

Potential for classical biocontrol of silverleaf nightshade in the Mediterranean Basin

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Unlike biocontrol of insect pests, biocontrol of invasive weeds is not largely studied in Eurasia, but remains an ecologically sound approach to invasive species management. The case study of silverleaf nightshade (*Solanum elaeagnifolium*) is a good example of a New World weed which has been introduced and is spreading over the Mediterranean Basin. *S. elaeagnifolium* economically impacts agricultural areas by competing with cereal crops, damaging pastures, and infesting meadows and roadsides. This paper deals with classical biological control of *S. elaeagnifolium* in the Mediterranean basin with natural enemies from the region of origin of the target plant, using studies conducted on other continents. Natural enemies are listed and their capability to attack and control the target plant is discussed. Special attention is devoted to *Leptinotarsa texana* and *L. deflecta*, chrysomelid beetles already released with success against *S. elaeagnifolium* in South Africa, one of the five Mediterranean-type regions of the world.

Introduction

Biocontrol of weeds is not largely performed in Eurasia, unlike biological control of insect pests. Although classical biocontrol of weeds has been practiced in some Eastern European countries, to date no exotic biocontrol agents have been released in Western Europe against an exotic weed (Sheppard *et al.*, 2006). However, classical biocontrol remains the only strategy which can provide permanent management of invasive weeds ecologically and permanently.

Recently, Sforza & Sheppard (2006) discussed case studies showing the potential for biocontrol in the Mediterranean Basin of five exotic weeds including shrubs, grasses, and trees, based on data and results obtained from past projects funded and managed in other Mediterranean-type regions of the world. This was followed by a list of the top 20 European environmental weeds, including silverleaf nightshade (*Solanum elaeagnifolium* Cav.), selected for their potential to be biologically managed (Sheppard *et al.*, 2006). The overall purpose of this review is to demonstrate to the European research community and extension services that opportunities for biocontrol in weed management exist.

Based on a literature survey, this paper specifically discusses the prospects for the biocontrol of *S. elaeagnifolium* in the Mediterranean Basin using American natural enemies.

Origin and Distribution

Solanum elaeagnifolium belongs to the Solanaceae family which also includes food plants, poisonous, medicinal and ornamental plants, and several noxious weeds. *S. elaeagnifolium* is a close relative of tropical soda apple (*Solanum viarum* Dunal), wetland nightshade (*S. tampicense* Dunal), and turkey berry (*S. torvum* Swartz), all perennial exotic invasive weeds in

North America that have been identified as candidates for biological control (Cuda *et al.*, 2002). *S. elaeagnifolium* is native to the Americas, although it is unclear whether it originates from North America or South America. However, the most likely centre of geographic origin is south-western USA or northern Mexico (Boyd *et al.*, 1984). Goeden (1971) remarked that the insect fauna on the target plant increased rapidly as the Texan/Mexican border was approached and sampled.

Interest in *S. elaeagnifolium* increased in the 1970s as its populations spread outside their native range. It is now known from Australia, Egypt, Greece, India, Israel, Zimbabwe, Sicily, Greece, South Africa, the Maghreb countries and Spain (Boyd *et al.*, 1984; Bouhache & Tanji, 1985), and is on the top 20 weed list in the Mediterranean islands. Introduced in the 1950s into Morocco by contaminated cotton seeds, it is now considered the nation's most noxious weed (Taleb & Bouhache, 2006). It is also a potential threat to thousands of hectares of Tunisian irrigated fields in arid and semiarid regions (Mekki, 2006). It is interesting to note that in its native range, *S. elaeagnifolium* is listed as a noxious weed in 21 US states (Roche, 1991).

Economic impact and spread

The major economic impact that this plant causes is to agricultural areas. *S. elaeagnifolium* competes with winter crops and pastures by taking up water and nutrients from soils during the previous summer. In the USA, it can cause a reduction in wheat yield of up to 50%. In pasture it mainly competes with perennial grasses, while pushing out more valuable plants with its unpalatability to livestock (Boyd *et al.*, 1984).

The plant typically occurs on coarse-textured, sandy soils (Molnar & McKenzie, 1976 cited in Boyd *et al.*, 1984). In its native range, *S. elaeagnifolium* is a problem in areas where the vegetation has been disturbed such as roadsides, construction

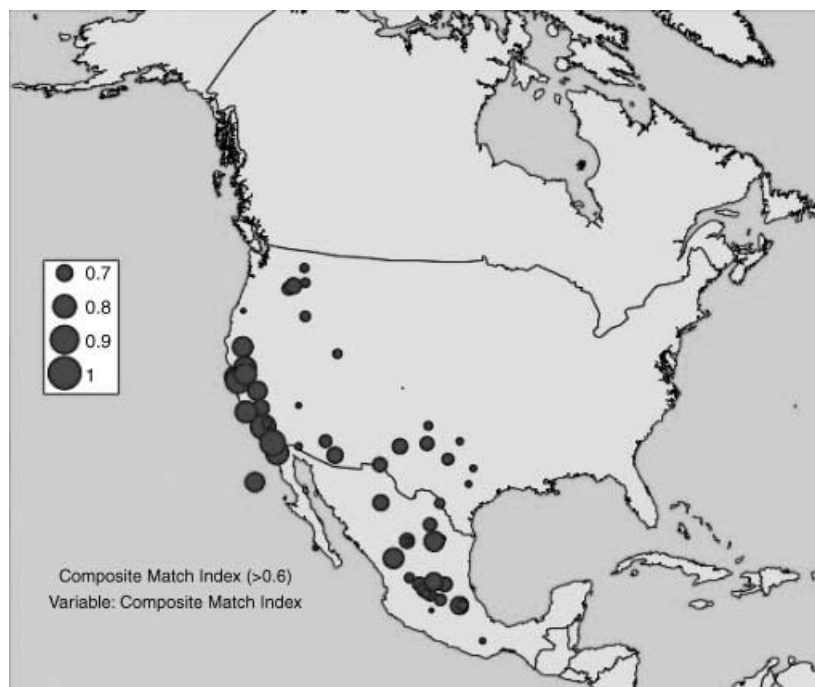


Fig. 1 Climate matching between Casablanca (Morocco) and North America.

sites, livestock feeding and watering areas and cultivated fields. It is considered a problem in cereal grain, alfalfa, grain sorghum and cotton. The species is also toxic to livestock. *S. elaeagnifolium* contains toxic alkaloids that combine with sugars to produce glycoalkaloids that irritate the gastrointestinal tract.

However, the berries can be eaten by sheep, which can carry the seeds in their gut for up to a month. Seeds can also be carried by flood waters or as a contaminant in fodder. They are slow to germinate, capable of remaining over 10 years in the soil and germinating only in occasional years. The plant spreads mainly by seeds but regeneration by cut root pieces have been observed in some places (Fernández & Brevedan, 1972).

Climatic considerations

Prior to initiating search and collection of potential natural enemies, it is prudent to identify areas within the native region that are climatically similar to the destination region. The climate matching software 'CLIMEX'® (Sutherest *et al.*, 2004) was used to make a generalized prediction of the suitability of Mediterranean climate areas for potential natural enemies introduced from native areas in North America. The 'Match Climates' function was used to compare the long-term meteorological data for selected Mediterranean ('Away') locations with the climate of the North American ('Home') location. The level of similarity was compared using default settings in the 'Climate Match Index' which is the product of six component indices: (1) maximum temperatures, (2) minimum temperatures, (3) total rainfall, (4) rainfall pattern, (5) relative humidity and (6) soil moisture.

For the purposes of this study, a simple comparison was made using the climate databases for Casablanca (Morocco)

and Tunis (Tunisia) and compared with matching sites in North America. Default matches (at 70-100% match) for these two sites show that locations within the North American climate database (south-central USA, Mexico and California) were similar to both North African climates (Figs 1 and 2). To identify which areas in Europe and Africa contained climates similar to that in the presumed origin of silverleaf nightshade, Brownsville (Texas, USA) was used as the home location of the plant. Brownsville is on the extreme southern tip of the USA, adjacent to Mexico, within the native range of *S. elaeagnifolium*. Climate types in Europe that are the nearest match to Brownsville lie mainly in southern Europe (Fig. 3), with up to 70% matches along the southern border of the Sahara, and along the Mediterranean coast. In Europe, the nearest matches to Brownsville (Texas) border the Mediterranean Sea (Fig. 4).

These preliminary results can be modified to accommodate irrigation levels, and any of the other factors used in the program, to make these matches more precise.

Biocontrol agents and their potential for the Mediterranean Basin

The potential for biocontrol of over 20 invasive weeds in Mediterranean Europe was recently discussed by Sheppard *et al.* (2006). They recommended that biocontrol is a valuable long-term strategy for managing *S. elaeagnifolium*. Over the last two decades, biocontrol of *S. elaeagnifolium* has been considered as a management strategy in Australia, North America and South Africa.

Considering North America as the main source for candidate natural enemies, surveys in Arizona, New Mexico, and Texas

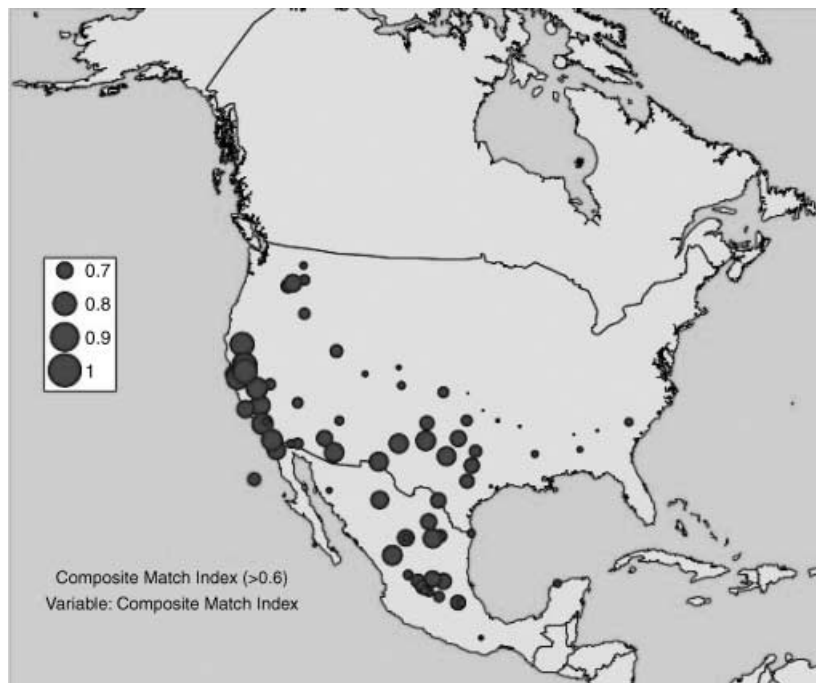


Fig. 2 Climate matching between Tunisia (Tunisia) and North America.

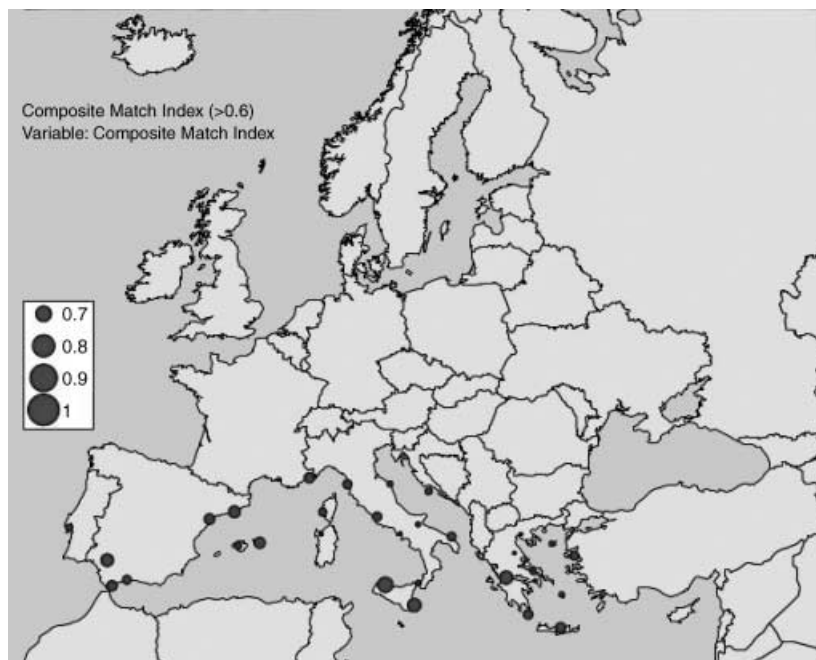


Fig. 3 Climate matching between Brownsville (Texas, USA) and Southern Europe.

identified 116 insects collected from *S. elaeagnifolium*. However, it is still a weed in these areas (Goeden, 1971). Surveys conducted during the last two decades have shown evidence of specific natural enemies feeding on *S. elaeagnifolium* and closely related species (Wapshere, 1988; Cuda *et al.*, 2002). Adapted from the literature, we present here a list of natural enemies collected in the native range, including their host range and plant parts attacked (Table 1).

Several other biological control agents have been tested around the world. Two species of leaf-eating *Leptinotarsa* beetles have been released in South Africa, and their impacts are currently being evaluated. Because *S. elaeagnifolium* originates from an area with dry winters and wet summers, any potential biological control agents are likely to be ineffective in winter rainfall areas. The only way control can be achieved is by preventing plants from producing seeds, but the nature of the weed indicates that

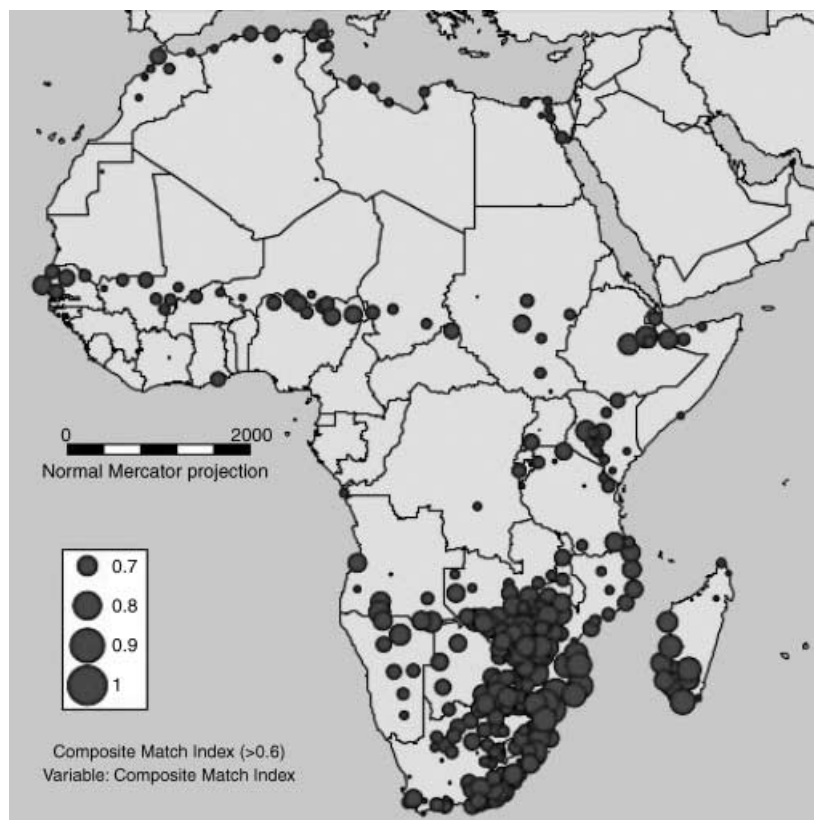


Fig. 4 Climate matching between Brownsville (Texas, USA) and Africa.

Table 1 Main natural enemies of *Solanum elaeagnifolium* Cav. in its native range of Northern Mexico (adapted from Wapshere, 1988).

Group	Natural enemies	Part attacked and damage	Field host range	Used as Biological Control Agents? Where?
Chrysomelidae	<i>Leptinotarsa texana</i>	Leaf – defoliation	<i>Solanum elaeagnifolium</i> and <i>S. rostratum</i> (?)	Yes (South Africa)
	<i>Leptinotarsa defecta</i>	Leaf – defoliation	<i>Solanum elaeagnifolium</i> and <i>S. dimidiatum</i>	Yes (South Africa)
	<i>Gratiana pallidula</i>	Leaf – defoliation	<i>Solanum</i> spp.	No
Tingidae	<i>Gargaphia arixonica</i>	Leaf – defoliation	<i>S. elaeagnifolium</i>	No
	<i>Gargaphia opacula</i>	Leaf – defoliation	Solanaceae	No
Cecidomyiidae	undetermined	Stem galling	<i>S. elaeagnifolium</i>	No
Gelechiidae	<i>Frumenta nephalomicta</i>	Fruit & seed feeding	<i>S. elaeagnifolium</i>	Yes (South Africa)
Tephritidae	<i>Zonosemata vittigera</i>	Fruit & seed feeding	<i>S. elaeagnifolium</i>	No
Curculionidae	<i>Trichobaris texana</i>	Stem boring	<i>S. elaeagnifolium</i> and other <i>Solanum</i> spp.	No
Nematoda	<i>Orrina phyllobia</i>	Leaf galling	<i>S. elaeagnifolium</i>	No

defoliating agents would be the most effective (Olckers & Zimmermann, 1995).

Olckers *et al.* (2002) recorded eight herbivore species, which is a typical number for enemies attacking *Solanum* species when compared to the numbers collected from *S. mauritanium* (19), *S. sisymbriifolium* (8), and *S. viarum* (8). It is interesting to note that different parts of the target plant can be attacked, which might be helpful in case of multiple species releases. As discussed earlier, seed feeders may play a crucial role, if specific enough, in reducing spread of *S. elaeagnifolium*.

We provide details below for the insect species listed in Table 1 which have already been released for biocontrol elsewhere, and will discuss their potential for release into the Mediterranean Basin. South Africa is a key country in terms of biocontrol programmes against *S. elaeagnifolium* as it was the first country in the world to study, import and release insects on solanaceous weeds. In addition, South Africa contains one of the five Mediterranean-type regions of the world, and the success of release and establishment of natural enemies there provides optimism for future considerations in the Euro-Mediterranean countries.

***Leptinotarsa texana* and *L. defecta* (Col. Chrysomelidae)**

S. elaeagnifolium is the primary host of both chrysomelid beetles and neither species has been recorded feeding on any solanaceous crops in the Americas (Olckers & Zimmermann, 1995). Both adults and larvae are defoliators in Mexico and Texas where *L. texana* is the most widespread species. Individual females may oviposit more than 2000 eggs. Mature larvae burrow into the soil to pupate and overwinter in the soil. Adults start feeding immediately after emergence. *Leptinotarsa texana* is considered a successful biocontrol agent in South Africa (Olckers *et al.*, 1999). Laboratory tests have shown that neither species can survive on solanaceous crops including potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum* Mill.), green pepper (*Capsicum frutescens* L.), tobacco (*Nicotiana tabacum* L.) and gooseberry (*Physalis peruviana* L.) (Olckers *et al.*, 1995).

***Frumenta nephalomicta* (Lep. Gelechiidae)**

Larvae of this moth eat out the centre of fruits, completely destroying seeds, and pupate within fruits, causing enlargement of infested berries. It is considered specific to *S. elaeagnifolium* (Wapshere, 1988). It was released several times in large numbers in South Africa but establishment has not been recorded (Olckers *et al.*, 1999).

***Orrina phyllobia* (Nematoda) (= *Nothanguina phyllobia* Thorne)**

This foliar nematode is specific to *S. elaeagnifolium* (Robinson *et al.*, 1979) and it is considered to be the most promising organism, causing leaf and stem galling (Roche, 1991). Galls appear on the leaves of regenerating stems shortly after the nematodes appear in spring, with galling continuing throughout the summer (Wapshere, 1988). The nematode overwinters in a quiescence stage. It has been considered a valuable biocontrol agent in the USA (Parker, 1986).

***Gargaphia* species (Hem. Tingidae)**

All nymphal stages and adults destroy leaves by sucking cell contents, damaging plants by a high infestation rate. The more specific species is *G. arizonica* Drake and Carvalho, which does not include cultivated solanaceous plants as hosts (Wapshere, 1988).

Other natural enemies

The tortoise beetle, *Gratiana pallidula* (Col. Chrysomelidae) is, common on *S. elaeagnifolium* in its native range, but was recorded as feeding on eggplant (*Solanum melongena* L.) (Zimmermann, 1974 cited in Wapshere, 1988), although this needs to be confirmed.

Zonosemata vittigera (Coquillett) (Dipt. Tephritidae) attacks fruits of *S. elaeagnifolium* by laying eggs inside them. Larvae destroy the interior of the berries and exit into the soil to pupate. Laboratory tests have shown that *Z. vittigera* does not oviposit on any of the fruits

of cultivated or wild solanaceous plants that have been exposed to it (Goeden & Ricker, 1971). Apparently it is not considered as an effective control agent of the plant in its native range because it causes no appreciable seed damage within the fruit; however, this has to be reconsidered in the case of classical biocontrol.

Conclusion and discussion

Risk assessment has been a cornerstone of the practice of weed biological control since its inception because of safety concerns for crop and ornamental species (Strong & Pemberton, 2000). Clearly, any insect introduced for the biological control of a weed must not itself become a plant pest. The rigorous screening process ensures that nonspecialist insects capable of reproducing on economically important or environmentally sensitive species that are close relatives of the target weed are dropped from further consideration. Finding a biological control agent for *S. elaeagnifolium* or other invasive *Solanum* spp. has additional complications due to the large number of agronomic crops in Solanaceae like potato, tomato and aubergine. The latter two plants are widely commercially cultivated in irrigated areas of Maghreb countries.

However, the Solanaceae family originates from the Americas, and in Europe only three out of the 15 species recorded (Sheppard *et al.*, 2006) are native. For example, in Tunisia, only seven species are reported (Mekki, 2006). In the frame of each weed biocontrol programme, the number of closely related native species is critical. Thus, regarding risk assessment, Europe appears more appropriate for biocontrol programmes than South Africa, which contains at least 30 indigenous species within Solanaceae (Olckers *et al.*, 1999). Our preliminary overview for biocontrol in Europe shows that chrysomelid beetles and nematodes have a strong potential in terms of specificity and climatic adaptation. Regarding specificity, it is noticeable that *S. dulcamara* L., a European native, was attacked in the laboratory by both *Leptinotarsa* spp., but was not a host under field conditions (Wapshere, 1988).

Another major aspect of biocontrol against *S. elaeagnifolium* was that during host-specificity tests under artificial conditions, the acceptance of eggplant as a host plant by most, if not all, candidate natural enemies of solanaceous weeds appears to be the rule rather than the exception (Olckers *et al.*, 1999). Additional tests were made over the years, and results provided convincing evidence that eggplant is not threatened by the two *Leptinotarsa* species.

It is well known that the genus *Leptinotarsa* contains one of the world's most notorious insect pests, the Colorado potato beetle, *L. decemlineata* (Say). The consideration of these two beetles for biocontrol in Europe is challenging, as it was in South Africa some years ago. Nevertheless, the beetles have become established on *S. elaeagnifolium* in South Africa, and, in the case of *L. texana*, became abundant with no risk to native *Solanum* species (Olckers & Zimmermann, 1995). In conclusion, biological control of *S. elaeagnifolium* within an integrated control framework may provide a solution to the problem, and initial efforts should be devoted to future biological and impact studies of *Leptinotarsa* spp. in Europe.

Regarding nematodes as potential biocontrol agents of *S. elaeagnifolium*, it is remarkable to note that foliar disease-

causing nematodes are widespread. Some species that can cause leaf or branch galls have been evaluated as biocontrol agents for weeds: *Subanguina picridis* (Kirjanova) Brzeski against Russian knapweed, *Acroptilon repens* (Watson, 1986), and *Ditylenchus drepanocercus* against the velvet tree, *Miconia calvescens* (Seixas *et al.*, 2004).

The preliminary results for climate matching appear to confirm that climate is a factor in the occurrence of silverleaf nightshade, and that natural enemies from Mexico and south-central USA should be acclimated to potential release sites in infested area within the Mediterranean Basin.

To conclude, it appears that classical biological control of *S. elaeagnifolium* in the Mediterranean Basin could be an effective management tool and go far to minimize the continuous and costly mechanical and chemical treatments currently required to control this weed within affected areas. Previous programmes conducted in other countries provide good array of knowledge regarding host plant relationships, and which species are likely to become established and beneficial.

Potentiel pour le control biologique classique de la morelle jaune en Méditerranée française

Au contraire de la lutte biologique contre les insectes ravageurs, la lutte biologique contre les plantes envahissantes exotiques n'est pas suffisamment étudiée en Eurasie, bien que restant une approche fortement écologique dans la gestion des espèces invasives. Le cas de *Solanum elaeagnifolium* est un bon exemple d'une plante exotique originaire du Nouveau Monde, introduite et pullulant dans le bassin Méditerranéen. Elle influe sur la dynamique économique des zones agricoles en entrant en compétition avec les céréales cultivées, en infestant les prairies et pâturages, et en colonisant les bords de route. Cet article s'intéresse au devenir de la lutte biologique classique contre *S. elaeagnifolium* dans le bassin Méditerranéen en utilisant des ennemis naturel de l'aire d'origine de la plante cible, au regard des travaux conduits sur d'autres continents. Les auxiliaires sont listés et leurs capacités à attaquer et à contrôler la plante cible sont discutées. Une attention particulière est accordée à *Leptinotarsa texana* et *L. deflexa*, deux chrysomèles déjà relâchées avec succès contre *S. elaeagnifolium* en Afrique du Sud, l'une des cinq régions climatiques méditerranéenne du Monde.

Потенциал для классического биологического подавления паслена линейнолистного в Средиземноморском бассейне

В отличие от биологического подавления вредных насекомых, биологическое подавление инвазивных сорняков в Евразии широко не изучалось, однако оно остается экологически правильным подходом к управлению инвазивными видами. Конкретный случай исследования паслена линейнолистного (*Solanum elaeagnifolium*) представляет собой хороший пример сорняка Нового Света, который, будучи интродуцирован, теперь

распространяется по Средиземноморскому бассейну. *S. elaeagnifolium* экономически воздействует на зоны сельскохозяйственного производства, успешно конкурируя с зерновыми культурами, нанося ущерб пастбищам, засоряя луга и обочины дорог. В статье рассматривается классическая биологическая борьба с *S. elaeagnifolium* в Средиземноморском бассейне с помощью естественных врагов из региона происхождения растения-мишени с использованием при этом исследований, проводившихся на других континентах. В статье перечисляются естественные враги и рассматривается их способность поражать и подавлять растение-мишень. Особое внимание уделяется *Leptinotarsa texana* и *L. deflexa*, жукам-листоедам, с успехом выпускавшимся для борьбы с *S. elaeagnifolium* в Южной Африке, одном из пяти регионов средиземноморского типа.

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