

Managing plant invasions that pose risk to protected areas: a case study

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Abstract

Invasive non-native plants in the surroundings of municipal protected areas were eliminated while determining best management methods and recording control costs. Control methods were defined for the key invasive non-native species in the ecosystem, all identified as introduced through the ornamental plant trade. The selection of high-risk species was made based on the plants' history of invasion in similar ecosystems in other areas in Brazil or locally, corroborated by expert opinion. Control costs were calculated from the total investment divided by the number of working hours and subdivided in cost categories, registered in detail to provide reference for future contracts issued by the municipality. A series of tests were performed for *Asparagus densiflorus*, with best control results obtained with a solution of Metsulfuron Methyl 0.15g/l + 1% Glyphosate + 15 drops penetrant + 20 drops dye + water, and for *Furcraea foetida*, with high efficacy obtained with a 2% solution of Triclopyr + dye + water applied to the base of cut leaves and central stem. The same method and solution were successfully applied to cut stumps and the base of the central stem of *Yucca filamentosa*, while *Asparagus setaceus* was highly susceptible to 1% Glyphosate + dye + water. *Carpobrotus acinaciformis* was fully controlled with a solution of Glyphosate at 1% dilution. The total cost amounted to US\$ 51,894.00, a cost per hour of US\$ 23.25. Financial mechanisms such as the public policy applied to our work may be a model for potential adoption by other countries.

Keywords: biological invasion, coastal ecosystem, chemical control, control costs, coastal scrub, invasive non-native plants, *restinga*.

Resumo

Plantas exóticas invasoras nas imediações de unidades de conservação municipais foram eliminadas, ao mesmo tempo que permitiram definir métodos de controle e registrar custos do manejo. Métodos de controle foram definidos para as cinco espécies de maior risco para a restinga, todas introduzidas como plantas ornamentais nas proximidades. A seleção de espécies de alto risco foi feita com base no histórico de invasão em ecossistemas análogos em outras áreas no Brasil ou localmente, corroborada pela opinião de especialistas. Os custos de controle foram estimados a partir do investimento total dividido pelo número de horas trabalhadas e subdivididos em categorias, com registros detalhados a fim de prover futura referência à gestão municipal. Diversos testes de controle foram realizados para *Asparagus densiflorus*, com melhores resultados obtidos com uma solução de Metsulfuron Metil 0.15g/l + 1% Glifosato + 15 gotas de penetrante + 20 gotas de corante diluídos em água, e para *Furcraea foetida*, com alta eficácia obtida com o uso de solução de Triclopyr em diluição de 2% em água com corante, aplicada na base das folhas e do broto apical. O mesmo método e a mesma solução foram aplicados com sucesso a tocos e na base do broto apical de *Yucca filamentosa*. *Asparagus setaceus* foi altamente suscetível a uma solução de 1% Glifosato diluído em água com corante. A mesma solução foi empregada com sucesso para *Carpobrotus acinaciformis*. O custo total do controle foi de US\$ 51.894,00, ou US\$ 23,25 por hora de trabalho. Mecanismos de financiamento como a política pública de compensação ambiental aplicada a este trabalho podem servir de modelo para adoção por outros municípios e estados brasileiros, assim como por outros países.

Palavras chave: invasão biológica, restinga, controle químico, custos de controle, plantas exóticas invasoras.

Introduction

Invasive non-native species are listed among the five major causes of biodiversity loss worldwide (Roy et al. 2023). In protected areas, some causes of biodiversity loss are minimized, highlighting biological invasions as a major concern along with the effects of global climate change, which can exacerbate the impacts of invasions (Roy et al. 2023; Dudley et al. 2010). Because protected areas host important natural remnants and threatened species, the impacts of invasive species can be even worse than in other areas (Foxcroft et al. 2014).

Controlling invasive non-native plants in the surroundings of protected areas is a strategic preventative approach to protect biodiversity. Intentional introduction pathways, such as escape and release, have played a major role in plant introductions (Roy et al. 2023). The global trade in ornamental nursery stock is the dominant pathway by which invasive non-native plants have been introduced worldwide (Hulme et al. 2017) and in Brazil (Ziller et al. 2026) and are often prevalent in protected areas, as observed in Kruger National Park, where 80%

of the invasive plants are ornamentals (Foxcroft et al. 2019). This approach carries additional challenges linked to the need of reaching out to the public with the aim of increasing awareness, but also dealing with lack of understanding or simply, lack of cooperation of private property owners. In a context where specific regulations are not available for certain areas or species, working around protected areas can be key to prevent future invasions, but also frustrating due to the difficulty of legal enforcement for public cooperation.

From a preventative point of view, it is relevant to consider a broader landscape, identifying sources of propagules that may reach protected areas and start new invasion processes. This approach also favors the best use of scarce financial resources, enabling control actions in order to avoid invasion and further spread. Complementarily, records of costs and yield are important for planning and supervision of results. Given usual funding restrictions, the cost of inventorying every plant to be taken out would hinder the feasibility of actual control. Therefore, instead of investing in a detailed survey, work may be paid per area or working day, and daily results carefully

recorded for future cost reference and yield (Ziller et al. 2021).

Another challenge lies in the need to adapt control methods indicated in the global literature because herbicides or active ingredients are often not available locally, requiring efficiency trials before the work can be scaled up. Adaptive management is therefore the option, with trials conducted over relatively large areas until the desired control efficiency is reached. Responses to specific management actions are context specific, influenced by the current status or structure of the system (Seastedt et al. 2008).

Our objectives were to determine control methods for high-impact non-native invasive plants in order to reduce impacts on protected areas and their surroundings, and derive cost estimates for invasive non-native plant control to subsidize future contracts. Our case study showcases a model of public policy used to fund ongoing management in Brazil that may be applied in different contexts and countries.

Materials and methods

Study area

The work was conducted at Praia Mole and Morro do Gravatá, in Florianópolis, Santa Catarina, Brazil (coordinates -27.604620, -48.434455) (Figure 1). The climate is classified as humid subtropical (Cfa in the Köppen-Geiger classification), with hot and humid summers and cool to mild winters. Praia Mole is a stretch of beach and *restinga* extending approximately one kilometer in length. “Restinga” ecosystems are characterized by thickets of bushes and herbal species growing on sand dunes and sandy soils along the coast, with influence of salt from the ocean and frequent strong winds. The southern end of the beach gives way to a rocky coast (Costão do Gravatá) below a hill covered in Atlantic Forest (Morro do Gravatá).

Part of the hill has been impacted by deforestation and the establishment of African molasses grass (*Melinis minutiflora* P. Beauv.) for pasture, while most of the area is characterized by Atlantic Forest in an intermediate stage of development, with trees up to 18 meters in height and a thick undergrowth. The rocky coast is made of large granite boulders and basalt rocks along the shore, on and among which specialized plants have their habitat. Specific legislation exists to protect these ecosystems from human intervention, as well as to restore areas that have been degraded in the past. Therefore, we interacted with owners and the general public with the aim of obtaining permission to work in private areas, as well as to raise awareness on problems caused by non-native plants and promote their replacement by indigenous species.

Five beach restaurants/bars line the shore on the beach. Invasive non-native ornamental plants cultivated in the gardens of restaurants have spread to the vicinity and are increasingly gaining territory, functioning as propagules for colonization of protected areas.

This area was selected by the municipality as a strategic priority for the control of invasive non-native plants in order to prevent spread to nearby municipal protected areas, especially Monumento Natural Municipal da Galheta (Galheta Municipal Natural Monument) to the North, and Parque Natural Municipal das Dunas da Lagoa da Conceição (Lagoa da Conceição Dunes Natural Municipal Park) to the West (Figure 1).

Species inventory and high-risk species for control

A rapid inventory was conducted in an area of approximately 100 hectares over three days of field work. All existing trails and the entire stretch of beach were surveyed, as well as the rocky coast and the adjacent hill to mark all non-native plant occurrences with a GPS. The data were compiled in a Microsoft Excel spreadsheet, then converted to a spatial file used on

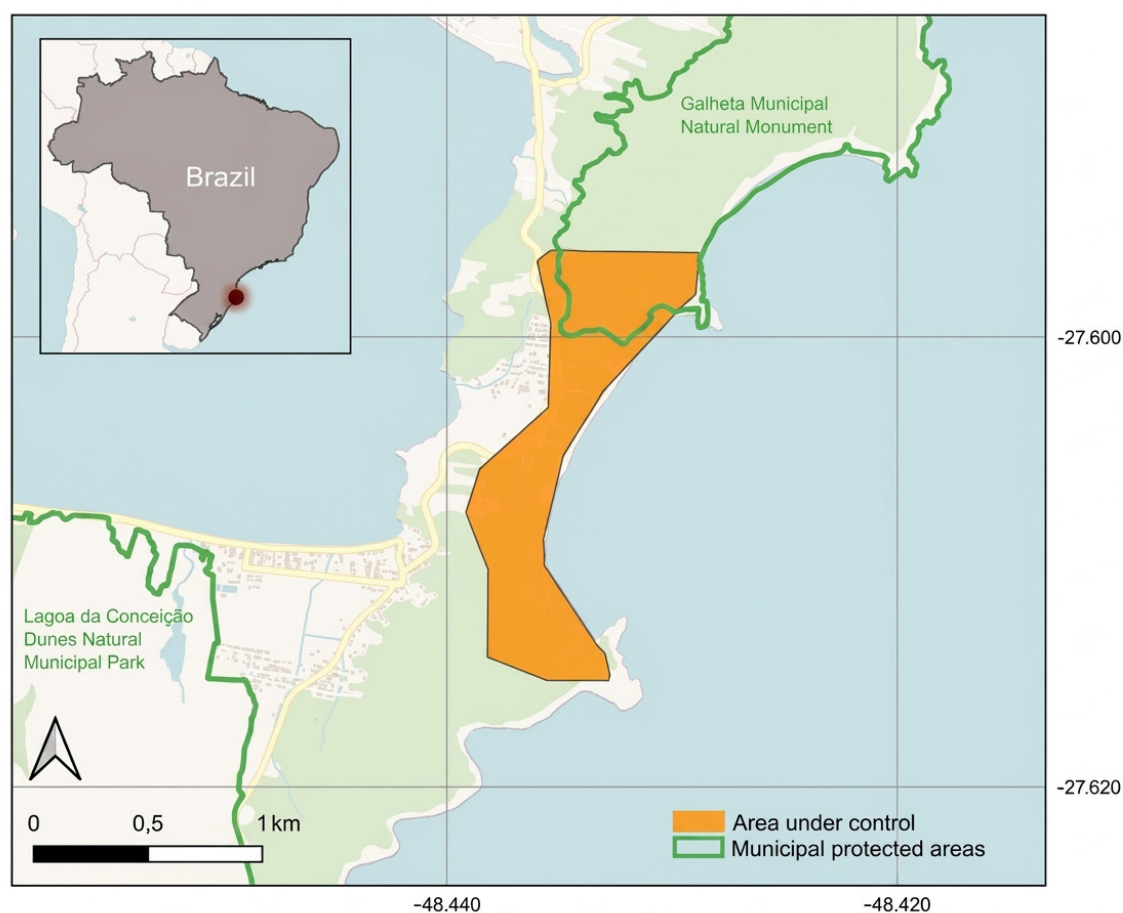


Figure 1. Map of the area under control of invasive non-native plants at Praia Mole and Morro do Gravatá, in Florianópolis, Santa Catarina, Brazil. The municipal protected areas nearby are shown: Monumento Natural Municipal da Galheta (Galheta Municipal Natural Monument) to the North, and Parque Natural Municipal das Dunas da Lagoa da Conceição (Lagoa da Conceição Dunes Natural Municipal Park).

Google Earth in the control work. The majority of plants was identified based on existing knowledge, while a few species were photographed and identified from ornamental plant books and digital references.

Species were classified as invasive when listed as such in the National Invasive Alien Species Database (The Horus Institute 2023). The selection of high-risk species was made based on the plants history of invasion in similar ecosystems, in other areas in Brazil, or locally, corroborated by expert opinion. Although all species classified as invasive may pose some level of risk, we used local expert knowledge and data on actual invasion processes already recorded for the species to corroborate the level of invasion risk to the ecosystems in the local context. High risk species are those seen to frequently invade *restinga* areas and exclude native vegetation; moderate risk species are less frequent, often established, but not capable of dominance; and low risk species are most often planted or cultivated, not being able to expand distribution.

Four of the five species described below belong to the Asparagaceae family. Other five Asparagaceae species were present, but deemed of medium (*Dracaena fragrans* (L.) Ker Gawl.) or low invasion capacity. The fifth species is in family Aizoaceae (*Carpobrotus acinaciformis* (L.) L.Bolus). The following five species described were prioritized for control due to their overall presence in the area, reproductive capacity, persistence, level of dominance (in the case of *Asparagus* spp.), and invasive capacity in *restinga* ecosystems.

Furcraea foetida (L.) Haw. is native in Central America, Colombia, the Guianas, and Suriname, and most likely the islands closest to the coast of northern South America (CABI Invasive Species Compendium 2024a). In Brazil, the oldest records date from the seventeenth century, when it was cultivated for fiber (García-Mendoza 2001). It reproduces by growing a long, thick central stem up to 5m in height, on which flowers bloom, then develop into bulbils, vegetative reproductive structures that fall to the ground ready to take root and develop into full plants. One large plant can generate more than 2,500 bulbils in the reproduction phase. Eventually, the stem will fall over, the impact of the fall serving to catapult bulbils in the surroundings for new growth to begin. As plants often grow on rocky shorelines, bulbils falling on the water float until they find a suitable spot where they develop. The occurrence of isolated plants away from other populations in *restingas* and forests indicates that dispersal probably also occurs by animals, most likely bats (PIER 2013).

Yucca filamentosa L. is native to the eastern side of the United States, and cultivated as an ornamental plant in many countries. Information on the invasiveness of this species is scarce, with references in South Africa and Belgium (Verloove 2010) as occurring in natural areas.

Asparagus setaceus (Kunth) Jessop is native to Eastern Africa. It has been widespread for ornamental use and is listed as invasive in Australia, New Zealand, Cuba, and Hawaii, as well as on many islands in the Pacific Ocean (CABI Invasive Species Compendium 2024b). It is a climber that can smother native plants and form dense thickets.

Asparagus densiflorus (Kunth) Jessop, formerly identified as *Asparagus aethiopicus* L., is native to South Africa. References of invasiveness are available for the United States (Florida, California, and Hawaii), Australia (California Invasive Plant Council 2024), New Zealand, Cuba, and the Bahamas (CABI Invasive Species Compendium 2024c). It is a highly invasive, shade-tolerant perennial plant very difficult to control once established due to its extensive, thick root structure and the ability to regrow from small parts of roots. Colonies are readily formed, displacing native vegetation and preventing the reestablishment of indigenous species (University of Florida 2024).

Carpobrotus species are succulent plants mostly indigenous to South Africa that have been introduced for ornamental use as well as to stabilize coastal dunes worldwide. They are invasive in the United States, Mexico, Argentina, Cabo Verde, Azores, Spain, France (Novoa et al. 2023; CABI Invasive Species Compendium 2024d). In southern Brazil, *Carpobrotus acinaciformis* has become more frequent as people try to protect frontal dunes from erosion aggravated by extreme weather events such as extra tropical cyclones forming on the ocean.

Table 1. Chemical control treatments applied to priority invasive non-native plants in Praia Mole, Florianópolis, Brazil.

Scientific name	Chemical treatment
<i>Asparagus densiflorus</i>	Foliar spray with Metsulphuron Methyl 0.15g/l + 1% Glyphosate + 15 drops penetrant + 20 drops dye + water
<i>Asparagus setaceus</i>	Foliar spray with Metsulphuron Methyl 0.15g/l + 1% Glyphosate + 15 drops penetrant + 20 drops dye + water
<i>Carpobrotus acinaciformis</i>	Foliar spray with Glyphosate at 1% dilution in water + surfactant + dye
<i>Furcraea foetida</i>	Cut all leaves and main stem, spray with Tri clopyr at 2% dilution in water + dye
<i>Yucca filamentosa</i>	Remove main central stem and spray with Tri clopyr at 2% dilution in water + dye

Control methods

A review of control methods was conducted for the priority species from invasive species databases available online and technical publications using the combination of Scientific name + invasive + control in the Google Search Engine. The control methods applied are summarized in Table 1.

The method defined for *Asparagus densiflorus* was only reached after performing 12 trials with different herbicides mixes (Supplementary material 1).

Control costs

The costs of control during the period of work were recorded in order to provide reference for the municipal environmental agency for further action in the area and in other areas in the municipality. Records were taken of the number of hours worked each day, number of workers, activities performed and occasional constraints, such as rain when the work was interrupted, and lack of permission by property owners to perform the work. In order to obtain the cost per working hour, the total investment was divided by the number of working hours and classified in categories, while all expenses and numbers of plants eliminated were registered for future reference of costs and yield. Costs included workers’ pay, fuel for transportation, food, herbicides, protective equipment, sprayers, and tools such as saws and machetes.

Results

A total of 58 non-native species were found in the target area (Supplementary material 2), which included *restinga*, Atlantic Forest, and the rocky coast. The most abundant high-risk invasive species in *restinga* were *Furcraea foetida* (Mauritius hemp), *Asparagus densiflorus*, and *Asparagus setaceus* (asparagus ferns) along with *Carpobrotus acinaciformis* and *Yucca filamentosa* (Adam’s needle) in smaller proportions. In the adjacent hill, in the forest undergrowth, and on the rocky coast, *Furcraea foetida* was the most frequent invasive species. The main pathway of introduction of all invasive species in the area was ornamental with purposes other than horticulture (IUCN 2017), which depicts the potential impact of the unregulated ornamental plant trade to natural areas.

Furcraea foetida was the species that required more working hours, given its widespread distribution and invasiveness in *restinga*, rocky coast and forest undergrowth. For lack of control reference, we conducted a pilot test using a Triclopyr solution at 2% in water with dye that resulted in high effectiveness, as none of the 13 plants treated survived. A total number of 292,325 *Furcraea foetida* plants were eliminated in the entire area. Of these, 173,720 were bulbils crushed mechanically with a machete or rock, 115,802 were small plants in the initial phase of development (plants up to 20cm in height), pulled out by hand and destroyed with a machete, and 2,803 were medium to large plants (with hardened leaves and structure) treated with chemical control (Figure 2). The leaves and central stem were cut at the base with a hand

saw or a machete, then the herbicide solution was immediately applied on all exposed tissue. Herbicide solutions were prepared in water rather than oil to avoid pollution by diesel in the area and to avoid the cost of vegetable oil. During follow-up operations, 739 of the medium to large plants, equivalent to 26.4% of all plants controlled, were retreated because sprouts were found growing around the central stem or on the sides of the stump, or because they seemed to be vigorous enough to sprout back. These plants did not survive after the second treatment, rotting slowly over time.

Furcraea foetida was practically eradicated from the *restinga* along the beach, as well as *Yucca filamentosa*. In forest areas and along the rocky shore, however, while adult *Furcraea foetida* plants were eliminated, bulbils were left behind, as they are produced by the thousands and spread into native vegetation. Given restrictions of time, especially at the end of the last contract, it was not feasible to find and destroy the thousands of bulbils and plantlets produced by *Furcraea foetida*. Time was more efficiently used to control the 2,803 medium and large plants, which were all controlled and retreated if sprouting. Of these, only 15.5% were reproductive, representing 0.96% of the total number of *Furcraea foetida* plants and bulbils eliminated. Still, 26.4% of medium/large plants had to be retreated. As in the beginning we had yet to define an efficient control method for this species, the efficiency was lower, especially when plants were left with the leaves intact. The use of Triclopyr in 2% dilution in water with dye applied to all the exposed tissue immediately after the leaves and central stem were cut off produced the best results, and reduced the percentage of survival in follow-up operations. Still, the area has to be covered again in 2-3 years to eliminate new plants growing from existing bulbils after natural selection reduces their numbers from thousands to hundreds of successful adults.

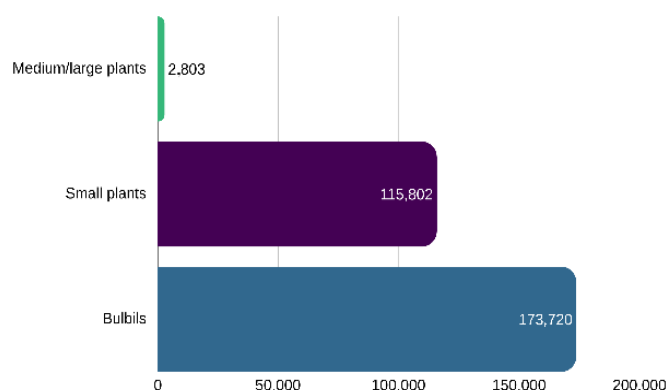


Figure 2. Number of *Furcraea foetida* plants by size and reproductive structures (bulbils) controlled in Praia Mole, Florianópolis, Brazil. Small plants: up to 20cm in height; medium/large higher. Flowering stems indicate the number of medium/large plants in the reproductive phase.

Yucca filamentosa occurred only occasionally, but was found in isolated rock outcrops with *Furcraea foetida*, which indicates the existence of a propagule carrier, probably bats, as suspected for *Furcraea foetida* (PIER 2013). *Yucca filamentosa* populations amounted to 337 plants controlled in different areas, mostly in *restinga*, but also growing on rocks along the shoreline. Follow-up operations were essential to prevent plants left on the ground from taking root again, as well as to destroy sprouts growing from the cut stems. Only two of the large plants eliminated with the Triclopyr herbicide mixture had to be retreated, but 308 new sprouts were eliminated from a pile of plants left on the sand to dry (Figure 3). Pulling out the central growth stem and applying herbicide to the bottom of the stem also proved to be efficient with the same herbicide mixture, and a better option than cutting the base of the stem, which seems to improve resprouting capacity.

The area of approximately one hectare along the beach more intensely invaded by *Asparagus densiflorus* and *A. setaceus*, chosen for the application of 12 different control treatments, was last retreated on 30 August, 2023, then monitored in January and March, 2024. We chose to work in this area until a definite control solution could be identified to

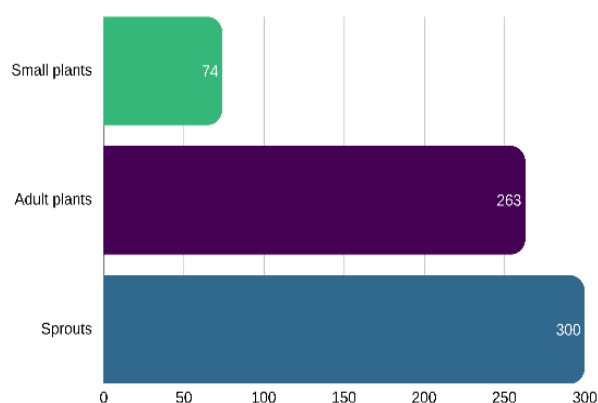


Figure 3. Numbers of *Yucca filamentosa* plants treated and retreated in Praia Mole, Florianópolis, Brazil. Size classification range is the same as used for *Furcraea foetida* (Figure 2).

avoid wasting control funds on inefficient methods, then extend control to other areas and populations along the beach and the rocky coast and forest undergrowth once an efficient method was identified.

Asparagus densiflorus was resistant to applications of Triclopyr and Glyphosate. Plants dried up only partially, and recovered completely when interventions were interrupted over the summer months. The application of Metsulphuron Methyl 0.15g/l + 1% Glyphosate + 15 drops penetrant + 20 drops dye + water was the only mixture resulting in the total death of plants without need for retreatment. Still, results were not homogeneous, as some shrubs dried up completely, while others dried up partially, maintaining one or two green stems. Metsulphuron Methyl is commercialized in water dispersible granules (commercial names Accurate © and Zartan ©) which are mixed in water with Glyphosate, a penetrant, and dye. In order to maintain the product active, the herbicide solution needs to be agitated continuously to prevent decantation. We believe that the heterogeneous results obtained are a result of uneven application of the herbicide solution, and that more attention has to be given to agitating the solution while spraying. Plants that dried up completely were giving way to native species occupying open spaces. Complementarily, 1,502 *Asparagus densiflorus* plants were taken out with a hand saw used to cut the roots below the woody base underground. The number of plants treated with herbicide was not quantified because it is not viable to individualize the bushes once they grow side by side and are entangled in native vegetation.

Although *Asparagus setaceus* was more sensitive to Glyphosate, the plants were able to recover even after repeated treatments. Therefore, the same herbicide solution using Metsulphuron Methyl was applied and found to be effective. As they occur in the same area and are often mixed with *A. densiflorus*, using the same herbicide solution optimized the work and yielded better results.

While very small *Asparagus* plants were dug out by cutting the roots below the woody clump on which the stems grow, mechanical control is not viable for large plants, as the underground woody base is too large to dig out by hand, and the use of machinery is not feasible because it would get stuck in the sand and destroy native vegetation, increasing the impact on the ecosystem. As they grow, *Asparagus* shrubs often become entangled with native plants, most commonly with shrubs such as *Cordia verbenaceae*, *Scaevola plumieri*, *Guapira opposita*, *Clusia criuva*, *Epidendron fulgens*, *Vitex megapotamica*, and others, in a way that it is nearly impossible to avoid affecting non-target plants. Still, once mixed up in the *Asparagus* bushes, native plants tend to be smothered and die. Therefore, the loss of non-target plants as a side impact of control is acceptable in the lack of ideal management options.

Carpobrotus acinaciformis occurred in small pockets along the frontal dunes. Populations were sprayed only once with a mixture of Glyphosate at 1% dilution in water with a surfactant and dye. This was sufficient for all plants treated to dry up and allow indigenous species to recolonize the treated area over time. Chemical control proved to be a better option than mechanical control, as it avoids soil disturbance,

stems dry up and remain in place for months, preventing erosion, and no residues are generated, avoiding the risk of creating new invasion *foci* somewhere else after transportation.

Control costs

A specialized team of 8 people worked over a period of 93 days distributed in 17 months, equivalent to 2,232 working hours. The total investment amounted to US\$ 51,894.00. Divided by the number of working hours recorded, the cost per hour was US\$ 23.25 (twenty-three dollars and twenty-five cents). The costs include all taxes (13.8%), transportation and materials (1.8%), planning, financial management and reporting (7.1%), insurance (0.8%), administrative costs (7%), and labor (69.4%). During this period, emphasis was given to the species described as high risk of invasion to local ecosystems.

Discussion

We were able to determine efficient control methods for the highest risk invasive non-native species in the area, eliminate the majority of targeted adult invasive plants, and record the control costs. All five species considered of high risk to *restinga* ecosystems are ornamental plants used in the vicinity, with *Carpobrotus acinaciformis* introduced mainly for dune stabilization.

The initial lack of technical reference for the control of *Furcraea foetida* and *Yucca filamentosa* was overcome by adaptive management, as different concentrations of herbicides were tested. In Hawaii, treatment of *Furcraea foetida* with Triclopyr in oil, applied to the bases of leaves around the whole meristem, was effective, but not when mixed in water (Motooka et al. 2002). Another study found that applying 4% Triclopyr to cuts in the base of the plants was 100% effective, but injection of 48% Triclopyr to the base was not effective (Dechoum and Ziller 2013). We found that Triclopyr diluted in water at 2% was effective as long as applied to the base of all cut stems and leaves. The same solution was applied to *Yucca filamentosa* due to the similarity between the species, by applying the herbicide mixture to the base of the central growth stem, which is easily removed by hand. Foliar spraying was not an option in the case of these plants, as the leaves are very long, hard, and smooth, with a thick cuticle, allowing the herbicide to run off; besides, it is almost impossible to reach the leaves in the center of the plants without cutting off the outer ones.

Asparagus densiflorus proved to be more persistent than all other species, especially as Metsulphuron Methyl was not available in the beginning of the control work. Glyphosate was recommended for control at 1% dilution with 0.25% surfactant followed by retreatment (University of Florida 2024), but this mixture was not effective. After testing 11 combinations of herbicide solutions (see Supplementary material 1), a mixture of Metsulphuron methyl 0.15g/l + 1% Glyphosate + 15 drops penetrant + 20 drops dye + water proved to be efficient.

Control efforts were used as a way to reach out to property owners to raise awareness on the impacts of invasive non-native plants, avoid new introductions of non-native species, promote the replacement of invasive plants used in gardening with native plants, and seek cooperation for the restoration and conservation of *restingas* and the adjacent hill and rocky shore. While the lack of awareness can easily create obstacles to prevent or mitigate the impacts of invasive non-native species (Meyerson, Pysek 2014; Genovesi, Monaco 2014), there is little evidence towards the efficacy of awareness campaigns due to the lack of standardized metrics (Haley et al. 2023). In South Africa, however, public awareness seems to increase public support for invasive species management (Novoa et al. 2017). In our case, some property owners did not allow certain plants to be taken out, especially in the beginning; one insisted that *Furcraea foetida* was native because it has been present for over a century; two owners did not allow us to remove *Carpobrotus acinaciformis* from the beach front; others were supportive and encouraged our work. A community meeting was widely advertised so that the work could be explained, but attendance was insignificant. Printed folders were then distributed to mailboxes in the area in order to inform residents about the work. Ten printed signs were placed along the beach with images of the main invasive non-

native plants in the area at the end of 2022, but were destroyed or taken away over the summer months, and not replaced.

The record of costs and yield is relevant to provide reference for other actions to be conducted by the municipality, also providing a realistic notion of the time needed for the successful control of persistent plant invaders such as *Furcraea foetida*, *Yucca filamentosa*, and *Asparagus* species. Other work in the municipality registered costs and yield of controlling pine invasions in different environmental conditions such as vegetation type, slope, and density (Ziller et al. 2021). These records help municipal managers to estimate the costs of control work in new contracts, as well as to have a notion of yield and effectiveness of control for different species and environmental conditions. Decision-makers and stakeholders often do not have practical experience in management, which makes it difficult for them to evaluate whether management costs in work proposals are reasonable. Invasive species occur scattered over the landscape, rarely in any structured pattern, in variable densities, so it is usually not viable to estimate costs or control time per area. Records of control work costs based on overall time and area covered are therefore useful to provide a notion of yield, as long as other factors such as accessibility and plant density are also considered.

Providing feedback on invasive plants to the environmental agency has proven valuable, as public nurseries no longer produce non-native plants for use in the city, and the use of non-native species in restoration work is no longer allowed. The main challenge concerning management of the ornamental plant pathway is that establishments in the ornamental trade are not required to have environmental permits. The state list of invasive non-native species was reviewed and published in May, 2025 (Resolução CONSEMA SC 271 de 30/05/2025), including the species identified in this area. Although issuing lists of prohibited species may be very helpful in raising awareness, more work needs to be done to inform plant vendors, producers, and users on the impact of non-native species to the environment, as well as on existing regulations.

Brazil may provide an interesting funding model for other countries. The federal law that established the National Protected Area System (Federal Law 9985/2000), regulated by the Federal Decree 4340/2002, instituted a mechanism for environmental compensation (Article 36), in which development works, such as the construction of roads, dams, buildings and other large-scale endeavors, revert 0.5% or more of the total cost to an environmental fund managed by federal, state or municipal environmental agencies. At each level, the respective agency maintains an advisory chamber that directs funds to specific environmental projects.

In Florianópolis, capital of the state of Santa Catarina, environmental compensation funds are used to pay for invasive species control in priority areas, especially in protected areas and their areas of influence through the municipal environmental agency FLORAM. One of the advantages of this mechanism is that contracts are signed directly between entrepreneurs and service providers based on terms of reference produced by the environmental agencies, avoiding governmental bureaucracy for hiring. Initially applied only by federal and state agencies, this mechanism is being gradually extended to municipalities. Florianópolis established a Compensation Chamber in 2019 (Portaria Floram nº 11/2019) and ruled the use of the funds for the following purposes: (a) restoration of permanent preservation areas; (b) restoration activities in protected areas; (c) land compensation in protected areas; (d) funding of environmental projects managed by the municipal agency; (e) improvements to the physical, material and technological infrastructure of the municipal agency; and (f) capacity building for the agency's employees. The municipal environmental compensation fund allowed us to carry on control work for a period of 17 months, interrupted during the summer due to high tourism activity and climatic conditions. It is important that the work is continued, especially as methodological control issues have been solved and control can now be applied at large scales. This public policy is currently the best mechanism available to fund control actions, at least at the municipal and state levels, as monitoring and follow-up are required to ensure the restoration of selected sites.

Conclusions

The Florianópolis environmental agency FLORAM defined Praia Mole as a strategic priority area to prevent the invasion of nearby protected areas by ornamental plants used in restaurant and bar gardens along the beach. This pathway management approach required the engagement of the public in the area, raising awareness on biological invasion issues. The municipality of Florianópolis is pioneering the use of environmental compensation funds for restoration of areas invaded by non-native plants. Protected areas and their surroundings are key areas for the application of this policy and of a preventative approach on invasive non-native species management, as well as other natural areas hosting threatened or rare species that are relevant for biodiversity conservation. The development of municipal strategies for invasive species that include a selection of priority areas inside and in the surroundings of protected areas facilitates the application of environmental compensation funds once they become available, optimizing time and resources.

The management of invasive non-native species requires continuity, which can be provided by this public policy to generate positive results in the restoration of natural areas and biodiversity conservation. The work carried out resulted in a landscape change due to the elimination of invasive non-native plants, opened up space for indigenous species, and contributed to an increase in the resilience of *restingas*. Although highly challenging due to the need for public engagement, the work conducted reduced the amount of high-risk invasive plants in *restingas*, the rocky coast, and forests, providing technical management solutions and providing cost references for future work. These results are assets for governmental management that contribute to more efficient control work and the formulation of public policies to restrict the use of invasive ornamental plants in the municipality.

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