MASTER

INNOVATION AND RESEARCH FOR SUSTAINABILITY

MASTER'S FINAL WORK

PROJECT

GREENER HIGHWAYS: MANAGING INVASIVE PLANT SPECIES AT BRISA CONCESSÃO RODOVIÁRIA

RODRIGO MATOS TINOCO

FEBRUARY – 2026

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SUPERVISION:

PROFESSOR TIAGO CAPELA LOURENÇO

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GLOSSARY

AAVN – Areas of High Natural Value (Áreas de Alto Valor Natural)

AC – Classified Area (Área Classificada)

AHP – Analytic Hierarchy Process

AEBT – Autoestradas do Baixo Tejo

AELO – Autoestradas do Litoral Oeste

BAS – Brisa Áreas de Serviço

BCR – Brisa Concessão Rodoviária

BGI – Brisa Gestão de Infraestruturas

BIO – Brisa Infraestruturas e Operação

BOM – Brisa Operação e Manutenção

CO – Operational Center (Centro Operacional)

CREL – Circular Regional Externa de Lisboa

IAS – Invasive Alien Species

ICNF – Institute for Nature Conservation and Forests (Instituto da Conservação da Natureza e das Florestas)

LCCA – Life Cycle Cost Analysis

OASN – Other Semi Natural Areas (Outras Áreas Semi Naturais)

OPS – Operational Priority Score

PK – Kilometer Profile (Perfil Kilométrico)

SNAC – Sistema Nacional de Áreas Classificadas

ABSTRACT

The main objective of this project at Brisa Autoestradas is to develop a strategic score for the management of invasive plant species in highway slopes within Brisa Concessão Rodoviária (BCR), aligning these practices with Grupo Brisa's broader sustainability commitments. The project focuses on the identification and mapping of invasive alien plant species in roadside areas, and in the prioritization of on-site interventions, in line with ecological, legal, and corporate sustainability goals.

Invasive plant species, such as *Arundo donax* (Giant Reed), *Acacia dealbata* (Silver Wattle) and *Cortaderia selloana* (Pampas Grass), represent a growing challenge in road infrastructure management. They compromise native biodiversity, increase maintenance costs, and may heighten risks related to soil erosion, wildfires, and road safety. At the same time, road verges and slopes have the potential to provide ecological value when managed sustainably, offering habitats, supporting pollinators, and contributing to ecosystem connectivity.

To address these challenges, this research applies an action-oriented methodology combining a field survey of the BCR network, desk research on invasive species impacts, and management practices. This mixed approach enables both the collection of primary data (mapping presence of priority invasive species) and secondary data (legislation, corporate sustainability reports, technical manuals).

Based on these inputs, Brisa's Risk and Invasive Species Assessment - Operational Priority Score (BRISA-OPS) is proposed, considering ecological risk, dispersal potential, and infrastructure management. This outcome is a strategic score that provides clear recommendations for invasive species management in BCR's network, structured around intervention levels. By aligning invasive species control with sustainability objectives, the project contributes not only to reducing ecological and economic impacts but also to enhancing the role of road infrastructure in promoting greener and more resilient landscapes.

KEYWORDS: Invasive Plant Species; Slopes; Highways; Drainage Systems; Biodiversity; Multi-Criteria Analysis

JEL CODES: O13; Q15; Q57; R41

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AI Disclosure

I formally declare that certain artificial intelligence (AI) tools were used in the development of this project. To assist in the generation and formatting of bibliographic references and for brainstorming and outlining purposes only.

All final writing, critical analysis, synthesis, and conclusions presented in this project are entirely my own work. Care has been taken to ensure that the use of AI tools has not compromised the originality, integrity, or academic rigor of this research. This work was conducted in accordance with ethical research standards and with a commitment to the responsible use of AI technologies.

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GREENER HIGHWAYS: MANAGING INVASIVE PLANT SPECIES AT BRISA CONCESSÃO RODOVIÁRIA

By Rodrigo Tinoco

This project develops a strategic score to manage invasive plant species on highway slopes within Brisa Concessão Rodoviária. The project maps the invasive species and evaluates their ecological and operational impacts. The resulting prioritization score considers ecological risk, dispersal potential, and infrastructure constraints, providing intervention guidelines to reduce environmental impacts, optimize maintenance, and promote more sustainable and resilient roadside landscapes.

1. INTRODUCTION

Grupo Brisa is the leading Portuguese mobility and infrastructure conglomerate. The company was originally founded in 1972 to plan, build, operate, and maintain Portugal's highway network under concession arrangements, and since then has evolved into a diversified group operating across multiple business lines (Grupo Brisa, 2026a). Brisa's core identity lies in its concession model for highway operation. Over its history, it has managed multiple highway concessions that form critical arteries of Portugal's road network. Currently, Brisa Auto-Estradas de Portugal oversees approximately 1,500 km across five main concessions and operates 24 service areas nationwide (Grupo Brisa, 2026b). The flagship and main concession - Brisa Concessão Rodoviária (BCR) - is the largest national tolled highway system, currently managing 11 highways under contract until 2035 (Brisa Concessão, 2026). The concession portfolio also includes participation in other road concessions, namely: Concessão Atlântico (AEA) (operator of A8 and A15), Brisal (Litoral Centro A17), Autoestradas do Baixo Tejo (AEBT), and Subconcessão do Litoral Oeste (AELO) (Grupo Brisa, 2026b). Annex's 2 Figure A1 illustrates the operations of Grupo Brisa, depicting the BCR network and the sub concessions where Brisa participates.

Grupo Brisa is structured into five distinct, but integrated business units. These allow Brisa to create synergies across mobility, infrastructure, and service provision, making its operational footprint beyond mere highway concessions. The five business units of the Brisa Grupo are:

a) Brisa Autoestradas / Highway Concessions & Road Services:

This unit handles highway concessions, maintenance, asset management, operations, and engineering services. Brisa Infraestrutura e Operação (BIO) includes two distinct business units: Brisa Operação e Manutenção (BOM) and Brisa Gestão de Infraestruturas (BGI). (Grupo Brisa, 2026b). Through these, Brisa executes the on-the-ground management of roadway corridors, which is directly relevant to any ecological interventions.

b) A-to-Be:

A-to-Be is Brisa's technological and innovative unit in mobility solutions. It develops software, intelligent transport systems, tolling solutions, and other platforms for mobility operators (Grupo Brisa, 2026b). As of recent years, A-to-Be has extended its reach internationally, especially in the U.S., where it operates in different market sections and concessions. (Grupo Brisa, 2026a).

c) Via Verde & Mobility Services:

The Via Verde system is Brisa's ubiquitous electronic toll-collection network. Over time, Via Verde has expanded beyond tolling to integrate mobility services (e.g., parking, fuelling, electric vehicle charging). Brisa holds a majority share (60 %) in Via Verde's capital.

d) Controlauto:

Controlauto oversees vehicle inspection services across Portugal. It is part of Brisa's "vehicle services" business line, operating many technical inspection centres (Grupo Brisa, 2026b).

e) Colibri (Brisa Áreas de Serviço (BAS) / Retail in Service Areas):

Colibri is active in the service area retail and operations domain. Created through a partnership between Brisa's service area branch and the Spanish retail operator Areas, Colibri administers shops, food & beverage, and customer amenities in service areas (Brisa internal info).

1.2 Strategic Position and Relevance to Sustainability

Grupo Brisa's trajectory over the past five decades illustrates a transformation from a company dedicated only to the design, construction, and operation of highways, into a broader mobility group. Today, Brisa positions itself not only as an infrastructure manager, but also as a provider of integrated mobility solutions, combining technology, services, and environmental responsibility, including broader commitments to innovation and sustainability. According to KPMG (2025), sustainability, digitalization, and resilience are becoming central pillars in infrastructure management worldwide. This strategic pivot is aligned with global and European trends that place sustainability, digitalization, and low-carbon development at the centre of infrastructure management.

The Group's sustainability strategy rests on three complementary pillars: efficiency, technological integration, and environmental responsibility. Efficiency refers to the optimization of operations, energy use, and maintenance practices across thousands of kilometres of highway concessions. The primary goal is to achieve Net-Zero by 2040, preceded by an interim target of reducing Scope 1 and 2 emissions by 60% by 2030. (Grupo Brisa, 2026c). Scope 1 emissions are the direct greenhouse gas emissions produced from sources such as fuel combustion in company vehicles or facilities. Scope 2 emissions are the indirect greenhouse gas emissions associated with the generation of purchased electricity. (Grupo Brisa, 2026c)

Technological integration reflects Brisa's investment in intelligent transport systems, electronic tolling, mobility platforms (e.g., Via Verde), and digital monitoring of infrastructure. Environmental responsibility is embedded in corporate objectives that promote biodiversity, managing resources responsibly, and enhancing road safety and user well-being.

As a long-term concessionaire, Brisa manages vast tracts of land that extend beyond the highway lanes themselves, to include berms, slopes, service areas, and associated drainage and green infrastructure. In addition, Brisa also possesses 15 Operational Centres (CO), namely (from north to south): Ponte de Lima, Maia, Feira, Mealhada, Marinha das Ondas, Leiria, Carregado, Loures, Carcavelos, Estremoz, Salvaterra de

Magos, Vendas Novas, Coina, Grândola and Almodôvar. Each CO is responsible for a certain stretch of one or more highways and provides the needed assistance.

This unique territorial footprint means that Brisa is particularly well placed to develop and implement sustainability strategies with both operational and ecological significance. For example, roadside vegetation management, renewable energy deployment, and carbon reduction initiatives (e.g., fleet electrification) can all be integrated into concession management, creating opportunities for Brisa to demonstrate leadership in sustainable mobility. In addition to these initiatives, Brisa has shown a strong commitment to circularity projects, exploring the incorporation of recycled plastics and/or tire rubber into noise barriers; using recycled milling material in new paving; refurbishing vertical signage that is in suitable condition for reuse; and studying the possibility of repurposing safety barriers (Brisa, personal communication, 2025).

From a governance perspective, Brisa has also embraced ESG reporting and accountability. The Group regularly communicates its performance in terms of environmental indicators, safety metrics, and community engagement. (Brisa Concessão Rodoviária, 2025) This enhances transparency and strengthens its position among stakeholders, regulators, and investors.

This strategy is aligned with global and European sustainability trends placing climate neutrality and biodiversity at the centre of infrastructure management. The European Green Deal frames climate neutrality by 2050 as a legal and strategic objective for the EU (European Commission, 2026a), while recent analyses highlight how infrastructure, transport, energy, and biodiversity policies are being integrated under this framework (Koundouri et al., 2024). Moreover, regulatory pressures at the corporate level, such as EU sustainability regulation and reporting requirements, further compel infrastructure operators to act as agents in the transition (Deloitte, 2025). In this context, projects that address ecological management challenges within highway corridors become highly relevant. Brisa's concession scale and its institutional leverage, through specialized business units and strong relationships with regulators and partners, creates favourable conditions for implementing sustainability strategies that combine technical feasibility with strategic value. Finally, its sustainability alignment ensures that ecological initiatives can be directly connected to Brisa’s corporate objectives, ESG commitments, and operational efficiencies.

This project is justified on three levels. Scientifically, it addresses a research gap on the role of highway corridors in biodiversity conservation and invasive alien species (IAS) management in the Portuguese context, where ecological fragmentation pressures are pronounced. Practically, it responds to the operational challenges of road concessionaires, who must balance safety, cost-efficiency, and ecological sustainability in vegetation management. Finally, at the corporate level, the project aligns with the sustainability strategy of Grupo Brisa, which has committed to Net-Zero targets and biodiversity integration within its Environmental, Social, and Governance (ESG) framework.

1.3 Internship and Study Objectives

As part of a one-year professional internship at Brisa Autoestradas, the opportunity was proposed to develop, over a three-month period, a project related to invasive plant species.

In its initial phase, the project aimed to survey and record all locations containing invasive and infestant species within the BCR concession areas. To achieve this objective, field surveys were conducted throughout the entire extent of the BCR network during this period.

The primary goal of the project was the creation of Brisa’s Risk and Invasive Species Assessment – Operational Priority Score (BRISA – OPS). This score is designed to redefine intervention priorities for invasive species by evaluating a range of factors relevant to the subject.

2. LITERATURE REVIEW

2.1 The Importance of Sustainability in Highway Infrastructure Management

According to Medeiros et al. (2025), the infrastructure of highways plays a fundamental role in economic development, territorial connectivity, and social well-being, as these investments significantly contribute to economic growth, productivity, and access to essential services. However, the construction and operation of road networks can also generate significant social and environmental impacts, from greenhouse gas emissions and energy consumption to land degradation. Habitat loss, and biodiversity decline also represent notable factors. For instance, the rehabilitation of road pavements involves emissions throughout the life cycle, from material production to maintenance (Elliot, 2023). In Mediterranean environments, road-related fragmentation and traffic noise are key factors of biodiversity loss and decline. A study by Konstantopoulos et al. (2020) conducted in Cyprus, found that road characteristics, such as, total extent and length, could explain 59% of the variation in breeding bird species richness across the island. The combined effects of habitat fragmentation and noise created impact 'hotspots', even within designated protected areas, highlighting the pervasive ecological footprint of road networks (Konstantopoulos et al., 2020). In this context, sustainability has become a central pillar of infrastructure management, moving beyond the traditional focus on mobility and safety to incorporate ecological, social, and economic dimensions in line with global and European policy frameworks.

From an environmental perspective, highway corridors represent both challenges and opportunities. On the one hand, they contribute to carbon emissions, which can be related to building undertakings, energy consumption or even with the associated traffic density (Dobrow, 2024). On the other, they offer extensive linear spaces, where sustainable management can mitigate impacts and even deliver ecological value. Practices such as energy efficiency in operations, incorporation of circular economy principles in construction materials, and ecological management of roadside vegetation illustrate how infrastructure management can contribute to climate neutrality and biodiversity objectives. (Brisa, personal communication, 2025).

The social dimension of sustainability is also relevant, as road infrastructure is directly linked to user safety, community health, and quality of life. A study developed by Kutela et al. (2025) demonstrates that transportation attributes, particularly the feeling of safety, can play a decisive role in shaping residents' quality of life. In the same study, similar patterns were observed with perceptions of safety when walking downtown or sharing the road with other drivers, indicating that safety in transport systems is not only a functional necessity but also a determinant factor of broader community well-being (Kutela et al., 2025). By integrating sustainability into corporate strategy, infrastructure operators position themselves as socially responsible actors, aligning with evolving societal expectations and regulatory pressures (Montgomery, 2015; Imran Kays & Sadri, 2022).

From an economic and strategic perspective, sustainability enhances the long-term resilience of infrastructure assets. As highlighted by Ahmadi et al. (2025), adopting mitigation and adaptation measures such as durable materials, advanced construction techniques, and effective asset management reduces degradation rates and long-term maintenance costs, while Life Cycle Cost Analysis (LCCA) demonstrates that sustainable practices extend asset lifespans and minimize regulatory and operational risks. At the same time, alignment with sustainability standards increases access to responsible investment and strengthens the reputation of infrastructure companies in increasingly competitive markets. In this context, sustainability is not only a normative obligation but also a driver of innovation and competitiveness.

Finally, the policy and governance context reinforce the strategic importance of sustainability in highway management. The European Green Deal and the EU Climate Law establish climate neutrality by 2050 as a legally binding target, while the EU Biodiversity Strategy 2030 calls for the restoration of ecosystems and the sustainable management of land use. (European Commission, 2026b). In parallel, the Corporate Sustainability Reporting Directive (CSRD) imposes new requirements for environmental, social, and governance reporting, making sustainability performance a critical dimension of corporate accountability. (Latham & Watkins, 2025)

2.2 Invasive Species in Highway Corridors and Biodiversity Potential of Roadside Slopes

Highway corridors function as critical interfaces between infrastructure and the environment. (Coffin, 2007). Roads influence ecosystem structure, biodiversity, and ecological processes, as physical barriers and as zones of continuous interaction between what is built and what is nature. To better understand biodiversity across its highway concession and support decision-making, Brisa commissioned in 2023 the development of a strategy to address this issue, to an external consultancy company (NBI, 2023). Under this strategy, all highway's verges were divided into 5 km-long sections that were ranked according to their ecological and landscape value. These were categorised into either Areas of High Natural Value (AAVN) or Other Semi-Natural Areas (OASN) (NBI, 2023). Naturally, AAVN represent areas where a greater presence of natural habitats and a bigger potential for biodiversity and ecosystem services are present. Figure A2 in Annex 2 illustrates all the AAVNs that can be found along the BCR network.

These segments have also been overlapped with the Classified Areas (AC), defined by the National System of Classified Areas (Sistema Nacional de Áreas Classificadas - SNAC, in its Portuguese designation). (DL nº 242/2015). This results in four different and distinct types of classifications applicable to BCR highway corridors (see table 1).

TABLE 1 – AREA CLASSIFICATIONS

BCR Classified Area Type	**Key features**	**Total estimated area in BCR concessions (ha)**
Areas of High Natural Value (AAVN)	High biodiversity, landscape diversity, and strong potential for ecosystem service provision	675,2
Areas of High Natural Value + National Classified Areas (AAVN + AC)	High biodiversity, landscape diversity, and strong potential for ecosystem service provision, overlapped with a National Classified Area	146,81
Other Semi-Natural Areas (OASN)	All green areas that are not considered Areas of High Natural Value	3487,5
Other Semi-Natural Areas + National Classified Areas (OASN + AC)	All green areas that are not considered Areas of High Natural Value overlapped with a National Classified Area	500,45

According to Lemke et al. (2018), road corridors constitute ecological disturbance zones that often facilitate the spread of IAS, creating potential invasion corridors. The authors showed that traffic intensity is a key predictor of dispersal success - higher traffic volumes led to longer dispersal distances and greater colonization rates - and conclude that traffic-mediated dispersal is a routine and predictable process that substantially accelerates the spread of invasive roadside populations, due to vehicle slipstream (Lemke et al., 2018).

Numerous factors including road type, traffic density, and type of road management determine the ecological profile of highway corridors. The type of road is vital, as wide multilane highways exert stronger barrier effects on wildlife movements and fragment habitats more severely than secondary or local roads (Coffin, 2007; Forman et al., 2003). Traffic density also amplifies these effects, as high volumes of vehicles increase wildlife mortality through collisions (Follak, 2018; Coffin, 2007). Finally, the type of road management plays a decisive role. Vegetation management regimes, like mowing frequency, herbicide application, and revegetation strategies, can either mitigate ecological impacts and support biodiversity or accelerate habitat degradation and invasive spread when poorly designed (Forman et al., 2003; Coffin, 2007; Follak, 2018). Taken together, these factors make highway corridors ecologically active, as they seem to be dynamic environments, whose impacts and opportunities depend on both structural and managerial variables.

Additionally, roadside verges and slopes hold a significant potential as habitats and biodiversity reservoirs. The linear configuration and connectivity of road verges allow them to function as ecological corridors, supporting pollinators, small mammals, and another biota (Phillips, 2019; Phillips et al., 2020). Studies on roadside slope restoration have shown that vegetative interventions are able to accelerate the recovery of plant communities and strengthen habitat structure (Wang et al., 2021).

Similarly, research on the woody colonization of slopes indicates that these structures can become valuable vegetated corridors when favourable conditions are provided (Arenas et al., 2015). Vegetation enhances slope stability through both hydrological and mechanical processes. MacNeil et al. (2001) demonstrated that roots increase soil shear strength by reinforcing the substrate, while transpiration and canopy interception reduce moisture content and pore water pressure. These combined effects reduce erosion risks and contribute to the long-term stability of slopes. Pollinator-oriented roadside management, like reduced mowing or native plant establishment, has been formally recommended by transportation and conservation agencies.

The US Federal Highway Administration's guidance (Hopwood et al., 2015) emphasizes that these practices can enhance pollinator habitats while reducing maintenance costs and aligning with safety and aesthetic requirements at the same time. Recent research indicates that even road verges dominated by non-native species can sustain generalist pollinators and maintain essential pollination services in highly disturbed landscapes (Martini et al., 2025). However, native-plant-based management remains the best approach for maximizing ecological value (Martini et al., 2025).

2.3 Key Invasive Alien Species in Brisa Concessão Rodoviária's Highway Slopes

According to Brisa's Desmatações e Abates Ficha de Trabalho (2025), a total of ten invasive and infestant species had been previously identified as having a high likelihood of occurring on highway slopes within the BCR network. (See Table 2)

TABLE 2 – SPECIES PREVIOUSLY IDENTIFIED BY BRISA (2025)

Species identified by Brisa
Acacia spp.
Ailanthus altissima
Arundo donax
Phragmites communis
Rubus ulmifolius
Eucalyptus spp.
Ricinus spp.
Cortaderia selloana
Hakea sericea

From this list, three key species of invasive alien plant species emerge as the most relevant in the Portuguese context: *Arundo donax*, *Acacia dealbata*, and *Cortaderia selloana.* These are detailed below:

2.3.1 Arundo donax (Giant Reed)

Arundo donax is one of the world's most widespread and ecologically disruptive invasive grasses, thriving particularly in Mediterranean and semi-arid environments (Kato-Noguchi and Kato, 2025). The U.S. Fish and Wildlife Service Ecological Risk Screening Summary (ERSS, 2017) characterizes this species as a high-risk invader, which is already established across every continent except Antarctica. Originally native from some parts of Asia, *Arundo donax* was historically transported by humans for multiple uses including roofing, musical instruments, fencing, and erosion control (CABI, 2014; Perdue, 1958). From these intentional introductions, it has spread aggressively throughout warm-temperate and subtropical regions, including the Mediterranean Basin, where it is now naturalized and highly invasive (GISD, 2011).

Arundo donax can be described as a tall, bamboo-like grass that can reach up to six meters in height, forming dense, clonal stands composed of thick culms and extensive rhizome networks (GISD, 2011). The leaves are large and sharply margined, and the plant produces a conspicuous panicle in late summer. However, unlike many grasses, it reproduces almost exclusively vegetatively (new shoots emerge from rhizomes or from stem fragments capable of rooting wherever they contact moist soil). The ERSS 2017 report highlights that *Arundo donax* can expand through layering as much as seven times faster than through rhizome growth alone, particularly in flood zones (Benton et al., 2006; Boland, 2006). The dispersal of seeds is primarily facilitated by human and natural mechanical means, such as machinery, floods, and debris transport (CABI, 2014).

Ecologically, this species is classified as a hydrophyte, preferring moist riparian environments with shallow water tables and high nitrogen availability (GISD, 2011). It tolerates a wide range of soil types and exhibits strong resilience to salinity and disturbance (Ambrose & Rundel, 2007). This tolerance can allow the species to dominate disturbed areas such as riverbanks, drainage ditches, and roadside slopes, precisely the types of microhabitats common along highway concessions such as those of Brisa Concessão Rodoviária. Once established, *Arundo donax* can form root mats more than one meter thick, enabling it to monopolize resources and exclude native vegetation (GISD, 2011). Its growth rate is estimated to be two to five times faster than that of native riparian plants, allowing it to rapidly convert diverse plant assemblages into extensive monocultures (McWilliams, 2004). The species consumes significantly more water than native vegetation, reducing groundwater levels and altering flow regimes (Iverson, 1994). Additionally, *Arundo donax* modifies fire regimes: it is highly flammable and capable of recovering from fire three to four times faster than native vegetation, thereby establishing a self-reinforcing invasive plant-fire cycle (GISD, 2011). As Lambert et al. (2010) emphasize, invasion by *Arundo donax* drastically reduces arthropod diversity, disrupts food webs, and causes declines in avian abundance and richness in riparian systems. From a management perspective, *Arundo donax* is recognized as an ecological and economically high-risk species. The ERSS (2017) concludes that control, eradication, and remediation efforts are extremely costly and rarely fully effective. Conventional control methods include mechanical cutting and herbicide application, but long-term success depends on repeated treatments and restoration with native vegetation to prevent reinvasion (Team Arundo del Norte, 2002).

In the context of Brisa's highway network, *Arundo donax* represents a dual challenge: an ecological invader that threatens riparian biodiversity and an operational hazard that increases maintenance costs and infrastructure vulnerability. Its presence in drainage lines and water-adjacent slopes within the BCR system mirrors global invasion pathways observed along rivers and irrigation channels. Given its established distribution across Portugal's Mediterranean regions (centre and south) and its resilience to standard control measures, *Arundo donax* should be prioritized as a high-risk invasive species within Brisa's ecological management framework.

2.3.2 Acacia dealbata (Silver Wattle)

Acacia dealbata is one of the most aggressive invasive trees within Mediterranean Europe and is currently among the three most prolific *Acacia* invaders in western Iberia (Vieites-Blanco & González-Prieto, 2020). Native to southeastern Australia and Tasmania, it was intentionally introduced to the Iberian Peninsula in the nineteenth century to stabilize railway margins, serve as vineyard guides, and provide ornamental value. Since then, the species has already escaped controlled cultivation and expanded rapidly across forested and mountainous regions of Portugal, with ongoing expansion rates estimated at thousands of hectares per year (Vieites-Blanco & González-Prieto, 2020).

The species' success is also given by a suite of ecological factors that offer high resilience to disturbance and a competitive advantage over native species. These include a high seed production following fire (Le Maitre et al., 2011), which can be common in the Portuguese scenario, due to the occurrence of wildfires during summer periods.

In the Iberian Peninsula, *Acacia dealbata* typically colonizes forest edges, eucalypt plantations, riparian corridors, and disturbed soils (habitats whose microclimatic conditions favour its establishment). Its occurrence correlates positively with areas of frequent wildfire, as burning stimulates seed germination and creates a self-reinforcing fire–invasion cycle (Lima et al., 2024).

Beyond soil alteration, *Acacia dealbata* profoundly affects hydrology and biodiversity. Le Maitre et al. (2011), demonstrate that invasive acacias reduce surface runoff and groundwater recharge, due to high transpiration rates, leading to lower water availability for native species (similar to *Arundo donax*). The habitat homogenization is a result of the presence of this species, since it diminishes floristic diversity and alters natural dynamics in affected ecosystems.

In western Iberia, this species is now present in numerous protected areas, including Peneda-Gerês, Montesinho, and Southwest Alentejo & Vicentine Coast Natural Parks, where eradication efforts have largely been unsuccessful (Vieites-Blanco & González-Prieto, 2020). Control remains challenging, as cutting stimulates vigorous coppicing, herbicide treatments are restricted near water bodies, and repeated interventions are required to deplete the long-lived soil seed bank. Although biological control using seed-feeding beetles (*Melanterius maculatus*) has proven effective in South Africa, authorization for its release in Portugal and Spain is still under assessment (Vieites-Blanco & González-Prieto, 2020). Restoration of invaded slopes or forest margins must, therefore, combine mechanical removal with post-treatment revegetation using native species, alongside measures to reduce nitrogen enrichment.

Acacia dealbata exemplifies the complex ecological and operational threats posed by woody invaders in Mediterranean landscapes. Its persistence and ecosystem-level impacts on fire regimes, soil chemistry, and native biodiversity require long-term, adaptive management strategies integrating prevention, rapid response, and ecological restoration. Within Brisa's highway network, the species' proliferation along forested slopes and riparian buffers increases wildfire risk, obstructs maintenance access, and disrupts ecological connectivity, underscoring the importance of aligning invasive-species control with sustainable infrastructure management.

2.3.3 Cortaderia selloana (Pampas Grass)

Cortaderia selloana, also known as Pampas Grass, is native to the temperate and subtropical regions of South America, particularly southern Brazil, northern Argentina, Uruguay, and central Chile (Lázaro-Lobo et al., 2024). Introduced to Western Europe during the nineteenth century primarily for ornamental purposes, it rapidly became established in a variety of anthropogenic and natural habitats. Historical records indicate that this species was cultivated in botanical gardens across Europe as early as the 1840s, spreading from Ireland and the United Kingdom to continental Europe by the mid-century (Lázaro-Lobo et al., 2024). The species' aesthetic appeal, fast growth, and tolerance to environmental stressors led to its extensive use in landscaping, dune stabilization, and erosion control, inadvertently facilitating its escape and naturalization outside its native area.

Once introduced, *Cortaderia selloana* demonstrated exceptional adaptability, thriving across a broad range of climatic and edaphic conditions. The species is tolerant of drought, salinity, and soil pollution, and is capable of germinating and persisting in sandy, nutrient-poor, and disturbed environments such as road verges, coastal dunes, and construction sites (Lázaro-Lobo et al., 2024; Domènech and Vilà, 2008). Female plants can produce up to 100,000 wind-dispersed seeds per inflorescence, allowing colonization over large distances. The seeds germinate readily in open, high-light environments (Lázaro-Lobo et al., 2024). Furthermore, this species regain strength to grow vigorously after cutting or burning, which complicates eradication efforts and allows populations to persist even under mechanical disturbance (Domènech and Vilà, 2008; Lázaro-Lobo et al., 2024). *Cortaderia selloana* also poses significant threats to native biodiversity and ecosystem functioning. In its invaded range, the species alters successional trajectories and nutrient dynamics by forming dense, monospecific stands that suppress native vegetation through shading and resource competition (Domènech et al., 2008; Lázaro-Lobo et al., 2024). The species produces allergenic pollen capable of extending the grass allergy season in northern Spain by up to three months each year, and its sharp leaf margins can cause skin injuries (Roldão Almeida et al., 2023).

Portugal has recognized this species as invasive through Decree-Law No. 92/2019 and Spain through Royal Decree No. 630/2013. It is currently under evaluation for inclusion in the list of invasive alien species of European Union concern (EU Regulation 1143/2014). Despite this regulatory framework, management remains challenging. Control methods rely primarily on mechanical removal, which is labour-intensive and often ineffective due to rapid regrowth. Herbicidal treatments, though efficient, are restricted in environmentally sensitive zones such as riparian areas.

Public awareness and social participation have emerged as critical elements in the management of the species. Roldão Almeida et al. (2023) highlight that while most Portuguese and Spanish citizens recognize the species and are aware of its invasiveness, knowledge of existing legislation and management practices remains limited. Education level and occupation strongly influence awareness levels, emphasizing the need for targeted outreach initiatives. Projects such as "INVASORAS.PT[1]" have proven effective in raising public consciousness through citizen science, media campaigns, and technical training (Roldão Almeida et al., 2023). Increasing societal engagement is particularly relevant for ornamental invaders like pampas grass, where human preferences and horticultural practices have historically driven propagation and spread.

Cortaderia selloana exemplifies a highly adaptive invasive grass that bridges ecological disturbance and socio-cultural dynamics. Its success in Mediterranean and Atlantic landscapes stems from a combination of ecological plasticity, reproductive efficiency, and anthropogenic facilitation. Within infrastructure corridors, particularly highway slopes, the species not only displaces native flora but also increases maintenance costs and fire risk, challenging both biodiversity conservation and operational safety. Managing its spread requires a dual strategy: integrating ecological restoration techniques with public engagement and policy enforcement to achieve long-term containment and rehabilitation of invaded landscapes.

[1] Homepage | Plantas Invasoras em Portugal

3. METHODOLOGY

3.1 Study Area

This project followed a structured, multi-stage methodology, which included field work designed to identify, map, and characterize the distribution of invasive and fast-spreading plant species along the highway corridors managed by Brisa Concessão Rodoviária (BCR) (Annex 2 - Figure A3).

The following highways were included in this project: A1 – Autoestrada do Norte; A2 – Autoestrada do Sul; A3 – Autoestrada Porto/Valença; A4 – Autoestrada Porto/Amarante; A5 – Autoestrada da Costa do Estoril; A6 – Autoestrada Marateca – Caia; A9 – Circular Regional Externa de Lisboa (CREL); A10 – Autoestrada Bucelas – Carregado; A12 – Autoestrada Setúbal – Montijo; A13 – Autoestrada Almeirim/Marateca; A14 – Autoestrada Figueira da foz/Coimbra norte.

3.2 Field Work Preparation and Pilot Study

Desk research was carried out in advance of field work, and a pilot study was designed to prepare and test *in situ* work conditions.

The first step consisted of a review of official Portuguese databases and scientific literature to identify the most common invasive and infestant species present in Portugal. This included sources such as the national platform Plantas Invasoras em Portugal (Invasoras.pt[2]), the Institute for Nature Conservation and Forests (ICNF), and relevant scientific literature, allowing the establishment of a list of species with the greatest ecological and operational relevance for highway management.

Secondly, a two-day pilot in July 2025 was set up along the A1 (Autoestrada do Norte) in the south–north direction between Lisbon and Porto, covering a section from kilometre 28+000 to kilometre 95+000, which included subsections from Castanheira do Ribatejo to Torres Novas.

Prior to the fieldwork, a safety training session organized by Brisa's Health and Safety Department was done, covering traffic safety protocols, high visibility signalling, and

[2] Fichas de espécies invasoras em Portugal | Plantas Invasoras em Portugal

emergency procedures to ensure safe operations when conducting field work in highway verges.

Digital tools, and GPS-assisted data registration within the company's internal sustainability platforms were used in the project, as the observations in each segment were done using the internal app *CCO+* and data was stored in the internal platform *Portal de Sustentabilidade*. The mobile application PictureThis[3] was selected for its ability to identify plant species from photographs using artificial intelligence, providing real-time confirmation of field identifications and improving data reliability.

This phase enabled the operational testing of Brisa's internal georeferenced platform *CCO+*, which, through GPS recognition, automatically identifies the highway, direction, and kilometre profile (PK), allowing users to record the estimated percentage of area occupied by each invasive species relative to the total concession area for that surveyed point (e.g., a record from PK 5+000 to PK 5+250 with 20% coverage corresponds to 20% occupation by the target species in that surveyed area).

It should be noted that each surveyed point did not have a predefined fixed area, since each observation was highly constrained by the physical characteristics of the highway profile and its surroundings (i.e., slope type, soil characteristics, and natural features).

The pilot study allowed to improve the system's interface, making it more user-friendly. All collected data were stored in Brisa's internal sustainability database, accessible through an internal web portal.

3.3 Field Observations

Using the knowledge gained during the pilot study, field observations were carried out in both directions of the 1100 kilometres of BCR concession highways, totalizing 2200 kilometres of field work. A total of 1182 surveyed points were recorded. Each surveyed point represents an area where at least one Invasive/Infestant Species were recorded. Each point may contain more than one species.

The observations were conducted from a vehicle travelling at low speed along the shoulder of the highways. In specific cases, it was necessary to stop to inspect slopes that could not be adequately assessed from within the vehicle. Full survey observations were

[3] PictureThis - Plant Identifier App | Plant Identification Online

conducted across the entire BCR network and lasted approximately three months. Table 3 presents all surveys dates and the extensions covered. Details for each observation point and respective survey results can be found in Annex 1.

TABLE 3 – FIELD SURVEY INFORMATION: HIGHWAYS, DATES AND EXTENSIONS COVERED

Highway	Survey dates	Total extension covered (Km)
A1	July and August 2025	592.8
A2	August 2025	469.6
A3	September 2025	225.6
A4	September 2025	102.6
A5	September 2025	50
A6	September 2025	315.8
A9	September 2025	68.8
A10	September 2025	79.6
A12	August 2025	58.2
A13	August 2025	157.4
A14	September 2025	79.8

3.4 Prioritization Criteria for Invasive Species Control at Brisa Concessão Rodoviária

From an analytical perspective, the development of a scoring framework for the prioritization of control activities against invasive species in highway corridors at BCR, required the definition of an actionable indicator able to support decision-making within Brisa's sustainability and maintenance programs.

Four indicators and respective scoring criteria, were defined, reflecting both ecological value and operational risk:

1. **Interference with drainage/infrastructure (I)**, reflects the interaction of invasive species with critical infrastructure elements, particularly drainage systems. If the invasive species are partially or fully blocking these structures, it scores higher because of the increased risk of flooding, erosion, and pavement damage.
2. **Location in High Natural Value Area (L)**, reflects the presence of invasive species in areas of higher natural conservation priority, and evaluate their potential impacts on conservation targets. The higher the conservation (protection) status the higher the scoring. In accordance with previous works from Brisa when developing the company's strategy to address the challenge nature conservation (NBI, 2023), this study divides

BCR highway verges into 5 km-long segments (sections) reflecting fairly homogeneous ecological and landscape value. All surveyed points inside each segment are attributed the same conservation (protection) status.

3. **Slope type and role in stability (S)**, distinguishes occurrences according to the slope typology of highway verges (i.e., cut slope or embankment). Scoring criteria recognizes that in cut slopes invasive vegetation may temporarily contribute to soil stabilization and control (lower scores). In such situations, the priority for immediate removal may be downgraded, favouring a more phased control combined with the establishment of native vegetation. Conversely, the presence of invasive vegetation in embankments with no critical stabilising function is scored higher.
4. **Percentage of cover (C)** reflects the spatial dominance of invasive vegetation in each surveyed point. The larger the reported percentage of area covered by invasive vegetation in the surveyed point (using 25% intervals), the higher the score. Accordingly, each surveyed point is associated with a value that reflects the extent of occupation of the corresponding slope by invasive vegetation.

Each indicator is scored along a scale of 1 (minor/small) to 4 (major/large), reflecting the relative importance of the assessed criteria (see Table 4):

TABLE 4 – INDICATORS AND SCORING CRITERIA USED IN THE EVALUATION OF INVASIVE SPECIES CONTROL NEEDS

Indicators	Category / Description	Score
Interference with drainage/infrastructure (I)	No interference	1
	Up to 50% of blocking	2
	Up to 75% of blocking	3
	Fully blocking culverts, ditches or outlets	4
Location in High Natural Value Area (L)	Other Semi-Natural Areas (OASN)	1
	Other Semi-Natural Areas + National Classified Areas (OASN + AC)	2
	Areas of High Natural Value (AAVN)	3
	Areas of High Natural Value + National Classified Areas (AAVN + AC)	4
Slope type and role in stability (S)	Cut slope where vegetation contributes to stability	1
	Embankment or verge (no critical stabilising function)	4
Percentage of cover (C)	1 - 25	1
	26 - 50	2
	51 - 75	3
	76 - 100	4

3.4.1 Analytic Hierarchy Process

In order to define indicator relevance to decision-making, the four indicators were aggregated into a composite score using a weighted linear combination approach. Weights were derived using the Analytic Hierarchy Process (AHP) approach to reflect differences in the relative importance of the evaluated factors.

According to Saaty (1990), the AHP is a multicriteria decision-making method that enables pairwise comparisons, resulting in the definition of relative weights for decision factors. Criteria in the AHP are compared in pairs using a numerical scale from 1 to 9, where 1 indicates equal importance and 9 indicates extreme importance of one criterion over another. These pairwise judgements are then used to derive relative weights that reflect the priorities of the criteria. (Saaty, 1987).

By applying the AHP method in this project we defined that:

- Interference with drainage/infrastructure (I) has “extreme importance” compared to the other indicators, corresponding to nine times more relative importance.
- Slope type and role in stability (S) has intermediate importance, being moderately more relevant (value of 3) than both the location within High Natural Value Areas (L) and the Percentage of cover (C).
- Percentage Cover (C) and Location in High Natural Value Area (L) contribute similarly (value of 1) to the overall prioritization.

Table 5 presents the numerical relative weights’ Matrix following Saaty (1990) AHP.

TABLE 5 – ANALYTIC HIERARCHY PROCESS (AHP) RELATIVE WEIGHTS’ MATRIX

	Interference with drainage / infrastructure (I)	**Location in High Natural Value Area (L)**	**Slope type and role in stability (S)**	**Percentage of cover (C)**
Interference with drainage/ infrastructure (I)	**1**	9	9	9
Location in High Natural Value Area (L)	1/9	**1**	1/3	1
Slope type and role in stability (S)	1/9	3	**1**	3
Percentage of cover (C)	1/9	1	1/3	**1**
∑	1.33	14	10.67	14.00

According to Saaty (1990) method, additional steps are required to determine the final weights assigned to each indicator, therefore representing their relevance to decision-making.

First, the relative weights matrix needs to be normalized, by dividing each value in the original matrix by the sum of its respective column (see Table 5). This procedure yields the following normalized matrix (1):

$$(1)\quad \begin{bmatrix} (\frac{1}{1,33}) & \frac{9}{14} & \frac{9}{10,67} & \frac{9}{14} \\ \frac{\frac{1}{9}}{1,33} & \frac{1}{14} & \frac{\frac{1}{3}}{10,67} & \frac{1}{14} \\ \frac{\frac{1}{9}}{1,33} & \frac{3}{14} & \frac{1}{10,67} & \frac{3}{14} \\ \frac{\frac{1}{9}}{1,33} & \frac{1}{14} & \frac{\frac{1}{3}}{10,67} & \frac{1}{14} \end{bmatrix}$$

Secondly, the eigenvector of the normalized matrix needs to be determined, by calculating the mean value of each row in the normalized matrix. This procedure yields the following normalized matrix (2):

$$(2)\quad \begin{bmatrix} 0,72 \\ 0,06 \\ 0,15 \\ 0,06 \end{bmatrix}$$

The resulting final weights of these procedures were respectively 0.72 (72%) for Interference with drainage/infrastructure, 0.15 (15%) for Slope type and role in stability, and 0.06 (6%) for both Location in High Natural Value Area and Percentage of cover. All consistency criteria were tested and verified, thereby ensuring the reliability of the method.

Finaly, equation (3) is obtained,

$$(3)\ Score = (0,72\, S_I + 0,06\, S_L\ + 0,15\, S_S\ + 0,06\, S_C)$$

where S_I represents the score assigned to the criterion Interference with drainage/infrastructure, S_L is the score attributed to Location in High Natural Value Area, Ss the score attributed to Slope type and role in stability, and S_C the score attributed to Percentage of cover.

3.4.2 The Binary Adjustment

A binary adjustment to the above equation was incorporated as a soft constraint. In multi-criteria evaluation, constraints may act either as strict Boolean exclusions or as softer limiting conditions when no clear boundary can be defined. Soft constraints reduce suitability without eliminating alternatives and therefore provide a more realistic representation of the result. (Eastman, 1999). In the construction of composite indices, adjustment factors external to the weighted aggregation are typically defined based on a sensitivity analysis to ensure robustness (OECD/JRC Handbook on Composite Indicators, 2008).

In accordance with this practice, a penalty parameter of 0.25 points, or approximately 6% of the scoring range (1-4), was assigned when only infestant species, as opposed to invasive species, were observed in surveyed points, as infestant species may not exhibit invasive behaviour and therefore lower the priority score for interventions.

The magnitude of the penalty was selected to represent a moderate adjustment and was evaluated through sensitivity testing to validate the stability of the prioritization outcomes across plausible parameter values.

3.5 Brisa Risk & Invasive Species Assessment - Operational Priority Score (BRISA-OPS)

As a result of the above-described steps, an integrated index to support the prioritization of invasive species control at BCR was developed.

Brisa's Risk and Invasive Species Assessment - Operational Priority Score (BRISA-OPS) is calculated using equation (4):

$$(4)\ Brisa - OPS = (0{,}72\ S_I + 0{,}06\ S_L\ + 0{,}15\ S_S\ + 0{,}06\ S_C) - 0{,}25^*$$

where all variables are the same as in equation (3) and the coefficient 0,25* represents the penalty applied when only infestant species are observed in the surveyed point.

Because of the associated penalty the final BRISA-OPS scoring framework scale is modified to include a minimum final operation score of 0.75 (lowest priority), and therefore $BRISA\text{-}OPS\ \in [0.75, 4]$.

The final range of values for BRISA-OPS invasive species control priorities is presented in table 6 below.

TABLE 6 - BRISA-OPS INVASIVE SPECIES CONTROL OPERATIONAL PRIORITY LEVELS

BRISA-OPS value	Operational Intervention Priority Level
[0.75 – 1.00]	Low priority
[1.01 – 1.69]	Moderate priority
[1.70 – 2.49]	High priority
[2.50 - 4]	Very High priority

BRISA-OPS evaluates the 1182 surveyed points recorded during the field surveys, attributing to it a final classification of Prioritization, based on defined classes.

These classes were defined by partitioning the composite score into four intervals, corresponding to increasing levels of management urgency. Sites classified as Very High Priority (scores between 2,50 and 4,00) require immediate or short-term management intervention due to their elevated potential for infrastructure interference. High Priority sites (scores between 1,70 and 2,49) also present significant management concerns and therefore warrant targeted monitoring and preventive measures to prevent escalating into critical conditions. Moderate Priority sites (scores between 1,01 and 1,69) exhibit acceptable conditions and are suitable for routine monitoring, with intervention triggered by observed changes in key indicators. Finally, Low Priority sites (scores between 0.75 and 1.00) are characterized by minimal interference and low potential impact, requiring only periodic or opportunistic monitoring.

3.6 Study limitations

The methodology adopted in this project has limitations, mostly related to field work and observation recording. These must be acknowledged and considered when interpreting the results.

First, the estimation of percentage cover for each invasive or infestant species was carried out visually in the field, meaning that all the percentages are approximate and inherently subjective. All observations were carried out by a single observer, which adopted a consistent criteria. However, the method cannot be considered a strictly quantitative measurement and should be interpreted as a semi-quantitative indicator of relative abundance.

Second, in several sections of the highway network, the presence of high or steep slopes made it difficult and even unsafe to access the full extent of the vegetated surface, particularly on tall cut slopes. In these cases, cover estimates had to be made from the verge or carriageway, which may reduce the observation accuracy for species growing in the upper parts of the slope.

Third, there are segments of the highway network without a continuous verge or with restricted shoulder width, which prevents driving at very low speed for detailed observation. In such locations, some occurrences may have been under-detected or only partially recorded.

Together, these factors imply that the dataset is not an exhaustive or perfectly accurate census of every individual plant but rather a robust overview of patterns and hotspots of invasion at the corridor scale.

4. RESULTS

This chapter analyses the spatial distribution of invasive and fast-spreading plant species across the highway corridors managed by BCR and the results of the testing and application of the Brisa Risk & Invasive Species Assessment - Operational Priority Score (BRISA-OPS) as a tool for invasive species operational control.

4.1 Spatial distribution of invasive plant species

A total of 1182 points where IAS and/or infestant species were observed was recorded during this project. These points were surveyed in detail for species identification and application of the BRISA-OPS tool. Table 7 identifies all the invasive and infestant species found during the surveys.

TABLE 7 – INVASIVE ALIEN SPECIES (IAS) AND INFESTANT SPECIES FOUND

Species Found in BCR network
Acacia dealbata
Acacia longifolia
Ailanthus altissima
Arundo donax
Calystegia silvatica
Cortaderia selloana
Eryngium pandanifolium
Eucalyptus spp.
Hakea sericea
Phragmites communis
Ricinus spp.
Rubus ulmifolius

Of the 1.182 surveyed points, 514 were located along the A1 (Autoestrada do Norte), accounting for approximately 43% of the total observations. The second highest concentration was observed on the A3 (Autoestrada Porto - Valença), which represented about 17% of all recorded points, followed by the A4 (Autoestrada Porto - Amarante), with approximately 9% of the total.

This spatial distribution indicates a markedly higher prevalence of IAS and infestant species in the northern region of the country. In contrast, the A2 (Autoestrada do Sul), despite encompassing approximately 480 km of surveyed roadway, yielded only 67 surveyed points, corresponding to roughly 6% of the total.

This disparity suggests that regional environmental conditions and landscape characteristics may play a significant role in influencing the distribution and intensity of IAS and infestant species occurrences across the network.

Figure A4 in Annex 2 illustrates the overall distribution of points across the BCR network where IAS were surveyed and recorded.

Figure 1 in depicts the corresponding spatial map of the distribution presented above.

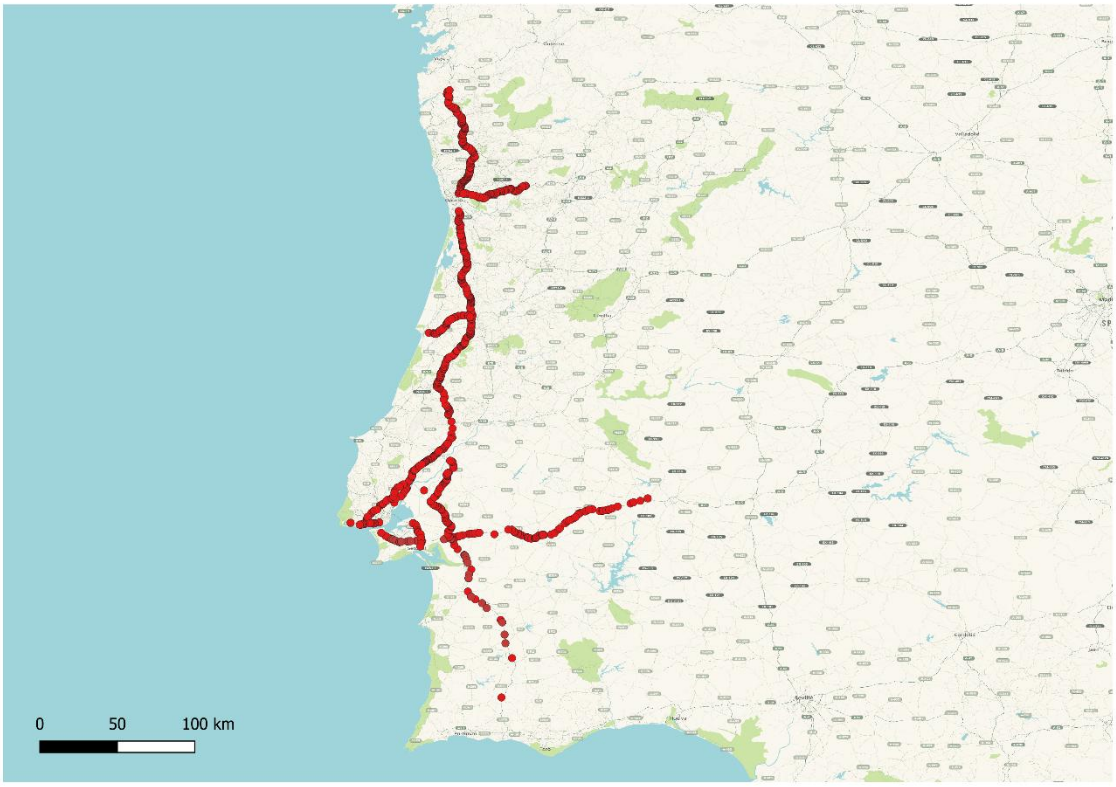

FIGURE 1 – Points where IAS/Infestant Species were observed, surveyed and recorded across the BCR Network

The project further revealed that the three most prevalent IAS within the BCR network are *Arundo donax*, *Acacia dealbata*, and *Cortaderia selloana*, with a particular concentration in the central and northern regions of the country. *Arundo donax* accounted for approximately 14% of all recorded species occurrences, being present at 239 points across the network.

In second place, *Acacia dealbata* was identified at 160 points, representing about 9% of the total species records. Similarly, *Cortaderia selloana* ranked third, with 151 points, also corresponding to approximately 9% of the total. It is important to note that each surveyed point may include one or more species.

Two non-invasive but infestant species accounted for a substantial proportion of the total records. *Rubus ulmifolius* represented approximately 39% of all species occurrences, with 665 points, while *Eucalyptus spp*. accounted for about 13%, totalling 223 points.

In Portugal, the extensive presence of *Eucalyptus* plantations is primarily the result of deliberate human introduction rather than natural dispersal or intrinsically invasive behaviour (Invasoras.PT, 2026). So, for the purpose of this project, this species was considered to be infestant, rather than invasive.

In addition to the presence of IAS, the extensive occupation by species exhibiting this infestant behaviour constitutes a significant and widespread condition throughout the network. The presence of *Eucalyptus* spp. on highway slopes poses a significant risk of tree failure, particularly under adverse meteorological conditions such as intense rainfall, and strong winds. This may result in the obstruction of traffic lanes, damage to safety barriers and drainage infrastructure, and the creation of hazardous conditions for road users. Consequently, the management of *Eucalyptus* spp. in slope environments is critical to minimizing the probability of tree fall and associated safety risks, especially in regions subject to frequent extreme weather events.

Figure 2 illustrates the proportion of species registered across all the surveyed points.

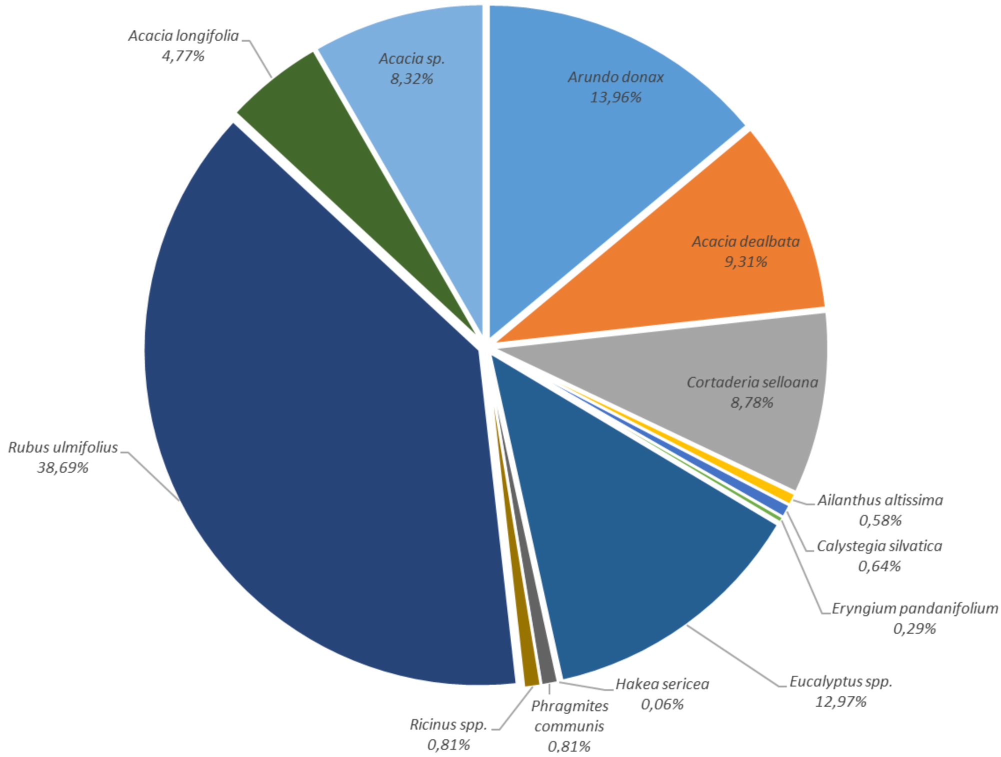

FIGURE 2 – Proportion of species observed, surveyed and recorded across the BCR

4.2 BRISA-OPS Indicator Results

4.2.1 Interference with drainage / infrastructure

The project identified twenty points at which the presence of IAS or infestant species compromises the infrastructure drainage system. Of these twenty points, fourteen were classified as interfering with up to 50% of the drainage system associated with the respective slope, while six were considered to interfere with up to 75% of that system. No evidence was found of drainage systems being fully obstructed by the presence of IAS or infestant species.

Of the 1182 points, 1162 were classified as exhibiting no interference with drainage systems, corresponding to 98.31% of the total. This outcome is attributed to the continuous maintenance and intervention to which these systems are subject, as it is the responsibility of Brisa Autoestradas to ensure both the proper upkeep of the infrastructure and the associated standards of road safety.

Table 8 presents the number of surveyed points exhibiting interference with the infrastructure, while Figure 3 presents the corresponding spatial map of this distribution.

TABLE 8 – POINTS EXHIBITING INTERFERENCE WITH THE INFRASTRUCTURE

Interference with infrastructure	Number of Points	%
No interference	1162	98.31%
Up to 50% of blocking	14	1.18%
Up to 75% of blocking	6	0.51%
Fully blocking	0	0.00%
Total	1182	100%

FIGURE 3 – Spatial Distribution of Interference with Drainage Systems

4.2.2 Location in Natural Area

Of the 1182 surveyed points, 938 (79.36%) were located in Other Semi-Natural Areas (OASN). Among the remaining points, 80 (6.77%) were situated in Other Semi-Natural Areas combined with National Classified Areas (OASN + AC), 142 (12.01%) occurred within Areas of High Natural Value (AAVN), and 22 (1.86%) were recorded in Areas of High Natural Value combined with National Classified Areas (AAVN + AC).

Table 9 presents the distribution of surveyed points per type of natural location.

TABLE 9 – DISTRIBUTION OF SURVEYED POINTS PER TYPE OF NATURAL LOCATION

Natural Location	**Number of Points**	**%**
Other Semi-Natural Areas (OASN)	938	79.36%
Other Semi-Natural Areas + National Classified Areas (OASN + AC)	80	6.77%
Areas of High Natural Value (AAVN)	142	12.01%
Areas of High Natural Value + National Classified Areas (AAVN + AC)	22	1.86%
Total	1182	100%

4.2.3 Slope Type

Of the 1182 surveyed points, 482 (40.78 %) were registered in cut slopes, whereas the 700 (59.22%) remaining points were registered in embankments.

Table 10 presents the distribution of surveyed points per slope typology.

TABLE 10 – DISTRIBUTION OF SURVEYED POINTS PER SLOPE TYPOLOGY

Slope type	**Number of Points**	**%**
Cut Slope	482	40.78%
Embankment	700	59.22%
Total	1182	100%

4.2.4 Percentage of Cover

Of the 1182 surveyed points, 905 (76.57%) were registered with a percentage cover of 1-25%, 159 (13.45%) with a percentage cover of 26-50%, 92 (7.78%) with a percentage cover of 51-75%, and 26 (2.20%) with a percentage cover of 76-100%.

Table 11 presents the distribution of surveyed points per percentage cover.

TABLE 11 – DISTRIBUTION OF SURVEYED POINTS PER PERCENTAGE COVER

Percentage Cover	Number of Points	%
1 - 25%	905	76.57%
26 - 50%	159	13.45%
51 - 75%	92	7.78%
76 – 100%	26	2.20%
Total	1182	100%

4.3 Application of the BRISA-OPS, Concern Points and Priorities for Action

Based on the BRISA-OPS operational priority levels presented in Table 6, the classification of surveyed points reveals a highly asymmetric distribution of intervention needs, with the vast majority concentrated in the lower to moderate priority ranges and only a very small fraction requiring urgent action.

The project concluded that 6 points were classified as Very High Priority for Intervention, representing only 0.51% of the total points. These points demand immediate attention due to the severity of the detected conditions. They are associated with sites where interference with the drainage infrastructure reached up to 75% blockage, indicating a critical reduction in hydraulic capacity. At this level of obstruction, the system's ability to convey stormwater is significantly compromised, increasing the risk of localized flooding, structural deterioration of adjacent assets, erosion processes, and potential safety hazards. These situations likely require urgent corrective measures, such as mechanical removal of invasive vegetation, structural cleaning, and possibly localized rehabilitation of affected drainage components.

A total of 16 points (1.35%) were classified as High Priority. Most of these locations exhibited interference levels of up to 50% blockage of the drainage infrastructure. Although less critical than the Very High Priority cases, these sites still represent substantial impairment of system performance. A 50% reduction in effective drainage capacity can lead to reduced flow efficiency during high-intensity rainfall events, thereby increasing vulnerability to overflow and sediment accumulation. These points warrant prompt intervention within short-term maintenance planning cycles to prevent progression to more severe obstruction levels. Preventive management at this stage is both technically advisable and cost-effective, as it reduces the likelihood of emergency interventions later.

793 surveyed points (67%) were assigned a Moderate Priority classification. These sites generally reflect early- to intermediate-stage interference conditions, where invasive species presence or sediment accumulation does not affect drainage performance. These points should be incorporated into routine monitoring and medium-term maintenance schedules. Strategic management at this level is essential to prevent escalation into higher priority categories, particularly in areas prone to rapid vegetative growth or recurrent sediment deposition.

Finally, 367 points (31%) were categorized as Low Priority. In most cases, only minor vegetation presence or early signs of encroachment were observed. Although intervention is not urgently required, continued periodic inspection is recommended to ensure that conditions remain stable and to support adaptive management strategies.

The distribution of priority levels demonstrates that while severe obstruction cases are rare, there are a small number of points where critical vulnerabilities within the drainage network may occur. Conversely, the predominance of Moderate and Low Priority classifications indicates that most of the infrastructure remains functionally adequate, provided that systematic monitoring and preventive maintenance strategies are consistently implemented. This prioritization framework supports efficient allocation of operational resources, directing immediate attention to the most critical sites while maintaining proactive oversight across the broader network.

Table 12 presents the number of points for each Priority of intervention.

TABLE 12 – NUMBER OF POINTS FOR EACH PRIORITY OF INTERVENTION

Priority of Intervention	Number of Points	%
Very High Priority	6	0,51%
High Priority	16	1,35%
Moderate Priority	793	67,09%
Low Priority	367	31,05%
Total	1182	100%

5. CONCLUSIONS AND FUTURE WORK

5.1 Main Findings

This project developed a strategic and operational score, BRISA-OPS, designed for the management of IAS and infestant species along the highway slopes of BCR, integrating ecological risk and infrastructure safety.

Results demonstrate that invasive and fast-spreading species are widely distributed across the BCR network, although their spatial occurrence is heterogeneous and strongly influenced by regional environmental conditions. Northern areas particularly around the A1, A3, and A4 showed the highest concentration of surveyed points, whereas southern corridors exhibited comparatively lower densities of occurrences.

Among the recorded species, *Arundo donax, Acacia dealbata, and Cortaderia selloana* emerged as the most relevant invasive species.

BRISA-OPS constitutes the central methodological contribution of the project. By combining ecological sensitivity (AAVN presence), infrastructural interference (especially drainage obstruction), slope stability role, and species' percentage cover, the result enables a transparent classification of intervention urgency. The application of an Analytic Hierarchy Process (AHP) weighting scheme further strengthens the robustness of the prioritization logic, emphasizing drainage interference as the dominant indicator.

Despite the widespread presence of IAS and infestant species, only a very small proportion of surveyed points required immediate intervention, with most locations classified as moderate or low priority

5.2 Future Work

Future research should expand the present assessment beyond spatial prioritization and ecological risk classification toward the quantitative evaluation of ecosystem-service outcomes associated with IAS control, particularly in relation to carbon sequestration, biodiversity recovery, and slope-stabilization functions.

This project establishes a strategic framework for identifying priority intervention areas along the BCR network, but it does not directly quantify the biophysical benefits derived from replacing IAS-dominated vegetation with native plant communities, which can be considered a knowledge gap for sustainability-oriented infrastructure management.

Future studies should focus on slopes exhibiting a high percentage cover of IAS and quantify both above-and below-ground carbon stocks. This should allow to compare the amount of carbon sequestered in these areas with that stored on slopes dominated by native vegetation. Such analysis may provide evidence of a potential positive contribution to the Brisa Group's Net Zero target for 2040.

A second line of investigation relates to the role of vegetation composition in slope stability and hydrological regulation. Although IAS may temporarily contribute to soil reinforcement in certain contexts, long-term dominance by invasive monocultures can alter root architecture, water consumption, and fire regimes, potentially undermining ecosystem resilience and infrastructure safety.

Future experimental trials comparing root tensile strength, evapotranspiration rates, and erosion resistance between IAS and native assemblages would clarify whether native restoration simultaneously enhances carbon storage and geotechnical stability, thereby strengthening the business case for ecological intervention.

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ANNEX

The online Annex 1 can be found here: [BRISA - OPS.xlsx]
The online Annex 2 can be found here: [Figures' Annex.pdf]