The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

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The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

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“The spread of invasive alien species is creating complex and far-reaching challenges that threaten both the natural biological riches of the earth and the wellbeing of its citizens. While the problem is global, the nature and severity of the impacts on society, economic life, health, and natural heritage are distributed unevenly across nations and regions. Thus, some aspects of the problem require solutions tailored to the specific values, needs, and priorities of nations while others call for consolidated action by the larger world community.”

Yvonne Baskin
Todas as correções determinadas pelo Jornal e só essas, foram efetuadas.

O Presidente do Jornal.

Porto, _____/_____/

MSC
Acknowledgements

Particularly to my family (Dad, Mum, Little Brother, Boyfriend) for the absolute support, care and understanding in all, ALL moments.

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Abstract

Biological invasions are a common ecological process and a part of evolution of Life on Earth. But biological invasions mediated by humans take along serious impacts to species and ecosystems. Alien invasive species spread from native ranges to several new locations where they can pose a great threat to biodiversity and ecosystems. Nonetheless, along with negative effects, invasions can also have positive effects on several components of invaded ecosystems. In this thesis we addressed the several negative and positive impacts of invasive species. We start with a search of peer-revised literature (papers, books) through the VPN connection and databases, that describe examples, for several taxa, of negative impacts, positive impacts, the type of impacts and mechanisms by which they arrived to species and ecosystems. Then we focus on invasive plants and addressed their ecological impacts with additional detail. We conclude the research by exploring the example of *Acacia dealbata*, as it is widely spread in Portugal and has been characterized as a major threat to native biodiversity and ecosystem services, due to its traits and life history.

Keywords: Biological invasions, invasive alien species, ecological impacts, negative impacts, positive impacts, *Acacia dealbata*, biodiversity, ecosystem services.
Resumo

As invasões biológicas são um processo ecológico comum e fazem parte da evolução da Vida na Terra. No entanto, as invasões biológicas mediadas pela acção humana acarretam sérios impactos para diversas espécies e ecossistemas. As espécies exóticas invasoras dispersam dos locais de origem para variados locais novos onde apresentam grande perigo para a biodiversidade e ecossistemas. Ainda assim, as invasões não apresentam só efeitos negativos, mas também podem apresentar efeitos positivos em inúmeros componentes dos ecossistemas invadidos. Nesta dissertação referimos os vários impactos negativos e positivos das espécies invasoras. Começamos por pesquisar papers, livros, e bases de dados, através da ligação VPN, que descrevessem exemplos, para os diferentes taxa, de impactos negativos e positivos, tipos de impactos e os mecanismos pelos quais afectavam as espécies e ecossistemas nativos. De seguida focamo-nos nas espécies de plantas invasoras e debruçamo-nos nos seus impactos ecológicos detalhadamente. Por fim concluímos a pesquisa explorando o exemplo da Acacia dealbata, sendo esta uma espécie amplamente distribuída em Portugal, e tendo sido caracterizada como um grande risco para a biodiversidade nativa e serviços de ecossistema, devido às suas características e história.

Palavras-chave: Invasões biológicas, espécies exóticas invasoras, impactos ecológicos, impactos negativos, impactos positivos, Acacia dealbata, biodiversidade, serviços de ecossistema.
Contents

Abstract i
Resumo ii
List of figures iii
List of tables iv

1. Introduction
   1.1. Invasive species and the invasion process 1
   1.2. Objectives and methodological approach 6

2. Common effects of invasive species 7
   2.1. Negative effects 8
   2.2. Positive effects 24

3. Effects of invasive alien plants on biodiversity and ecosystem services 31
   3.1. Negative effects 31
       3.1.1. Negative effects of invasive alien plants species on populations and communities 32
       3.1.2. Negative effects of invasive alien plants species on ecosystems and their services 37
   3.2. Positive effects 44
       3.2.1. Positive effects of invasive alien plants species on populations and communities 44
       3.2.2. Positive effects of invasive alien plants species on ecosystems and their services 45

4. An example – *Acacia dealbata* in Portugal
   4.1. Genus *Acacia* in Europe and in Portugal 48
   4.2. *Acacia dealbata* 49
4.3. *Acacia dealbata* in Portugal

4.4. Effects of *Acacia dealbata* on native biodiversity and ecosystems
   
   4.4.1. Negative effects
   
   4.4.2. Positive effects

5. Conclusions

6. References
List of figures

Fig. 1: Pictures of some endemic species of the Mediterranean area 2
Fig. 2: Graphic illustration of the invasion process for some invaders 3
Fig. 3: Trachemys scripta, American common slider 9
Fig. 4: Felis catus, feral cat 10
Fig. 5: Salvelinus fontinalis, brook trout 11
Fig. 6: Cygnus olor, mute swan 13
Fig. 7: Oxyura jamaicensis, ruddy duck 16
Fig. 8: Myocastor coypus, coypu 17
Fig. 9: Ambrosia artemisiifolia, common ragweed 20
Fig. 10: Ficopomatus enigmaticus, polychaete 25
Fig. 11: Lymnaea stagnalis, pond snail 28
Fig. 12: Invasive alien plant species 36
Fig. 13: Zostera japonica, seagrass 44
Fig. 14: Acacia dealbata, silver wattle 49
Fig. 15: Mechanisms of propagation in Acacia dealbata 50
Fig. 16: Distribution map of Acacia dealbata in Portugal 53
List of tables

Table 1 – A simplified frame to classify paths of initial introduction of alien species into a new region 6

Table 2 – Type of impacts caused by IAS (invasive alien species) separated in 4 categories 22

Table 3 – Troublesome alien species in Europe and their multiple impacts 23

Table 4 – Mechanisms of facilitation of alien species to native species (several taxa) 30

Table 5 – Main type of impacts caused by invasive alien plants separated in main 4 categories 43

Table 6 – Mechanisms of facilitation of alien plant species to native species 47
1. Introduction

1.1. Invasive species and the invasion process

Invasive species can be seen as species that are introduced in a new region, and that spreads rapidly (Ricciardi and Cohen, 2007), and can also be defined by “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.” (Federal Register/ Vol. 64, No.25/ Monday, February 8, 1999/ Presidential Documents). The first option is more likely to be used by ecologists as the second definition appears in a widely range of governmental, policy and legislation papers (Ricciardi and Cohen, 2007). But, in 2002, in the Convention of Biological Diversity, from now on CBD, a more thorough designation came through: “An alien species is an organism introduced outside its natural past or present distribution range by human agency, either directly or indirectly. This definition implies an active movement facilitated by humans through a number of different pathways, and covers both intentional and unintentional movements of species. Introductions can in fact be intentional — as in the case of species released to the environment for hunting, angling, aquaculture, forestry, agriculture, horticulture and gardening — and accidental, as in the case of hitchhikers or stowaways, or aquatic species transported through ballast water. Those alien species which cause negative impacts on biodiversity, socio-economy or human health are considered as invasive.” (European Environment Agency technical report No 16/2012, “The impacts of invasive alien species in Europe”, henceforward EEA 16, 2012).

Biological invasions seem to exist at least since the Neolithic Age, and there are records, by Pliny the Elder, an early Roman Empire natural philosopher and encyclopaedist, about the severity of some, for example the introduction of rabbit in Balearic Islands, who`s control needed the help of Emperor Augustus troops. However, as we said, these introductions probably remote to the Neolithic Age, especially on the Mediterranean, where those species have become part of heritage of the diverse countries (EEA 16, 2012). The Mediterranean is one of the world’s hotspots for animal and plant diversity. The combination of geography, history and climate ran to an evolutionary radiation, as animals and plants adapted to several different regions (Vié et al., 2009).
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

This region is mostly distinguished for its plants. We have 25,000 native species and more than a half are endemic. Along with a great richness of plants, a high percentage of animals are endemic as well to the region (Fig. 1): 2 out of 3 amphibian species; half of the crab and crayfish; 48% of the reptiles; 25% of mammals; 14% of dragonflies; 6% of sharks and rays and 3% of the birds (Myers et al., 2000). Mediterranean has its importance also because it supports millions of migratory birds that seeks breeding sites and other provisions. This area is too inhabited by 455 million human beings and has the visit of several millions more (246 million in 2005) (Vié et al., 2009).

Fig. 1 - Pictures of some endemic species of the Mediterranean area: 1 – *Chiloglossa lusitanica*, gold-striped salamander (http://anfibiosemportugal.blogspot.pt); 2 – *Emys orbicularis*, European pond terrapin (http://naturlink.sapo.pt); 3 – *Lynx pardinus*, Iberian lynx (www.iucn.org); 4 – *Aquila adalberti*, Iberian imperial eagle (www.sciencedaily.com); 5 – *Iberochondrostoma lusitanicum*, the boga-portuguesa (http://animenatura.blogspot.pt).

At this point we need to distinguish between natural biological invasions and human introduced invasions: natural biological invasions occur since the dawn of times, been it sources animals, such as birds, wind, water, and other natural elements. The time scale for these invasions can go from few to several years. After an alien species invade a new place, by this kind of invasion, it happens a “lag phase”, that can be from decades to centuries before the “exponential phase” where it spreads rapidly (Dogra et
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services (Dogra et al., 2010). The human introduced invasions are quicker and turn very fast the “target” native community. Although the impacts of either of them are very similar, the time scale if very dissimilar (Dogra et al., 2010). Even if organisms that invade certain regions are destroyed in large quantities, some amount leaves descendants. Even so, their descendants may only survive for few generations. However a small fraction subsists and establishes becoming naturalized (Fig. 2 – 1 to 5) depending on the population characteristics and adaptation and the environmental forces of the new area. After this severe process a few will go on and become invaders. This process has often a lag phase characterized by a delay, followed by a log phase with an exponential growth of the invader, until species reaches the limits of its new range and stabilizes (Fig. 2 – 6 and 7). But there are many variants of this situation. For example, the invasions by Africanized bees in the American continent and by zebra mussels on the Great Lakes (North America) only had a brief lag phase or not at all. Then again, there are invaders that have an enduring lag phase, for example the fungus Entomophaga maimaiga. It was introduced in the United States for control of the gypsy moth, Lymantria dispar. During 79 years it disappears. It only re-emerges in 1989. Brazilian pepper, Schinus terebinthifolius, was introduced in Florida in the 19th century but only become widely perceptible in 1960s (Keller et al., 2011; Barney, 2006; Mack et al., 2000).

Fig. 2 – Graphic illustration of the invasion process for some invaders (from Mack, R., et al., 2000): 1 – Limits on the detection of a population growth; 2 – The number and arrangement of infestations of aliens; 3 – Natural selection among rare or newly created genotypes adapted to the new range; 4 – Environmental forces; 5 – Naturalization; 6 – Invasion; 7 – Rapid and accelerated growth, in numbers and areal spread; 8 – Environmental and geographical limits in the new range; 9 – Persistence (not expansion) in the new range.

Indeed, a biological invasion can be understood as an uncontrolled increased of a species or several species (Elton, 1958) that reached high population densities and
that causes negative impacts on the invaded ecosystem (Mooney e Hobbs, 2000). So, species can go out of their native range arriving in new areas and:
- fail to persist and disappear;
- subsist and become naturalized, with no disturbance to native species;
- became invasive and affect native species and ecosystems, by some kind of trigger (edaphic – climatic conditions, native species traits, alien species traits);
- some native species could also become invaders if, in a certain moment, these triggers act together;
The same species could act as an invader in a certain area and if moved into a different area does not present this behaviour.

These biological invasions mediated by humans are stimulated by globalization. The globalization phenomenon, in spite of stimulating wealth and integrate people and communities around the world, promotes transfer of organisms between ecosystems, where they previously didn’t exist (Keller et al., 2011; Vitousek et al., 1996). There are recorded impacts, around the earth, caused by these invasions, on ecology and economy (Vilà et al., 2010; Vitousek et al., 1997). Human activities, such as industry and agriculture, change the biogeochemical cycle of nitrogen and other elements, increase the carbon dioxide in the atmosphere, produce and release persistent organic compounds like chlorofluorocarbons, alter use and land coverage and promote biological invasions by non-native species, causing environmental changes (global climate change and/or loss in biodiversity). The geographical barriers that create and kept the typical regions of natural fauna and flora, are been threatened by biological invasions and regional differences are more faded (Vitousek et al., 1997).

This is caused by human activities but also because invasive species have extremely advantageous characteristics, as the excellent dispersal mechanisms (Elton, 1958). It’s urgent to study, understand and act in this area, as exotic species that became invasive have serious impacts and effects across many levels and time. Nonetheless, is necessary to remind that, there are numerous introduced species that are essential to mankind, though it would be impossible to feed, for example, the population of United States, only by indigenous species (Vitousek et al., 1997). However, due to the impacts that can provoke in the environment, it’s rather consider exotic species to be invasive and with potential risk, until prove otherwise (Arroyo et al., 2000).

Biological invasions by non-indigenous species are an environmental problem that has been affecting aquatic and terrestrial environments and there are several factors that can affect their success. The second cause of biodiversity loss, only overtaken by direct destruction of habitats (land-use change) is the introduction of potential invasive non-indigenous species, promoted by globalization, with consequent
increase of traffic of people and goods (Levine et al., 2003; Dogra et al., 2010). It is usual to distinguish three mechanisms which alien species can reach and move into a new region – importation of a commodity, arrival of a transport vector and/or dispersal from a nearby region where the species is already alien. The three mechanisms can be parted in six pathways: release, escape, contaminant, stowaway, corridor and unaided. Through importation, alien may be introduced as a deliberated release (biocontrol agents, plants for erosion control, etc.) or unintentionally as an escape from captivity (pets, garden plants, etc.). It can also be unintentionally transported as a contaminant of an imported commodity (pathogens, pests, etc.).

With the arrival of a vector, stowaways unintentionally arrive, independently of a specific commodity (but directly associated with human transport) like organisms transported in ballast water, cargo and airfreight. By dispersal mechanism, aliens can unintentionally attain new regions over corridors (via human transport infrastructures) and/or unaided situations (natural dispersal) (Hulme et al., 2008; Holeck et al., 2004; INSPECT-Projecto-ICNB). Afterward a simplified scheme of the previous ideas, from Hulme et al., 2008 framework:
### Table 1 – A simplified frame to classify paths of initial introduction of alien species into a new region (adapted from Hulme et al., 2008).

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intentional Commodity</strong></td>
<td>Intentional introduction as a commodity for release</td>
<td>Biocontrol agents, game animals, plants for erosion control</td>
</tr>
<tr>
<td><strong>Release</strong></td>
<td>Intentional introduction as a commodity for release but escapes unintentionally</td>
<td>Livestock, pets, live baits, garden plants</td>
</tr>
<tr>
<td><strong>Escape</strong></td>
<td>Unintentional introduction with a specific commodity</td>
<td>Parasites, pests, commensals of traded plants and animals</td>
</tr>
<tr>
<td><strong>Unintentional Contaminant</strong></td>
<td>Unintentional introduction attached to or within a transport vector</td>
<td>Hull fouling, ballast water/ sediment organisms/ soil</td>
</tr>
<tr>
<td><strong>Vector Stowaway</strong></td>
<td>Unintentional introduction via human infrastructures linking previously unconnected regions</td>
<td>Lessepsian migrants</td>
</tr>
<tr>
<td><strong>Dispersal Corridor</strong></td>
<td>Unintentional introduction through natural dispersal of alien species</td>
<td>Potentially all alien taxa capable of dispersal</td>
</tr>
</tbody>
</table>

At this moment it’s important to say that actual invasions are strictly connected with human activities, been the strength of the vector directly proportional to the scale of human involvement, and that previous introductions can facilitate the introduction and success of subsequent invasions (Holeck et al., 2004).

### 1.2. Objectives and methodological approach

With this work we aim to achieve a general view about biological invasions, particularly their impacts on biodiversity and ecosystem services.

The three main objectives that we propose to achieve are:

1. Analyse the most reported impacts (with mechanisms inherent), positive and negative, in the literature;
2. Compile in one document the positive and negative impacts studied by the scientific community, for a better perspective of the theme and supress the need of having in one document a global view of impacts of invasive alien species on communities and ecosystem services;
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

The first approach will be overall the taxa, and then the focus will be on invasive alien plants and the effects, both positive and negative, that can be caused on biodiversity and ecosystems. Ultimately an example will be given, with the genus *Acacia* in Portugal.

The methodology consists in search the literature, using internet (Google Scholar and the VPN connection to *Faculdade de Ciências*) to pursuit for papers, books and databases with the thematic.

2. Common effects of invasive species

Alien invasive species are one of the significant responsible of biodiversity loss and ecosystem service changes. For the past centuries they have been threatening biodiversity, and studies show an array of 33% endangered species of birds, and 11% of amphibians (EEA 16, 2012; European Environment Agency technical report No. 15/2012 – EEA 15, 2012). It is the fifth threat to amphibian, the third to birds and mammals and much more data will be needed to know about plants (Vié *et al.*, 2009).

Terrestrial invertebrates and terrestrial plants are the groups with most species triggering impacts. The first ones create more economic than ecological impacts, second ones are the reverse (EEA 16, 2012).

The costs of biological invasions in Europe, in an economic level, are assessed in EUR 12 billion per year, nonetheless, introductions are still growing for all groups but mammals, and currently over 10 000 alien species exist in Europe. Besides, together with climate change, biological invasions are one of the hardest drivers of change to invert, and once alien invasive species established, they can even be impossible to eradicate.

On the other hand, the introduction of alien species takes along benefits to some areas, for example when used in agriculture, animal farming, fishery, wood production, medicine, aesthetic enjoyment, hunting or trade of ornamental plants. They can even have a positive effect in natural environment, for example when they function as a food resource for native species or when they replace vegetation cover that had previously been damaged (Davis *et al.*, 2011; EEA 16, 2012). Nevertheless, we should consider these positive effects very carefully, because in almost every case, if not in all, the benefits run into harmful long-term effects to natural environments and species (Rodriguez, 2006; Kopp and Jokela, 2007; Davis *et al.*, 2011; EEA 16, 2012).
2.1. Negative effects

There are impacts of invasive alien species in biodiversity but also in human welfare, because of the economic alterations, for example in agriculture, forestry and fisheries, and because the effects they could have in our health (EEA 16, 2012).

The invasive alien species which leads to negative impacts are in a group that includes: fire stimulators and cycle disruptors, water depleters, disease causers, crop damagers, forest destroyers, fisheries disruptors, impeders of navigation, clogger of water, destroyer of homes and gardens, grazing land destroyers, species eliminators, noise polluters and modifiers of evolution (CBD, 2001).

So, having in mind the EEA technical report 16/2012, the invasive alien species impacts can be categorized in four groups: impacts of alien species on biodiversity; on ecosystem services; on human health and on economic activities.

The impacts on biodiversity can be various in the gene, species and ecosystem level. And the main threats to native species are brought by competition, predation and transmission of diseases, particularly on islands and isolated continental ecosystems.

The direct and indirect assistance of ecosystems to human health are classified as ecosystem services and can be separated in four classes: provisioning services (water, food, genetic resources, wood, fibre and medicines); regulating services (climate stability, natural hazard regulation such as flood control, water purification, pollination and pest control); cultural services (recreational, religious, spiritual and intellectual enrichment) and supporting services (ensure soil formation and nutrient cycling, provide habitat for migratory species and preserve feasibility of gene pools), which can be unbalanced (EEA 16, 2012; Vié et al, 2009; Vicente et al., 2013).

Nonetheless, some invasive alien species have at the same time several types of impacts not constrained to a single ecosystem service. They may drastically change the ecosystem functioning by altering species composition, physical habitat components, nutrient cycling, and primary production or disturbance regimes. The perfect example of this is the zebra mussel, that can modify supporting, regulating and, ultimately, provisioning services in aquatic ecosystems by the alteration of water quality and bioaccumulation for example.

Human health can be affected by the impacts of alien invasive species as they can be vectors of diseases. Problems can go from skin lesions, rhino-conjunctivitis to asthma, by contact with allergenic pollen, or virus.
The impacts in economic activities are frequent and sometimes difficult, for example the damage in infrastructures, landscapes and agriculture (see table 3). These kinds of impacts are easier observed and reported than the ecological impacts.

We can start to present the examples found in literature for impacts on biodiversity by predation of local species. The poster presented in CBD 2001, by Adams et al., showed that the introduction of trout in western North America altered native population, and large-bodied size zooplankton (calanoid copepods) and amphibian larvae significantly declined comparing invaded and uninvaded waters, due to predation. The habitat changes (loss of seasonal wetlands, more permanent hydroperiods) are detrimental to native species and supported the spread of alien species of fishes and bullfrogs, and the first ones facilitated the survival of the last ones.

American common sliders (Fig. 3), *Trachemys scripta*, are opportunistic predators that changes from carnivorous in juvenile stage to omnivorous as an adult, feeding on plants and animals, insects and other invertebrates to vertebrates such as amphibians, reptiles, small mammals and birds. Then again, the antipredatory behaviour that some native amphibian tadpoles have in the presence of native terrapins, doesn’t show in the presence of common sliders. Common sliders have negative impact on biodiversity as they eat several aquatic plants, which could deeply alter local vegetation, and also because it competes for other food items, basking and nesting sites, with native turtles. It can be a vector of dangerous diseases to humans, like *Salmonella*, and some can impose painful bites, and can spread other diseases and parasites to native turtles and wildlife, for example nematodes and bacteria (EEA 16, 2012).

![Fig. 3: Trachemys scripta, American common slider (photo by Greg Hume) (http://nas.er.usgs.gov/)](http://nas.er.usgs.gov/)
Feral cats (Fig. 4), *Felis catus*, are generalist predators, what means that they can prey on a variety of native species. This is particularly problematic on islands when they are introduced there. In Great Britain there are documented studies which report that cats killed 25 to 29 million birds per annum. In the Canary Island four endemic species (1 bird and 3 giant lizards), out of a total of 68 species that includes even invertebrates, are feral cats’ prey and considered threatened. In New Zealand there are several cases reported, similar to this and in the islands worldwide (EEA 16, 2012).

The Harlequin ladybird, *Harmonia axyridis*, is native of Central and East Asia. It was used as a biological control agent in European greenhouses, where it escaped and rapidly spread through Europe. It is an avid predator that feeds on aphids, scales and on other insects that feeds on its prey (other ladybirds – native species). They decline diversity of native ladybirds. If thousands of individual aggregate to hibernation in buildings they became a nuisance, they can even affect wine production when invade vineyards (EEA 16, 2012).

In Guam, 9 of 12 forest birds and 7 of 13 lizard species have been extremely reduced or even extinct after the accidental introduction of the brown treesnake, *Boiga irregularis*. Having lack of predators and lack of co-evolution with its prey, the brown treesnake efficaciously established in the area. The human health got threatened not only because of the snake bites but also because of diseases carried by insects that previously were eaten by lizards and birds. The livelihoods and economy were directly affected by the large blackouts that this species caused in the island (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

*Nothofagus* beech forests in the northern part of the South Island of New Zealand have large populations of native honeydew-producing insects. Honeydew is a great energy source to many trophic levels (birds, lizards and insects). When it falls to the ground,
adds a high quantity of carbohydrate and affects microorganisms and therefore nutrient cycling. Common wasps, *Vespula vulgaris* (which compete for honeydew and predate insects), browsers (brushtailed possums and red deer) and predators like stoats, rats and possums are alien species that have been invading these forests and disturbing the honeydew availability and native biodiversity, for example the kaka, *Nestor meridionalis* and robin *Petroica australis* are two of many species affected by predation of alien species introduced (Wilson *et al.*, 1998; CBD, 2001). *Arthurdendyus triangulatus* is the New Zealand flatworm. It's a terrestrial planarian who prey earthworms, and may reduce population of the last ones, what affects indirectly the fertility of soils and consequently indirectly the plants. It has been introduced from New Zealand into Northern Ireland, Scotland and England during the 60's and in the Republic of Ireland and the Faeroe Islands during the 90's, probably by potted plants, and could establish in other areas of Europe (CBD, 2001).

The brook trout (Fig. 5), *Salvelinus fontinalis*, example can translate the complexity of the invasion process and of the relationships between native and alien species: it competes with other salmonids for food and shelter and predates on native fishes. Native salmonids like the brown trout (*Salmo trutta*) can be replaced and that leads to reduction or even extinction of the freshwater pearl mussel (*Margaritifera margaritifera*), whose biological cycle depends on native salmonids. Brown trout is the host of the glochidia, the larval stage of the pearl mussel. It attaches to the host trout gills and feeds as a parasite, during winter. If native trout declines, the pearl mussel will too. The brook trout introduction was overdue to sport fisheries and aquaculture.

![Fig. 5: Salvelinus fontinalis, brook trout (http://www2.dnr.cornell.edu/)](http://www2.dnr.cornell.edu/)

The food habits of this predator vary with age and it has been a harsh problem, causing great impacts on native communities. At the first stages it feeds on insect larvae, then as adult it can feed on diverse native organisms like worms, leeches, crustaceans, insects, molluscs, fish, amphibians and also small mammals, as voles. Besides, the brook trout can hybridise with native brown trout, and some hybrids turn to be fertile,
what can conduce to a loss of local adaptations and reproduction of native populations (EEA 16, 2012; www.michigan.gov/dnr/).

Next, we could focus on impacts on biodiversity due to transmission/cause diseases/harm to local species. The red swamp crayfish, *Procambarus clarkii*, is a very aggressive species, generalist and opportunistic feeder, feeding mostly on juicy green plants, microbially-enriched detritus, invertebrates (planktonic and benthic), individuals of the same species, and amphibians. It is a chronic carrier of *Aphanomyces astaci*, a fungus that originates the crayfish plague in Europe. It shows that it is resistant to the disease and only acts as a carrier vector of the fungus that rarely kills its host. This co-evolution didn’t exist with European populations so this hostile pathogen created serious problems in all infected areas. It leaded to the decay of the native European white-clawed crayfish, *Austropotamobius pallipes*, and because of this decay there were more introductions in Europe of other species (of North American origin) for replacement in farming and repopulation. It is also connected to a virus that causes vibriosis in crayfish farms and it’s also intermediate host of helminths parasites in vertebrates. It likewise replaces the European crayfish as it exercises competitive exclusion, differential susceptibility to predation and reproductive interference. And because of its burrowing activity, it could cause large economic costs in agricultural and recreational areas (rice plantations, irrigation structures, dams and dykes, in rivers and lakes where they can weaken banks, alter soil hydrology, increase water turbidity and cause water leakage) (EEA 16, 2012).

The gumwood tree, *Commidendrum robustum* is endemic to the island of St Helen, in South Atlantic Ocean. In the 1970s/80s an alien insect, *Orthezia insignis*, Kew bug, South America native, was accidentally introduced in the island and rapidly threatened by extinction several endemic trees, as the gumwood tree. Though the use of a specialized predatory insect, coccinellid beetle, *Hyperaspis pantherina*, also south America native, was very effective in the control of Kew bug, better than insecticides (risk of non-target effects) (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

Recurrent alien species invasions have greatly altered species composition in the forest of the United States. American chestnut, *Castanea dentata* was well in the Appalachian Mountains until the chestnut blight, *Cryphonectria parasitica*, a pathogenic fungus killed nearly all the chestnuts throughout its range. This eradicated an important wildlife food source and amplified erosion. The whitebark pine, *Pinus albicaulis*, also North American native, is an important food source for wildlife. An introduced fungus, white pine blister rust, *Cronartium ribicola*, has killed more than 90% of the whitebark
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

The wood packaging material like pallets, crates, wooden spools for cable, and others, are a main pathway for introduction of forest pests, and responsible for this problem. So, the use of substitute materials and/or the fumigation of wood packaging could be a solution (CBD, 2001; www.cfia-acia.agr.ca).


Dutch elm disease, *Ophiostoma ulmi*, a fungus native of Asia was introduced in Holland and them in North America, most likely by imported wood. In Europe the fungus is spread naturally (short distances) by the elm bark beetles, *Scolytus scolytus* and *Scolytus multistriatus*. Human activities mediated the distribution, over long distances, contributing to the spread of this elm disease (CBD, 2001).

In North America, red oaks are being affected by the oak wilt, and other oaks also have serious damages by this disease, caused by the fungus *Ceratocystis fagacearum*. It is spread naturally (short distances) from tree to tree through root grafts and also by insect vectors. Human activities facilitated long distance spreading (CBD, 2001).

The impacts on biodiversity by competition of alien invasive species with local species also have several examples. *Cygnus olor*, the mute swan (Fig. 6), is an European species introduced in North America with aesthetical purposes in parks, zoos and private collections. With escapes from captivity and establishment of breeding population, they have negative effects on submerged aquatic vegetation and on the nesting of other aquatic birds (competition with native species for food and habitat) (CBD, 2001).

![Fig. 6: Cygnus olor, mute swan (http://www.allaboutbirds.org/)](http://www.allaboutbirds.org/)

*Mustela vision*, American mink, introduced in Europe for breeding in fur farms, escaped systematically but initially weren’t able to established permanent population in the wild. With the liberations carried out by animal protection activists, major escapes took
place, and the spread rapidly increase. The pressure especially on amphibians populations (Rana esculenta e Rana ridibunda), also fish, birds and small mammals, became very high, by this voracious predator. Furthermore, it seems that they are displacing the European mink, Mustela lutreola (threaten by extinction) and European polecot, Mustela putorius (CBD, 2001; EEA 16, 2012).

Another example can be given with the tropical algae Caulerpa taxifolia, killer alga. This Pacific alga has invaded Mediterranean waters significantly replacing Posidonia oceanica, Neptune grass. With this situation major change in communities and ecosystem functions and services appears. The killer alga was accidently introduced in the Mediterranean after an escape from a public aquarium in Monaco. It has a high growth and spread rate and can form dense fields in many substrates. It is also able to stand difficult conditions like nutrient limitation, eutrophication and pollution (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012).

But it seems that in the last years another species of algae is spreading and even out-competing Caulerpa taxifolia: Caulerpa racemosa (sea grapes). It invaded Mediterranean from the Red Sea, through Suez channel on ships’ hulls or ballast water (EEA 16, 2012).

The American bullfrog, Rana catesbeiana, lives in a wide range of aquatic habitats (lakes, ponds, swamps, bogs, marshes and backwaters). It shows a preference for artificial and largely modified habitats, such as millponds, livestock grazing ponds, reservoirs, irrigation ponds and ditches. Adults and larvae can both exert competitive behaviours relatively to native species. The American bullfrog tadpoles have a great negative effect on native tadpoles as they exert interspecific competition for resources, like algae. A curious fact about this interaction between the American bullfrog and native species is the occurrence of interspecific amplexus with the red-legged frog and the Oregon spotted frog. This situation could have negative consequences for the native frogs as it reduces the numbers of males coupling with conspecifics during the breeding time. The bullfrog also seems to take advantage from the presence of some other non-indigenous species in the ecosystem. In western North America a non-indigenous fish, the bluegill, is enabling the bullfrog invasion as it lowers the abundance of native dragonfly nymphs, one of the rare predators of the bullfrog tadpoles. It exists also the risk of channelize diseases and parasites to the native ecosystem. The bullfrog appears to be involved in the spreading of Chytridiomycosis, a fatal disease to the native amphibian fauna, caused by the fungus Batrachochytrium dendrobatidis. This spread is due to the escapes from breeding facilities where it was
farmed for human consumption and from garden ponds. The species also was intentionally released to attain wild populations or to be a predator of some insect pest, in Hawaii (EEA 16, 2012).

The main effect of rabbits (*Lepus curpaeums*) is on biodiversity by affecting habitat ecosystem and changing habitats, after overgrazing and burrowing activities (cause of erosion of soils and ultimately precede the altering of local composition and abundance of plants and animals). They are specialists’ feeders and can also be coprophagic. This species is used to a variety of habitats and is highly fecund. They are not only the source of loss of plant cover and destruction of habitats, but the competition with native population for food and shelter is another issue (Rabbit Welfare Association and Fund in: http://www.rabbitwelfare.co.uk/; EEA 16, 2012).

Alien invasive species hybridizing with native species causes also an impact on biodiversity. The Canada goose, *Branta canadensis*, is an omnivorous bird that feeds on aquatic plants, grasses, roots, stems, leaves, seeds and fruits and even on crops as an adult. As a juvenile he eats insects, small crustaceans and molluscs. Hybridisation can occur among several species. For example, ruddy duck and the native white-headed duck can hybridise, as well Canada goose with other geese species. That represents a great threat because it can reduce genetic variation and erode gene pools, by introducing maladaptive genes in the wild population what consequently result in more invasive hybrids (EEA 16, 2012).

The hybridisation of the Canada goose with other geese species seems to be rare but not inexistent in nature but easily observed in captivity. The hybridisation is linked to a behavioural mechanism of numerous goose species – interspecific nest parasitism and brood amalgamation. The result would be an offspring imprinted sexually on other species than in due time look for a mate resembling their “foster” parents rather than conspecifics resulting on hybridisation. Other negative impacts are competition with greylag goose and territory dislocation to killing of individuals of coots and moorhens.

The agricultural sector, parks and recreational areas are also negatively affected as a result of feeding and trampling. Some habitats can be injured by grazing and trampling of goose. The water bodies could suffer from eutrophication from the algae blooms caused by the deposition of nutrients of goose defecation. There is some worry when we talk about the excess of droppings contaminating soils and water because it can serve as a vector of several diseases that can affect human health. Lastly, the environments delivered by airports for grazing and resting is very appreciated by this species and for that it could be a threat to air safety because of the collisions with airplanes (EEA 16, 2012).
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

The ruddy duck (Fig. 7), *Oxyura jamaicensis*, is posing a great threat to the white-headed duck, *Oxyura leucocephala*, particularly in Europe.

![Oxyura jamaicensis](https://www.allaboutbirds.org/)  

Fig. 7: *Oxyura jamaicensis*, ruddy duck (photo by Brian L. Sullivan) (http://www.allaboutbirds.org/)

It is due to the tangible risk of hybridisation and the consequent genetic swamping; besides it compete for food and nesting sites with the indigenous species. Ruddy ducks were introduced in Europe to be a part of a private collection but eventually some individuals escaped. Now that that the two species geographically overlap, and are no longer geographically isolated like in this few million years ago, the genetic exchange is a concrete problem menacing native populations. On top of that the hybrids are fully fertile (EEA 16, 2012).

The impacts on economic activities could be due to the damage on agriculture. *Psittacula krameri*, the Rose-ringed parakeet can endure a wide range of temperatures. Its native range goes from the African continent, south of the Sahara to South Asia. It was introduced in Europe and eventually escapes from aviaries and became noxious. The individuals of this species are generalist feeders (eat a variety of fruits, flowers and nectar). Even in a part of their native areas they are recorded as one of the most damaging bird pests for agriculture (for example in India and Pakistan). In Australia it is the source of great destruction in plantations as they strip the bark from young stems affecting and killing trees, and by that changing the arboreal composition. In Europe most populations were introduced in urban environments. Nonetheless they are now spreading into rural environments. But the negative effects don’t stop here, they are a threat to native birds as they compete with them (habitats, food) and even be a vector of diseases like Newcastle’s disease and cryptosporidium, dangerous to poultry and for that affecting that industry. To humans the psittacosis can be problematic. In residential areas they are a noise annoyance (EEA 16, 2012).

*Sciurus carolinensis*, the grey squirrel is capable of disrupting the agriculture and the forestry activities and enhances ecological problems in forest ecosystems. It is a North American species that were imported and introduced intentionally as an ornamental species in parks and woodlands. It causes massive damage by selective bark stripping activity (exposes the timber to fungal and insect attack, disrupts the flow of nutrients up
the tree and weakens the stem and can change composition of forests, can be a negative impact for nesting birds) - though it affects ecosystem functioning. It out-competes the native red squirrel, *Sciurus vulgaris*, essentially for food resources and even is a vector of a deadly disease, the *poxvirus*, which kills red squirrels populations but is non-threatening to grey squirrels. It can be infectious to humans (EEA 16, 2012).

Yellow nutsedge, *Cyperus esculentus* was unintentionally introduced in the Netherlands by the import of gladiolus corms from the USA. It also could be spread through nursery stocks, infested soil and machinery. It can reduce crop yields (CBD 2001; University of California Agricultural and Natural Resources in: http://www.ipm.ucdavis.edu/).

The impacts on economic activities could also be felt by the damaging in infrastructures. The coypu (Fig. 8), *Myocastor coypus*, is native of Patagonia and it has escaped recurrently from the fur farms or was released into the wild with the objective of being captured for its fur.

Its burrowing behaviour causes great economic loss as it ruins human infrastructures like riverbanks and dykes, what can disrupt drainage systems and flood some areas. This invasive species is also an enormous damage to agriculture for the foraging feeding, and a potential injury to urban wetlands such as golf courses. Mostly they feed on crops if the natural vegetation is scarce. The feeding on aquatic plant species causes massive reduction and even elimination of the native species, besides this behaviour can affect aquatic birds as it destroys their nests and resting points. So, biodiversity is at risk. The human health also, as it probably is a part on leptospirosis epidemiology (CBD, 2001; EEA 16, 2012).

The alien zebra mussel competes with the native clams and can lead to extinction several native molluscs. Its introduction in Europe and North America resulted in great changes in water quality, as the invasive mussel alter the structure and function of the entire ecosystems (EEA 16, 2012). The aquatic ecosystem could be altered by them, as the energy flow is redirected (pelagic to benthic food webs). *Dreissena* are filter-
feeding species. When large densities are reached, the suspended organic material is removed from the water column. The fact could increase aquatic vegetation, blue-green algae and intensification of use of aquatic herbicides in inland waters (CBD, 2001). Zebra mussels form thick clusters attached to hard substrates and even on other bivalves, crustaceous, snails. It can be responsible of fouling pipes, ship hulls, navigational constructions, cages of aquaculture, can diminish angling catches, clogged water intake/supply, and many more infrastructures. In addition, when the mussels die, the falling-off of the filaments of the byssus accelerates corrosion of metal structures as the bacteria proliferates, affecting with their activity iron and steel surfaces. Additional costs can be made by maintenance. Recreational boats, fishing nets and any equipment in contact with the water can also be damaged what translates additional maintenance costs. It can affect human health too as it can turn into injuries to bathers. It out-competes native bivalves (EEA 16, 2012).

The damages to human infrastructures are other great problem when this species invade certain areas. The invaded sites are more vulnerable to invasions than uninvaded ones (Limnoperna fortune, the golden mussel, have the invasion facilitated by Dreissena). Prevention is largely more effective than control (CBD, 2001; EEA 16, 2012).

Besides, there are known effects that involve more than two alien invasive species, like for example Dreissena polymorpha, zebra mussels and Dreissena bugensis, quagga mussels, extremely effective invasive species in North America (CBD, 2001) are native of Russia (Global Invasive Species Database in: http://www.issg.org/database/welcome/).

The damaging of landscapes is another great economic impact. The red palm weevil, Rhynchophorus ferrugineus, is native of Southern Asia and Melanesia, and was introduced via nursery stocks and international trade of plants in Europe. It can cause substantial damages in a numerous variety of palms. This species are considered an ornamental and even main crop species generally in the Mediterranean area and coastal cities. The dead of palm trees by this weevil can cause big aesthetical and economic impact (moreover when it is known that the weevil can undertake long flights) (EEA 16, 2012).

The horse-chestnut leaf-miner, Cameraria ohridella, has its origin on the Balkan area. It made impacts in aesthetical and socio-economic areas. The larvae of this species feed on leaves what causes damages (browning and premature leaf-fall). That diminishes vitality of horse-chestnut tree (Aesculus hippocastanum) but do not cause the death of the trees. It can be seen in infected trees a decrease of carbohydrate concentration, twig starch, average seed weight, seed germination and relative growth rates.
Reproduction seems to be very negatively affected. Horse-chestnut is a species commonly planted in European urban habitats, so, this alien moth has a negative aesthetic impact. Besides that, the nuisance to people that uses parks and gardens where are infected trees is disturbing. The loss of photosynthetic activity also decreases so, climate and air regulation are threatened (EEA 16, 2012).

There are also reported impacts on human health as aliens often are vectors of diseases. The tiger mosquito, *Aedes albopictus*, native from Oriental region of the tropics of Southeast Asia, the Pacific and Indian Ocean Islands, through China, Japan and Madagascar, is a dangerous vector of diseases to humans, like yellow fever, Rift Valley fever, chikungunya and sindbis recorded in the Mediterranean and dengue, West Nile and Japanese encephalitis viruses. It can also carry parasites that can origin serious illness in other animals like the dog heartworm. The invasion by this alien also brings great economic impacts beside health effects. The prevention and implementation of strategies and management activities have high costs. And in many places it is displacing the so-called yellow fever mosquito *Aedes aegypti*, a native species from Africa (Global invasive Species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012).

*Nyctereutes procyonoides*, the raccoon dog, native of East Asia and introduced in Europe as fur game, can be a vector of several diseases and parasites. It is one of the leading terrestrial rabies vectors in Europe. It is also a reservoir and vector of other dangerous parasites that can infect humans, like the sarcoptic mange, the trichinella worms and fox tapeworm, SARS (Severe Acute Respiratory Syndrome), canine distemper virus (CDV) and avian H5N1. Besides the danger to human and other animals’ health, the ecological and economic impacts can be substantial. It is an opportunistic omnivore that may become a threat to bird species, as well as amphibians (EEA 16, 2012).

There are impacts on human health also because the direct health impacts that invasive alien species could impose. *Heracleum mantegazzianum*, the giant hogweed was introduced as an ornamental plant in Europe, from its native site Asia. And also poses major impact on human health as its photosensitive metabolites (furanocumarins) react under ultraviolet radiation (sunlight) on human skin and leaves a burning sensation reaction that can cause severe skin lesions. The compact monodominant stands reduces composition and diversity of native species so the negative impact on biodiversity is very high. The impact is also negative on cultural services as it changes the recreational areas and it accessibility (EEA 16, 2012).

The common ragweed (Fig.9), *Ambrosia artemisiifolia*, native of North America, was introduced as a contaminant of agricultural products, machinery and construction
materials into Europe. It can have serious effects on human health as its pollen is very allergenic. It can generate hay fever, rhino-conjunctivitis, and severe asthma. Due to the lightness and very high production of the pollen it is spread by the wind through large distances and so allergic reactions can be recorded in a distance quit far from where the plants are. In addition, there is evidence of cross-reactivity between the allergens of other species of ragweed what can point toward a high risk of evolve multi-hypersensitivity. This species also contains volatile oils that might cause skin irritation, hypersensitivity dermatitis, development of serous vesicles and itching. The economic costs are elevated. The robust growth of the aerial and underground parts, turns this weed into a severe problem to numerous crops, as it may be a reason of quick drying (it uses two times more water than cultivated plants) and may deplete the soil. The livestock doesn´t feed on it (and if some does, it taint dairy products) and its presence could critically reduce the fodder quality of pastures. It hard stems, turn the harvest of cereals and other plants with agrarian machines challenging. The dense invasions of this weed also distress the biodiversity of native vegetation (EEA 16, 2012).

The ecosystems services are impacted particularly the cultural services in the examples given afterward. The killer shrimp, *Dikerogammarus villosus*, native of Caucasus area, is an omnivorous predator, with an extensive range of environmental tolerance. It invaded new sites by the countless human activities. This one can cause significant ecological disturbance, like reducing biodiversity and even local species extinction, by predation or through indirect effects in different levels of the food web. Native gammarid are one of the species displaced or extinct by this alien invasive species. Another great impact is the decline of leaf decomposition, what have an intense effect on nutrient dynamics in invaded areas. This alien also eats fish eggs, fish fry and small fishes. By this we can see the great direct economic and social impacts caused by changing fisheries quality and on recreational activities. So, the killer shrimp have definitely impact on ecosystems cultural services (recreational activities like
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

angling) and on ecosystems supporting services (habitat). It can be a vector of parasites like acanthocephalan that could affect salmonids and then be another negative impact on fisheries. It looks like it has co-evolved with zebra mussel therefore is very linked to it and together seems to have invaded many freshwater areas and affected many communities as they took advantage of each other (Great-Britain Non Native Species Secretariat in: https://secure.fera.defra.gov.uk/; EEA 16, 2012). The provisioning services of ecosystems are affected by the Spanish slug, *Arion vulgaris*, as it feeds on horticultural plants and vegetable gardens and in agricultural species in general. Norway reported more than 50 % crop loss of strawberry. In natural habitats, it is very negative to biodiversity, as it predates, outcompetes and hybridises with native slugs. It also influences plant species diversity what modifies the successional change. No positive effects of this slug species was recorded in the introduced range (EEA 16, 2012).

*Vespa velutina*, the yellow-legged hornet, native of Southeast Asia, introduced accidentally by horticultural trade, predaes mostly social wasps and bees, but has an extensive diversity of insect prey, as the European hornet and are of great concern to the ecosystem regulating services. It predaes very effectively honeybees and many other pollinators becoming a threat to this wild species. Thus it is a wide impact on native insect diversity. By this it can also be said that the yellow-legged hornet might negatively affect ecosystems providing services, predominantly pollination. The beekeeping activities suffer a big negative impact (besides the other factors that affect it like air pollution, climate change, decrease of flowering plants, fungus and parasites outbreak and pesticides). The human health can be threatened too, as the stings can cause a problematic allergic reaction (Global Invasive Species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012).

The former ideas are synthesized in the framework - table 2 - based on the framework presented on EEA technical report 16/2012 and in remain literature. The examples of species recorded in this technical report and consequently in the framework of table 2, were selected having in mind the fact of being representative of all main taxa; the existence of strong data about the impact created by the alien and being a species where the European Commission spend more resources to decrease their impact. At this point we must regard that most of the time there are several impacts from one alien species (table 3). Here we are going to describe what the literature considered the direct ones, keeping in mind the cascading effects that usually invasive alien species inflame through time and/or simultaneously.
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

Table 2: Type of impacts caused by IAS separated in 4 categories adapted from EEA 16, 2012 and remaining literature:

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Mechanisms</th>
<th>Examples</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impacts of IAS on biodiversity</td>
<td>Competing with local species</td>
<td>American mink, Bullfrog, Mute swan, Killer alga</td>
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<td>Predating local species</td>
<td>Brook trout, Common slider, Brown treesnake, Common wasp</td>
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<td></td>
<td>Transmitting/ causing diseases/ harm to local species</td>
<td>Red swamp crayfish, Chytric fungus, Kew bug, Chestnut blight, White pine blister rust, Pine wood nematode, Dutch elm disease, Oak wilt</td>
<td>CBD, 2001; <a href="http://www.cia-acia.agr.ca/">www.cia-acia.agr.ca/</a></td>
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<td>Hybridizing with native species</td>
<td>Canada goose, Ruddy duck</td>
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<td></td>
<td>Affecting habitats ecosystem engineering/ modifying or changing habitats</td>
<td>Rabbit, Killer alga</td>
<td>EEA 16, 2012; <a href="http://www.rabbitwelfare.co.uk/">www.rabbitwelfare.co.uk/</a></td>
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<td>Interfering with habitats ecosystem engineering/ modifying or changing habitats</td>
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<td>EEA 16, 2012; <a href="http://www.issg.org/database/welcome/">www.issg.org/database/welcome/</a></td>
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<td>Interfering with provisioning services</td>
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<td>Interfering with regulating services</td>
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<td>Health impacts</td>
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<td></td>
<td>Damaging landscapes</td>
<td>Red palm weevil, Horse-chestnut leaf-miner</td>
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<td>Damaging agriculture</td>
<td>Grey squirrel, Rose-ringed parakeet, Yellow nutsedge</td>
<td>CBD, 2001; <a href="http://www.ipm.ucdavis.edu/">www.ipm.ucdavis.edu/</a></td>
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</table>

Note: IAS – invasive alien species
Table 3 – Troublesome alien species in Europe and their multiple impacts (EEA technical report 16/2012)

<table>
<thead>
<tr>
<th>Alien species</th>
<th>Competing with local species</th>
<th>Predating local species</th>
<th>Transmitting diseases/harm to local species</th>
<th>Hybridizing with native species</th>
<th>Affecting habitats ecosystem engineering or modifying habitats</th>
<th>Interfering with supporting services</th>
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Note: x - impact that the specific species exemplifies (not necessarily the most prominent). 0 - other impact that can occur. The vertical arrow enhances the plant alien species – more present than other taxa.
2.2. Positive effects

There are several mechanisms how alien species can facilitate native ones, like habitat modification (the most documented, also referred as ecosystem engineering), trophic subsidy, pollination – direct interactions – and competitive and predatory release – indirect interactions (Rodriguez, 2006; Barber, et al., 2008) (see table 4). The facilitative interactions can be divided in three types: substitutive, novel and indirect. Novel facilitation exists if alien species is functionally different from native species what make available a new resource utilizable by native species. Substitutive facilitation is when an alien species functionally take the place of a native facilitator species (the invader outcompetes the native facilitator). The abundance or biomass of native species that are been facilitated doesn´t change whatsoever. Only if the invader is removed and the native facilitator isn´t re-established the negative effects will show. The indirect facilitation is when a native competitor or predator has a reduction by an alien species, what makes the native prey or native competitively inferior species increase. It´s important to study these kinds of interactions because they can happen between alien and endangered species. By that it could have results in important management, eradication and restoration repercussions, which would help to choose wisely the best solution. In Azores and Madeira, seven species of endemic land snails are now in need of the habitat created by non-indigenous plants that completely substituted native endemic forest (Rodriguez, 2006) – facilitation by habitat modification (substitutive facilitation). So, with the alien invasive species issue, we know that the first thing that comes to mind is their eradication and the restoration of the native species that could be moved. But this is very improbable to happen because most, if not in all, of the times disturbance regimes (fire, flooding) are completely altered, what makes it economically unbearable and ecologically complicated and sometimes unsuccessful. So, in face of that, occasionally aliens are the solution for the viability of native species, even for some endangered species. For example, throughout the Muddy River in the Mojave Desert, North America, Tamarix ramosissima, the salt-cedar, has moved the cottonwood, Populus fremontii, the willow, Salix spp., and the mesquite, Prosopis sp., Nevertheless, several native birds, including the endangered Empidonax trailli, south-western willow flycatcher, uses the salt-cedar for nesting and shelter, even if some native trees remain. Probably because the total volume of food available was greater than before or because many birds didn´t have a solid predilection for the tree species in which they nest or because Tamarix ramosissima is functionally equivalent to the native Salix sp., lastly it could also be because the birds
used a small proportion of plants present in the habitat (Fleishman et al., 2003) – facilitation by habitat modification (substitutive facilitation).

There are many others examples of facilitation by habitat modification: Sites invaded by *Dreissena polymorpha*, zebra mussel, *Musculista senhousia*, Japanese mussel, and *Lymnoperna fortunei*, golden mussel, form dense and complex colonies that make refuge and significantly enlarges invertebrate diversity and abundance. The yellow perch, *Perca flavescens*, also had bigger growth rate due to the increase availability of invertebrates concomitant with zebra mussels' invasions. The provision by zebra mussels of new habitat to native species is in the matrices they create (Global Invasive species Database in: http://www.issg.org/database/welcome/; Rodriguez, 2006) – novel facilitation.

The invasive reef constructor polychaete *Ficopomatus enigmaticus* (Fig. 10), also creates refuge for native crab species, *Cyrtograpsus angulatus* (but also indirectly and negatively affects other organisms, like macroinfaunal organisms that are predated by the crab species – increased of the predation pressure. Besides novel habitats can be a facilitative way to the arrival of many other species.) (Schwindt, 2001; Rodriguez, 2006) - novel facilitation.

The ascidian *Pyura praeputialis* recently invaded the rocky coast of Chile and provides shelter to seventy-nine species of invertebrates (Rodriguez, 2006) – novel facilitation. Lately it was found the direct or indirect positive effects on estuarine macrofauna of invasive invertebrates and seaweeds. The example comes from Virginia, North America, the native polychaete *Diopatra cuprea* establishes habitat for the invasive seaweed *Gracilaria vermiculophylla*, native of the West Pacific, and this seaweed proportionate extra habitat for bryozoans, crustaceans, polychaetes, gastropods and algae (Thomsen, 2010) – novel facilitation.

Facilitation relationships by trophic subsidy also have some examples. We can say that, for example, nitrogen-fixing plants can facilitate neighbour plants. In the Wadden

Invader can be a source of diversification. In Flathead Lake, Montana, North America, the introduced Kokanee salmon (introduced for recreational fishery) is been preyed by native predatory birds, like bald eagles, and mammals (Spencer et al., 1991) – novel facilitation.

Zebra mussel is considered an essential food component for some fish, crayfish and birds. It shells can even be used as fertilisers and poultry food. The increase of water clarity known in several lakes after the invasion can neutralize the negative effect of eutrophication and pollution from human activities (it can bioaccumulate pollutants) (Global Invasive Species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012) – novel facilitation.


The red swamp crayfish has some positive effects that can be noted on the community of predators. In some countries (Italy and Spain) the number of little egrets, purple herons, cormorants and even endangered species, like the bittern had improved with the enlarged population of red swamp crayfish. It can be too an important resource for local population, that capture to sell and eat them (EEA 16, 2012) – novel facilitation.

Species introduced as a biological control, for example non-indigenous insects to control alien plant species, can also become prey. It’s the case of two gall fly species of the genus *Urophora* that were introduced to try to control spotted knapweed, *Centaurea maculosa*. The native mice *Peromyscus maniculatus* consumed an average of 247 larvae of these flies per day what automatically leaded to the growth of population size and mice survival, although decreasing the efficiency of reduction of target alien (Pearson et al., 2000) – novel facilitation.

Rabbits can have positive effects on native predators and ecosystems. For example, in United Kingdom and Germany it maintains short sward heights and serves as a prey for many native predators. Like in the Iberian Peninsula were some predators populations declined after an outbreak of myxomatosis virus introduced to control the rabbit populations (Rabbit Welfare Association and Fund in: http://www.rabbitwelfare.co.uk/; EEA 16, 2012) – novel facilitation.

Introduced subspecies of the alga *Codium fragile*, felty-fingers, presumably from Japan shores and very widespread, are chosen by sea slugs rather than the native *Codium* species in the British Virgin Islands, Australia (Trowbridge, 2004) – novel facilitation.
In Azores, a plant community almost composed totally by alien species delivers the biggest winter food source to the endemic bullfinch, *Pyrrhula muriana* (Rodriguez, 2006) – novel facilitation.

The part of alien species on trophic subsidies is especially interesting partly because aliens most of the times get high abundances and could represent an important food source to native predators (herbivores feeding on non-indigenous plants, frugivores consuming fruit of non-indigenous plants, consumers that could eat non-indigenous animals). For example, the gypsy moth, *Lymantria*idae, an Eurasian species introduced in North America, abundance influenced the natives’ yellow-billed cuckoo number, *Coccyzus erythropthalmus* Wilson. The last ones abundance is greater when an outbreak of the first one happens. In the Channel Islands, California, the endangered island fox, *Urocyon littoralis* Baird, was predated by golden eagles introduced there. Then later feral pigs were also introduced to act as a trophic subsidy, allowing eagles to colonize the islands and choose this other prey instead of island fox (Barber *et al*., 2008) – novel facilitation.

It is possible that invasive species function as host specie which supplies food and habitat to native species. The example in California, where native butterflies oviposit or feeds on alien plant species (34% of the about 236 native butterfly species) and a range expansion can be observed as increased population size and/or extra time of the breeding season (Graves and Shapiro, 2003) – novel facilitation. Also, Acanthocephalan parasites, parasites of freshwater amphipods, are more predominant in alien amphipod species than in native communities and interestingly permit the coexistence of alien and native species (Rodriguez, 2006) – novel facilitation.

One of the hypotheses sustaining the success that alien species can get is the “enemy release” hypothesis. Alien species become inapplicable hosts to native parasites, which gives a clear advantage to the invader, particularly at early stages of invasion. But not only would the alien species benefit from this, native communities could also take advantage from the presence of the invader, as the alien species adds a potential host into the community, creating a “dilution” of the risk of infection for the native host species. Experimentally, the European invader *Lymnaea stagnalis* (Fig. 11), pond snail, and the native New Zealand *Potamopyrgus antipodarum*, New Zealand mudsnail, freshwater snails, were mixed or separately exposed to the native trematode parasite *Microphallus* sp.. It was observed that the rate of infection was significantly lower in the native New Zealand mudsnail when it was exposed mixed with the alien pond snail.
Kopp and Jokela, 2007, also talked about the work of Telfer et al., 2005, where they checked for flea-transmitted haemoparasites (genus *Bartonella*) infections in invaded and unininvaded areas in Ireland for the alien bank vole, *Clethrionomys glareolus*. With the increase of bank vole density, the infection on native wood mice, *Apodemus sylvaticus*, had an important decline (Kopp and Jokela, 2007; http://www.scholarpedia.org/article/Lymnaea; Global Invasive Species Database in: http://www.issg.org/database/species/ecology.asp?si=449; Telfer et al., 2005) – novel facilitation.

Alien species can also act as pollinators facilitating some native species. In Hawaii, many native birds got extinct or are consider endangered, and there the Japanese white-eye, *Zosterops japonica*, converted to the principal pollinator of the Hawaiian ieie vine, *Freycinetia arborea* Gaud (Cox, 1983) – novel facilitation.

In facilitation interaction by competitive release the competitive dominant species abundance is reduced by an alien species and a competitive inferior native species could be facilitated. Like the case of the invasive European green crab, *Carcinus maenas*, that would opt to prey dominant infaunal clam species, which will create greater abundance of many benthic invertebrates – indirect facilitation.

In the same order of ideas, if native consumer abundance lows by invasive species, the abundance or biomass of native prey increases – facilitation by predatory release. This is the case of the toad, *Bufo marinus*, that was introduced and by that facilitates native anuran, because it predates native predatory anuran (Rodriguez, 2006).

The mongoose, *Herpestes javanicus*, native from the area from Middle East to the Malayan Peninsula, had been introduced in many tropical regions (Hawaiian Islands, Mauritius, West Indies, etc.) to serve as a control of rats and poisonous snakes. But the decline of many native species is recorded as it has a generalist feeding behavior. The study that took place in Amami-Oshima Island, Southern Japan, evaluates the positive role that this species could develop to some native species. The mongoose had deleterious effect on seven larger animals and the medium size animals and small ones had the predation pressure decreased, having an increase in their abundance as
the large native animals were predated by the alien mongoose (as a generalist predator it select the most profitable prey) (Watari et al., 2007) – indirect facilitation. The recreational fishing community perceive the brook trout as a provider of economic benefits to local communities (EEA 16, 2012).
Table 4: Mechanisms of facilitation of alien species to native species (several taxa).

<table>
<thead>
<tr>
<th>Mechanisms of facilitation</th>
<th>Definition</th>
<th>Examples</th>
<th>The 3 types of facilitative interactions</th>
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<td>Competitive release</td>
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<td>European green crab</td>
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3. Effects of invasive alien plants on biodiversity and ecosystems services

In this section we will focus on both negative and positive effects, described in literature, only of alien invasive plant species. These effects can be felt on biodiversity and ecosystem services and there will be given several examples studied in the past years.

3.1. Negative effects

Biodiversity creates and stands all life processes on Earth (Millennium Assessment, 2005). Species give us essential goods like food, fuel, material to build our homes and clothes, medicine, prevention of soil erosion, pollination of crops, regulation of climate and others. They also are resources for economic activities like tourism, fisheries and forestry. We can say that they too have aesthetical and spiritual values. Therefore the decrease of species would automatically reduce our live quality and economic security. Unfortunately lots of examples proliferate in our days: invasive species that are destroying grazing lands and that make fruit industry rely on wild pollinators; fisheries falling all over the world, and many more (IUCN, 2009).

The effects of invasive alien plants could be very deleterious in different levels. They affect the habitats they invade, and the effects could go from altering the native biodiversity, soil nutrient composition, fire cycles, threat the endangered/threatened native plant species or even reduce productivity of invading ecosystems (Dogra et al., 2010). In the next sections we will review the negative impacts of alien invasive plant species on populations and communities and on ecosystems services, in natural environments but also give some examples of invasive alien species that especially affect areas where a big human interference is felt, as they can pose a threat to nearby natural environments, and by that they must be recorded and monitored.

To systematize the understanding of the effects of alien species on populations and communities, we can use the classification adopted by the EEA, and give the several examples over it. So, we can give the examples, divided by impacts of invasive alien species on biodiversity, on ecosystem services, on human health and on economic activities (see table 5).
3.1.1. Negative effects of invasive alien plant species on populations and communities

Alien species cause serious ecological effects that affect distribution, abundance and reproduction of various native species, and even can influence their evolution (Dogra et al., 2010). Some studies estimate that about 20% of plants in continental areas are considered exotic, and the number could be higher than 50% to several islands (Dogra et al., 2010).

Generally speaking they can modify species composition of the invaded space; alter community structure; reduce species diversity and even extinct some of them; change the nutrient cycle, regional microclimate and fire regime; compete with native species in an advantage way; can introduce diseases, plagues and parasites for whom receptor communities don’t have means to fight against; promote hybridization; modify hydrology; and promote huge economic losses just for the attempt of controlling and harvest loss, as aesthetic and recreational damages (Spuhler and Harrington, Fifteen North American Prairie Conference; Arroyo et al., 2000; CBD, 2001).

Native species can alter anti-predator defences, can change the spectrum of resources and habitats used, only trying to persist in the invaded areas (Dogra et al., 2010).

Inside each impact type, we can report the way by witch the impact is produced. At this point we are going to refer the impacts felt on biodiversity, expliciting the way it is originated, whereas invasive alien species are competing with local species, predating them, transmitting/causing diseases to native species, hybridizing with native species and affecting/changing local habitats. It is needed to have in attention that most of the times there are a combination of factors and not only one that impacts biodiversity.

There are several examples on literature referring alien species competition the mechanism of transformation of native biodiversity. Competition for nutrients, light, water, pollinators and seed bedding. It leads to a decrease or even elimination of native species (CBD, 2001; EEA 16, 2012).

By the direct competition between native and alien species, that generates impacts on biodiversity by this mechanism, the result can be monocultures of alien species like the case of Psidium cattleianum Sabine, commonly named strawberry guajava, in Mauritius, and Parthenium hysterophorus L., white top, in Australia and India (Dogra et al., 2010).
American rope, *Mikania micrantha* and congress grass, *Parthenium hysterophorus* are Neotropical plants that established in India and became very invasive the first introduced as a cover crop (after Second World War it was introduced in India to cover airfields) and *Parthenium hysterophorus* accidentally. Nowadays, *Mimosa invisa* to (giant sensitive plant). *M. micrantha* competes with other plants for water nutrients and light, climbing and smothering them, being in natural environments or in crop fields. It’s believed that it has allelophatic substances that inhibit other species. *P. hysterophorus* has a vigorous growth and outcompetes native flora, also for its allelophatic properties. It can cause serious allergic reaction in humans. *M. invisa* form dense mats that impede animals to reach and use native vegetation, and choke crops, leading to crop and pastures loss (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

Alligator weed (Fig. 12), *Alternanthera philoxeroides* have also been identified in irrigation water in Sri Lanka. It also affects biodiversity by competition with native species. It forms mat clogs that impede light penetration affecting and altering the native community and promotes health problems by generating habitats for mosquitos (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

*Rhododendron ponticum*, pontic rhododendron is a highly competitive species that shades all plants that try to growth beneath it. The seedlings of the trees that growth above it, yet, cannot establish underneath rhododendron and so forests are transformed into monodominant rhododendron stands. The leaves of this species have toxic chemicals that protect it from herbivores and can emanate phenolic compounds that constrain the growth of near vegetation. Also, it can be a vector of diseases that can affect other trees, like oaks. By this native species can be displaced, diversity reduced and species composition changed. In some areas it has been recorded that stands growing unsettle food webs, creating community structures with low invertebrate abundance and also suppressed algal production (EEA 16, 2012).

The introduction in the South Hemisphere of pines, affected areas of natural grass and shrub lands that led to the decrease of species composition, modified vegetation patterns and nutrient cycles. Worldwide there are examples like this, where exotic trees were introduced and became serious invaders. Australia, New Zealand and South Africa had in hands a difficult situation with different pine species that invaded natural habitats (Dogra et al., 2010).

South African ragwort, *Senecio inaequidens*, native to South Africa, Lesotho e Swaziland was introduced via importations (wool) to Europe and spread from Belgium to Germany by wind, specially through anthropogenic constructions like railways and
highways. It’s very resistant to herbicides and the maintenance of structures as well as mowing stimulates its growth. It appears to occupy empty ecological niches, in locals lacking vegetation, mainly greatly transformed by human activities. As a perennial herb that forms stands capable of strong competitive pressure to ruderal species (e.g. shade) and skillful to spread to disturbed sites, overlook is necessary to near-natural locations, as they could pose a problem to native species. With their inherent toxicity and capability to spread to pastures it affects negatively livestock health (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

In North America the control of leafy spurge, *Euphorbia esula* (native to Europe and temperate Asia) and Canada thistle, *Cirsium arvense*, has lean on introduction of biological control insects, like flea beetles *Aphthona spp.*, and application of herbicides. The leafy spurge, *Euphorbia esula*, out-competes native vegetation for water and nutrients, and constrains growth of nearby plants by shading. When in grazing pastures, it reduces species desirable to cattle that avoid it. It can interfere with pollination. Canada thistle, *Cirsium arvense*, reduces crop yield as they compete for water and nutrients. It can be the host of insects that reduces other crops production (CBD 2001; Global invasive Species Database in: http://www.issg.org/database/welcome/).

Siam weed, *Chromolaena odorata* and lantana, *Lantana camara*, native of Neotropical region, were introduced in India by Calcutta Botanical Garden (CBD 2001). *L. camara* and *C. odorata* both growth in dense thickets what prevents the setup of other species. That reduces biodiversity. The allelopathic characteristics of these species impact nearby plant species. *L. camara* and *C. odorata* changes fire regimes and the first can cause allergic reactions leading to skin lesions and asthma. The second one even interferes with the nesting of Nile crocodiles, as it forms dense mats, what changes the sex-ratio of the offspring (Global Invasive Database in: http://www.issg.org/database/welcome/).

Ice plants, *Carpobrotus edulis*, are natural from Cape Region of South Africa and were introduced in Europe as an ornamental plant. They can spread over large areas and reduces native biodiversity by direct competition. It can compete for nutrients, water, light and space and can stifle the growth of native seedlings and adult plants. On invaded areas the carbon and nitrogen of soil increases while pH decreases, basically owed to litter accumulation of this species, and as secondary compounds diminished decomposition rates. Hybridisation of ice plant species in Europe is often recorded and hybrids actually show larger strength and invasion capacity. Similar occurrences are observed in other alien hybrid plants species like for example knotweed species (EEA 16, 2012).
Herbaceous and lianas are the dominant exotic species in Bangladesh, growing in the wild or as a crop. Plant introduction has a long history in this country, as plants of economic relevance were introduced over time (naturally or planned). Some common fruit trees like litchi, *Litchi chinensis*, pineapple, *Ananas sativus*, watermelon, *Citrullus lanatus*, coconut, *Cocos nucifera* and guava, *Psidium sp.* are also introduced. Also important vegetables as cucurbits, *Cucurbita spp.*, radish, *Raphanus sativus*, potato, *Solanum tuberosum* and carrot, *Daucus carota* are also introduced and became naturalized in the country. In cultivated fields are also seen species like joyweed, *Alternanthera*, broom sedge, *Scoparia* and heliotrope, *Heliotropium spp.* and also found in water land as water hyacinth, *Eichhornia*, spikerush, *Eleocharis* and pondweed, *Monochoria sp.* (CBD, 2001; United States Department of Agriculture, Natural Resources Conservation Service in: http://plants.usda.gov/). However, a good number of exotic plants grow in nature. They were first introduced as garden/ornamental plants and later strongly established in different places, and became dominant and harmful weeds of forests and wastelands, like Siam weed, *Eupatorium odoratum* (= *Chromolaena odorata*), heartleaf hempvine, *Mikenia cordata*, croton, *Croton sp.* etc.. (CBD, 2001; United States Department of Agriculture, Natural Resources Conservation Service in: http://plants.usda.gov/). In 19th century the introduced tree species are teak, *Tectona grandis*, silk trees, *Albizia spp.*, rain tree, *Samanea saman* (currently *Albizia saman*), ironwood burl, *Xylia kerrii*, and Honduras mahogany, *Swietenia macrophylla*. In the 20th century some Australian species were introduced like *Eucalyptus camaldulensis*, river red gum, *Acacia mangium*, brown salwood (Fig. 12), *Acacia auriculiformis*. The last one has pollen that is creating many allergic reactions in the population. Most of the introduced species have an intense growth that repressed growth of the native species, which drives to loss of indigenous floral diversity. It can be seen that in undisturbed natural forests the resistance is bigger to invasion, but the degraded areas don´t have that resistance (CBD, 2001; www.kew.org/; www.anbg.gov.au/).
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

In 2009, Hejda et al., studied the impact of invasion of 13 invasive species among invaded communities compared with non-invaded ones. There were found major differences in species richness between invaded and uninvaded areas for five species. The total number of species in the community was reduced by almost 90% and the similarity between invaded and uninvaded areas also reduced. *Heracleum mantegazzianum*, giant hogweed, *Aster novi-belgii*, New York Aster, and *Fallopia bohemica* (fertile hybrid from *Fallopia sachalinensis* and *Fallopia japonica*) were responsible for great changes in species composition and decrease similarity between invaded and uninvaded areas (33 – 36%). For the remaining species the invaded and uninvaded areas similarity were about 42% to 75%. *Impatiens glandulifera*, Himalayan balsam and *Mimulus guttatus*, common monkey-flower had minimum impact. The effects were correlated to alien species and local species traits, and community characteristics.

*Schinus terebinthifolius*, the Brazilian pepper, *Melaleuca quinquenervia*, the Australian paperbark and *Casuarina sp.*, the Australian pine, were invasive trees introduced in Florida, USA, and originate great problems to native vegetation (Dogra et al., 2010).

According to Vilà et al., 2011, local plants can have their fitness lowered by 41,7% and their growth by 22,1% by the action of alien ones, that implies a drift in plant community structure, decreasing species abundance (43,5%) and diversity (50,7%).

3.1.2. Negative effects of invasive alien plant species on ecosystems and their services

We can say that: Ecosystem Functioning = Ecosystem Properties + Ecosystem Goods + Ecosystem Services.

Ecosystem Properties include the pools of materials (carbon; organic matter) and rate of the processes (fluxes of materials and energy);

Ecosystem Goods are ecosystem properties that have direct market value (food; construction materials; medicines; genes; tourism and recreation);

Ecosystem Services are ecosystem properties that directly or indirectly benefit human welfare (hydrologic cycles; regulation of climate; pollination; soil genesis; storage and cycling of nutrients).

But there are other divisions depending on author (Srivastava et al., 2005).

Ecosystem properties have a great dependence on biodiversity. The fundamental characteristics of the species (dominant species, keystone species, ecological engineers and the interactions among species like competition, predation, facilitation, mutualism...) present in certain ecosystems, its abundance and distribution together with the climate and nutrient availability affect them. So, the different components of biodiversity (species richness, species abundance, composition, presence/absence of keystone species) can affect differently ecosystem properties. Under similar conditions, the susceptibility to invasion by alien species normally decreases with the increase of species richness. Having a range of species that responds widely diversely to disturbance would create a stable ecosystem (Hooper et al., 2005).

Human activities are responsible for several alterations (in local and global scales), such as the ones generated by alien species invasions. Most of the times leading to changes in the biota structure and composition of communities. This quickly transforms how ecosystems perform, the ecosystem properties (Hooper et al., 2005; CBD, 2001; Chapin III et al., 2000).

Species composition, richness, evenness and interactions, all respond to and at the same time influence ecosystem properties (Hooper et al., 2005; Shea and Chesson, 2002; Chapin III et al., 2000).

A great number of natural (ex.: forest) ecosystems are put on the line because of alien species invasions. Invasive plants are a menace to ecosystems as they decrease biodiversity, deteriorates ecosystem properties and services. They can directly or
indirectly alter forests important functions which carry changes in plant community composition/structure leading to disrupted ecosystem services (Devine and Fei, 2011). Some invasive alien species has at the same time several types of impacts not constrained to a single ecosystem service. They may drastically change the ecosystem functioning by altering species composition, physical habitat components, nutrient cycling, and primary production or disturbance regimes (EEA 16, 2012). Several ecosystems attain multiple invasive species and Johnson et al., 2009, with an experiment proved, with the aliens Bellamya and Orconectes and the effect they had on native snail communities, that the alien species affected native species and ecosystem properties. Many invasive plants have the ability to transform above and belowground ecosystems, especially when they have different traits from native species and those traits are a driving force of ecosystem processes, changing ecosystem properties (Simberloff et al., 2013). There are studies that document the allelophatic effects of invasive alien plant species on native plant communities. For example Centaurea species which discharge chemicals that suppress native species and alter the structure of native plant communities. Interactions between soil microorganisms and new allelochemicals only recently became studied, but it is of important value since soil microorganisms have a key role in the structure and dynamics of plant communities and could be affected with alien invasions. Like the example of Pinus radiata rhizosphere which alters bacterial communities of pastures soils. The invasive Alliaria petiolata release chemical compounds that inhibit mycorrhizal fungi of invaded fields. The Chromolaena odorata accumulates fungal pathogens in its rhizosphere which creates negative impacts on native plants. It is possible that native soil microorganisms are not able to degrade the novel allelochemicals compounds and that could lead to its accumulation up to toxic levels. Only with the past of time can be revealed the resistance gained by the soil community to some compounds during A. petiolata invasion (Lorenzo et al., 2013). The supporting services of ecosystems have serious trouble with the black locust, Robinia pseudoacacia a nitrogen fixing species. In invaded sites it strongly changes species composition. At the same time it is affecting ecosystem services and providing additional ones. Its large root system can sometimes interfere with mowing. It is regarded as very effective stopping erosion of degraded slopes. It also can compete with native plants for pollinating bees, thus affecting regulating ecosystem services (but it is valued by some beekeepers that are disposed to produce honey from its flowers) (EEA 16, 2012).
The North and North-west of India experienced substratum degradation, in semi-arid and arid areas, caused by *Prosopis juliflora* (Mesquite). In areas where native *Prosopis cineraria* (jandi) prevailed this wasn’t observed (Dogra *et al.*, 2010).

Ice plants can also have a major impact on ecosystems supporting services (habitat) as they grow as a dense mat of dominant monoculture (EEA 16, 2012).

Japanese knotweed (Fig. 12) can adversely affect ecosystems supporting services too. The rhizome system of this species damage infrastructure, like buildings, together with archaeological sites and flood defences structures, river bank stabilisations and water channels, roads and construction land. Japanese knotweed, *Fallopia japonica*, was introduced in Europe to be an ornamental plant in parks and gardens. It harmfully affects ecosystems supporting services (habitat) by changing species diversity, physico-chemical properties and then the structure of invaded areas. It originates dominating, big and dense monocultures that reduces light availability to the understorey, inhibiting growth of seedlings and shading other plants species, which results in an altered succession. Its allelopathics properties affect negatively other plants, as it excludes them. By out-competing with native plants it exerts negative impact on specialised insect species, because their host plants are substituted. The richness, abundance and biomass of invaded sites are lower than the one of uninvaded ones (lower plant and invertebrates’ richness). The composition of soil nutrient also modifies, with an increase of organic material, water and nutrient levels. Scarce herbivores feed on it, what favours the invasion success. The invertebrates’ communities are modified: diversity and abundance of snails and isopods decreased and predatory species increase (they gain with the simplified vegetation structure). This means that the invaded areas changes from a plant-based to a detritus-based food chain (EEA 16, 2012). In the work of Hejda *et al.*, 2009, the highest impact on species composition in the invaded communities was verified for *Fallopia sachalinensis*, giant knotweed, and *Fallopia japonica*, Japanese knotweed (that low to 17% and 23% respectively the similarity among invaded and uninvaded areas).

In the hardwood forests of New Jersey and in Europe, an increase of pH in soils under the invasion of *Berberis thunbergii* (Japanese barberry) and *Microstegium vimineum* (Japanese stiltgrass), compared with soils under native shrubs *Vaccinium sp.* (blueberry) were measured. The values of available nitrate and net potential nitrification were also higher in soils occupied by the two invasive species (Dogra *et al.*, 2010).

The pontic rhododendron generates negative impacts that are felt too in landscape aesthetics, and forestry. This alien invasive species also alters regulating ecosystem services like water retention, and provisioning services such as wood production (EEA 16, 2012).
Ecosystem regulating services suffered alteration like in the example of *Eichhornia crassipes*, water hyacinth, native to South America, introduced as an ornamental plant in some tropical and sub-tropical countries in the nineteenth century. Since then it has rapidly dispersed through inland water globally. It blocks rivers, lakes, canals, with an enormous impact in the function of invaded ecosystems, affecting local communities. Herbicides can control it but is expensive and could damage non-target species. The weevils, *Neochetina eichhorniae* and *Neochetina bruchi* are some of the plant feeding insects that have been showed to be very host specific to water hyacinth. They have been released, individually or in combination, in affected continents, demonstrating good control in almost every area affected. Fungal pathogens are being studied as a possibility of control agents to the water hyacinth to (CBD, 2001; Cornell University, College of Agriculture and Life Sciences, Department of Entomology in: http://www.biocontrol.entomology.cornell.edu/; EEA 16, 2012). The roots of this species can form dense mats that change dramatically the ecosystem conditions underneath. It obstructs light penetration which decreases photosynthetic activity and abundance of phytoplankton. This affects algae primary production, increases water clarity and drops oxygen levels. This leads to a reduction of food source and then predatory zooplankton and subsequently fish abundances often decrease. The nursery grounds of some fish species can no longer have easy access as the dense mats limits it. So, native fish stocks can be reduced. The native vegetation is totally eliminated or greatly reduced by this invasive species.

Sometimes may be observed great concentrations of insects (mostly bees and butterflies) at the flowers of some invasive alien plant species. Several successful invasive plants are wind pollinated, such as *Bromus tectorum*, cheatgrass, other alien plant species produce fragrant flowers that are detected to generalist nectar feeders like *Cirsiuma arvense*, Canada thistle, and *Carduus nutans*, musk thistle. That favours alien invasive species and disturb native plant and pollinator interactions. This situation may result in reduction of fruits and seeds production and establishment of native plants. The accomplishment of alien plant invasion is also improved. Besides, adult butterflies could feed from a wide variety of nectar-producing plants, but butterfly larvae frequently feed on only a few species of native plants. Loss of native flora could affect butterflies reproduction. It has a negative impact on crops, like rice, as it suppresses the crop plants, and difficults harvesting. It has high evapotranspiration rate what results in indirect negative ecological and socio-economic effects in some regions, as the dense mats obstruct the water body usage like ship navigation, access to the water for recreation, fisheries, consume, tourism, and others. (CBD, 2001; EEA 16, 2012).
Giant salvinia, *Salvinia molesta*, native of Brazil, was introduced to Sri Lanka for scientific interests. It’s a main aquatic weed in this country that chokes irrigation canals, water bodies and invades rice fields. The biological control with salvinia weevil, *Cyrtobagus salviniae* is successful in many regions in Sri Lanka, not in cooler climates (CBD, 2001; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

Max Finlayson *et al.* (CBD 2001), identify the problem of the rapid range that mimosa, *Mimosa pigra* (Fig. 12), can attain. A specie native to tropical America, it was introduced in other areas and rapidly became a widespread trouble, particularly in wetlands. In the floodplains and swamp forest of Australia, they formed dense monospecific stands almost with no understorey. The impact on lifestyles of indigenous people is also real, as they can’t count on natural environment. The water stock, irrigation, tourism and recreational activities can be disturbed. In Thailand the irrigation systems and reservoirs also were affected, and floodplains areas had restricted access, what create impact in tourism and other associated services activities. The economic cost of controlling this weed is also a great impact and difficult to result. In north Australia, the recommended strategy of control this invasive species is prevention, above all (inspect and clean machinery) and create an awareness for the problem within population. For infected large areas an approach involving biological control, chemical and mechanical means, fire and pasture management should be used. In Vietnam it is also considered a serious environmental problem. If detected early, eradication is more effective, with low cost, using manual elimination methods. In areas where detection of mimosa was postponed, stem cutting, fire and even combination of both, were ineffective. It can be observed in these cases that fire could trigger germination of mimosa seeds, being the chemical control the recommended programme.

This demonstrates that consciousness and early intervention are the effective and inexpensive way of eradication of alien species (CBD, 2001; Xuan and Wyatt, 2006; Global Invasive Species Database in: http://www.issg.org/database/welcome/).

The cultural services provided by ecosystems are also impacted by invasive species. Tree of heaven, *Ailanthus altissima*, is native of Northern China and parts of East Asia to Australia, prefers disrupted areas, with huge human intervention (waste lands, abandoned buildings, fissures in street concretes, along motorways and railroads) causing big economic costs owed to harm in infrastructure. Italy and Portugal have some trouble with its root system that damages historic buildings. The invasion of natural areas is a concern because of the competitive abilities that cause loss of native biodiversity. It has allelopathic properties that diminish herbivory, belowground
dominance, it rises nitrogen and carbon rates in the soil as well as pH, changing soil chemistry (Global Invasive Species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012).

Agreeing with Vilà et al., 2011, it is needed a strong framework to understand impacts and support some ideas: various invasive plants are known to diminished native plant diversity, alter the rate of nutrient cycling, increase ecosystem productivity and thus have impact on ecosystem services.
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

Table 5: Main type of impacts caused by invasive alien plants separated in 4 main categories adapted from EEA 16, 2012 and remain literature:

<table>
<thead>
<tr>
<th>Impacts of IAS on biodiversity</th>
<th>Competing with local species</th>
<th>Examples</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strawberry guava</td>
<td>Dogra et al., 2010</td>
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<td>American rope</td>
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<td>Congress grass</td>
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<td>Alligator weed</td>
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<td>Pontic rhododendron</td>
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<td>Pines</td>
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<td>South African ragwort</td>
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<td>Leafy spurge</td>
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<td>Lantana</td>
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<td>Ice plant</td>
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<td>Rain tree</td>
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<td>Ironwood burl</td>
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<td>Honduras mahogany</td>
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<td>Eucalyptus camaldulensis</td>
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<td>Acacia mangium</td>
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<td>New York aster</td>
<td>Dogra et al., 2010</td>
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<td>Fallopia bohemica</td>
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<td>Dogra et al., 2010</td>
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<tr>
<th>Impacts of IAS on ecosystem services</th>
<th>Interfering with supporting services</th>
<th>Examples</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Black locust</td>
<td>EEA 16, 2012</td>
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<td></td>
<td>Mesquite</td>
<td>Dogra et al., 2010</td>
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<td>Ice plant</td>
<td>EEA 16, 2012</td>
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<td></td>
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<td>EEA 16, 2012; Hejda et al., 2009</td>
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<td>Hejda et al., 2009</td>
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<td>Dogra et al., 2010</td>
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<td>Dogra et al., 2010</td>
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<th>Impacts of IAS on ecosystem services</th>
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<th>Examples</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>Musk thistle</td>
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<td>Giant salvinia</td>
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<th>References</th>
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<td></td>
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Note: IAS – invasive alien species
3.2. Positive effects

At this point we can say that perhaps Simberloff et al., 2013, had the broad idea: the dichotomy native species “good” and alien species and their impacts “bad”, makes not so much sense. They are neither. It depends on perspectives. The next topics will focus on “the bright side” of alien plant species invasions.

3.2.1. Positive effects of invasive alien plant species on populations and communities

Water hyacinth has some positive effects that can be documented like the accumulation of pollutants and the used as a vegetable in East Asia, and for handcraft and animal feeding and fertilizer in Africa. It can be thought as a bioenergy plant, because it growths fast (Global invasive species Database in: http://www.issg.org/database/welcome/; EEA 16, 2012) – trophic subsidy (novel facilitation).

Seagrass (Fig. 13), *Zostera japonica*, in invaded sites increment the benthic invertebrate that refuges in its root matrices (Rodriguez, L., 2006) – habitat modification (novel facilitation).

The plant hydrilla, *Hydrilla verticillata*, native of the warmer regions of the Old World, invaded Chesapeake Bay, North America, and invigorates growth and survival of native benthic invertebrates, most likely because of the reduction in predatory competence leaded by the increase of habitat complexity (Rodriguez, 2006; University of Florida in: http://plants.ifas.ufl.edu/) – habitat modification (novel facilitation).

Monocultures of alien tree species affect very negatively native ecosystems as they exert competition and alter nutrient availability and dynamics. Nonetheless there are some evidences that some alien tree areas, plantations, could facilitate the recuperation of native plants communities as they deliver shelter and draw in seed dispersers. Nevertheless, conflict about this idea still exists as it is not yet known if they cause mostly positive or negative effects on the native ecosystems. However, some authors found evidences that a few tree plantations facilitate quicker restoration of
native species below them by the shelter and the attraction of seed dispersers they afford. There’s an example on Tenerife Island where the native forest had been destroyed over the years and the exotic *Pinus radiata*, the Monterey pine, native of Central coast of California (and classified as endangered in its native ecosystem) and the Australia native *Eucalyptus globulus*, Tasmanian blue gum, were introduced. The regeneration and recovery of canopy of native laurel forest were higher in *Pinus radiata* areas than in *Eucalyptus globulus* areas but still it could be observed that these plantations could be used to recover native forests due to its rapid growth that prevents erosion to continue and provide shelter to early native species. (Arevalo et al., 2011; http://www.iucnredlist.org/; Giant trees consultative committee, USDA Forest service in: http://www.na.fs.fed.us/) – habitat modification and pollination (novel facilitation).

Giant hogweed has decorative value, the usage by beekeepers and hunters, and the use as fodder crop (Global Invasive Species Database in: http://www.issg.org/database/welcome/) – pollination (novel facilitation).

3.2.2. Positive effects of invasive alien plant species on ecosystems and their services

*Mimosa pigra* could be used as firewood by people (CBD, 2001) – improve provisioning services.

The Japanese knotweed has a few of positive aspects that need to be said: is used in folk medicine in Asia and North America and secondary compounds are important to pharmaceutical industry. It also decontaminates heavy metals polluted soils and can be used for erosion control. This alien is considered appropriated for biofuel because of its strong growth. Still, this may even improve its invasion (EEA 16, 2012) – bioaccumulation and folk medicine.

*Senecio inaequidens*, narrow-leaved ragwort, has a positive effect as it leaves have anti-diabetic and anti-oxidant properties (Global Invasive Species Database in: http://www.issg.org/database/welcome/) – folk medicine.

In Argentina pampas´ the alien narrow-leaved birdsfoot trefoil, *Lotus tenuis*, native of Western and Southern Europe and Southwest Asia, had an increasing effect on the vegetative growth and above ground biomass of native perennial grass, probably because of its medium nitrogen-fixing ability, and is acceptable forage (Rodriguez, 2006; http://www.fao.org/) – increase of ecosystem productivity.
Siam weed, *C. odorata* could also be used to soil stabilization and moisture retention. It can be used as medicinal plant and firewood by population (Global Invasive Species Database in: [http://www.issg.org/database/welcome/](http://www.issg.org/database/welcome/); CBD, 2001) – improving provisioning services, soil stabilization and folk medicine.

Tree of heaven positive effects consists of the decorative value and function as windbreak hedges, control erosion, used as firewood and in China it is used in folk medicine (Global Invasive species Database in: [http://www.issg.org/database/welcome/](http://www.issg.org/database/welcome/); EEA 16, 2012) - improving provisioning services, soil stabilization and folk medicine.
Table 6: Mechanisms of facilitation of alien plant species to native species.

<table>
<thead>
<tr>
<th>Mechanisms of facilitation of alien species to native species</th>
<th>Examples</th>
<th>The 3 types of facilitative interactions</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat modification</td>
<td>Seagrass</td>
<td>X</td>
<td>Rodriguez, 2006</td>
</tr>
<tr>
<td></td>
<td>Hydrilla</td>
<td>X</td>
<td>Rodriguez, 2006; <a href="http://plants.ifas.ufl.edu/">http://plants.ifas.ufl.edu/</a></td>
</tr>
<tr>
<td></td>
<td>Monterey pine</td>
<td></td>
<td>Arevalo et al., 2011; <a href="http://www.iucnredlist.org">www.iucnredlist.org</a>;</td>
</tr>
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<td></td>
<td>Tasmanian bluegum</td>
<td></td>
<td><a href="http://www.na.fs.fed.us/">www.na.fs.fed.us/</a></td>
</tr>
<tr>
<td>Trophic subsidy</td>
<td>Water hyacinth</td>
<td>X</td>
<td>EEA 16, 2012; <a href="http://www.issg.org/database/welcome/">www.issg.org/database/welcome/</a></td>
</tr>
<tr>
<td>Pollination</td>
<td>Monterey pine</td>
<td>X</td>
<td>Arevalo et al., 2011; <a href="http://www.iucnredlist.org">www.iucnredlist.org</a>;</td>
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<td></td>
<td>Tasmanian bluegum</td>
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<td></td>
<td>Giant hogweed</td>
<td>X</td>
<td><a href="http://www.issg.org/database/welcome/">www.issg.org/database/welcome/</a></td>
</tr>
<tr>
<td>Bioaccumulation</td>
<td>Japanese knotweed</td>
<td>EEA 16, 2012</td>
<td></td>
</tr>
<tr>
<td>Folk medicine</td>
<td>Siam weed</td>
<td>CBD, 2001; <a href="http://www.issg.org/database/welcome/">www.issg.org/database/welcome/</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Narrow-leaved ragwort</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Tree of heaven</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improve provisioning services</td>
<td>Mimosa pigra</td>
<td>CBD, 2001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tree of heaven</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase ecosystem productivity</td>
<td>Narrow-leaved birdsfoot trefoil</td>
<td>Rodriguez, 2006; <a href="http://www.fao.org/">www.fao.org/</a></td>
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<td>Tree of heaven</td>
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4. An example – *Acacia dealbata* in Portugal

4.1. The Genus *Acacia* in Europe and in Portugal

As we said before, the transfer of plants seems to happen since the agrarian practices diffused meanwhile the Neolithic, but the European navigation had given an incredible impulse, never seen until then, back in the XV century, and were the motto to several intricate transactions of plants. The needs and food preferences had a particular significance in this trade and the value as medicinal, ornamental or raw material species, contribute to this agenda too.

This phenomenon, in the majority of cases, profoundly changes through time, the ecology the culture and landscapes where the new species were introduced. And these alien species, in spite of sometimes being a source of economic and food resources, is a main concern nowadays because of the risk posed of ecosystem homogenization and loss of biodiversity.

The genus *Acacia* (*sensu lato*) is quite an example of that. Australia is the country with the biggest diversity of this species (1012 recorded as native species), then America (185 species considered native), then Africa (144 species esteemed native) and Asia (85 species regarded native).

Particularly the Australian acacias, very well adapted to moderate climates, are considered a very good model to analyze the interaction between evolution, ecology and socioeconomic factors of the transfer of plant species (Fernandes, 2008; Richardson *et al.*, 2011; Fernandes, 2012; Bhat *et al.*, 2012).

The motive of the intercontinental transfer of plants was initially the scientific and ornamental interest, with the plantation of Australian species in European gardens in the end of the XVIII century and the Kew Gardens, London, has been one of the crucial locals of "acclimation". The commerce was also a motive, all together leaded to the transformation of local landscapes and other problems (Marchante *et al.*, 2005; Richardson *et al.*, 2011; Fernandes, 2012).

The introduction of Australian acacias in the Southwest of Europe took place in the XIX century. Several species were introduced in Portugal, Spain, France and Italy due to the ornamental interest and economical viewpoint (source of raw materials).
In the end of the XIX century the priority of Administração Geral das Matas, was the fixation of the dune system with *Acacia longifolia* (Andrews) Willd., *A. melanoxylon* R. Br. and *A. saligna* (Labill.) H.L. Wendl. And in mountain areas the plantation of *Acacia melanoxylon* and *Acacia dealbata* (Fig. 14). This “fever” was a mix of scientific and ornamental interest and possibility of industrial production and carried on since 1897 to 1914.

In some occasions these species spread outside the plantation areas because of the demographic/ecological opportunities given by the surroundings, soon presenting negative effects (in spite of the invasive character already been seen, it still existed legislation saying that it was “the most convenient way of seizing the terrain” (Art.º 1.º Decreto-lei nº 28039). Only in the next decade the invasive characteristic of these species were recorded and signaled (Fernandes, 2012).

There are records of 386 species that relocated outer Australia through human activities, 71 of which become naturalized and 23 are strong invaders. And like was referred earlier, many factors facilitate this late case. One third of the land surface in the world is climatically proper for Australian acacias species. Also they have been used and commercialized for many resolutions and so widely planted. Thus, we have different human awareness of acacias in the different corners of the world (Richardson et al., 2011; Carruthers et al., 2011; Griffin et al., 2011; Kull et al., 2011). Nowadays and accordingly to Dec.-Lei nº 565/99, Anexo I of Portuguese legislation, *Acacia dealbata* Link. is referred as one of the plant invasive species in Portugal.

### 4.2. *Acacia dealbata*

![Fig. 14: Acacia dealbata 1- Detail of the bean (photo by Joana Vicente); 2 - Flowers (http://invasoras.uc.pt); 3 – Verge of a road invaded by this species (http://invasoras.uc.pt); 4 – Invaded riverine zone (http://invasoras.uc.pt).](image)
A. *dealbata* is a fast growing species (1 to 1.5m per year) highly adapted to temperate climates, with rain between 600 to 1000mm per year. With extraordinary adaptability to cold and frost, their sprouts can endure -7.5ºC and the seeds can be dormants in the soil with viability of 300-400 years (Fernandes, 2008). This tree may go up to 30m high with silvery hairy foliage (Kodela and Tindale, 2001; Marchante *et al.*, 2005).

It could spread by seminal way and/or vegetative propagation and the fire disturbance is a requisite needed to regeneration success. By that it becomes an early competitor if a fire episode happens.

*A. dealbata*, like other species of the same genus, has a radicular system that goes through the underground and has adventitia buds in the lateral roots with the ability of budburst and formation of aerial sprouts that may reach a certain distance of the mother-plant – vegetative propagation. If a stem suffers an injury, particularly in a young plant, it can regenerate very quickly. The figure 4 illustrates the mechanisms of dissemination previously described:

![Mechanisms of propagation in *Acacia dealbata* Link: 1- Regeneration; 2- stem roots; 3- seed germination. A e B represent, respectively, seminal and vegetative ways (from Fernandes, 2008)](image)

This aggressive Australian species invades disturbed areas, relatively intact forest understories, abandoned arable lands and watercourses (fresh valleys, mountain zones, rivers) and also communication routes. It invades mostly after fires (Invasoras in: [http://invasoras.uc.pt](http://invasoras.uc.pt); Lorenzo *et al.*, 2013).

It seems to owe its success to its phenotypic plasticity, enormous resprouting capacity, very rapid response to anthropogenic disturbance and production of allelophatic compounds. Also it is documented that it can alter nutrient pools, soil microbial community structure and diversity and richness of soil microorganisms (Lorenzo *et al.*, 2013). Lack of enemies (pests, pathogens) in their new range also increases competitiveness (Cappuccino and Carpenter, 2005; Lorenzo *et al.*, 2010).
This species, being a *Leguminosae* (*senso latu*), has the aptitude of fixing nitrogen, due to the symbiotic relation with *Rhizobium* bacteria that clusters in the roots. This is a factor that creates an advantage competition (Lorenzo *et al.*, 2013). It increases concentrations of potentially available nitrogen and organic carbon and reduces soil density (Lorenzo *et al.*, 2010).

It is recognized that this species have allelopathic features what can help other alien species to became successful in the invaded area. Exotic plants often release allelochemical substances, novel in the new region, which contributes to their capacity of turning into invasive alien species. These allelopathic exchanges could have negative impacts on native communities, affecting ecosystem functioning (Lorenzo *et al.*, 2013).

The *A. dealbata* flowering seems to be somehow connected to the increase of phytotoxicity capacity. It runs simultaneously with the germination of other species under their canopy (Fernandes, 2008; Lorenzo *et al.*, 2010).

It was also found that invasive species, on average, have 96% less leaf damage (herbivory). Hence, herbivory could function as a predictor of the possibility of recent introduced species become invasive. Less herbivory could mean allelopathic ability and this allelopathic compounds could function in multiple ways, not only protecting plants from herbivory, but also it could alter the soil microbial community and increase competition (Cappuccino and Carpenter, 2005; Lorenzo *et al.*, 2010).

The fire regularity and strength increase with alien plant species invasion what favors condition to their continuation. Besides, almost most of them, if not all, are advantageously adjusted to regenerate after fire (fire-stimulated germination of the seeds stored in the soil) comparing to the native species, what leads to a quick recolonization or invasion after a fire, changing long-term composition even if the native species have good fire-adapted capacities. In African fynbos, there are species with reproductive adaptations to fire, but even so, it seems that fire favors alien species (like acacias) that invade these areas. Alien invasive species that have this behavior, modification of disturbance regimes, seems to have a bigger impact on native species and ecosystems (Pauchard *et al.*, 2007; Lorenzo *et al.*, 2010; Richardson *et al.*, 2011).

Rapid and great allocation to root mass - directly to deep roots (important in dry periods) and to the extensive shallow root system (help in periods of great benefit) (Morris *et al.*, 2011). The reproductive biology of *Acacia* species is more studied in their native range and very sparse in other areas. In spite of the crucial aspects that seed and pollination have, they continue unstudied for most species. In Europe *A. dealbata* flowers from January to March but the reproductive phenology is very variable. The inflorescence is an open structure therefore quite accessible to a great number of
pollinators, which enhance capacity to invade new areas. Female and male functions are separated in most *Acacia* species and flowering is often asynchronous. Due to the presented traits and changes that are increasing in the Southern regions of Europe, *A. dealbata* is becoming a very dangerous species in these regions.

The Coimbra University (*Centro de Ecologia Funcional and Escola Superior Agrária*) created a platform where invasive plant species can be mapped. There are workshops to form collaborators to use and participate in this platform (the last one was *Workshop práctico sobre plantas invasoras – identificação e mapeamento*). There also are CTC (*Campo de trabalho Científico*) every year, having in mind the control of alien invasive plant species that organizes expeditions to eradicate them (http://invasoras.uc.pt).

### 4.3. *Acacia dealbata* in Portugal

The first record in Portugal is from 1850 in Quinta do Lumiar, Lisboa, where it were planted several species of Australian origin, including *Acacia dealbata* Link. The industrial culture of Australian species in Portugal began with William Tait, a businessman living in Porto that planted in 1880 numerous hectares of acacias and eucalyptus near Abrantes, making the farmers and forest holders very curious. He published some notes about the interest that the acacia bark had to the tannery industry as a source of tannin. Jaime de Magalhães Lima were another supporter of Australian plants and around 1900 initiate the plantation of acacias and eucalyptus in Quinta de S. Francisco near Aveiro, enhancing their qualities as a wood source, especially *Acacia dealbata* (Fernandes, 2012). There are records that in 1871 it was planted in Praça D. Pedro, Porto (Fernandes, 2008).

In France in 1931, on Mandelieu-la Napoule, began a celebration of Mimosa (*Fête du Mimosa*), especially *A. dealbata*, which continue in our days and with a similar meaning in several other areas. In Portugal, celebrations took place in the 70´s and 80´s in Alto Minho but they were stopped in 1988.

The introduction of acacias in diverse parts of the World happened in numerous times. In two centuries *Acacia dealbata* has become a globally spread species and it is present in all countries except Antarctica (Fernandes, 2008).

Only a small percentage of the plants established out of its origin area become invasive. The capacity of forecast the exotics that would turn noxious, has major importance to advance effective strategies of control.
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

The majority of studies focused on studying the common traits among invasive species, involving the life-history traits in spite of the interactions between plants and natural enemies (Cappuccino and Carpenter, 2005).

*Acacia dealbata* is widely distributed in Continental Portugal and Madeira Island as we can observe in the following distribution map (Fig. 16):

![Distribution map of Acacia dealbata in Portugal](http://invasoras.uc.pt)

Fig. 16: Distribution map of *Acacia dealbata* in Portugal (http://invasoras.uc.pt) – areas in red.

### 4.4. Effects of *Acacia dealbata* on native biodiversity and ecosystems

#### 4.4.1. Negative effects

Invaders like *Acacia*, have strong effects on the factors that regulate ecosystem processes and their interactions. The alteration of ecosystem processes alters ultimately the corresponding ecosystem services (Le Maitre et al., 2011).

As silver wattle seedlings grow taller and faster than the native ones, it competes with native species for light. The understory stays bare. Capability of nitrogen fixation, nutrient conserving sclerophyllous phyllodes and the slow decomposition rate – together alter soil nutrient cycling. The intensification of water use by *Acacia* is a major impact in the invaded ecosystems. Evapotranspiration by these species also is higher than in native species. The invaded ecosystems suffer water depletion by the invasion of *Acacia* species (Morris et al., 2011). The allelopathic compounds may modify the soil microbial community and intensify competition (Cappuccino and Carpenter, 2005; Lorenzo et al., 2010). Some studies refer that *A. dealbata* natural washes affects germination, seedling growth, net photosynthetic rate and respiration of agricultural or native species. But much are yet to be said about the interactions of allelochemicals and the soil microbial communities. In the study of Lorenzo et al., 2013, it was supported the idea that the *A. dealbata* allelopathic compounds are responsible for alterations in functional and genetic diversity of soil microbial communities. The
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

An interesting thing is that it were observed more alterations in soil microbial communities of pine forests than in those of mixed oak forest. This shift in soil functional microbe diversity or composition may influence nutrient cycling and ecosystem processes. In spite of all that, the fungal communities of invaded shrublands and grasslands did not presented changes (it might have more stability than soil bacterial communities). The quality and quantity of organic matter also interferes in allelochemicals fate. The mixed Mediterranean oak forests have greater understory plant diversity and soil nutrient than pine forests. That influences and create higher microorganism diversity, for that, increased interactions microorganisms–allelochemicals and so the degradation/transformation of *A. dealbata* allelochemicals are increased. The opposite happens in pine forests, what favors the process of invasion (Lorenzo *et al.*, 2013). The studies of *A. dealbata* allelopathy are mostly laboratory experiments but, in Galicia, a research provided evidences that leachates of this species present inhibitory effects on germination and growth of *Lactuca sativa*, during *A. dealbata* flowering period (that coincides with the time of germination period of native species). The negative impacts caused by this feature are felt by herbivore insects in invaded communities. They are scarce in communities invaded by *Acacias* in South Africa’s Western Cape. Coleoptera richness and abundance values were significantly lower in this area. In Europe there are no studies about this subject but we could extrapolate and it is reasonable to predict the same scenario. *Acacia dealbata*, *A. melanoxylon* and *A. longifolia* are very common invaders in France, Italy, Portugal and Spain, been *A. dealbata* widely spread in Southern Europe, occupying a great number of habitats. Nevertheless, *A. longifolia* is the most studied wattle species. Nonetheless we could say that the various subgroups of *Acacia* share the basic features (Lorenzo *et al.*, 2010). So, next we present some studies in Portugal with this species. For example, the one carried out to access the possibility of biological control of *A. longifolia* (until now the use of mechanical control was the most common attempt) with the bud-galling wasp, *Trichilogaster acaciaelongifoliae*, with positive results on the prevention of the escalation of invasion and its negative impacts (Marchante *et al.*, 2010).

In 2008, two studies were made by Marchante *et al.*, with this species in dune ecosystems that reiterate the idea that invasions alter the decomposer community and the decomposition rates of organic matter. This has implications in nutrient cycling and ecosystem-level processes (Marchante *et al.*, 2008a). There are increases of nitrogen-cycling dynamic and carbon accumulation after invasion of *Acacia* species. Areas recently invaded have a possibility of more successful restoration than areas invaded for a long period of time (Marchante *et al.*, 2008b). The long-invaded regions have
higher nutrient content what might hinder the rescue of dune communities for many years and help to launch other exotic species (Marchante et al., 2009).

Rodríguez - Echeverría et al., 2013, studied in Portugal the joined effect of soil and competition on plant performance and invasion by Acacia dealbata. They studied the growth and competition between A. dealbata and Pinus pinaster in three different soils (native – Pinus pinaster area; disturbed – with E. globulus and invaded – with A. dealbata). The competition was greater in native soils and A. dealbata invaded P. pinaster forest. During invasion, A. dealbata alters soil conditions and promotes its own germination and growth and increase P. pinaster mortality. The allelochemicals released by the invader also stimulates P. pinaster decrease. The E. globulus augmented seedling mortality and inhibit germination and growth of this invasive species (but it is needed more study to understand this situation). A. dealbata did not have any effect on E. globulus.

The composition of an invaded area changes due to a very quick regeneration of acacias after a fire. Alien invasive species that present this performance modifies disturbance regimes, which presents larger impacts on native species and ecosystems (Pauchard et al., 2007).

The negative impacts on native communities are due to the non-existent co-evolution between native and exotic species (Lorenzo et al., 2013).

So, systematizing and providing some examples, ecosystem functioning and structure are greatly impacted by invasive Acacia species resulting in serious problems. Acacia species are a threat to native ecosystems by competing with native species replacing grass communities, reducing native biodiversity and increasing water loss. These problems are enhanced by its great colonizing ability (Lorenzo et al., 2010).

### 4.4.2. Positive effects

Silver wattle, a fast-growing tree, have been recorded as a very important species in the balance of nitrogen losses ought to timber harvesting and slash-burning, by that reducing the need of fertilizer application (May and Attiwill, 2002).

Many acacias seeds, foliage, wood and bark have been used for centuries by humans as a fodder crop to animals, source of food, medicine and fuel. The rapid growth, dense wood, attractive flowers, capacity to survive and to blossom in poor nutrients or even ruined areas make them very desirable in several parts of the
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

world (Richardson et al., 2011; Carruthers et al., 2011; Griffin et al., 2011; Kull et al., 2011). The flowers are even used to perfume production (Fernandes, 2008).
For instance, in Portugal, Acacia species were often used to control erosion in dune ecosystems, particularly Acacia longifolia (Andrews) Willd (Marchante et al., 2008a).

5. Conclusions

At this point of our work we can say that our main objectives were achieved: the most reported impacts with the mechanisms inherent were analyzed, both positive and negative. Then the compilation in this one document was done, finishing with the example of Acacia dealbata, a very aggressive invasive alien species in Portugal.
With our search we can say that there are some preponderant factors to invasion and some ecosystem characteristics such as: 1) similarity between donor and recipients environments, usually exists a tendency to invade habitats different from those of origin, because there are no predators; 2) species traits, for example the growth rate of population, existent on the local; 3) the habitat degree of disturbance - the higher the degree of disturbance the easiest the introduction of non-indigenous species; 4) the complexity of the habitat - the more complex communities are, the less vulnerable the habitat gets (Holeck et al., 2004, INSPECT-Projecto-ICNB); 5) such as the climate of the region - temperate zones are more susceptible than extremely dry – deserts, or cold regions – polar areas (Vitousek et al., 1997); 6) the invasive species vicissitudes also determine the success of invasion like the propagule pressure on the environment (high fecundity), short generations, high tolerance to environmental conditions, diet plasticity and early sexual growth (Holeck et al., 2004, INSPECT-Projecto-ICNB); 7) one common trait that is recorded as a trait that rises the success of invasions is the ability of attaining limiting resources better than natives.
Invasions are relatively low in the tropics and higher in temperate areas (Vitousek et al., 1996). Invasive species may profit of global changes around the world either because they are stronger competitors for resources or because the stress caused to native species decreases its competition (Morris et al., 2011).
In our study we could find evidences of what previously was said: that intense dominating alien plants are more probable to cause alterations in species, communities or ecosystems (Vilà et al., 2010) and Claussen, in 2001, wrote that it was reported that
in Christmas Island, Australia, 52.7% of species were alien, most of them confined in disturbed regions (Dogra et al., 2010).

We could also see that the studies related to invasive species had mainly focused the perspective of competition and predation. But there should be other studies regarding other type of interactions like parasitism/disease, mutualism, symbiosis, as it can influence the course of a species and/or a community – facilitative interactions. (Kopp and Jokela, 2007; Rodriguez, 2006; Barber et al., 2008; Thomsen, 2010). However recent literature found that these interactions happen in a significant range of habitats, triggering cascading effects through trophic levels, alter community structure and even conduce to evolutionary changes (Rodriguez, 2006; Barber et al., 2008). We can see that facilitative interactions by habitat modification are the most common (particularly when we talk about plants) followed by facilitation by trophic subsidy in other taxa. There seems to be more examples of facilitative interactions regarding other taxa then plants. The negative effects of invasive species could be felt directly or indirectly. Most of the times, several effects could happen simultaneously. However, depending on the temporal scale used, we can observe that these negative effects unchain a flow of events, developing a net of undesirable effects to species and native ecosystems. The impacts on biodiversity are without a doubt the most regarded and studied among taxa. The impacts on ecosystem services have more preponderance within plants.

There are assumptions of greater abundances of alien invasive species in recipient communities that in native ones. It seems to be true to a number of invasive (for example Aliiaria petiolata (Bieb.), garlic mustard; Centaurea maculosa Lam., spotted knapweed; Lonicera japonica Thunb., Japanese honeysuckle and Bromus tectorum L., (cheatgrass)). Nonetheless, many exotics occur at only moderate densities in recipient communities, even occurring at the same densities in native and recipient communities. Some species like Ulex europaeus, do not have differences in seed size, otherwise what expectations said. There are not even consistent evidences that invasive alien species has larger biomass or size in recipient communities (some are, like Solidago gigantea Ait. but others are not like Lythrum salicaria L.). Likewise, there are no reliable evidences of increase in fecundity: Echium plantagineum L. do not show differences in fecundity while comparing regions but Chrysanthenoides monilifera (L.) T. Nord, Acacia longifolia (Andr.) Willd. and C. scoparius showed to have higher fecundity in introduced regions when compared with native ones.

A ground-breaking work of Vitousek, in 1987, about the impact of Myrica faya, nitrogen–fixing tree introduced in Hawaii, came with the idea of large impacts by nitrogen–fixing alien species on recipient ecosystems. Recent confirmation show us that nitrogen–fixing alien species have strong effects on nitrogen and carbon cycling,
when compared with non–nitrogen–fixing species, but there are no such differences for other impacts on ecosystem processes or community structure (Liao et al., 2008).

In spite of that, total community production increased 56.8% after invasion. The microbial activity; nitrogen availability; nitrogen, phosphorus and carbon pools also rises (32.3%; 53.7%; 22.1%; 19.7% and 11.6% respectively). It can be noticed a pH decrease of 3%. On average we can say that invasions decrease litter decomposition (15.6%), but there are no consensus among studies. The alien nitrogen–fixing species affect notoriously the nitrogen pools and nitrogen nitrification. Nitrogen–fixing species tend to decrease Carbon/Nitrogen while non–nitrogen–fixing species increase their values. The impact of nitrogen–fixing alien plants seems to be similar of any other non–nitrogen–fixing species for any other impact (Vilà et al., 2011).

*Acacia dealbata* is a very strong invasive species in Europe, in regions with high similarity of those of its origin. This achievement is linked to phenotypic plasticity, long-term soil-stored seed banks, ability to prosper in low-nutrient substrates, generalist pollination and generalist seed dispersal, high capacity of resprouting and very rapid response to anthropogenic disturbance and is in part due to the capacity of allelophatic compounds release, that affect native plant species, nutrient pools, soil microbial community structure, diversity and richness (Lorenzo et al., 2010; Lorenzo et al., 2013).

Plants can change the soil (biotic an abiotic properties) were they develop (Rodríquez-Echeverría et al., 2013). But very little study was done about its effects on soil microbes (Lorenzo et al., 2013) or about interaction of soil effects and plant performance and invasion (Lorenzo et al., 2013, Rodríguez-Echeverría et al., 2013)

Recent studies shows that it definitely affects and modifies soil bacterial functional diversity in pine forests (contributing to the process of invasion) and interestingly doesn’t affect soil microorganisms if in a mixed oak forest. The soil bacteria are more sensitive than soil fungi to this allelophatic compounds. For example, *Pinus pinaster* mortality increase with *Acacia dealbata* invasion, by changes in soil conditions (Lorenzo et al., 2013).

Nonetheless acacias are several times the subsistence of populations with very few resources. Is it fair or ethical to eradicate this species unregarding poor populations that depend on it? We should fight to have healthy natural environments, with pristine characteristics, for the well of a sustainable future of all living beings of the planet, but we should and have the moral imperative of give alternative to these populations that already incorporate invasive species in their way of life along the years (Kull et al., 2011). So, non-indigenous species are inset in ecological networks and have both negative and positive impacts with native species (Barber et al., 2008) and we should regard the historical and social aspects of its introductions.
The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services

There are evidences that alien plant species have significant impacts on many ecological features, and the magnitude and direction of these impacts vary in result of the levels of ecological complexity. Impacts on species and communities are significant while those on nutrient cycling are minor, which could indicate that by the time impacts on nutrient cycling are detected, plant species and communities have already been distressed by alien plant invasion. The most remarkable finding is that the diversity of local plants is reduced however the production of the community enlarges by alien plant species (Vilà et al., 2011).

So, as the local plant diversity is threatened and reduced by plenty invasive plants (Gaertner et al., 2009; Hejda et al., 2009; Vilà et al., 2010; Powell, 2011), invasive plants also seem to increase ecosystem productivity, change the rate of nutrient cycling (Liao et al., 2008) and create impact on ecosystem services (Pejchar and Mooney, 2009).

Thus, usually the evolutionary changes that can occur in native species in reaction to alien species introduction and selection are disregarded (altered anti-predatory defences, changes in the use of habitat and resources, etc.). Sometimes native species would be unsuccessful to evolve or adapt and could became local or globally extinct. Others could adapt and even evolve what weaken the impact of the invader and can endorse coexistence of both, alien and native species. The ability of evolutionary response to selection of invasive species, hang on the demographic impact of the invader, the genetic architecture and variability of native population and the history of previous invasions. This possible evolution of native species most of the times takes place in a very short-time scale (Strauss et al., 2006).

At this point, regarding everything that was read, we can say that in the beginning, with the first exploration journeys, the exchanges of organisms between different places were exaggerated with no conscience of possible impacts nonessoever. In a second approach, with the advance of Science, the exotic species were seen with prejudice and rejection. Nowadays, alien species are known to be the source of positive and negative impacts on native species and ecosystems. Much more is needed to study and each case is unique.

We found that, supported by Hierro et al., 2005, more studies should be made regarding a biogeographical approach, and that can be a perspective to future work: studying invasive alien species in their natural range and in the invaded areas for it could help to perceive and provide clues why they became invaders, why invasiveness is different in some locals, even with the same species, and go deeper in the subject, even helping with the difficulty that sometimes appears of knowing the mechanisms underlying alien species invasions (many times because there are multiple impacts).
Also, there is little work that includes the invasive alien species problematic with other disciplines (Ethic, History, Philosophy, and Sociology) and Australian acacias are a good model to start. One impressive aspect is that in most situations the human mediated dispersal of plant species was from the “Old World” to the “New World” but the acacias case was the opposite, probably because of their traits and the needs that these species satisfied in humans, and the bioclimatically similar areas it reached. Molecular techniques could boost the understanding of mechanisms behind successful invasions and by that providing insight to a sustainable management. And definitely traits related to reproduction and spread are essential to naturalization and invasion of alien species in new areas (Richardson et al., 2011; Carruthers et al., 2011). And we would like to highlight the fact that in almost the entire bibliography read, the economic perspective about the impacts of invasive alien species is always present. Ecosystem services are until now an asset to human welfare and profit (Potschin and Haines-Young, 2011). Shouldn’t it be considered of value intrinsically and shouldn’t societies contemplate this value sustainably? We could regard from now on the proposal for a Common International Classification of Ecosystem Services and leave the concept created around ecosystem services for years, and that goes beyond the scientific community – human profit. We have to look for this value and have in mind sustainability and not unregardless gains.
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The paradox of alien invasive species: negative and positive effects on biodiversity and ecosystem services


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