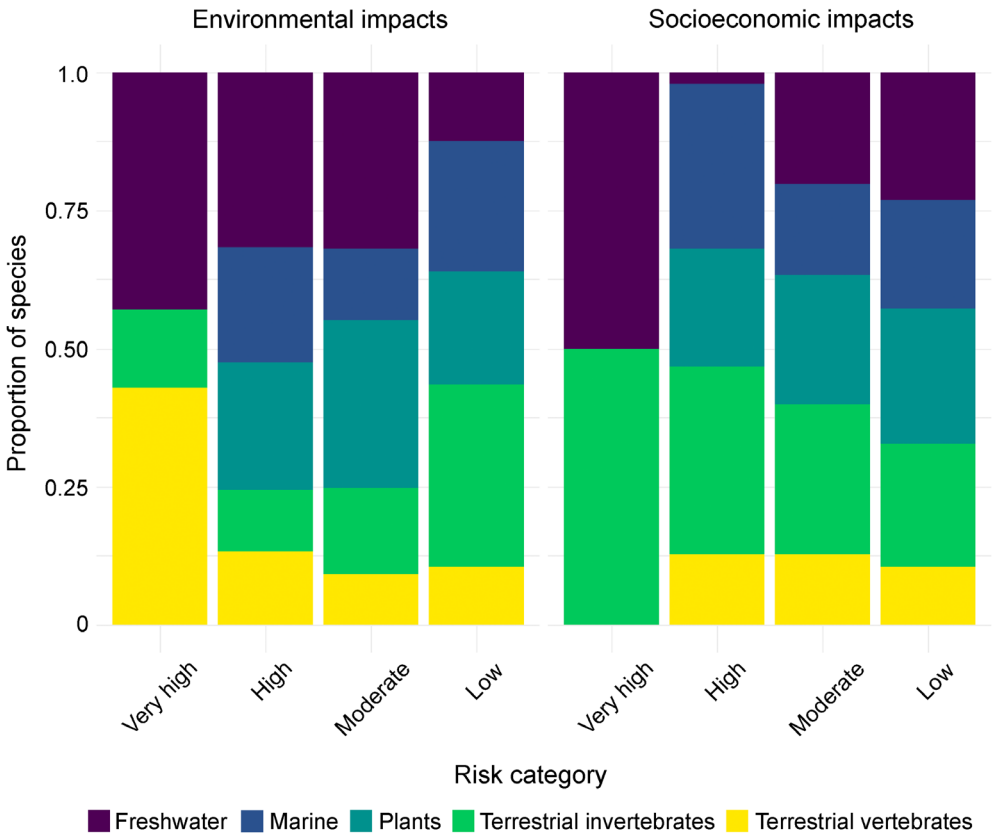


FIGURE 3 | Proportion of non-native species classified as very high, high, moderate and low risk in the Horizon Scanning exercise for the Canary Islands, thematic group (marine species, freshwater animals, terrestrial vertebrates, terrestrial invertebrates and plants), shown separately for environmental and socioeconomic impacts.

not independent, even though they are not strongly correlated (Figure S1.4), which emphasizes their individual importance.

We identified 94 species as priorities for prevention (those classified as very high and high risk) due to their potential environmental impacts and 49 species due to potential socioeconomic impacts (Figure 5). Among the species with very high environmental impacts, the majority were lizards and snakes (Squamata; $n = 4$) and freshwater fish (Actinopterygii; $n = 3$), while those classified as high risk were primarily dicotyledonous plants (Magnoliopsida; $n = 16$), freshwater fish ($n = 15$) and insects ($n = 9$) (Figure 5A). In contrast, all species assigned to a very high socioeconomic impact were insect pests (*R. ferrugineus* and *A. aegypti*), which also comprised the bulk of species with high risk for socioeconomic impacts ($n = 15$). Additional high-risk groups included dicotyledonous plants ($n = 10$) and ascidians ($n = 5$) (Figure 5B).

3.3 | Comparison With the National HS

The species evaluated in the previous national HS (Cano-Barbacil et al. 2023) and in the current assessment for the Canary Islands (only environmental impacts) differ significantly in composition ($\chi^2 = 496.83$; $p < 0.001$), although 71% of experts participated in both assessments. This disparity reflects both the ecological distinctiveness of the archipelago and the differing study area, which also reflects different climatic matching with species, applied in each assessment. A total of 351 species were shared between the two studies, while 468 species were uniquely considered in this study and not in the national HS. Some of them were excluded from the national analysis either because they are native to mainland Spain (e.g., *S. scrofa*, *Z. scalaris*) or because they were already established in the Iberian Peninsula (e.g., *Alburnus alburnus*, *R. ferrugineus*). Conversely, 582 species were unique to the national assessment, many of which are associated with temperate climates (e.g., *Prunus serotina*) not found in the Canary Islands (Figure S1.5). The national HS included priority species from a broader range of taxonomic groups (Figure S1.6), even though it was dominated by Magnoliopsida and Actinopterygii. In contrast, the current study prioritized species within the Actinopterygii, followed by Magnoliopsida and Insecta. Approximately 30 species were classified as priority in both assessments (Figure 6), with correlated total environmental scores (Figure S1.7).

4 | Discussion

This study presents the first HS explicitly designed for the Canary Islands, revealing a concerning number of non-native species likely to invade the archipelago over the next decade. Using expert-based assessments, we identified 94 species posing high or very high environmental risks and 49 species with potential notable socioeconomic impacts. Vertebrates and arthropods dominated the priority list, with clear taxonomic patterns: lizards and snakes and freshwater fish were most frequently linked by experts to environmental threats, whereas insects were the

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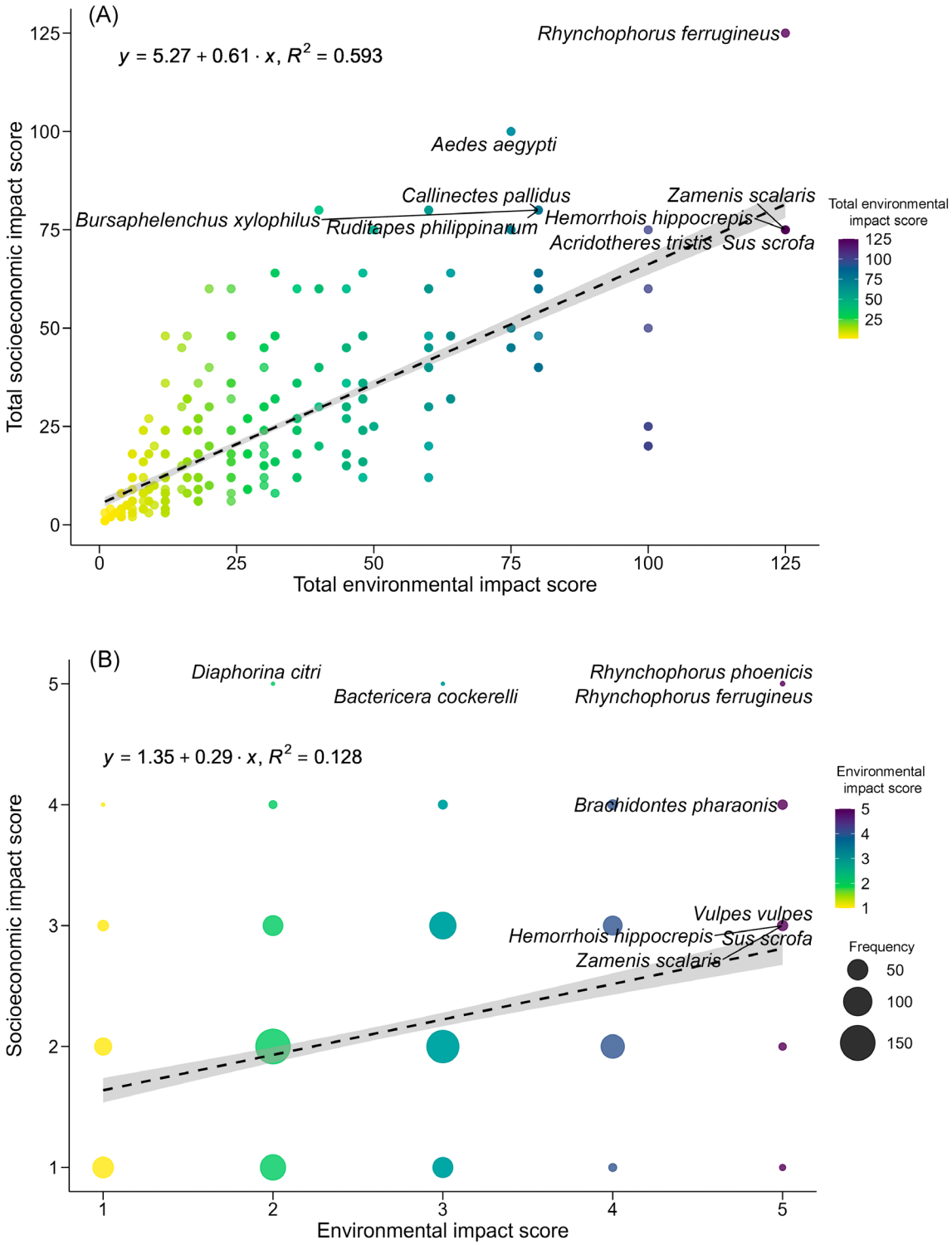


FIGURE 4 | Relationship between (A) the total scores of environmental and socioeconomic impacts and (B) the specific scores assigned to the environmental impact and the socioeconomic impact for each species. The size of the dot is proportional to the number of species. The linear regression analyses are shown.

main taxon associated with socioeconomic impacts. Despite moderate overall agreement among experts, our consensus-based prioritization offers a useful tool for guiding surveillance, resource allocation and risk analyses in the Canary Islands. These results underscore the need for preventive measures and risk-based management, focused on the taxonomic groups most likely to invade and cause major impacts.

Our study is the first HS to explicitly and independently evaluate both environmental and socioeconomic impacts of potential invasive species, allowing the monitoring and eventual management of species that would, otherwise, be overlooked due to their low environmental impacts, even though they have high potential for socioeconomic impacts. We found limited overlap between impact sources, with no clear correlation

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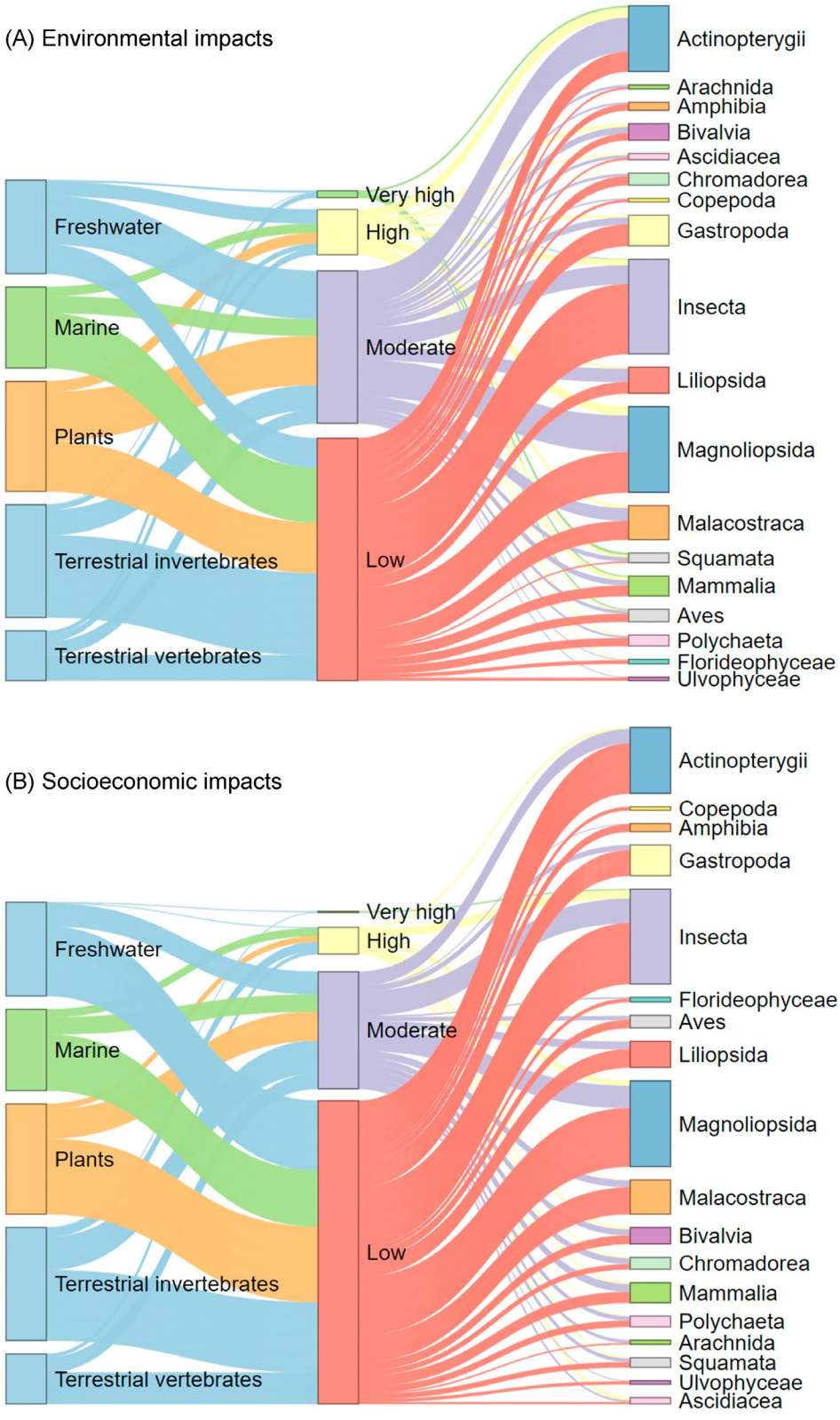


FIGURE 5 | Sankey diagram illustrating the relationships among thematic groups, risk categories and taxonomic classes for non-native species, based on (A) environmental and (B) socioeconomic impacts. Flow widths represent the number of species transitioning among categories. Thematic groups are positioned on the left, risk categories in the middle and taxonomic classes on the right.

between their scores. This highlights the value of including separately both impact domains for a more comprehensive risk evaluation and to better inform management strategies targeting simultaneously biodiversity conservation and human well-being (Bacher et al. 2018). For example, several insects such as *Diaphorina citri*, *Leptinotarsa decemlineata* and *Anopheles quadrimaculatus* received high scores for socioeconomic impacts but low for environmental impact. The first

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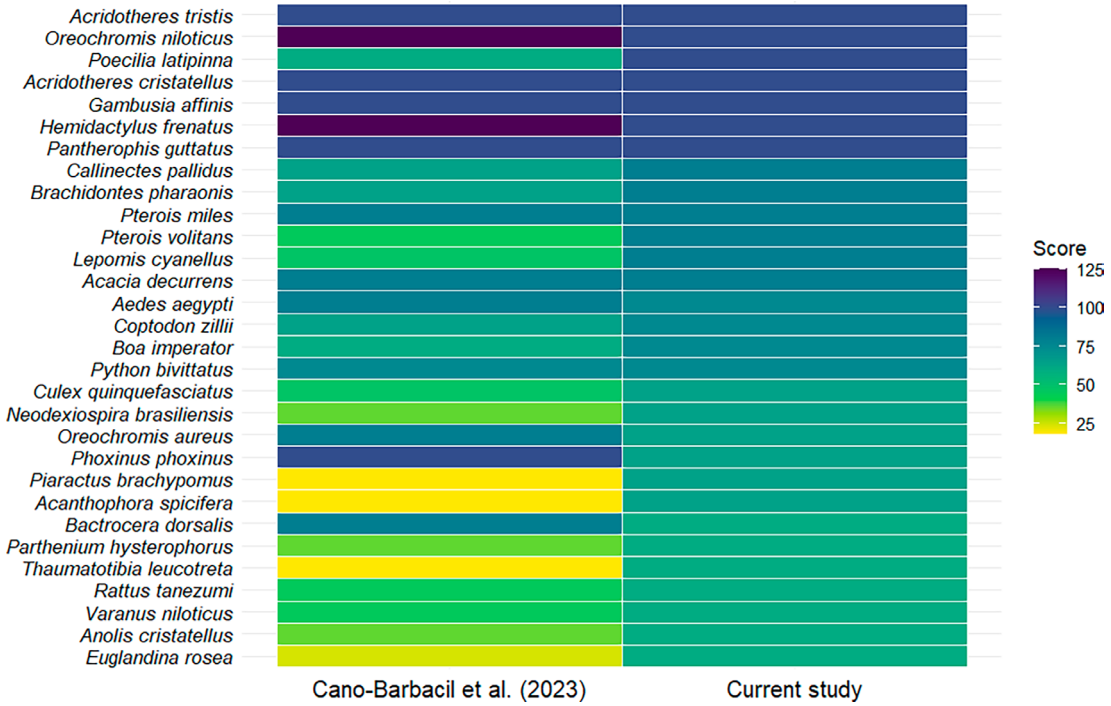


FIGURE 6 | Comparison of environmental risk scores for species shared between the current Horizon Scanning (HS) for the Canary Islands and the national HS conducted by Cano-Barbacil et al. (2023). Each tile represents a species (*y*-axis) evaluated in both assessments (*x*-axis), with colour scaling indicating the overall environmental score assigned in each study. Only species considered as priority in both assessments are shown.

two species are major agricultural pests causing crop damage by transmitting plant diseases (e.g., Huanglongbing disease by the Asian citrus psyllid *D. citri*) or by phytophagy (e.g., crop defoliation by the Colorado potato beetle *L. decemlineata*) (Grafius 1997; Bayles et al. 2017; Schoville et al. 2018). The mosquito *A. quadrimaculatus*, on the other hand, is a vector for human diseases such as malaria, Cache Valley virus, West Nile Virus and St. Louis encephalitis and can also transmit parasites affecting domestic animals (e.g., the dog heartworm *Dirofilaria immitis*) (Ludlam et al. 1970; Hernandez-Valencia et al. 2023; Global Invasive Species Database 2025). Conversely, species like the corn snake *P. guttatus*, the mosquitofish *G. affinis* and the rosy wolfsnail *Euglandina rosea* show high environmental but low socioeconomic risks, largely due to their impacts on native species through competition and predation (Kinzie III 1992; DeGregorio et al. 2016; Magellan and García-Berthou 2016). This two-domain approach emphasizes the importance of socioeconomic perspectives in invasive species risk assessments by capturing species whose threat to human health, livelihoods or economic sectors might otherwise be missed, advocating for a One Biosecurity approach to prevent the impact of biological invasions (Hanley and Roberts 2019; Hulme 2020; Angulo et al. 2021). Furthermore, socioeconomic impact assessments can justify preventive actions, which are consistently more cost-effective than post-invasion management (Bradshaw et al. 2024; Heringer et al. 2024). Therefore, future HS efforts should integrate the socioeconomic risk domain to improve prioritization frameworks and support more efficient and proactive prevention of biological invasions.

Another aspect relevant to impact evaluation is the Canary Islands' high levels of endemism and the restricted distribution of many native taxa. Several of the species prioritized in this HS exercise have the potential to directly affect endemic or highly localized species through competition, predation, habitat alteration, or ecosystem-level changes (Simberloff 1995; Lüderitz et al. 2016). For example, the non-native aquatic beetle *Meladema coriacea* has already displaced the endemic *Meladema imbricata* from most freshwater streams in Tenerife, restricting the endemic species to a few remaining localities (Lüderitz et al. 2016). In marine ecosystems, invasive macroalgae such as *Caulerpa racemosa* and cyanobacterial blooms of *Lyngbya majuscula* have been associated with the degradation and replacement of *Cymodocea nodosa* seagrass meadows, which provide important nursery and refuge habitats for native coastal communities (Verlaque et al. 2004; Riera et al. 2014). Likewise, invasive vertebrates prioritized in previous assessments, such as *Lampropeltis getula* and *Acridotheres tristis*, represent major threats to endemic vertebrate fauna through predation, competition and disruption of breeding habitats (Cano-Barbacil et al. 2023). These examples illustrate how biological invasions in oceanic islands may disproportionately affect species with narrow ranges and specialized ecological requirements, increasing the risk of irreversible biodiversity loss. Such impacts are especially relevant in the context of current global biodiversity targets aimed at reducing the effects of invasive alien species on threatened and endemic taxa (Martín 2009).

The estimation of the invasive potential of non-native species is inherently influenced by several factors, such as experts' experience (e.g., extent and bias of knowledge), subjective interpretations of evidence, professional interests or even experts' degree of involvement in species evaluation (Sutherland et al. 2011; McGeoch et al. 2012; Bernardo-Madrid et al. 2022). These challenges are especially critical

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in data-deficient contexts, such as tropical and subtropical islands, where epistemic uncertainty (i.e., lack of knowledge or measurement error) is elevated (McGeoch et al. 2012). Furthermore, risk assessment protocols are often constrained by vague criteria, inconsistent definitions and limited guidance on evidence inclusion, which leaves considerable room for interpretation and may reduce inter-expert objectivity. In our case, as in Cano-Barbacil et al. (2023), we adopted a structured, criteria-based scoring framework with a consensus-building procedure to reduce individual bias and improve comparability among experts. We also explicitly quantified expert agreement and consistency using two complementary metrics. Although Krippendorff's alpha values were relatively low, which is consistent with previous HS exercises (e.g., Cano-Barbacil et al. 2023), Kendall's concordance indicated a higher level of consistency in species rankings, suggesting that experts tended to prioritize similar species even when absolute scores differed. Importantly, this distinction is relevant, as Krippendorff's alpha is sensitive to absolute scoring disagreement, whereas Kendall's W better captures consistency in ordinal prioritization, which is the primary objective in HS. The robustness of the prioritization was further evaluated by comparing pre-consensus and post-consensus scores, which showed a substantial effect of the consensus process (Figure S1.4). This indicates that while expert opinions varied at the individual scoring level, structured discussion and aggregation led to convergence in final prioritization outcomes. However, this also highlights that species ranking in horizon scanning is not fully invariant to methodological choices, particularly the consensus mechanism and therefore some degree of structural uncertainty remains inherent to the approach. Socioeconomic impacts, in particular, carried high uncertainty, reflecting limited or context-specific knowledge. While certain species, such as mosquitoes or crop pests, are well-known for their socioeconomic impacts (Bernardo-Madrid et al. 2022), others lack sufficient data, leading to cautious or speculative assessments. Unlike Cano-Barbacil et al. (2023), we found a weak correlation between agreement and consistency, indicating that these metrics capture different dimensions of expert uncertainty. Overall, despite these limitations, the use of transparent criteria, structured scoring and consensus-based refinement provides a robust and widely used framework for HS. Nevertheless, our results reinforce that expert-driven prioritization should be interpreted as a probabilistic and flexible ranking rather than a fixed or deterministic outcome.

Regional HS efforts are extremely important to better assess risks of invasion by non-native species, since invasion is a populational phenomenon highly dependent upon the context. A comparative analysis between our regional HS and the national assessment by Cano-Barbacil et al. (2023) revealed significant differences in species prioritization, highlighting the role played by context-dependent processes. The discrepancies found may reflect small-scale ecological sensitivities and the varying potential impacts of species across different environments, especially since Cano-Barbacil et al. (2023) considered the peninsular territory of Spain, the Canary and the Balearic Islands, which means that a greater variety of habitats and ecosystems, along with a higher climatic variation, was incorporated in their assessment. For instance, the results obtained by Cano-Barbacil et al. (2023) identified 47 species with very high risk to biodiversity, which served as focal points for detailed risk analyses and management planning. Therefore, we expect that our findings will prompt further evaluations of the risks of non-native species on the Canary Islands by providing a list of species that could be incorporated into a watch list or be considered for specific risk assessments.

Even though HS provides a valuable framework for prioritizing invasive species risks, our assessment has inherent limitations that should be considered. The initial list of species is not comprehensive, since the CABI tool selects species based on matching climatic conditions. Experts noticed a taxonomic bias in the output of the CABI tool which seemed to have overestimated tropical species' suitability while neglecting temperate and Mediterranean-climate invaders (particularly plants), despite the archipelago's climatic heterogeneity. Regarding terrestrial invertebrates, experts also noticed a bias towards crop pests, instead of potential invasive species that are known to cause harm to biodiversity. Therefore, experts suggested several species, known to be prone invaders into subtropical areas, as long as species listed in the Spanish Catalogue of Invasive Alien Species, to be incorporated in the scoring list. Furthermore, species currently established on only one island, such as the California kingsnake (*Lampropeltis californiae*) in Gran Canaria, could have significant ecological impacts if introduced elsewhere in the archipelago (Piquet and López-Darias 2021), a scenario not evaluated in our study, despite representing a potentially important invasion pathway in insular systems and which is also commonly overlooked in most other HS where within-region spread is not explicitly considered. These knowledge gaps are most pronounced for freshwater systems, with all the streams unmonitored and not protected by the EU Water Framework Directive (allegedly due to their small size and high flow intermittency) and a general public perception of low ecological value (and, consequently, low invasion risk) of these systems, even though they are very rich in species, many of them endemic. Marine environments also face several gaps, as data on ecological and socioeconomic impacts remain scarce despite evidence of potential threats (McGeoch et al. 2012; Watkins et al. 2021). Future HS and risk assessments should therefore incorporate climate-specific filters and improve the evaluation of species impacts, particularly under uncertainty in establishment likelihood, while addressing these gaps through enhanced monitoring and data collection.

Our results provide a strategic tool for informing risk assessments and prioritizing management efforts in the Canary Islands. The inclusion of both ecological and socioeconomic domains highlights species that might otherwise be overlooked in traditional assessments. These findings are of high applied relevance, as they can support the development of early warning systems, rapid response measures, surveillance strategies and biosecurity measures aligned with regional conservation priorities. Moreover, the consensus-based approach we employed enhances the credibility of our prioritized lists, which can serve as a reference for regional authorities when developing watch lists, proposing candidates for risk analysis, or implementing preventive and regulatory actions. By anticipating future threats, this HS strengthens the scientific and policy foundation for proactive

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invasive species management in one of the EU's most biodiverse and vulnerable island systems.

Author Contributions

A.C.S.F., E.G.-B., C.M.M., M.C., P.C.-D., M.G.D., J.A.J., M.L., M.L.-D., M.N., M.R., X.T. and M.V.: Conceptualization, methodology. A.C.S.F.: Data curation, formal analysis, writing – original draft. E.G.-B.: Writing – original draft, supervision, project administration, funding acquisition. All authors: Investigation, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data is available as Appendices S1–S3 for this article.

Peer Review

For transparency, the peer review documents associated with this article are available at https://doi.org/10.1111/ddi.70248.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1.1:** Map of the study area in the Canary Islands, with the vegetation zoning based on the altitudinal thermal gradient (available at https://www.miteco.gob.es/content/dam/miteco/es/biodiversidad/servicios/banco-datos-naturaleza/series_c_tcm30-199925.zip). The isobaths (in m) are represented in orange. **Table S1.1:** Summary table of the species evaluated by each thematic group. HS, horizon scanning. **Table S1.2:** Kendall's coefficients of concordance (W) of species scores and significance level (P) for each variable evaluated by thematic groups. **Figure S1.2:** Relationship between agreement (Krippendorff's α) and consistency (Kendall's coefficient of concordance) for the set of variables evaluated and by thematic group. **Table S1.3:** Number of non-native species classified as very high, high, moderate or low potential risk in the Horizon Scanning exercise for the Canary Islands, shown by thematic group (marine species, freshwater animals, terrestrial vertebrates, terrestrial invertebrates and plants) and separated by environmental and socioeconomic impacts. **Figure S1.3:** Relationship between pre-consensus and consensus scores for environmental (upper panel) and socioeconomic impacts (lower panel). Each point represents a species, with colour indicating the magnitude of pre-consensus scores. Dashed lines show linear regression fits, with corresponding equations and coefficients of determination (R^2) displayed in each panel. **Figure S1.4:** Pairwise relationships among arrival, establishment, environmental impact and socioeconomic impact scores. Diagonal panels show distributions, lower panels display scatterplots with fitted lines and upper panels present Kendall correlation coefficients. **Figure S1.5:** Venn diagram showing the overlap in number of species evaluated by the present study for the Canary Islands and the horizon scanning by Cano-Barbacil et al. (2023) for the whole of Spain. **Figure S1.6:** Taxonomic class composition of priority species (those with >60 total score points), based on a previous horizon scanning for the whole of Spain (Cano-Barbacil et al. 2023) on top and the current study for the Canary Islands (bottom). Bars represent the total number of species assigned to each class. Nematoda corresponds to a phyllum rather than a class according to GBIF and other sources. This comparison

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highlights differences in taxonomic representation between datasets. **Figure S1.7:** Relationship between the total environmental impact scores of the current study and those obtained in a previous horizon scanning performed for the whole of Spain (Cano-Barbacil et al. 2023). The linear regression analysis is shown. **Appendix S2:** Template for the scorings of the species selected for a horizon scanning exercise for the invasion risk of the Canary Islands in the next decade. **Table S3:** Results of the scores provided by the pannel of experts of a horizon scanning exercise for the risk of invasion of the Canary Islands in the next decade.

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