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GUECKO / DCEA, FCT, Universidade Nova de Lisboa, PT-2825-114 Campus de Caparica - Portugal
e-mail:mrp@mail.fct.unl.pt

Resumo
Muitas espécies exóticas acabam por estabelecer-se nas regiões onde foram introduzidas, causando problemas ecológicos e vultuosos prejuízos económicos nos meios que invadiram. Em Portugal, várias das situações críticas resultaram da introdução deliberada de algumas espécies e da cultura de outras que posteriormente escaparam ao controlo do Homem. Tal é o caso de algumas acácias *Acacia spp.*, ou do chorão *Carpobrotus edulis*, entre outras. Da substituição do coberto nativo por vegetação exótica resultam ecossistemas pouco diversificados, que em geral foram posteriormente colonizados por muitas outras espécies originárias da mesma região que as plantas introduzidas. Cite-se, como exemplo, as plantações de eucaliptos em Portugal, que se tornaram palco de uma sequência de invasões, colocando questões novas quanto ao controlo desses organismos exóticos. Quanto às introduções acidentais, as consequências também são geralmente lesivas, é o caso de muitas pragas agrícolas e florestais. Não obstante, pode suceder que algumas destas espécies venham a assumir, no seu novo meio, um duplo papel, parcialmente nocivo e parcialmente benéfico, como se verifica com a formiga argentina *Linepithema humile* , introduzida em Portugal no séc. XIX.

As opções existentes para a gestão das espécies invasoras são poucas, sendo a sua implementação geralmente laboriosa e dispendiosa. A melhor alternativa seria, sem dúvida, a adopção de medidas estrictas de quarentena que evitassem a sua entrada. Porém, após o estabelecimento de um organismo exótico, o seu controlo só poderá ter êxito caso se adopte uma estratégia integrada, manipulando a comunidade onde ele se inseriu. O delineamento da metodologia a aplicar é complexo e fica dependente de algum empiricismo, uma vez que na teoria ecológica se mantêm ainda em aberto questões fundamentais, tais como o estabelecimento de uma relação clara entre a biodiversidade do sistema e a sua resistência às invasões.

Palavras chave: Espécies invasoras, gestão.

Abstract
Most exotic species become permanently established in their areas of introduction, causing ecological and/or economic damage to the ecosystems invaded. In Portugal, several critical situations arose as a result of an initial deliberate spread and/or cultivation of organisms that later escaped control. Such is the case of some acacias *Acacia* spp. and of the ice plant *Carpobrotus edulis,* among others. Replacing the native cover by introduced vegetation creates little diversified exotic ecosystems, which sooner or later become prone to invasions, mainly by phytophagous organisms originating from the same region as the plants. As an example, eucalyptus plantations in Portugal have been invaded, over the past decades, by a sequence of exotic organisms posing new problems as to their control. Accidental introductions generally have equally disruptive consequences. However, under certain circumstances, an introduced species may come to play a mixed role, partially noxious and partially beneficial, in its new environment, as illustrated by the case of the argentine ant *Linepithema humile,* introduced in Portugal in the 19th century.

Management options for invasive species are scarce, laborious and expensive to implement. The best strategy to combat invasive species would be the enforcement of strict quarantine measures, aiming at the prevention of their introduction. This failing, after their establishment, exotic species can only be controlled through an integrated approach that is the manipulation of the local communities where they thrive. Nevertheless this strategy requires complex planning and has to rely upon a great deal of empiricism, since in the ecological theory important questions still remain open, like the establishment of a clear relationship between system diversity and resistance to invasions.

Keywords: Invasive species, management.

The problem

Identification

Darwin was one of the 1st scientists to pinpoint the problems caused by invasive species, as mentioned in the Origin of the Species (Darwin,1859): "*There are cases in which an introduced plant, in less than 10 years, spreads over a whole island. (...) For instance the artichoke and a species of a high thistle (...) in-*

troduced from Europe, which are distributed over the plateaux of La Plata, exclude almost all other plants across areas of many squared miles (...)". Nevertheless it was not until well into the 20th century that measures to prevent the introduction of alien species were widely adopted. Even today, while in the USA and Australia quarantine is taken as a serious matter, in Europe a more lenient approach has often been adopted. This paper will present a few consequences of this (lack of) policy.

Consequences

One of the most serious consequences arising from the spread of an invasive species in a new ecosystem is the loss of biodiversity. Figure 1 (Foin *et al.*, 1998) points to the relative importance of causes leading to the endangerment (and eventually extinction) of species in the USA. It can be seen that, after habitat destruction and modification, the introduction of exotics has been cited in 40% of the cases, as either being responsible for, or contributing to, biodiversity decline. Invasive alien species have high economic costs, as illustrated by Figure 2 (YFF Review 1998) showing that in the USA 97 000 million US $ was the value attributed to the cumulative economic losses caused by non-indigenous species, over a period of 85 years. It is impressive to note that insects caused 96% of the mentioned total damage.

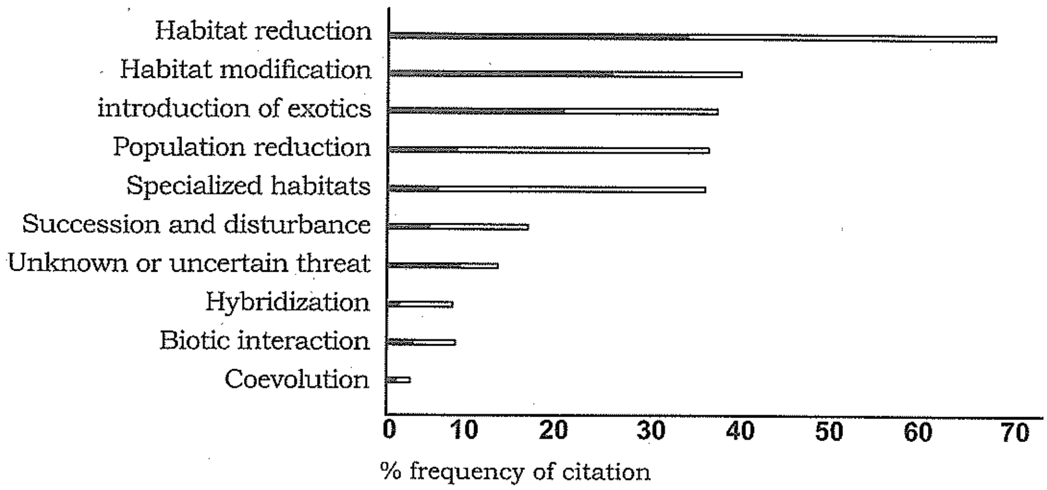


Figure 1: Relative importance of causes leading to species endangerment. [Source: Foin *et al.*, 1998 *Bioscience* 48, 3:181.© 1998 American Institute of Biological Sciences].

TAXON	NUMBER OF SPECIES CONSIDERED	LOSSES (SMILLIONS)
Plants	15	603
Terrestrial vertebrates	6	225
Insects	43	92,658
Fish	3	567
Aquatic vertebrates	3	1,202
Plant pathogens	5	867
Other	4	917

Figure 2: Estimated cumulative economic losses due to non-indigenous species, USA (1908-1991). [Source: YFF Review, Yale Univ., 1998.].

Potential management solutions

Biological invasions normally follow a sequence of phases, although each phase might have a variable duration: importation, introduction (that is spontaneous occurrence), establishment (once populations become self-perpetuating), outbreaks (pest status); finally a state of equilibrium might eventually be reached. Once an invasive species has become established, the potential application of management strategies must fulfil the following conditions: it should be technically possible, practically feasible, economically viable, socially and environmentally acceptable and politically desirable (modified form Norton & Mumford, 1983). Such a list of pre-requisites generally implies that, for most invasive species, its control is extremely difficult to achieve. On the other hand, eradication of the pest is only possible under island-type conditions, and might not even be desirable, after the exotic organisms become part of the local food webs.

Case studies in Portugal

An accidental introduction: the argentine ant *Linepithema humile*

This tramp species, which originates from South America, was accidentally introduced in Portugal around 1890. The Argentine ant is distributed in the tropical and warm-temperate zones of the world, becoming dominant between the latitudes 30° to 36° N and S. It is considered both as an agricultural pest, due to symbiotic relationships established with sap sucking insects, and as an urban nuisance, since it invades human settlements, particularly bathrooms and kitchens, looking for moisture and food (*e.g.* Paiva *et al.,* 1998). No records exist regarding the phases of importation, introduction and establishment of this pest in Portugal. 60 years after its arrival, when Silva Dias (1955) published the map shown in Figure 3, the outbreak phase that indicates pest status had long been attained. Apparently the counties colonized were the more densely populated zones, which are located closer to the sea and thus under a milder climatic influence.

Some 50 years later, an incomplete survey of the distribution of *L. humile* in Portugal was conducted by Way *et al.* (1997), revealing that its area of distribution remains fairly unaltered. Several ecological constraints appear to prevent its further expansion towards East (Way *et al.,* 1997; Paiva *et al.*, 1998).

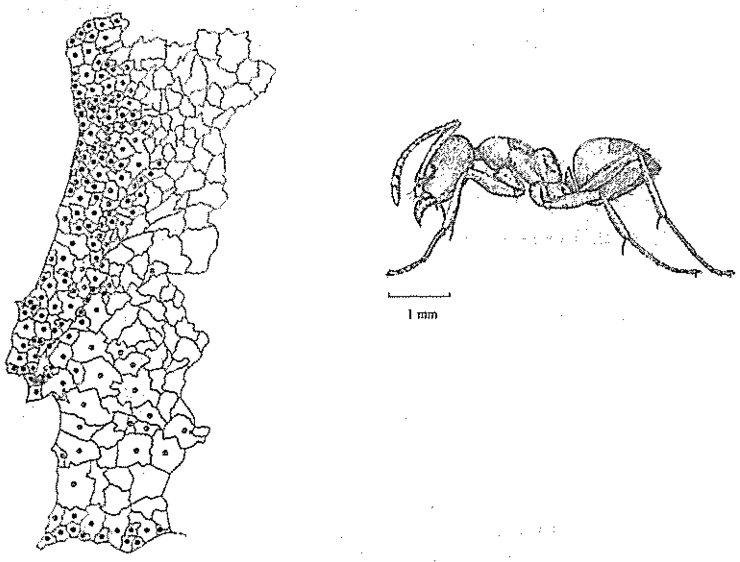


Figure 3: Distribution of the Argentine ant *Linepithema humile* in Portugal, 1950. [Source: Modified from Silva Dias, 1955].

Does this mean that a state of equilibrium has been reached? Yes and no, like for many other ecological questions, the answer might depend on the scale adopted for our observations. The Argentine ant is an aggressive competitor, that once established excludes all other dominant ant species (Cammell *et al.,* 1995) - Figure 4. Nevertheless, its ability to colonize a new habitat, or to expand its territory, depends, to a large extent, on the previous elimination of the native dominant ants (Way *et al.,* 1997).

This process (elimination of the native dominant species) is the outcome of the occurrence of perturbations, which affect the food supplies of the native species. The Argentine ant, being a more efficient forager (Way *et al.*, 1992), with a more diversified diet, is able to persist in habitats where other species

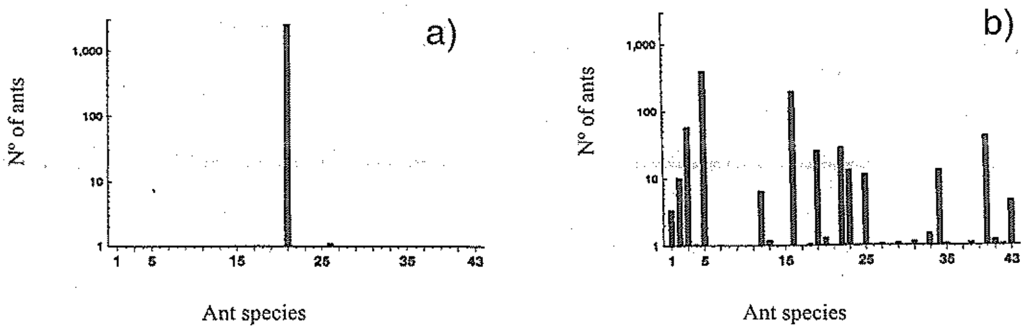


Figure 4: Number and relative abundance of ant species sampled in oak plantations in Portugal, when the Argentine ant was: a) Present; b) Absent. Numbers 1 to 43 refer to the different ant species identified. [Source: Modified from Cammell *et al.,* 1995].

would starve. Thus, at a local scale, its distribution will continue to expand and contract, according to temporary fluctuations of habitats colonized, while at a regional scale one, or more, powerful barriers (like, for instance, minimum winter temperatures and /or soil type) are probably in operation.

In the meantime, the Argentine ant has adjusted to practically all types of ecosystems in Portugal - agricultural, forestal, urban and natural - although different types of factors might promote, or impair, its establishment in a community. One of the consequences is that no longer should it be regarded as an exclusively noxious species since in forest plantations, the Argentine ant has proved to be a voracious predator of phytophagous insects, particularly of some major pests. Studies conducted in pine ecosystems, with emphasis on the pine processionary moth *Thaumetopoea pityocampa*, illustrate the issue (Way *et al.*, 1999). The caterpillars of this pest constitute the most important pine defoliator in most of the Mediterranean region. In some areas of the largest pine stand in Portugal, near Leiria, we observed that trees colonized by the Argentine ant remain free of the moth, while adjacent trees, in the same stand, which were either colonized by native ant species, or had no ants, experienced significant damage or even total defoliation - Figure 5. Technically possible and practically feasible methods to control the Argentine ant are not available. Poisonous baits and insecticides are often used, with consequent risks and environmental impacts. Repellents would ideally keep households free of ants, but no adequate repellent has yet been developed. In agro-forestry management of the populations of this ant might be practicable, to a limited degree, through the manipulation of the vegetation.

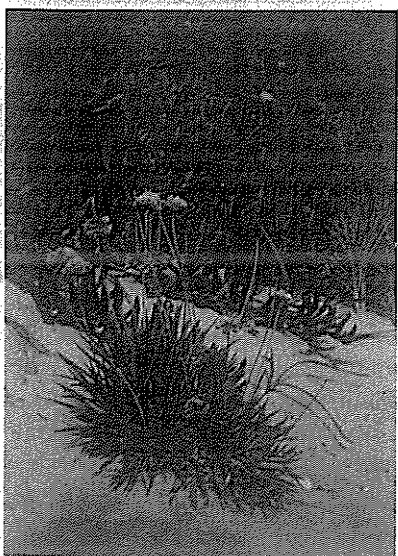
A deliberate introduction: the ice planta *Carpobrotus edulis*

This succulent, which originates from South Africa, started being cultivated in many regions around the world, including Portugal, aiming at dune stabilization. Although soil disturbance has been demonstra-

ANTS AT BAITS ACROSS TRANSECTS	Nº OF ARGENTINE ANTS / BAIT	% DAMAGE PINES		
	X + SE	ZERO	MODERATE	SEVERE
ARGENTINE ANT SECTORS	342 ± 42	78	22	0
TRANSITION SECTORS NATIVE ANT SECTORS	35 ± 12	0	88	12
NATIVE ANT SECTORS	0	0	78	22

Figure 5: Damage to pine trees by a defoliator moth across transects occupied by the Argentine Ant or by native ants in Portugal. [Source: Modified from: Way *et al.*, 1999].

ted to play a key role in the establishment of this invasive plant (D'Antonio, 1990), on unconsolidated dunes its performance is generally poor, while on coastal scrub, consolidated dunes and cliffs, among other types of habitats, it will form thick, impenetrable mats up to 55 cm deep (D'Antonio, 1993). In part, *C. edulis* invasive success is due to its ability to alter the soil pH and hence nutrient status (D'Antonio, 1993).



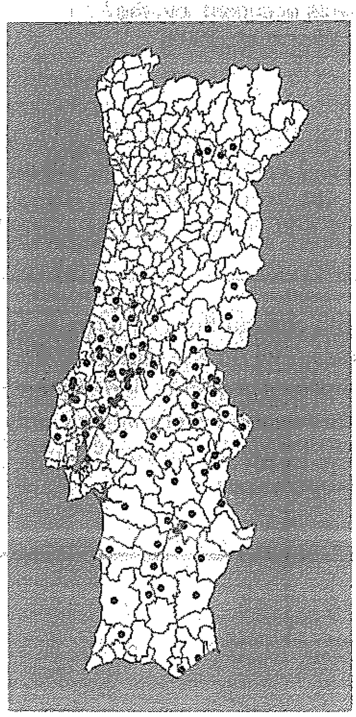
In Portugal *C. edulis* poses a threat to the coastal flora - Figure 6, in particular to endangered and rare species, like on the island of Berlenga to the endemic Plumbaginacea species *Armeria berlengensis* and *Herniaria berlengiana*. Control of this exotic perennial can only be done mechanically, that is by removal of the shrub roots, an expensive process of (obviously) questionable success.

Figure 6: *Carpobrotus edulis* invading coastal dunes and threatening the survival of native plants, such as *Armeria* sp. Mata de Leiria, Portugal, 1999.

An exotic ecosystem in Portugal

In Portugal an exotic ecosystem was created, based on the cultivation of the genus *Eucalyptus*. Trees are grown under short rotation, and used for pulp production. Although at least one specimen of eucalyptus was already present in Portugal a couple of centuries before the official discovery of Austrália, from where this genus originates, plantations were initiated in the 1960 ties and quickly expanded in the 1970 ties; they now extend over 0.7 million hectares, that is 21% of the total forested area of continental Portugal. The Portuguese plantations are almost exclusively made up by *E. globulus*, a species that in spite of its poor ecological adaptation to some regions is preferred by growers, due to its suitability for pulp production. Allelopathy is a noticeable mechanism operating in eucalyptus plantations, which inhibits the development of a vigorous shrubish undergrowth. But this exotic does not behave invasively, since it is unable of outcompeting the native arboreal species, namely *Pinus* spp. or *Quercus* spp.

For a couple of decades, eucalyptus were grown in Portugal practically "pest free", until 1984 when the longhorn borer *Phoracantha semipunctata* was detected. The cerambycid was certainly introduced with imported infested timber, and quickly expanded throughout the country (*e.g.* Farrall & Paiva, 1990). This insect, which also originates from Australia, is strictly monophagous on Myrtacea, and in absence of its native natural enemies, quickly gave rise to serious economic damage, becoming a major problem for eucalyptus growers. Soon, several species of invertebrates and vertebrates of the native fauna were observed parasitising or predating upon the borer, but generally showing a low rate of efficiency. However, one of the elements of the local, but non-native fauna, the Argentine ant, exhibited a high predatory activity. Unfortunately this factor of mortality alone is not enough to control the borer, for reasons identified by us, but too complex to explain here. Few methods are available for the control of *P. semipunctata*, a problem arising only in regions far away from Australia, where the borer remains in equilibrium with all other elements of the eucalyptus ecosystem, and outbreaks do not normally occur. Among them, the use of trap logs placed inside the stands to attract ovipositing females, requires the removal of the logs from the forest and their destruction before the emergence of the new generation of beetles. Although this practice is socially and environmentally acceptable, not always is it economically viable. Another type of control strategies, relying upon the importation of natural enemies from the area of origin of the borer, was considered as environmentally unacceptable, due to potential undesirable consequences, resulting from the introduction of (yet more) exotic organisms in Europe. However, in 1991 another accidental introduction was added to this exotic system. Farrall *et al.* (1991) detected in central Portugal the only egg parasitoid known for *P. semipunctata*. This hymenopter was identified as a species new to science (*Avetianella*...). In astonishment we later discovered that the parasitoid also originates from Australia, where nobody was aware of its existence. The wasp probably travelled around the world, and finally reached Portugal, sheltering underneath the elytra of the borer, being now distributed



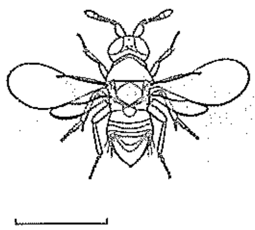


Figure 7: Distribution in Portugal of the accidentally introduced wasp *Avetianella longoi*, an agent of biological control of a serious pest, the eucalyptus borer *Phoracantha semipunctata*, in Portugal 1997. [Source: modified from Farrall *et al.*, 1997].

throughout the country. In this rare case, the lack of quarantine measures led to an unusual positive development: the accidental introduction of a beneficial insect, which contributes to the stabilization of the pest and is now distributed over most of the territory - Figure 7. Nevertheless it is still crucial to conduct research into other possible management strategies for the eucalyptus borer.

Invasions and ecosystem characteristics

In the last decades of the 20th century, a growing number of ecologists started working at the interface between population ecology and ecosystem dynamics. One of the most pertinent questions to be answered, "Is ecosystem resistance to invasions related to species diversity?" or, from an even broader perspective, " Does it matter to ecosystem functioning if biomass is divided among few or many species?" (Lawton, 1994) still remains open to debate. Several theories linking ecosystem functioning with species richness have been produced, attributing different intrinsic values to each one of their individual components. The redundant species hypothesis and the rivet hypothesis, present opposite views, while the idiosyncratic response hypothesis and the null hypothesis take a "middle of the road" approach.

The capacity of a tramp species to establish itself in a new habitat, appears to depend on the occurrence of perturbations in the areas invaded, this meaning that a stable habitat would than be less suitable for colonization. However, the definition of perturbation is not straightforward, since it depends on the scale adopted to express the amplitude and duration of the fluctuations, which are continuously in operation. As an example, the definition proposed by Sousa (1984), similarly to others, does not account for that, and it is thus of limited value: "A disturbance is a discrete punctuate killing, displacement or damaging of one or more individuals (or colonies) that directly or indirectly creates an opportunity for new individuals (or colonies) to become established".

However, after the phase of introduction, the capacity of the invasive species to successfully defend a territory, no longer appears to depend on the occurrence of perturbations at a large scale. Such a tendency can be inferred from Table 8 showing the number of ant species, which are able of coexisting with the Argentine ant, in different types of habitats. It can be seen that, in agricultural systems, where large-scale perturbations are inflicted several times per year, more native ant species dispute the same territory than under stable conditions, like those present in low management cork oak plantations. The performance of *Carpobrotus* also seems to indicate that, for a maximum reproductive success, the amplitude of disturbances in the habitat should remain within boundaries.

Table 8: Ant species diversity in four types of habitats, arboreal and arable, invaded by the Argentine ant. Modified from Cammell *et al.* (1996).

Habitat Type (Nr. of Stands or Sites Sampled)	Nr. of Ant Species Present (Including the Argentine Ant)	Nr. of Ants / Stand or Site ($\bar{x}$ ± s.e)	Diversity Index Margalef
Oak (n = 9)	2	2512 ± 588	0.20
Pine (n = 12)	3	738 ± 288	0.22
Eucalyptus (n = 10)	3	1368 ± 439	0.21
Arable (n = 14)	7	368 ± 138	0.81

Conclusions

Empiric evidence seems to point to the existence of a link between the amplitude and frequency of occurrence of habitat perturbations, and the ability of invasive species to establish themselves. Furthermore the process can apparently be reversed, even after a species has become established in a habitat (*e.g.* Paiva *et al.*, 1998). Also, an inverse relationship has often been detected between the degree of human intervention in a habitat, that is the occurrence of perturbations from anthropogenic origin, and the level of biodiversity present (*e.g.* Primack, 1995).

An integrated approach to the study of ecosystem functioning has just been initiated. It is thus not surprising that substantial evidence should still be lacking. A better understanding of the theoretical aspects pointed out would obviously contribute to the implementation of control programmes having a higher chance of success. Until than, our capacity to deal with invasive species will remain very limited.

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