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Opportunities for classical biological control of weeds in European overseas territories

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Summary

European overseas territories are home to biodiversity and endemism of worldwide importance, vastly superior to that of continental Europe as a whole. They are, however, much more threatened by invasive species, including hundreds of alien invasive plant species having a huge impact on natural and agricultural habitats. As in continental Europe, invasive plants have only recently been recognized as a threat to the local environment and biodiversity. Mechanical and chemical control programmes—underway for several decades—have not been entirely successful for permanent, cost-effective, environment-friendly management. Biological control of weeds has long been successfully used in other neighbouring countries with similar climates, environmental conditions and invasions, but has barely been implemented in European overseas territories. There have been very few attempts to set up classical biological control programmes in these regions—a few of the species that have been the focus of biological control are *Lantana camara* L., *Rubus alceifolius* Poir., *Opuntia stricta* (Haw.) Haw., *Acanthocereus tetragonus* (L.) Britton & Rose, *Ligustrum robustum* (Roxb.) Blume, *Miconia calvescens* DC., *Ulex europaeus* L., *Prosopis juliflora* (SW.) DC., and *Leucaena leucocephala* (Lam.) de Wit. Many invasive plants occurring in European overseas territories are also invasive elsewhere and already targets of biological control programmes. Biological control agent specificity requires particular attention due to the high level of endemism in such islands. This paper reviews some of the most threatening species for which classical biological control could be achieved through regional or international collaboration.

Keywords: tropical island, invasive plants, biological control agent.

Introduction

It is well known that invasive alien species are considered to be one of the greatest threats to biodiversity after habitat degradation, particularly in island ecosystems. European overseas territories consist of seven Ultra-Peripheral Regions (UPRs) that are an integral part of the European Union and 21 Overseas Countries and Territories (OCTs) that benefit from a system of close association (Table 1). Hereafter these two groups are jointly referred to as European Overseas Regions and Territories (EORTs). These EORTs are home to biodiversity of worldwide importance and vastly superior to that of continental Europe as a whole. Three French UPRs and 13 OCTs are involved in four of the 34 world biodiversity 'hotspots' (Conservation International, 2006; Mittermeier *et al.*, 2005). R.A. Mittermeier, President of Conservation International, stated that the most remarkable places on Earth are also the most threatened, and it is in these territories that the speed of species extinction is the fastest worldwide. These territories have also hosted many species introductions—mainly plants, some of which have become invasive. For instance, over the last 300 years,

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Table 1. European Overseas Regions and Territories selected according to their climate.[a]

European Overseas Regions and Territories	Country	European status	**Climate**
Azores	Portugal	UPR	warm temp./subtrop.
Canaries	Spain	UPR	warm temp./subtrop.
Guadeloupe	France	UPR	tropical
French Guiana	France	UPR	tropical
Madeira	Portugal	UPR	warm temp./subtrop.
Martinique	France	UPR	tropical
Réunion	France	UPR	tropical/temperate
Anguilla	United Kingdom	OCT	tropical
Aruba	Nederland	OCT	tropical
BAT (British Atlantic Territories)	United Kingdom	OCT	temperate
Bermuda	United Kingdom	OCT	tropical
BIOT (British Indian Ocean Territories)	United Kingdom	OCT	tropical
British Antarctic	United Kingdom	OCT	polar
BVI (British Virgin Islands)	United Kingdom	OCT	tropical
Cayman	United Kingdom	OCT	tropical
Greenland	Danmark	OCT	polar
Mayotte	France	OCT	tropical
Montserrat	United Kingdom	OCT	tropical
Nederland Antilles	Netherlands	OCT	tropical
New Caledonia	France	OCT	tropical
Pitcairn	United Kingdom	OCT	tropical
French Polynesia	France	OCT	tropical
Saint-Pierre et Miquelon	France	OCT	polar/temperate
St Helena (+ Ascencion, Tristan da Cuña)	United Kingdom	OCT	temperate/tropical
TAAF (Terres Australes et Antarctiques Françaises)	France	OCT	polar/temperate
Turks & Caïcos	United Kingdom	OCT	tropical
Wallis and Futuna	France	OCT	tropical

[a] European Overseas Regions and Territories shaded in grey were not considered in the study.

2217 plant species have been introduced on Réunion Island, 628 have become naturalized, and 62 were considered as invasive in the 1990s (Gargominy, 2003; Macdonald *et al.*, 1991). There are currently around 200 invasive plant species. For all the French overseas territories, Gargominy (2003) highlighted the negative role of invasive species with respect to biodiversity conservation. Weed control in EORTs is essentially mechanical and/or chemical (Hivert, 2003) and never succeeds in long-term regulation of populations (Brondeau and Triolo, 2007). Eradication appears to be an efficient way (technically and economically) to control aliens on islands but requires early invader detection and rapid political decision-making before the plant has time to spread throughout a large area (Loope *et al.*, 2006). Only a few biological control programmes have been implemented in the EORTs, all of which were local programmes without any between-EORT collaboration. In this paper, we analyse exotic flora of EORTs to identify species common to several EORTs. We selected five species among those present in more than five EORTs that are under efficient classical biological control in other parts of the world. Here we present classical biological control programmes that could be implemented as European collaborative actions between EORTs and international collaborations with other countries that have already successfully directed such control programmes.

Methods and materials

EORT climates range from polar to tropical, according to their geographical location. We selected EORTs with warm temperate, subtropical and tropical climates for this analysis. The degree of EORT invasion by alien plants was analysed on the basis of literature data and personal knowledge of certain situations (e.g. Réunion, New Caledonia, French Polynesia). A list of alien invasive species in EORTs was compiled from several databases, literature and ongoing synthesis projects in UK overseas territories (Varnham, 2005), the Canaries (Sanz-Elorza *et al.*, 2005), Madeira (Medeiros, 2006), Azores (Silva, pers. comm.) (Silva and Smith, 2004), Antilles (Joseph, 2006), French Polynesia (Meyer, 2000, 2004), New Caledonia (de Garine-Wichatitsky *et al.*, 2004; Meyer *et al.*, 2006), the Caribbean region (Kairo *et al.*, 2001) and the IUCN database of invasive species in French overseas territories, (Soubeyran, unpublished data). A species/EORT matrix was built. The nomenclature of plant species was verified according to the Global Compendium of Weeds (Randall, 2002). We analysed the number of species mentioned in several EORTs. Species present in five or more EORTs were selected. We compiled plant biological control research or action programmes implemented in EORTs, and species that are already under biological control in other countries (Julien and Griffiths, 1998). We considered the possibility of developing a biological control programme through collaborations between EORTs for each invasive species.

Results

Plant invasions in EORTs

From seven UPRs and 21 OCTs, we selected 22 EORTs with warm temperate, subtropical, or tropical climates (Table 1). Saint Helena, Ascension and Tristan da Cuna were considered as three different entities, which means we included 24 different sites in this study. A list of 1267 plant species was compiled from invasive plant lists for the different EORTs. The number of plants per site ranges from three for French Guiana and Aruba to 410 for Bermuda (Table 2). There are two explanations for this variation. The first explanation concerns the origin of the information. In some lists, only environmental weeds are considered to be the most important invasive species, while both environmental and agricultural weeds are taken into account in other lists. The second explanation is that EORT invasion patterns differ markedly between sites. For instance, Joseph (2006) recorded very few invasive plants (22) in Martinique compared to Réunion (178). It is also well known that continental sites such as French Guiana are less invaded than oceanic islands. We found 75 species that invaded at least five sites (Table 3). *Leucaena leucocephala* (Lam.) de Wit (recorded at 21 different sites) appears to be the most common and best-distributed species. Five other species are present at 10 sites at least (*Lantana camara* L., *Psidium guajava* L., *Albizia lebbeck* (L.) Benth., *Casuarina equisetifolia* L., *Ricinus communis* L.). There are about 851 and 205 species present at only one or two sites, respectively. Most of them are common weeds present in other EORTs, but are not considered as invaders or environmental threats and are thus not listed. However, some of them, even though they are only considered to be invasive at one site, are highly invasive, e.g. *Hiptage benghalensis* (L.) Kurz, which seriously threatens local vegetation in dry habitats of Réunion, and the small tree *Miconia calvescens* DC. in the French Polynesian rainforest.

Biological control programmes in EORTs

Only a few classical biological control research or action programmes of have been undertaken despite the extent of the invasive plant problems in most EORTs.

Table 2. Number of alien, invasive weeds per European Overseas Regions and Territories (EORT).

EORT	Number of weeds
F French Guiana	3
NL Aruba	3
NL Netherland Antilles	7
UK Turk & Caicos	8
P Madeira	10
P Azores	12
UK BVI	15
F Guadeloupe	18
F Martinique	22
UK Pitcairn	26
UK Montserrat	28
UK Tristan da Cuna	49
F New Caledonia	67
F Wallis Futuna	61
UK Cayman	74
F French Polynesia	96
UK Ascension	101
ES Canaries	151
F Réunion	178
F Mayotte	190
UK Anguilla	196
UK BIOT	230
UK St Helena	288
UK Bermuda	410

The first one was launched in the early 1900s, with the introduction and release of *Ophiomyia lantanae* (Froggatt) for *L. camara* control in French Polynesia (1916) and New Caledonia (1924). Then four other agents (*Teleonemia scrupulosa* Stal, *Syngamia haemorrhoidalis* Guen., *Octotoma scabripennis* Guérin-Méneville, *Uroplata girardi* Pic.) were released on this island over the next 50 years, with varying degrees of efficacy against *L. camara* (Gutierrez, 1976, 1979). This plant has also been biologically controlled in other places (Saint Helena, Ascension) (Julien and Griffiths, 1998). Finally, only seven EORTs have developed a biological control programme (New Caledonia, French Polynesia, Saint Helena, Ascension, Réunion, Montserrat and Cayman) and only nine plant species have been considered for biological control research programmes or release, including: *L. camara* (see above); *Opuntia stricta* (Haw.) Haw. (New Caledonia, Cayman), *O. triacanthos* (Willd.) Sweet (Montserrat) and *Opuntia* sp. (New Caledonia, Saint Helena, Ascension), using *Cactoblastis cactorum* (Berg) with good success; *Acanthocereus pentagonus* (L.) Britton & Rose (New Caledonia), using *Hypogeococcus festerianus* (Lizar & Trelles); *Miconia calvescens* DC. (French Polynesia), using *Colletotrichum gloeosporioides* L. f. sp. *miconiae*; *Rubus alceifolius* Poir. (Réunion), using *Cibdela janthina* (Klug); *Ulex europaeus* L. (Saint Helena), us-

Table 3. List of weed species considered invasive at five sites at least.

Species	Total
Leucaena leucocephala	21
Lantana camara	13
Psidium guajava	12
Albizia lebbeck	11
Casuarina equisetifolia	11
Ricinus communis	10
Acacia farnesiana	9
Argemone mexicana	9
Bryophyllum pinnatum	9
Melaleuca quinquenervia	9
Panicum maximum	9
Schinus terebinthifolius	9
Eicchornia crassipes	9
Cynodon dactylon	8
Commelina diffusa	8
Mirabilis jalapa	8
Solanum mauritianum	8
Tabebuia heterophylla	8
Tecoma stans	8
Pinus caribaea	8
Catharanthus roseus	7
Furcraea foetida	7
Melia azedarach	7
Canna indica	7
Syzygium jambos	7
Achyranthes aspera	6
Agave americana	6
Ageratum conyzoides	6
Antigonon leptopus	6
Bidens pilosa	6
Chamaesyce hirta	6
Cyperus rotundus	6
Grevillea robusta	6
Oxalis corniculata	6
Passiflora suberosa	6
Pennisetum purpureum	6
Pittosporum undulatum	6
Prosopis juliflora	6
Solanum nigrum	6
Spathodea campanulata	6
Terminalia catappa	6
Urochloa mutica	6
Ziziphus mauritiana	6
Adenanthera pavonina	5
Agave sisalana	5
Asclepias curassavica	5
Bambusa vulgaris	5
Carpobrotus edulis	5
Cenchrus echinatus	5
Clidemia hirta	5
Conyza bonariensis	5
Cryptostegia grandiflora	5
Eleusine indica	5
Eriobotrya japonica	5
Leucaena diversifolia	5
Manilkara zapota	5
Melinis repens	5
Mimosa pudica	5
Momordica charantia	5
Opuntia ficus-indica	5
Paspalum conjugatum	5
Passiflora foetida	5
Phoenix dactylifera	5
Physalis peruviana	5
Plantago major	5
Psidium cattleianum	5
Rubus rosifolius	5
Senna occidentalis	5
Sida acuta	5
Sorghum halepense	5
Sphagneticola trilobata	5
Sporobolus indicus	5
Stachytarpheta urticifolia	5
Tamarindus indica	5
Ulex europaeus	5

ing *Tetranychus lintearius* Dufour; *Prosopis juliflora* (Sw.) DC. (Ascension), using *Heteropsylla reducta* Caldwell & Martorell (and *Rhinochloa* sp. accidentally introduced); and *Ligustrum robustum* (Roxb.) Blume subsp. *walkeri* (Decne.) P.S.Green (Réunion), for which *Epiplema albida* (Cassino & Swett) has been tested but not yet released (CABI c.p., Julien and Griffiths, 1998; Meyer, 1998). The situation concerning *L. leucocephala* is interesting. This plant is considered as invasive almost everywhere it occurs and is the most widely distributed species throughout all EORTs. From 1985 to 1991, *Heteropsylla cubana* Crawford, a biological control agent, arrived naturally or accidentally in French Polynesia, New Caledonia, and later in Réunion and subsequently controlled this invasive plant. Because of a conflict of interest regarding this invasive species, which is also a forage plant, it was decided to biologically control *H. cubana* using the lady bird beetle *Olla v-nigrum* (Mulsant) (Chazeau *et al.*,1989; Quilici *et al.*, 1995). Some other biological control actions were also accidental, e.g. *Rhinochloa* sp. against *P. juliflora* in Ascension. For others, such as *U. europaeus* in Saint Helena, the biological control agent *T. lintearius* was introduced along with its predator *Phytoseiulus* sp., thus nullifying the biological control. Most biological agents released were arthropods. The only pathogen was *C. gloeosporioides* f.sp. *miconiae* for control of *M. calvescens* in French Polynesia (Meyer and Killgore, 2000). This review highlights the very low number of biological control actions undertaken in EORTs despite the fact that invasive plants are highly numerous and damaging to the environment and biodiversity. Nevertheless, many of these species are already targets of biological control actions or research in other parts of the world.

Biological control programmes that could be implemented in different EORTs

Cochereau (1972), proposed several strategies for classical weed biological control programmes in the Pacific, including targets such as *Psidium guajava* L., *Melaleuca quinquenervia* (Cav.) T.Blake, *Elephantopus mollis* Kunth, *Stachytarpheta jamaicensis* (L.) Vahl, *Mimosa invisa* C.Mart. ex Colla , *L. leucocephala, Solanum torvum* Sw., *Cyperus rotundus* L., *Rubus rosifolius* Sm., and *Ageratum conyzoides* L. Developing a new biological research programme (without any knowledge of the target plant or its natural enemies) is a very long process (more than 10 years) and very expensive with regard to a typical EORT budget, whereas transferring biological control technology from countries where programmes are already underway is much more time- and cost-effective. As many invaders are common to several EORTs, joint biological control programmes could easily be implemented at a European-overseas level. If EORTs decide to work together to solve the problem of alien plants, species should be selected that are common to several sites. We have noted that 78 plant species are invasive at five or more sites. It is clearly not possible to implement so many biological control programmes and most of these species are not yet biologically controlled elsewhere in the world. To illustrate opportunities for developing classical biological control actions in EORTs, we selected five species according to four criteria: (1) historical success of biological control of this target in other countries with ecological similarities, (2) taxonomic isolation of these weeds from indigenous flora in EORTs, (3) good knowledge of biological control agents that are suitable for use in EORTs, and (4) species that are not sources of any conflicts of interest, such as *Schinus terebenthifolius* Raddi for honey or spice production, *Psidium catleianum* Sabine and *P. guajava* for fruit production, or *Acacia* spp. for wood production. The authors understand that this selection cannot be considered a priority for every EORT, as each one has its own priorities in controlling invaders and/or biodiversity conservation. Nevertheless, the common feature of the following five examples is that they could be implemented easily, rapidly, with a high probability of success, and at low cost.

Case 1: *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae): Nine sites are affected (Canaries, Guadeloupe, Martinique, French Polynesia, New Caledonia, Réunion, Bermuda, BVI, Cayman). Water hyacinth is widely recognized as the world's worst aquatic weed. Native to the Amazon basin, it was exported throughout the tropics and warm temperate regions for its flower and for water treatment. It forms dense mats on water bodies, thus limiting access to water, navigation, and fishing. It produces H_2S in the water, reduces the water pH, increases evaporation, and reduces light penetration and oxygen content. This leads to dramatic biological changes, with social and economic consequences. Physical and chemical controls are very expensive, temporary, and ecologically and economically unsustainable. Classical biological control is the only feasible way to manage such widespread infestations. A number of biological control agents have now been introduced in about 30 countries. The species most widely used are *Neochetina* weevils, *N. bruchi* Hustache and *N. eichhorniae* Warner (Coleoptera, Curculionidae) (Julien *et al.*, 1999). With a 30-year history, the biologies, host ranges, rearing, release and monitoring techniques are well documented (Julien *et al.*, 1999), and the efficiency is fully recognized in many countries. Other agents are also used, such as the two moths, *Niphograpta albigutalis* Warren and *Xubida infusellus* (Walker) (Lepidoptera, Pyralidae), which have been released in 13 and three countries, respectively (Julien *et al.*, 2001). The weevils are currently reared in South Africa at PPRI and can be considered as the most suitable agents to initially release on tropical islands, with an expected high success rate within two to seven years (Le Bourgeois and Lebreton, 2006).

Case 2: *Ulex europaeus* L. (Fabaceae): Five sites are affected (Canaries, Réunion, Azores, Ascension, Saint Helena). Native to the Western coast of Europe (UK, France, Portugal), gorse is a prickly, perennial, evergreen legume which grows up to 3 m in height. It reproduces mainly by seed and is spread by machinery, soil movements, water and animals. It is a major weed problem in pastures and natural habitats, increasing the risk of brushfires, reducing land utilization by forming dense thickets, dramatically reducing stocking rates and competing with native species of subalpine shrublands. It is considered as a weed of national significance in Australia, New Zealand and Hawaii. Several biological control agents have already been used for gorse. The gorse seed weevil *Exapion ulicis* Forst. (Coleoptera, Curculionidae) was introduced into Australia in 1939 after being released in New Zealand. Its impact is limited because the larvae are not present during the second period of seed production. In 1998, the gorse spider mite *T. lintearius* was released in Australia and New Zealand. It forms colonies on plants and spin a tent-like white web and feed on the leaves and branches. This spider mite may have a substantial impact but is regulated by other mites such as phytoseids (Acari, Phytoseidae). Other agents are under study, including the gorse thrips *Sericothrips staphylinus* Haliday. In Monserrat, the introduction of *T. lintearius* had no impact on gorse populations of the island, likely due to the concomitant, accidental introduction of its predator *Phytoseiulus* sp. Pure populations of such biological control agents must be introduced from the beginning and studies should be conducted to determine if indigenous phytoseids already exist in the area of introduction (Anonymous, 2003; Davies *et al.*, 2004; Krause *et al.*, 1988).

Case 3: *Clidemia hirta* (L.) D.Don (Melastomataceae): Five sites are affected (Canaries, Mayotte, Réunion, Wallis and Futuna, Ascension). Koster's curse is native to tropical America (Mexico and the West Indies, and southward to central Brazil). This noxious weedy shrub grows up to 2 m tall in pastures and open forests. It is an aggressive invader which shades out all underlying vegetation. The seeds are principally dispersed by frugivorous birds but any organism moving through the thickets will carry seeds away with it. It is probably not resistant to fire, which is unlikely in its habitat, but it rapidly colonizes burned areas. Introduced in Réunion during the 1970s, it now colonizes the wet forest understorey on the southeast coast and roadsides and agricultural fields on the east coast. Several expeditions to find potential biological control agents have been carried out in Trinidad, and a number of insects were collected and screened. In Hawaii, a thrips, *Liothrips urichi* Karny (Thysanoptera, Phlaethripidae), which was introduced in 1953, works well in open areas but not in the shade of forests; while the fungus, *Colletotrichum gloeosporioides* (Penz) Sacc. f.sp. *clidemiae* (Coelomycetes, Melanconiales), introduced in 1986, is efficient in shady and wet places. Both the insect and pathogen would be complementary in Réunion and Mayotte settings. The Hawaii Department of Natural Resources and University of Hawaii are still testing other agents such as *Lius poseidon* Napp, a beetle; and moths *Antiblemma acclinalis* Hubner, *Carposina bullata* Meyrick and *Mompha trithalama* Meyrick (Julien and Griffiths, 1998; Nakahara *et al.*, 1992; PIER, 2006a; Trujillo, 2005)

Case 4: *Pistia stratiotes* L. (Araceae): Four sites are affected (Martinique, Réunion, Bermuda, New Caledonia). Its origin is unknown, but it is now pan-tropical. Water lettuce is a common aquatic weed in countries with hot climates. It is a floating, rosette-forming, stemless, stoloniferous herb. This plant usually propagates by means of stolons which break easily from the plant and it also propagates by seed. It causes similar problems as *E. crassipes* on bodies of water. The weevil *Neohydronomous affinis* Hustache (Curculionidae, Erirhinae), which was collected in South America, substantially reduced growth of *P. stratiotes* in Australia and Zimbabwe. It has now spread to more than six countries. This is the most sustainable method to control this free-floating weed. It has been readily established in six countries and has provided substantial to excellent control in all of them. For introduction in Réunion, *N. affinis* can be obtained from PPRI in South Africa (DeLoach, 1978; Dray and Center, 2003; Foxcroft and Richardson, 2003).

Case 5: *Ageratina riparia* (Regel) R.M.King & H.Rob. (Asteraceae): Three sites are affected (Canaries, Réunion, Bermuda). Mistflower is native to Mexico. It is a low-growing perennial with tiny, white, daisy-like flowers. It rapidly invades disturbed areas and tends to spread along gullies and river banks. It is rather a hemisciaphilous species which is confined to the forest margins, paths, and gullies in subtropical to temperate climates. Chemicals from its leaf-litter suppress the growth of other plants, giving mistflower a further competitive advantage. A plume moth, *Oidematophorus beneficus* Yano & Heppner (Lepidoptera, Pterophoridae), a gall wasp, *Procecidochares alani* Steyskal (Diptera, Tephritidae) and a smut fungus, *Entyloma ageratinae* Barreto & Evans (Ustilaginales, Basidiomycotina), were introduced in Hawaii to attack this aggressive weed in the mid-1970s. Biological control of mistflower in Hawaii has been an outstanding success. Of the three agents, the fungus was the most effective and it achieved total control of the plant in wet areas within 8 months, and in dry areas within 3–8 years. The plant has remained under control ever since. Mistflower has increasingly become a problem in northern New Zealand. A feasibility study showed that infested areas of New Zealand were likely suitable for the mistflower agents, so the smut fungus and the gall wasp were released in New Zealand in 1998 and 2001, respectively. Both are establishing and spreading rapidly and it looks promising that the plant will be successfully controlled there too. Technology transfer from Hawaii or New Zealand to Réunion, Canaries or Bermuda would be easy. In Réunion, no endemic species belonging to the Eupatoriae tribe are present, and there are only two indigenous species of the *Adenostemma* genus—these should be tested to determine the specificity of the potential agents (Frohlich *et al.*, 2000; Morin *et al.*, 1997; PIER, 2006b).

Conclusion

Biodiversity is more threatened by alien invasive plants in tropical European overseas departments, territories, and countries than in continental European countries but very few classical weed biological control programmes have been undertaken to date. Many invasive species are common to several EORTs and many of them are already under biological control programmes in other countries. These biological control agents and technologies could be easily transferred within collaborative European and international programmes. Prior to any introduction, a review of host-specificity test results is necessary to determine whether complementary tests should be done according to the indigenous or endemic flora conservation concerns in each setting. We have described some examples of invasive species that could be controlled with a high probability of success by several existing and proven biological control agents, such as *E. crassipes, U. europaeus, C. hirta, A. riparia,* and *P. stratiotes*. Many other weed species could also be targeted in EORTs by classical biological control throughout inter-EORT collaboration, e.g. *C. gloeosporioides* f.sp. *miconiae* from French Polynesia to control *M. calvescens* at an early invasion stage in New Caledonia and the Canaries, or through international collaborations (e.g. with Hawaii). EORTs should be highly suitable places to implement classical biological control of alien invasive plants.

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