Prosopis juliflora *can be found as multi-stemmed shrubby bushes or single stemmed trees. © Thamizhpparithi Maari. CC BY-SA 3.0.*

The management of mesquite (*Prosopis juliflora*)

Measures and associated costs

Scientific name(s)	*Prosopis juliflora* (Sw.) DC.
Common names (in English)	Mesquite
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Common names

BG	Мескит
HR	Meskit
CZ	Naditec jehnědokvětý
DA	Mesquite-træ
NL	Mesquite
EN	Mesquite
ET	Kahkjas meskiidipuu
FI	Meksikonmeskite
FR	Bayahonde
DE	Mesquitebaum
EL	Μεσκίτ
HU	–
IE	An mhéiscít
IT	Prosopis a fioritura estiva
LV	–
LT	Skėstašakis algarobas
MT	Il-meskita
PL	Jadłoszyn baziowaty
PT	Prosópis
RO	–
SK	Prozópa jahňadokvetá
SL	Mehiški meskit
ES	Mezquite
SV	Mesquite

Summary of the measures, emphasizing the most cost-effective options.

Prosopis juliflora is a legume tree or shrub native to northern South America, Central America and the Caribbean. It was introduced over the past two centuries, mostly to tropical drylands in Africa, Asia and Oceania, and widely planted in reforestation schemes, especially in the 1980s and 1990s, by international organizations and national authorities; these latter introductions became the source of many of the largest invasions. *Prosopis juliflora* is by far the dominant invasive species in the genus, especially in tropical regions, though it is occasionally found alongside the much less invasive *P. pallida* in some restricted areas. In more sub-tropical regions (for example, southern Africa and Australia, as well as in their native North American range), other species dominate (notably *Prosopis glandulosa, Prosopis velutina* and hybrids) and are also highly invasive.

In 2016, *P. juliflora* was prioritized (amongst 36 species from the EPPO List of Invasive Alien Plants and a horizon scanning study) for PRA within the LIFE funded project "Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014' (see www.iap-risk.eu). It was also one of 16 species identified as having a high priority for PRA. The species is certainly one of the most invasive woody weeds in the world's tropical drylands, and the genus as a whole was included in the widely cited '100 of the World's Worst Invasive Alien Species'. In a review of introductions of *Prosopis* species globally, Shackleton, Le Maitre, van Wilgen and Richardson (2014) found that 79% of introductions led to naturalization, of which 38% then became invasive.

There are only very few reports of any *Prosopis* species naturalizing in European Union countries. For *P. juliflora*, the only known reports for presence are of two planted trees in a sheltered valley in Almeria, south-eastern Spain (Pasiecznik and Peñalvo López, 2016), and reported as naturalised in a very limited area in Gran Canaria in the Canary Islands, Spain (Verloove, 2013, 2017). This author considers that the likelihood of other *Prosopis* species (such as *P. chilensis*, *P. glandulosa* and *P. velutina*) becoming invasive in Union countries is significantly higher than for *P. juliflora*. However, all the above species are very closely related, and proposed measures for management and control for *P. juliflora* contained herein would therefore also be relevant for any of the aforementioned species.

Based on current environmental conditions and species distribution modeling developed and used in the recent PRA for the EPPO region (EPPO, 2018), a number of suitable areas for establishment of *P. juliflora* were identified. This particularly includes the Mediterranean and Macaronesian biogeographical region of the Union, in largely frost-free coastal and low-lying inland areas. This includes parts of Cyprus, Greece (and the islands), Italy (including Sardinia and Sicily), Malta, Portugal (including Madeira and the Azores), and Spain (including the Canary Islands). Results of the PRA also concluded that *P. juliflora* poses a moderate risk to the endangered area (Mediterranean and Macaronesian biogeographical region) with a moderate uncertainty (EPPO, 2018). The major pathway to be considered is **Plants for planting**, for use in reforestation and as an ornamental. Given the significant impact of this (and closely related) species in other parts of the world and the identified risk to Union countries, a number of management needs should be considered. In summary, this requires regulation, and suggested measures are detailed in subsequent sections. Also, national measures should be combined with international measures, and international coordination of management of the species between countries is recommended.

(1) Prevention of intentional introduction and spread – the prohibition of import, sale and movement of plants and seeds, as would be required under Article 7 of the EU IAS Regulation 1143, if the species were to be listed.
(2) Prevention of unintentional introduction and spread –not applicable.
(3) Prevention of secondary spread of the species – Removal of naturalized individuals and populations where known to exist as prevention of secondary spread once well-established over a large area is not possible.
(4) Surveillance measures to support early detection – Undertaking full surveys in the endangered area, including full literature reviews, with an obligation to report findings if the species was regulated.
(5) Rapid eradication of new introductions – manual eradication to remove all identified plants.
(6) Management –manual control, and where widespread, countries must prepare and implement eradication and containment/management plans (that could also include mechanical, chemical and/or biological control methods).

Measures for preventing the species being introduced, intentionally and unintentionally.

This section assumes that the species is not currently present in a Member State, or part of a Member State's territory.

A ban on importing (pre-border measure), selling and movement of plants and seed as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *P. juliflora.*

MEASURE DESCRIPTION

The major pathway of introduction for the species to be addressed is **Plants for planting.** Therefore, to prevent intentional introductions of the species into the EU, the prohibition of import into and movement into the EU would be required, alongside banning the sale and planting of plants and seed of plants labeled or otherwise identified as *Prosopis juliflora*.

EFFECTIVENESS OF THE MEASURE

Effective.

Prevention of intentional introduction is the only fully effective measure, as once the species is established/naturalized over more than a limited area, eradication is considered impossible (Pasiecznik *et al.,* 2001). *Prosopis* species are also on the regulated list of other countries (see below). And, as to date, no alien *Prosopis* species are reported as naturalized on the continental USA and no further *Prosopis* species reported in Australia, these measures have proved effective.

Australia - *Prosopis* spp. (as a genus) is listed as one of the 30 Weeds of National Significance (www.environment.gov.au/cgi-bin/biodiversity/invasive/weeds/weeddetails.pl?taxon_id =68407), and includes *P. juliflora* as one of four naturalized species (the others being *P. glandulosa, P. pallida* and *P. velutina*, and hybrids).

South Africa - *Prosopis juliflora* is not listed as invasive, but under the country's National Environmental Management and Biodiversity Act (NEMBA), *P. glandulosa, P. velutina* and their hybrids are listed as Category 1b (may not be owned, imported or grown) in Eastern Cape, Free State, North-West and Western Cape, and Category 3 (may hold but cannot propagate or sell) in Northern Cape (www.environment.co.za/weeds-invaders-alien-vegetation/alien-invasive-plants-list-for-south-africa.html#notice1).

USA - *Prosopis juliflora* is not included in the USDA Federal noxious weed list (last updated 21 March 2017, www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/weedlist.pdf), although 20 of the 44 *Prosopis* species recognized by Burkart (1976) are listed, 16 as A1 weeds and 4 as A2 weeds. The reasons for not being included is unclear, however, but may be due, perhaps, to the mistaken view that *P. juliflora* is native to the USA, following Bentham's classification. Other native species (*P. glandulosa* and *P. velutina*) are also not listed. However, one US state, Hawaii, does include *P. juliflora* on its list of noxious weeds (see, Division of Plant Industry. List of plant species designated as noxious weeds (20 October, 2003). Hawaii Department of Agriculture, Hawaii. (in https://plants.usda.gov/java/reference?symbol=PRJU3)). Many other states contain the same species as listed in the federal USDA, with some variation, for example, the California State-listed noxious weeds (https://plants.usda.gov/java/noxious?rptType=State&statefips=06) includes *P. velutina* as the preferred name for *P. articulata* (whereas Burkart (1976) considered them as separate species and not synonyms). The whole genus is listed as a noxious weed in the State of Florida (https://plants.usda.gov/java/noxious).

DETECTION AND IDENTIFICATION

The following description is taken from Burkart (1976) as the over-arching species morphology, including all varieties from all parts of the world. Although some material that Burkart (1976) identified as *P. juliflora* is now likely to be *P. pallida* (Harris, Pasiecznik, Smith, Billington and Ramirez, 2003), this description is still accepted in the absence of a newer acknowledged taxonomy. *Prosopis juliflora* is a tree 3-12 m tall, sometimes shrubby with spreading branches; wood hard; branches cylindrical, green, more or less round- or flat-topped, somewhat spiny with persistent, green (sometimes glaucous or greyish, not reddish) foliage, glabrous or somewhat pubescent or ciliate on the leaflets; spines axillary, uninodal, divergent, paired, or solitary and paired on the same branches, sometimes absent, not on all branchlets, measuring 0.5-5.0 cm long, being largest on strong, basal shoots. Leaves bipinnate, glabrous or pubescent, 1-3 pairs of pinnae, rarely 4 pairs; petiole plus rachis (when present) 0.5-7.5 cm long; pinnae 3-11 cm long; leaflets 6 to 29, generally 11 to 15 pairs per pinna, elliptic-oblong, glabrous or ciliate, rarely pubescent, approximate on the rachis or distant a little more than their own width, herbaceous to sub membranous (not sub-coriaceous as in more xerophilous species and therefore often corrugated or curved when dried), emarginated or obtuse, pinnate-reticulately curved; leaflets 6-23 mm long x 1.6-5.5 mm wide. Racemes cylindric, 7-15 cm long, rachis puberulent; florets as usual, greenish-white, turning light yellow. Legume straight with incurved apex, sometimes falcate, straw-yellow to brown, compressed, linear with parallel margins, stalked and acuminate, 8-29 cm long x 9-17 mm broad x 4-8 mm thick; stipe to 2 cm; endocarp segments up to 25, rectangular to subquadrate, mostly broader than long; seeds oval, brown, transverse.

Prosopis species, however, exhibit high levels of variability in morphological characters in its native range. Self-incompatibility and obligate outcrossing tend to lead to large phenological variation, as a combination of both clinal variation in response to broad climatic factors and ecotypic (discontinuous) variation in response to disjunct environmental factors. Differences in continuous climatic clines such as temperature, rainfall and day length, and discrete differences in site such as soil type, salinity or depth combine to create a variety of phenological responses.

Identifying Tropical *Prosopis* Species: A field guide (Pasiecznik, Harris and Smith, 2004) provides the easiest to use means of separating the eight most common *Prosopis* species found in tropical regions, from field observations and measurements of morphological characteristics. It also includes a description of the most common misidentifications, and a simple key to separate *P. juliflora* and *P. pallida* using leaf/leaflet size and number. In addition, the fact that *P. juliflora* is confirmed as the only tetraploid species in the genus means that flow cytometry analyses of genome size can be used as a tool from separating this species from others (Trenchard, Harris, Smith and Pasiecznik, 2008).

However, ongoing taxonomic confusion surrounding *Prosopis* species within Section Algarobia must be highlighted, as this would impact on any proposed regulation, and some databases group all *Prosopis* species together or repeat taxonomical errors of the past. Furthermore, the general common name is mesquite or simply prosopis. Note also that as a common name, species of *Prosopis* are also referred to in normal script (not italics) and all in lower case, as are acacia, eucalyptus, leucaena, etc. In addition, as a common name, mesquite is also used for other species of Section Algarobia such as *P. glandulosa* (Lowe, Browne, Boudjelas and De Poorter, 2000), and occasionally for others outside of this Section, either with or without a specific epithet (for example. *P. glandulosa* should be honey mesquite, *P. velutina*, velvet mesquite, etc.).

The following information on taxonomy and nomenclature is adapted from the *P. juliflora* datasheet in the Invasive Species Compendium (CABI, 2018; prepared by this author), the most up-to-date review of the taxonomy of species. *Prosopis juliflora* (Sw). DC has had an array of synonymy since its first description in 1788. Originally known as *Mimosa juliflora* Sw., it became both *Algarobia juliflora* (Sw.) Benth. ex Heynh and *Neltuma juliflora* (Sw.) Raf. , during the last two centuries before both genera were incorporated into the single, overarching genus *Prosopis*. Bentham (1875) noted *P. limensis* (syn. *P. pallida*) from Peru as the only *Prosopis* species of section Algarobia he was aware of that was not sympatric with others in the section. This may assume that he was either unaware of *P. juliflora* and hybrids in Ecuador and northern Peru, or that he treated them all as the same species, distinct from the *P. juliflora* of Central America, Colombia and the Caribbean.

Prosopis juliflora was used by Pasiecznik *et al*., (2001) in its original, restricted and certainly biological sense, re-established by Burkart (1940) and accepted by Benson (1941) and Johnston (1962). The all-embracing, collective *P. juliflora* concept of Bentham (1875) was maintained by others and though this is rejected by most taxonomists, it is still used occasionally to this day. Confusion also occurs when referring to old literature, as the binomial *P. juliflora* was used to describe species now generally accepted as separate taxa. The following three varieties were accepted by Burkart (1976) and without any information to the contrary, also by Pasiecznik *et al*., (2001): *Prosopis juliflora* (Sw.) DC. var. *juliflora*, *Prosopis juliflora* (Sw.) DC. var. *inermis* (H.B.K.) Burkart and *Prosopis juliflora* (Sw.) DC. var. *horrida* (Kunth) Burkart. However, even then, the taxonomy seemed uncertain, with Burkart noting that var. *inermis* and var. *horrida*, differed from var. *juliflora* principally in the relative presence/absence of thorns, with no other striking morphological basis for separation. However, particularly at the limits of the native range, further revision is expected.

The '*P. pallida* – *P. juliflora* complex' was proposed by Pasiecznik *et al*., (2001) as a means to overcome the observed ambiguities at that time and the lack of agreement on how to deal taxonomically with tropical American Prosopis, and discusses previous proposals and revisions in detail. This followed the treatment by Johnston (1962), who divided *P. juliflora* into two races, the Central American, and Colombian-Caribbean race, mainly on the basis of leaflet length, and noted the similarities and the differences between these two and the truly South American *P. limensis* (syn. *P. pallida*). However, it has since been unequivocally shown that the two are distinct taxa, morphologically and genetically (for example Harris *et al*., 2003; Landeras, Alfonso, Pasiecznik, Harris and Ramirez, 2006; Catalano, Vilardi, Tosto and

Saidman, 2008; Trenchard *et al*., 2008; Palacios *et al*., 2012; Sherry *et al*., 2012). Comparing native range material with that from introduced populations, however, highlighted a number of serious misidentifications, notably being that the 'common' prosopis in the north east of Brazil, Cape Verde and parts of Senegal is in fact *P. pallida*, and not *P. juliflora* as it has always been referred to (Harris *et al*., 2003). *P. pallida* has also been positively identified in southern Mauritania (Pasiecznik *et al*., 2006) and Djibouti (Pasiecznik, 2013) from naturalized populations. However, notwithstanding this published literature, scientific publications from Brazil and Cape Verde, for example, still tend to incorrectly refer to *P. juliflora* as the dominant species there (for example: Fonseca, Albuquerque, Leite and Lira, 2016; Tavares and Barros, 2016)

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

There are no known environmental, social and economic side effects expected from the implementation of these measures, involving only the addition of a further species [or group of species] to the list of those plants that are regulated in the EU, and associated checks.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Prosopis julifora and other species are known to have benefits and costs in other regions of the word where they are invasive. This has led to contentious issues between stakeholders. However, *Prosopis* species are not widely planted in the EU, but as it is known as a street tree in other countries, that other *Prosopis* species are planted as ornamentals, and that *Prosopis* seed and plants are sold by commercial companies, there may be some resistance to regulation from commercial suppliers. But as it is only a very minor ornamental species, this is not considered as a significant factor. As such, *as Prosopis* species are not planted in the EU for ornamental or grown for any other reason, no objection may be expected from commercial suppliers or the public.

ADDITIONAL COST INFORMATION

Limited information is available on quantitative costs for action or inaction, though some references exist, such as in Ethiopia (Wakie, Hoag, Evangelista, Luizza and Laituri, 2016) and South Africa (Wise *et al.,* 2012). However, a recent PRA (EPPO, 2018) reported that impacts would be restricted to only small areas in the EU where *P. juliflora* can establish, but that in the absence of specific data on impacts the rating of magnitude "remains high for impacts on biodiversity, ecosystem services and socio-economic impacts, however, uncertainty is raised too high for all categories, as it is not clear if these impacts will be realised throughout areas of potential establishment..." In addition, it notes that "In the EU, in frost-free coastal and low-lying inland areas of Cyprus, Greece, Italy, Malta, Portugal, and Spain, impacts on biodiversity and impacts on ecosystem services could be similar to those impacts seen in the current area of distribution and the isolated areas of establishment in the EPPO region, with the exception, potentially, of significant impacts on communities and local livelihoods... However, for this to be realised extensive populations of the species would need to establish and this would be more uncertain of occurring compared to areas in Israel and Jordan. In addition, even though the species has been sold as an ornamental species and as a forestry species globally, this is unlikely to be a significant pathway into the EU in future.

Therefore, for EU Member States detailed in the endangered area (as above) a moderate rating has been given for impacts on biodiversity, ecosystem services and socio-economic impacts with a high uncertainty. The PRA (EPPO, 2018) concluded that "the risk of introduction [of *P. juliflora*] and the potential area for establishment are both perceived as low, leading the EWG [expert working group brought together by EPPO to undertake the PRA] to propose an overall phytosanitary risk score of moderate."

LEVEL OF CONFIDENCE[1]

Well established.

High confidence is based in the knowledge obtained from a number of previous PRAs, including the following.

1 See Appendix

Unintentional movement of seeds.

MEASURE DESCRIPTION

Unintentional introduction of *Prosopis* seed as a contaminant is considered very unlikely. The only other possibilities for unintentional introduction are via live livestock imports where the animals have been fed on *Prosopis* pods either just before, or during, transit. Oceanic dispersal into the EU is also a possibility, but the risk is considered very low.

Prosopis juliflora *mainly reproduces via seeds, producing one main crop annually © Forest and Kim Starr. Public domain.*

Measures to prevent the species spreading once they have been introduced.

Removal of naturalized individuals and populations where known to exist.

MEASURE DESCRIPTION

The prevention of secondary spread, once the species is well established, is deemed to be not possible. The only option is the removal of naturalized individuals and populations where known to exist. [The specific measures to achieve this objective are described in the Rapid eradication and *Management* sections below.]

Once established over a large area, it has been shown that prevention of further spread of *P. juliflora* is not possible as the species quickly builds up a considerable seed bank, requiring regular removal of all new seedlings over very many years, as seeds can remain viable for at least 40 years and probably much longer (Pasiecznik *et al.*, 2001), and seeds spread easily by water and animals, with rates of spread in South Africa noted at around 14% per annum (Wise *et al.*, 2012).

Means of spread described below cannot be realistically or effectively reduced. The only possible way would be to fence off effective areas thus prevent entry of livestock and large wild animals, but smaller mammals could still cause spread and thus is deemed relatively ineffective.

Natural (non-biotic) dispersal - Water is an important dispersal agent in desert ecosystems. Water dispersal ensures widespread dissemination of seeds during flooding or other high rainfall events when seedling establishment is favoured. *Prosopis* species are often found colonizing ephemeral watercourses and dispersal is aided by water flow in the rainy season, particularly during very wet years (Solbrig and Cantino, 1975). Oceanic dispersal is also important in coastal areas, and possibly for crossing large bodies of water such as in the Caribbean. Pods and endocarps float and are impervious to water infiltration, protecting the seed from the harmful effects of extended periods in sea water.

Vector transmission (biotic) - Pods have high sugar content, are low in anti-feedants, and are widely sought after by a variety of animals. Disjunct stands of trees near to old centres of population suggest that man has also been a dispersal agent in historic and prehistoric times. Livestock are now the primary dispersal agents, although the pods are also avidly consumed by a wide variety of wild animals that play a major role in seed dispersal. Birds, bats, reptiles and ants also feed on *Prosopis* fruits and are potential, if only minor, agents of dispersal, but it is generally accepted that the fruits and seeds are specialized for animal dispersion. Pods are eaten off the tree or off the ground and seeds are deposited in the faeces. Voided seeds are given a positive advantage by being placed in faeces, with their improved water-holding capacity and high levels of nutrients. Livestock may tend to spend more time on better pasture or by water sources but voiding of seeds in preferential locations is not guaranteed. However, different animals have very different effects on seed survival.

Agricultural practices - Pods and seeds may adhere to agricultural machinery, but this is considered as a minimal cause of spread. The principal reason for agriculture increasing spread is due to habitat modification (for example, resulting from overgrazing), which creates favourable conditions for the spread of *Prosopis*.

SCALE OF APPLICATION

The measure should be applied in areas where *P. juliflora* is known to be present in the EU, such as currently, only in a small area of Gran Canaria (Canary Islands) and Almeria, Spain.

EFFECTIVENESS OF MEASURE

Ineffective.

See *Rapid eradication* and *Management* sections below.

EFFORT REQUIRED

See *Rapid eradication* and *Management* sections below.

RESOURCES REQUIRED

See *Rapid eradication* and *Management* sections below.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Positive
See *Rapid eradication* and *Management* sections below.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
See *Rapid eradication* and *Management* sections below.

ADDITIONAL COST INFORMATION

See *Rapid eradication* and *Management* sections below.

LEVEL OF CONFIDENCE[1]

Established but incomplete.
See *Rapid eradication* and *Management* sections below.

1 See Appendix

Measures for early detection of the species and to run an effective surveillance system to detect efficiently new occurrences.

Undertaking active surveys in the endangered area.

MEASURE DESCRIPTION

Undertaking full active surveys in the endangered area, following a review of literature to identify high risk areas, with an obligation to report findings if the species was regulated.

Prosopis juliflora should be placed on NPPO's alert lists and they should report any findings, with increased surveillance in areas where there is a high risk the species may invade. NPPO's should also provide land managers and stakeholders with identification guides and information on control techniques and management, and facilitate regional cooperation.

All known populations, and individuals when presence is very restricted, should have their GPS coordinates recorded. Remote sensing has also proved effective in other countries to assess the scale of invasion and identify potential areas of invasion (for example, Maroni *et al.*, 2016), but results require ground-truthing over the areas where invasion is known. It is not believed to be an effective measure for early detection (and therefore a separate section is not provided). Remote sensing using satellite imagery data to map distribution of *P. juliflora* has been used in a number of countries, for example, Ethiopia (Wakie *et al.*, 2016), Somalia (Maroni *et al.*, 2016). This method can be applied to relatively large areas, for example, by Wakie *et al.*, (2016) to 95,266 km^2 in the Afar Region of Ethiopia, and by Maroni *et al.*, (2016) to 5,167 km^2 in Somalia. However, it is not considered that remote sensing would be required over the restricted areas where *P. juliflora* is found in the EU.

SCALE OF APPLICATION

This measure should be applied in all countries in endangered areas (including parts of Cyprus, Greece, Italy, Malta, Portugal, Spain), in areas identified following a full review of literature and targeted interviews, with obligations to report finding as stipulated with the NPPOs of these countries.

EFFECTIVENESS OF MEASURE

Effective.

NPPOs are accustomed to implementing obligations to report findings thus should be effective, but effectiveness cannot be ascertained. However, noting the restricted distribution, it may be assumed that it could be effective.

EFFORT REQUIRED

This measure would need to be applied indefinitely.

RESOURCES REQUIRED

Efforts for a review of literature would be minimal, requiring only a short desk study by an expert. Efforts for surveillance would be dictated by findings from such a review, but would considered as low cost. This would require site visits to ascertain presence and delimit the area(s) where the species in (i) present and (ii) naturalized.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

No side-effects are envisaged, but a potential positive side effect may result if/as surveys could also identify other alien invasive species.

ACCEPTABILITY TO STAKEHOLDERS

It would be assumed that could be no objections to any proposed surveillance measures.

ADDITIONAL COST INFORMATION

On-site surveys of high risk areas would require less effort than remote sensing plus required surveying (ground-truthing).

LEVEL OF CONFIDENCE[1]

Established but incomplete.

NPPOs could provide additional information, but it is assumed that there is confidence in this information.

1 See Appendix

Measures to achieve rapid eradication after an early detection of a new occurrence.

Manual eradication.

MEASURE DESCRIPTION

Trees reproduce only by seeds, and no natural vegetative propagation has been reported (Pasiecznik *et al.*, 2001). Hand clearance, or mechanical measures such as clearing/ root ploughing using Caterpillar tractors, can be used to fell trees and uproot stumps. It is essential that roots are cut below ground level. Plants cut at or above ground level will otherwise coppice (such as resprout). For larger trees where removal of the root is considered difficult, stumps can be killed either by (i) burning of the stump, or (ii) application of a chemical stump treatment (see *Chemical treatment*). However, it is considered that chemical treatments would not be required in the EU, considering the restrictive size of invasions and restrictive size of plants present. Follow on treatments are also required to ensure that seedlings emerging from any seed bank are also removed.

The only confirmed report of *Prosopis* in mainland Europe is in Almeria (two planted trees only: planted in 1988), south-eastern Spain (Pasiecznik and Peñalvo López, 2016). Elsewhere in the EU, it is reported as naturalized in a very limited area in the Canary Islands, Spain (Verloove, 2013, 2017). Here the species has been known since 2011 as an escape from cultivation in the drier southernmost parts of Gran Canaria. In 2015, it was recorded in several additional localities all in *barrancos* (seasonally dry valleys), and in one of these, the estuary of the barranco del Polvo in Arinaga, it is present in relative abundance and in various stages of development in natural coastal vegetation. Other reports of *P. juliflora* from Cyprus (Bovill, 1915; Frangos, 1923) and Italy in 1913 (Maniero, 2000) are considered invalid.

SCALE OF APPLICATION

This method has been applied to small areas infestations in Australia, Djibouti, India, Kenya and Somaliland, amongst others, often only a few hectares, and not exceeding a few tens of hectares. The measure could be applied in all areas where *P. juliflora* is reported to be present (see above).

EFFECTIVENESS OF MEASURE

Effective.

It has been applied to the small infestations listed above, but follow-up actions are also needed over many years depending on the size of the soil seed bank. Without effective and long term follow up, eradication of small areas has not proved to be effective (for example, Djibouti, India, Kenya).

Due to the very restricted areas of *P. julifora* reported in the EU at present, eradication is considered feasible. However, if it becomes established over large areas (which is not currently the case in the EU), there are no effective measures known to limit unintentional spread (see section above). To be certain that eradication can be undertaken at low cost, further information is required on the exact extent of *P. juliflora* population reported in Gran Canaria, as it is considered small but it could be larger. Additional surveys would be required to confirm these, alongside further literature reviews and surveys to assess the presence of any other populations.

EFFORT REQUIRED

Eradication of the small areas where *P. juliflora* is present is estimated to be possible in only a short period (of days to a week) by a small work team. However, if left to become more significantly established, then more costly measures would need to be implemented, to reduce unintentional spread.

Considering the limited naturalization in the EU, the areas should be monitored annually for at least five years, when a reassessment should be made. If no new seedlings have been reported and removed, monitoring can be reduced to every two years for at least 15 years, and then stop.

RESOURCES REQUIRED

Although very effective, manual clearing operations are labour-intensive and is practical only for small land holdings. If manual clearance is not undertaken immediately when areas are restricted and populations spread, then other methods may be required (see the *Management* section, below).

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

Manual cutting is by far the best method with limited areas/ numbers of plants, being very targeted. If larger scale mechanical methods are used, this would likely also uproot other (non-target) species and is as such less desirable as a control method (and more costly).

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
Having no economic, social or environment value in the EU, there would appear to be no reasons for stakeholders to object to eradication.

ADDITIONAL COST INFORMATION

The cost of inaction would increase significantly in the future as any management programme would have to take place on a larger scale and this would increase the cost of any measures.

As there are very limited occurrences of *P. juliflora* in the EU in the natural environment, implementation costs for Member States would be relatively low.

LEVEL OF CONFIDENCE[1]

Established but incomplete.
Manual eradication is known to be effective over small areas (Pasiecznik *et al.*, 2001), but there are no reports of complete eradication.

1 See Appendix

Measures for the species' management.

National Management plans.

MEASURE DESCRIPTION

As *P. juliflora* currently has only a very restricted distribution, it is proposed that only manual clearance will be necessary. Other sections follow, however, covering mechanical, chemical and biological control, but that will only be required if invasions become widespread, and should be implemented as part of a broader management plan).

Where widespread, countries must prepare and implement eradication and containment/management plans. Management plans, or national strategies usually encompass a series of integrated measures depending upon the objective and costs. The **individual measures include mechanical, chemical and biological control and are discussed separately in the following management sections,** as approaches to manage *Prosopis* populations once it is widely established. The information in the following management sections is adapted from Pasiecznik *et al.*, (2001) and CABI (2018), including those used on closely related *Prosopis* species, as it is considered that they can be applied equally on any species. Total tree kill may be possible with some treatments, but adequate techniques for preventing the re-introduction of seeds and re-establishment of trees have yet to be developed. It is considered that eradication over large areas is not possible using these techniques and, at best, only some form of integrated control is feasible.

Due to the very restricted known current distribution in the EU, as explained in previous sections, it is considered that the only known populations (in Spain – Almeria and Gran Canaria) can be quickly eradicated at low cost, and risks of establishment are considered as low (EPPO, 2018). However, if this is not done in a timely manner, or further naturalizations are identified and found to be widespread, integrated management plans may need to be prepared and implemented, to control populations. These will include manual and mechanical techniques, alongside monitoring and surveillance to include early detection for countries most prone to risk, and ideally public awareness campaigns to prevent spread from existing populations or from botanic gardens in countries at high risk (as discussed above).

SCALE OF APPLICATION

These integrated action plans are usually developed at a national scale. The following is the known list of national strategies, resulting from a global review undertaken in 2013, during the author's involvement in the preparation of a national strategy for Djibouti.

Australia

Australia was the first country to launch a national strategy on *Prosopis* in 2001 with the latest revision in 2012, and to date is the only country known to have such a strategy in place. Each state of Australia also has its own specific management plan for *Prosopis.*

Australian Weeds Committee, 2012. Mesquite (Prosopis spp.) strategic plan 2012–17. Weeds of National Significance, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, Australia. 37pp. www.weeds.org.au/WoNS/mesquite/docs/WEEDS-Mesquite-07-FINAL (18Mar13).pdf

Ascension Island

Significant attempts are known to have been made to control *Prosopis* on Ascension Island, and a management strategy is documented but no more recent information has been forthcoming.

Belton, T, 2008. Management strategy for Mexican thorn (Prosopis juliflora) on Ascension Island: An assessment of this species, and recommendations for management. RSPB, UK, and the Ascension Island Government Conservation Department. 23pp.

Botswana

Recognising that the management and control *of Prosopis* is a transboundary issue, the Kalahari Namib Project, funded by UNEP GEF has supported the Government of Botswana to develop an Integrated National Mesquite (*Prosopis* species) Management (INMM) Strategy based on experiences from participating partners in Namibia and South Africa. Taken from the following release, - www.unccd.int/en/about-the-convention/the-bodies/the-cop/cop11/Pages/Side_Event_RegItemView.aspx?ItemID=56 (Sept 2013).

Eritrea

A draft framework of appropriate measures within a national action plan on *Prosopis* for Eritrea was prepared as part of a PhD thesis [Page 169-179], although no further information was elucidated about whether action has been taken based on this work.

Bokrezion H, 2008. The ecological and socioeconomic role of Prosopis juliflora in Eritrea. An analytical assessment within the context of rural development in the Horn of Africa. PhD Thesis, Johannes Gutenberg University, Mainz, Germany. 227pp.

Ethiopia

A national *Prosopis* management plan was prepared in 2002 resulting from a FAO consultancy mission.

Felker P, 2002. Ethiopia - national plan for Prosopis. FAO, Rome, Italy. 46pp.

However, this was never adopted and by 2008 no clear policy or strategy was in place - "At the national level there is no clear policy or strategy about control and management of Invasive Alien Species in general and *Prosopis* in particular (Anage *et al*., 2004; Fisehaye, 2006)", cited in: *Tegegn GG, 2008. Experiences on Prosopis management. Case of Afar Region. FARM Africa, Addis Ababa, Ethiopia. 35pp. [Page 11, also citing Anage et al., 2004].*

Kenya

Kenya is the only country in Africa where a national *Prosopis* management strategy has been fully developed, where it is awaiting final agreement before being submitted for approval. Contact skchoge@yahoo.com. *KFS/KEFRI , 2011. Sectoral strategy for the management of prosopis species in Kenya, 2011–2015. Kenya Forest Service (KFS) and Kenya Forestry Research Institute (KEFRI), and the Ministry of Forestry and Wildlife Development, Nairobi. 32pp.*

Somalia

"In collaboration with the Ministry of Natural Resources, Somalia, Benadir Regional Assembly (Mogadishu Municipality) and UN-Habitat, CESVI and the Human Relief Foundation, work is currently underway in drafting a national urban strategy for the integrated management of *Prosopis* in urban areas of Somalia. It is anticipated that the national urban strategy will eventually form a component of a national *Prosopis* policy covering all geographical areas of Somalia as well as a range of eco-systems."

Email received by Nick Pasiecznik on 28 November 2013 from: Dr. Andrew Adam-Bradford, Director - Horn of Africa Unit, Human Relief Foundation.

South Africa

South Africa developed 20-year vision as a *de facto* 'management plan', when over 50 stakeholders, representing all spheres of society and government, met in Kimberley in November 2001 to discuss the 'status and long-term management of *Prosopis*'. The resulting declaration was: "In 20 years from now, invasive *prosopis* in Southern Africa will be under control and confined to areas where it can be managed to deliver sustainable benefits". They envisaged, among others, development of new and value-adding utilisation programmes, and integrated agroforestry systems, including switching to benign varieties. Taken from: *Zimmermann H, Pasiecznik NM, 2005. Realistic approaches to the management of Prosopis species in South Africa. Policybrief. HDRA, Coventry, UK. 4pp. www.gardenorganic.org.uk/pdfs/international_programme/SouthAfricaProsopisBrief.pdf.*

In addition, confirmation was received by Nick Pasiecznik (3 December 2013) in an email from Ross Shackleton of Stellenbosch University, South Africa, that he is in the process of producing a strategic plan for *Prosopis* management in South Africa, driven by Dave Richardson and Brian van Wilgen, published in 2017 (Shackleton, 2017).

Sudan

"During the early 1990s a popular opinion in parts of central Sudan and within the Sudanese Government had begun to consider *Prosopis* a noxious weed and a problematic tree species due to its aggressive ability to invade farmlands and pastures, especially in and around irrigated agricultural lands. As a consequence, Prosopis was deemed an invasive alien species, and on 26 February 1995, a presidential decree for its eradication [from everywhere in Sudan] was issued, which was followed by campaigning to execute the eradication." Page 11, in:

Laxén J, 2007. Is prosopis a curse or a blessing? – An ecological-economic analysis of an invasive alien tree species in Sudan. Tropical Forestry Reports 32. VITRI, Helsinki, Finland. 203pp. https://helda.helsinki.fi/bitstream/handle/10138/20611/isprosop.pdf?sequence=2

However, it appears that no national strategy is in place as of 2012, as "the establishment of appropriate management plans of *Prosopis* is keenly demanded", cited in the following paper.

Yoda K, Elbasit MA, Hoshino B, Nawata H, Yasuda H, 2012. Root system development of Prosopis seedlings under different soil moisture conditions. Journal of Arid Land Studies 22(1):13-16.

[See also Standard PM3/67 'Guidelines for the management of invasive alien plants or potentially invasive alien plants which are intended for import or have been intentionally imported' (IPPC, 2010)].

EFFECTIVENESS OF MEASURE

Neutral.

Significant efforts to contain *Prosopis* invasions have been implemented in Australia, but effectiveness has proved limited at best.

EFFORT REQUIRED

See individual sections below for measure specific information.

RESOURCES REQUIRED

No quantitative information is available. However, an initial estimate regarding the development of a national strategy could perhaps be assumed to cost less than €50,000,

Prosopis juliflora *(flowers) can also be roasted or made into a tea. © Forest and Kim Starr. CC BY 3.0.*

and possibly much less for an initial review. See individual sections below for measure specific information.

SIDE EFFECTS

Environmental: Positive

Social: Positive

Economic: Neutral or mixed

See individual sections below for measure specific information.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

There can be no considered reason why any stakeholder would object to the management of known *P. juliflora* trees in the EU.

ADDITIONAL COST INFORMATION

n/a

LEVEL OF CONFIDENCE[1]

Well established.

This information is based on significant previous knowledge of the author and numerous thorough reviews as cited and duplicated as required.

1 See Appendix

Mechanical control.

MEASURE DESCRIPTION

Mechanical site clearance involves tractor operations to remove trees, where roots are severed below ground level to ensure the tree is killed. These operations include root ploughing and chaining, which are often the most effective mechanical means. Root ploughing uses a mouldboard plough pulled behind a Caterpillar tractor, chaining involves pulling a heavy chain between two slow-moving Caterpillar tractors, with the effect of pulling over larger trees and uprooting them.

SCALE OF APPLICATION

On all areas where *P. juliflora* is identified as present.

EFFECTIVENESS OF MEASURE

Neutral.

For root ploughing, large trees must first be felled by hand, but this treatment has been used to remove stumps up to 50 cm in diameter without difficulty and has a treatment life of 20 years or more (Jacoby and Ansley, 1991). The soil should be neither too wet nor too dry for effective root ploughing. However, this method is one of the most expensive control treatments and is recommended only on deep soils that have a high potential for subsequent increased forage production (Jacoby and Ansley, 1991).

For chaining, soil moisture is again important, with soil that is dry on the surface and moist below giving the optimal conditions. If the soil is too dry, the stem breaks leading to coppicing, if too wet, the soil and under storey are damaged (Jacoby and Ansley, 1991). Smaller, unbroken trees have to be removed by other means. Although expensive, this treatment is effective where there are many mature trees. It is most widely used following herbicide application to remove dead standing trees. Clearance with a biomass harvester produces wood chips that can be sold for energy production offsetting the operational costs (for example, Felker, McLauchlan, Conkey and Brown, 1999).

EFFORT REQUIRED

For root ploughing only a single pass is required, and leads to improved soil water conservation, and there is a chance to reseed with improved forage species. For chaining, a second pass in the opposite direction ensures that roots on all sides are severed to ease tree removal (Jacoby and Ansley, 1991).

RESOURCES REQUIRED

Heavy machinery (Caterpillar tractors) and specialist equipment (for example, root ploughs, chain, etc.), labour.

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Negative

This is a costly measure and would also destroy all other vegetation in the treated area.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Environmental concerns may make the implementation of this measure unacceptable, especially due to impacts on non-target species.

ADDITIONAL COST INFORMATION

Not Applicable.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Not Applicable.

1 See Appendix

Biological approach.

MEASURE DESCRIPTION

Prosopis species continue to spread widely in parts of their native ranges where many native insect species (including bruchids, twig girdlers, psyllids and other injurious pests) are common components of the ecology. These regularly attack *Prosopis* but the trees have adapted to infestation by these pests and are still able to become invasive weeds over large tracts of land. But, several biological control programmes using species of seed-feeding bruchid beetles have been developed and implemented. The advantage with bruchids is their observed host specificity, with many species found to feed only on *Prosopis*, and some only on a single species. Other insect species known to have a deleterious effect on native and exotic *Prosopis* in the Americas, mainly twig girdlers and psyllids, have also been suggested as possible biological control agents. The twig girdler *Oncideres limpida* attacks *P. pallida* in Brazil (Lima, 1994), whereas *Oncideres rhodostricta* is seen as a serious pest of *P. glandulosa* in the USA (Polk and Ueckert, 1973). Psyllids are known to severely affect the growth of *Prosopis* (Hodkinson, 1991) and have been suggested for use in controlling invasions.

Most work on biological control of *Prosopis* to date has been carried out in South Africa and Australia, where several programmes are underway. The seed-feeding insects *Mimosetes protractus* and *Neltumius arizonensis* were introduced to eastern South Africa in conjunction with the bruchid beetles *Algarobius prosopis* and *A. bottimeri* for the control of invasive *Prosopis* species. *Neltumius arizonensis* and *A. prosopis* were successful in establishing themselves in large numbers and having a significant effect on *Prosopis* spp., whereas the other species were only found in low numbers (Hoffmann, Impson and Moran, 1993). Maximum damage to seeds occurred where grazing was controlled, as the multiplication and progress is hampered by livestock devouring pods before the insects destroy them. The same two bruchid species were also introduced to Ascension Island in an attempt to control *P. juliflora* which is present on 80% of the island, often in dense thickets. Two other species, one a psyllid and the other a mirid, were identified as attacking *P. juliflora* on Ascension Island and were thought to have been introduced accidentally from the Caribbean. The mirid *Rhinocloa* sp. causes widespread damage and is thought to lead to substantial mortality of trees (Fowler, 1998). In Australia, *Prosopis* infestations are at a relatively early stage and extreme care is being employed in the selection of suitable biological control agents, following the long history of problems caused there by plant and animal introductions. Insect species continue to be tested for their efficacy and host specificity as possible biological control agents of *Prosopis* species in Australia (for example, van Klinken, 1999; van Klinken, Hoffmann, Zimmermann and Roberts, 2009). Besides the two *Algarobius* species, the sap-sucking psyllid *Prosopidosylla flava* and the leaf-tying moth, *Evippe* sp. have both been found to provide some control in Australia. Where identified as an invasive species in dryzone in northern Myanmar (for example, Aung and Koike, 2015), there has been at least an initial focus on biological control agents for this forest invasive species (Than, 2011), with investigation for biological control agents conducted in Pyawbwe in January 2010. Damage was detected in the form of yellowing foliage and damage from pathogens around cuts during fuelwood harvesting, identified as *Fusarium* sp., *Tubercularia* sp. and *Nectria* sp., and small-scale trials have been initiated to examine the potential for these fungal pathogens to aid in biological control of *P. juliflora*.

It should be borne in mind that the release of biological control agents is currently not regulated at EU level. Nevertheless national/regional laws are to be respected. Before any release of an alien species as a biological control agent an appropriate risk assessment should be made.

SCALE OF APPLICATION

Programmes are usually initiated at country level, but it is best practice to engage with neighbouring countries who may also be potentially impacted by any resulting established bio-control agent.

EFFECTIVENESS OF MEASURE

Ineffective.

Biological control of *Prosopis* spp. has been attempted in Australia and South Africa but has not proved effective (for example, Rieks van Klinken, CSIRO, Australia, pers. comm.)

EFFORT REQUIRED

Biocontrol agents require significant time (over many years) to undertake the research, but after release, the aim is to produce self-sustaining populations of the agent that will require no further effort.

RESOURCES REQUIRED

Significant prior research to identify the effects of any proposed biological control agent on non-target species in the affected area, and which is likely to run into, potentially, millions of Euros.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

Biological control has proved very effective in many instances, but there are instances where the agent spreads and causes impacts on native species (for example, on *Opuntia* spp. in Central America).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Introduction of further non-native species is likely to draw the interest and possible concern from the public and environmental lobby groups.

ADDITIONAL COST INFORMATION

Not Applicable.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Not Applicable.

1 See Appendix

Chemical control.

MEASURE DESCRIPTION

Note: This section lists chemicals (PPP) that have been cited for use against the species. This does not mean the chemicals are available or legal to use and countries should check to ensure chemicals are licensed for use in their country. EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

Chemical treatments involve the use of herbicides to kill trees, with the most effective being stem or aerial applications of systemic herbicides. The formulation and application of chemicals for trees of mixed ages and sizes within a stand is difficult. Although 2,4-D provided excellent suppression of top growth, few trees were actually killed and such chemical treatments had to be applied periodically to ensure that forage yields were maintained. Many herbicides and herbicide mixtures have been tested, mostly on *P. glandulosa*. Potential environmental damage from widespread use of herbicides must also be taken into consideration.

Prosopis juliflora *(thorns and seedpods) can be eaten raw, boiled, stored underground, or fermented to make a mildly alcoholic beverage. © Forest and Kim Starr. CC BY 3.0.*

SCALE OF APPLICATION

On all affected areas in the endangered area.

EFFECTIVENESS OF MEASURE

Effective and Ineffective.

Effectiveness is dependent upon chemical uptake, which in *Prosopis* is limited by the thick bark, woody stems and small leaves with a protective waxy outer layer. The most effective chemical in the USA is clopyralid, but dicamba, picloram and triclopyr have also been successfully used, either alone or in combination (Jacoby and Ansley, 1991). In India, ammonium sulfamate was successful in killing *P. juliflora* trees and as a stump treatment (Panchal and Shetty, 1977). Use of chemical alone have proved ineffective in control large areas of prosopis invasions, such as in in the USA on *P. glandulosa* (see Pasiecznik, 2001). However, in restricted areas, chemicals have proved effective, also as cut stump treatments.

EFFORT REQUIRED

The effort required is significant, either as (relatively ineffective) aerial treatments, basal bark applications or treatment of cut stumps. Infested sites often needed spraying every 5-7 years.

RESOURCES REQUIRED

Trained labour, chemicals (which can be costly), application equipment (see below).

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Negative

The use of chemicals must have negative environmental effects from chemical residues, especially from foliar applications, less so for basal bark or cut stump treatments, yet these cannot be discounted. Impacts on human health of the applications may also be possible unless all safety precautions are strictly adhered to.

ACCEPTABILITY TO STAKEHOLDERS

Unacceptable.

There may be objections to the use of chemicals, especially in natural areas or regional parks, and especially where other safer measures (such as manual or mechanical removal) are available and effective.

ADDITIONAL COST INFORMATION

Information from the USA has indicated a high cost of chemical control (for example, Jacoby and Ansley, 1991).

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Further work is required to establish the effectiveness of chemical control.

1 See Appendix

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Appendix

Level of confidence provides an overall assessment of the confidence that can be applied to the information provided for the measure.

- **Well established:** provides an overall assessment of the confidence that can be applied to the information provided for the measure. *Note:* a meta-analysis is a statistical method for combining results from different studies which aims to identify patterns among study results, sources of disagreement among those results, or other relationships thatmay come to light in the context of multiple studies.
- **Established but incomplete:** general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps

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