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REVIEW

Propagation Model of Invasive Species: Road Systems as Dispersion Facilitators

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ABSTRACT

The globalization of the planet allowed plant species to emerge from their traditional habitats and spread to other territories. This dispersion, sometimes occasional, sometimes by the influence of man, reaches proportions today that, in some cases, affect the development of natural ecosystems and their sustainability. Thus, becomes imperative to know seeds dispersion occur, since only after can be taken measures to mitigate these processes. In the same way that natural communication paths, such as rivers, are responsible for the natural dispersal of seeds, man-made communication paths, such as road systems, can allow very rapid dispersion. This review article addresses this issue, raising a problem that can be observed in Portugal, but which can easily be transposed to other territories of the Mediterranean basin, given the similarities in these territories. The dispersion model described here, called Highway Flow Model, intends to show the mechanisms of seed dispersion through road systems, mainly due to the configuration of the road profiles, but also by the processes associated with the cleaning of the roadsides. This demonstrates the need to take measures, such as cleaning and inspecting the equipment used to clean roadside berths before moving them to a new service elsewhere.

1. Introduction

Portuguese forest undergone through periods when much has evolved, regressed, progressed and transformed, with its soil area being used for other purposes. These changes occurred sometimes driven by natural changes, while others occurred by human hand. Forest, like any living system, continues in this evolutionary and adaptive path, always affirming, at any time in history, to be fundamental to life, to be a source of wealth, and the stage of some of the most beautiful scenery in the country [1-3].

It is in this perspective that Portuguese forests reach present days, with a set of important challenges that mark its development and evolution for the upcoming times. Actually, contrary to what happened in the past, when changes occurred alternately with a more significant weight for the natural environmental causes, nowadays, forest has to evolve and adapt due to natural influence and man's hand at the same time, and even natural influence may also be enhanced by human action [4].

Considering the phenomenon of climate change as an occurrence, or rather a set of occurrences of natural cause,

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even if man-enhanced, or the introduction of species into habitats other than their originals, or intensive deforestation for industrial purposes and commercial, or the change of land use for other purposes, namely agricultural production, are all occurrences that only happen at this rate with the influence and intervention of man [5,6].

It is this subject that must be analyzed with some attention, especially regarding the introduction of new species, many of them with an invasive behavior, and that will be a problem of hard resolution, as alerted by Elizabete Marchante, a researcher from the University of Coimbra, in an interview with AGÊNCIA LUSA and presented in SIC NOTÍCIAS, on November 21 2017. She warned that "in coastal areas, such as the Pinhal de Leiria, Quiaios and Torcha, several acacias begin to be sprouted, one month after the fires October 2017, and the same happens in the interior of the Center region, where *Acacia dealbata* and *Acacia melanoxylon* are predominant." In this way the specialist in invasive species predicted that the situation of the invasion of these plants would be worst after the great fires of October 2017 [6]. She added that "both acacias and hakeas have the possibility of increasing their presence in the region, because they are pyrophytes. Each plant can reach 20,000 seeds per square meter and remain viable in the soil for many years. When the fire passes, the seeds can be stimulated and facilitate seed germination in areas that were already invaded by these species" [6].

According to Elizabete Marchante, if nothing is done, "areas with acacia trees will increase their number in the future. These areas must be helped in order to not be overtaken by these species, but reforestation plans must take into account their existence and not ignore the invasives" [6].

Elizabete Marchante concluded the interview warning that "if the window of opportunity is not used, the acacias will grow faster and in greater number, making the growth of other species unviable". Nevertheless, she argues that since "there are no resources to control all invasive species, priority areas must be defined to act before it becomes difficult to control" [6].

As seen so far, and as pointed out by the experts, forest is a complex system that is constantly evolving and adapting to new environmental conditions, but also subject to an increasing pressure from man, who exploits it and withdraws it benefits, not always, or better, almost never with a sustainable use perspective, that allows the evolution and adaptation to occur in a period of time consistent with the natural recovery capacities.

It has also been seen that there are permanent concerns throughout history with the ability to recover forests, not because of a widespread environmental awareness, but rather because of the fact that man has always been aware of the need of forest resources for its subsistence, carrying out permanent reforestation plans.

The objective of this review article is to analyze the different types of profile of road systems mostly available, using as an example the case of the Portuguese road system, since it is understood to be representative of what exists in other European countries, but mainly in the Mediterranean basin. This article also presents some examples of invasion and others of potential invasion in the near future, if early prevention and control measures are not taken. The discussion of the presented models tries to explain how the different profiles of conformation of the road system contributes to the dispersion of the vegetal species along its extension, potentiating the speed of dispersion of the seeds and, thus, increasing the radius of dispersion.

2. Invasive Species Dissemination

Following what occurs a little everywhere, Portugal has also suffered the entry and subsequent dispersion of a set of species that, over time, adapted to soil and climatic conditions of the territory and are, thus, conquering area to native species [7-9].

These species, characterized and designated as exotic and/or invasive, depend on a more or less aggressive behavior, regarding the potential for the occupation of an ecological space, and some of them becoming plagues that occupy lands of all kinds, damaging the income of both agricultural and forestry crops [10]. The dispersion form of the invasive species, or its dispersion model, varies among species, and depends on several factors, such as the species itself, soil and climatic conditions of the region, and external factors, where human intervention can be included [11].

However, despite continuing warnings from the authorities and many scholar experts, there is still some oversight regarding the introduction of alien species, many often with the most innocent of the intention, such as the use as an ornamental species, but also, and these are the most worrying situations, the introduction of species with the objective of producing some kind of raw material or supposed higher financial income, such as fast growing species for the production of wood, or for the production of fruits of high value, or some kind of chemical compound [5].

See the case of the *Opuntia ficus-indica*, a relatively common exotic species in the South of Portugal, mainly in Algarve, but which appears a little everywhere. Since 2015 it is possible to frequently find news in the media about cases of business creation, which are based on the production and marketing of the fruits and processed products of this plant, from which stand out micro enterprises created in Alentejo, such as the company CACTUS EXTRACTUS, which was reported in an article on VIDA RURAL [12].

Most likely due to this success, and because it is extremely simple to obtain specimens for planting, others may have the will and the temptation to replicate the process, even if they do not fully know if the plant adapts to the soil and climatic conditions of the region where they intend to do it. An example of this is the recent planting of a hillside along the A32 highway, just in front of the highway exit to São João da Madeira (Northern Portugal) (Figure 1).

Figure 1. Plantation of *Opuntia ficus-indica*

Although the introduction of alien species is regulated by national and international legislation, supposedly harmless "experiments" are still carried out with the intention of measuring the growth rates of these and other species compared to the native species of the territory. Often, under good peerage, specimens circulate between different hands, dispersing across different geographical areas, which will allow the plants to be "tested" under different conditions. As can be easily imagined, the probability of many of these specimens falling into oblivion and finding optimal conditions for their development is great, creating from the outset a colonizing embryo that may, in time, become a case of invasion.

An example of an occurrence with *Pawlonia* spp., which is still not yet a concern, should be analyzed, cataloged and, mainly, communicated to the competent authorities, so that they can act if any control intervention is necessary.

Pawlonia spp. has been used as an experimental species for wood production in Portugal for almost a decade, but it has not yet succeeded in establishing itself as a species capable of satisfying the needs of the market using wood, and much less for the market of biomass to energy, by the most diverse factors.

Notwithstanding this delay in its large-scale implantation, several planting trials are known in different geographical areas of the country, which keep the possibility of one day finally being able to prove that it is an economically viable species in Portugal.

Figure 2 and Figure 3 present two examples of experimental fields with plants of different ages located in the region of Viseu (central zone of Portugal).

Figure 2. Experimental field of *Paulownia* spp. planted in the region of Viseu (central region of Portugal)

Figure 3. Experimental field of *Paulownia* spp. planted in the region of Viseu (central region of Portugal)

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Most likely, was from these experimental fields who emerged from north to south of the country that left the specimens that can be found in a “spontaneous” way along some national roads, not knowing until now the origin of the specimens found, nor do they belong to the same species, since access to the specimens in question becomes practically impossible, since it is a fast road where it is not possible to stop and access the plants safely (Figure 4).

Figure 4. Specimens of *Pawlonia* spp. that can be found along the highway and highway that make the circular of Guimar**ã**es and that connects this city to Fafe, Felgueiras and Vizela in North Portugal (Source: own elaboration on an image collected in Google Maps)

These ripped specimens may prove the fact that not all *Pawlonia*s plantations are being carried out with sterile hybrids and that specimens capable of producing seeds may have been introduced, which then, in exactly the same way as it happens with other species, are dispersed and proliferate.

However, probably the most devastating introductions of invasive species had as their motto to achieve some objective and not simply ignorance. For example, massive production of some kind of raw material supported by a purely economic view of the forests, or the use of plant species for some indirect purpose, such as the stabilization of road slopes.

One example occurred in the 1980s when it was rumored that an industrial plant would be set up for the extraction and concentration of tannins in the region of Palmela, most likely to provide the growing wine industry at the date. With this information many landowners in the nearby counties rushed to plant *Acacia dealbata* in a rampant way, mainly in the alluvial plains of the zone of Pegões (Ribatejo region).

As time passed and the industrial project failed to materialize, *Acacia dealbata* grew and even began to expand neighboring lands, creating an extensive spot that occupied a few thousands of hectares under a monoculture regime, since no other species managed to survive at such a high density of Acacia delabata.

Almost 40 years later, and with the need to return the land to other crops, namely for orchards, vines and stone pine trees, the owners began a campaign for the irradiation of *Acacia dealbata*. In a specific situation, in a property called Herdade de Santo Isidro (Ribatejo region - South Portugal), in which a company occupies an area of approximately 400 hectares, and which is dedicated to the exploitation of a nursery of forest species, was developed a project to cut and unroot the entire property.

Taking advantage of this project, was quantified the available biomass per hectare, as well as the characterization of the biomass for a potential use as an energy resource, more concretely for its viability for the production of biomass pellets. But not all situations have the outcome of the case reported here, especially when can not be created a value chain or attributed some kind of utility to the invasive species in question. In fact, the most frequent case is the dispersion of the species in an almost uncontrolled way, especially when they face favorable conditions.

In this perspective, returning to the theme of dispersion models, probably the most problematic situations will be those where human intervention is felt with more intensity. For example, the pyrophilic behavior of many plant species, which take advantage of the “cleaning” caused by fire to occupy the space left by other species, is very well referenced in the bibliography [13-15], and the responsibility of the human hand in the great majority of the rural fires that occur in Portugal is also very well referenced [16, 17].

However, not all “cleanings” are made by rural fires, and may have anthropogenic or natural origin. Since the great rural fires of 2017 there has been a pressure to reduce the fuel load that is proliferating, especially when it accumulates near the population clusters and along the roads. This cleaning of the so-called protection bands, and fuel load control, normally carried out using mechanical equipment, lead to the proliferation of many invasive species and served as a sort of “fast track” for their dispersal.

Cleaning operations are by nature onerous tasks for those who order them, mainly because they require manpower and equipment, but it is also often difficult to carry out the tasks due to factors such as slopes, atmospheric conditions, the impossibility of using mechanical means, the type of vegetation in question, among others [18].

It is a common practice for these clean-up works to be carried out in “timber exchange”, as forestry operators call it. That is, the owner of a certain land contracts the services of a forestry operator to clean his land, and as payment gives the whole or a part of the wood cutted in that land. This possibility may appear to be a solution that would be available to all, and would allow the land to be

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cleared without its owners having to spend money to carry out a task which has become mandatory, especially when these lands are situated around of population centers or roads. However, this scenario presents some constraints that are explained below.

The first has to do with the type of vegetation that is in the ground. If the vegetation is composed of adult trees, such as wild pine and eucalyptus, it is very likely that forest operators, usually referred to as "loggers", are interested in such a transaction, since after the work can sell the timber, thus obtaining an income for the task. However, if the density of mature trees is reduced, this type of possibility is unlikely to be accepted since, in the end, it may not compensate the costs incurred with the forest clearing operation [19, 20].

However, even when forest density is high, forest operators may not be interested in receiving timber in exchange for work, especially when, at certain periods of the year, when there is a lot of material available on the market, and more quantity will force a reduction in the sales price [21-23].

For these reasons, forest cleanings must necessarily be carried out in the most mechanized and rapid manner possible to minimize operation costs, especially when the objective is solely and exclusively the cleaning of young trees, shrubs, bushes and herbaceous materials [24,25]. It is this type of cleaning that is most commonly seen along the roadsides and in the perimeter of settlements, where a tractor equipped with a decentralized arm wrecker, moves along the road and cleans the ground as far as the arm reaches, as shown in Figure 5.

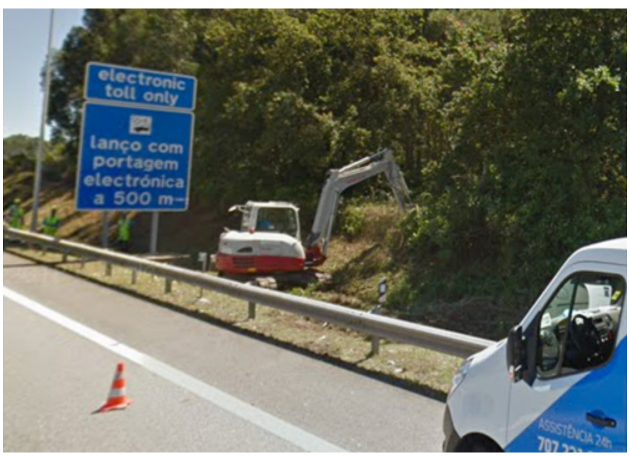

Figure 5. Tractor equipped with a removable arm breaker (grass-cleaner) in a slope cleaning operation on a *high*way

3. Road System Profiles

This may be precisely the main cause of the dispersion of some exotic and/or invasive species in the national territory, since there has been a growth that can be considered almost exponential, especially following the communication paths, in areas that have undergone processes of cleaning using heavy equipment. Thus, this dispersion process, which is called here the "Highway Flow Model", can operate in two different ways, involving different factors.

Figures 6, 7, 8, 9, 10, 11 and 12 present the most common profiles that can be found on national highways, but which can easily be generalized to any other country or region. Although it may also be considered that they may not be a totally determinant factor for seed dispersal, the differences between the different profiles may contribute to the fact that in some situations this dispersion may occur more quickly and with a greater scope. As can easily be inferred and understood, depending on the type of configuration that certain portions of a communication path may have, the dynamics can also evolve slower or faster processes, with more or less intensity, especially with respect to the circulation of the wind.

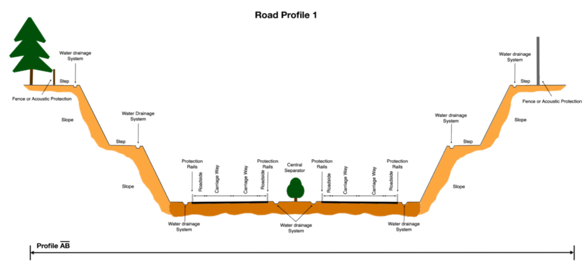

Figure 6. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

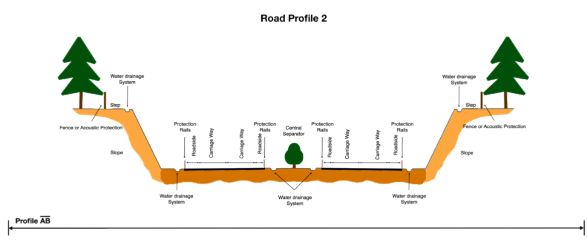

Figure 7. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

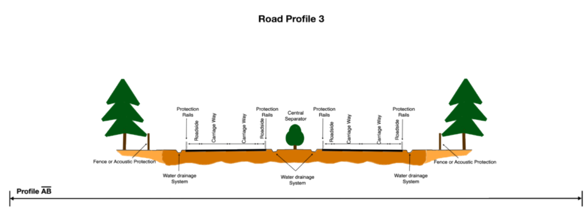

Figure 8. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

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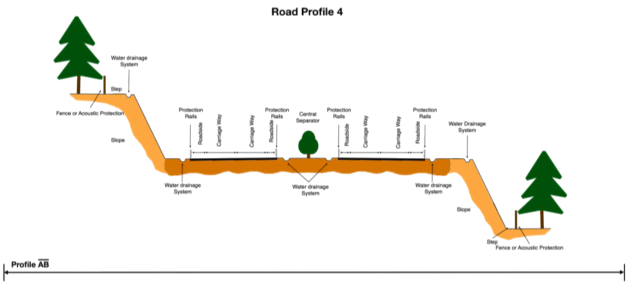

Figure 9. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

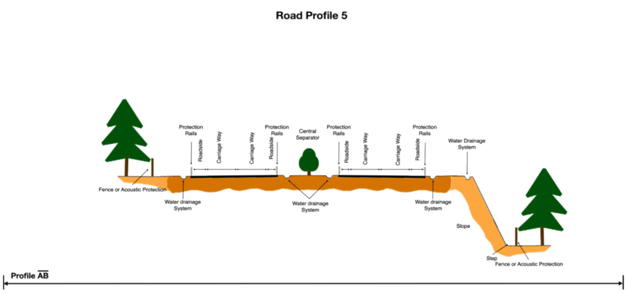

Figure 10. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

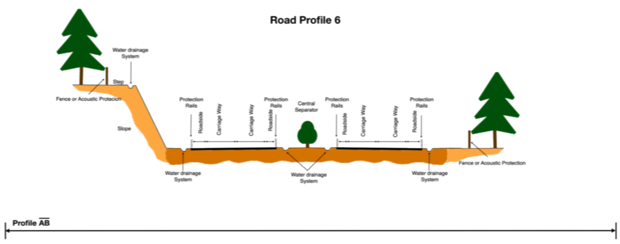

Figure 11. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

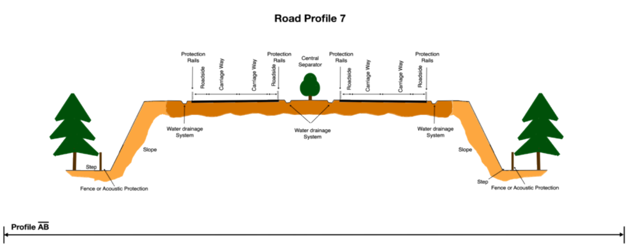

Figure 12. Representation of one of the most common profiles that can be found in the road channels in Portugal, especially on highways and expressways

The movement of the wind is certainly a major influence on the Road Profiles 1 and 2 shown in Figures 6 and 7, since the configuration of the profile allows the creation of a kind of flow channel, and this influence is greater as the larger is the extension of the channel. That is, it is different to have a configuration of this type that extends for a few hundred meters, or to have a situation in which the configuration extends for several kilometers. In this way winds are driven by the channel and will contribute to the dispersion of the seeds released by the species of plants that are colonizing the slopes and the higher levels of the profile of the communication route. It is also easily understood that this action will be more intense and efficient if the seeds in question are more likely to be dispersed by the wind, namely with respect to their shape, size and weight.

Species like *Cortaderia selloana* or *Arundo donax* are species clearly adapted to this type of dispersion, being therefore very common along road profiles throughout the country, but standing out the most coastal region due to soil and climatic characteristics (Aveiro, Coimbra and Leiria districts), in the corridors created by the A1, A29, A25, A17 and A8 highways (Figure 13 and 14). However, over time and with the establishment of increasingly viable communities, it is already possible to find examples, although in most cases isolated, in areas where it would not be expected to find, such as sections of the A3 and A7 , in the Minho region, sometimes already at considerable altitudes, which may indicate a certain adaptation to new conditions and habitats.

Figure 13. *Arundo donax* growing on one of the slopes of the A29 highway, in the Estarreja region (central area of Portugal)

In any case, these type of profiles by their configuration, which could potentially allow a faster and more efficient dispersion of the seeds along the roads, may also contribute to their confinement within the channel. However, since roads are constituted by a succession of the different profiles, the passage of the Road Profile 1 or 2 for profiles of the type shown in the Road Profiles 3, 5 or 7, it can rapidly move from a confinement situation within the channel to a lateral dispersion and invasion of the land contiguous to the road.

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Figure 14. *Cortaderia selloana* growing on one of the slopes of the A29 highway, in the region of Estarreja (North Portugal)

Other profiles, such as those shown in Road Profiles 4 and 6, as the configuration opens on one side of the channel, the influence of the wind will depend fundamentally on the dominant direction, since if it blows directly or obliquely against the slope will cause the dispersion of the seeds to occur mainly on the side of the slope. However, with the constant variations in wind directions the result will be similar to what happen with the Profiles 3, 5 and 7, that is, the open sides of the profiles can contribute to a dispersion to contiguous terrains of the roads.

4. Highway Flow Model

In addition to the influence of the dominant winds and depending on the configuration of the road profile, seeds will disperse in a certain way. However, there is another component that can also contribute to the dispersion and transport of the seeds, and that is the airflow caused by the car circulation. This flow, especially in roads where traffic flows at higher speeds, can play a very significant role and even contribute to the transport of larger seeds by dragging.

The vortex created by the vehicle circulation will drag the seeds that are deposited in the pavement of the roads, moving them even when there is no influence of the wind, or will start the movement of the seeds and break the barrier of inertia, and then, with the action of the wind, can be displaced to greater distances. This vortex also allows the seeds to move in the opposite direction of the wind, since the car circulation takes place in two directions.

Another important factor to take into account is that all roads routes have a drainage network for rainwater. This network aims to remove rainwater in order to prevent it from accumulating on the ground, making the car traffic more insecure. This network can also accumulate seeds that are then washed away by the water, thus being able to travel great distances, contributing to their dispersion.

This type of transport can disperse seeds of much larger size than the wind, since the water transport capacity will depend on factors such as the flow rate, but also on the buoyancy of the seeds. Figure 15 shows the schematic representation of the "Highway Flow Model" where it is possible to observe all the flow possibilities involved in the model.

This transportation model, associated with the process of slope cleaning, previously mentioned, will be responsible for the dispersion of the seeds, contributing to its faster dissemination. Slope cleaning, as described, in which heavy equipment are used, are moved from section to section along the road, transporting seeds from one place to another, since prior cleaning procedures are not applied before they are used in a new location.

Thus, with the interaction of the phenomena described here, it is possible to have a perspective how seeds dispersion occur, since an imminently natural process of adaptation to local conditions is no longer necessary, to pass to an accelerated dispersion process that allows several regions to be infested simultaneously, giving these species a greater possibility of survival, and hence of invasiveness.

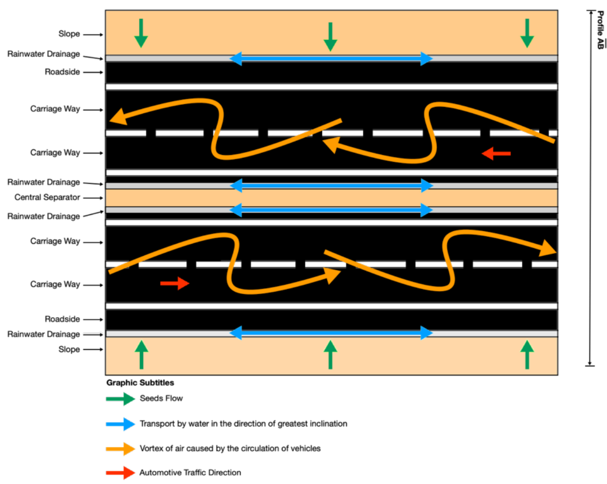

Figure 15. Schematic representation of the "Highway Flow Model" where the flows involved in the process of seed dispersion in the communication channel are presented

5. Conclusions

Invasive species are a reality that, due to phenomena such as climate change, have seen their expansive potential grow exponentially. These plants, when encountering favorable soil and climatic conditions, are able to quickly spread over ecosystems traditionally occupied by native species, since they usually have faster growth rates.

Since these species are already widely distributed from north to south of the country, it is urgent to understand which processes allow the seeds to spread more rapidly,

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so that solutions can be presented to avoid this dispersion. Assuming that road networks can work as seed dispersion corridors, dispersion is aided by the circulation of the vehicles, but also by the roadside cleaning equipments, which, due to lack of cleaning procedures, carry seeds from one place to another.

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