Parthenium hysterophorus *a single plant produces 15 000 seeds on average and up to 100 000 seeds*
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The management of whitetop weed (*Parthenium hysterophorus*)

Measures and associated costs

Scientific name(s)	*Parthenium* L. *hysterophorus*
Common names (in English)	Whitetop weed
Authors	F. Dane Panetta (The University of Melbourne, Australia)
Reviewer	Asad Shabbir (School of Life and Environmental Sciences, The University of Sydney Australia)
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Common names

BG	Алергизиращ партениум
HR	Partenium
CZ	Sambaba obecná
DA	Slør-partenium
NL	Schijnambrosia
EN	Whitetop weed
ET	Prügi-neitsirohi
FI	Piinahelmikki
FR	Parthénium matricaire
DE	Karottenkraut
EL	–
HU	Keserű hamisüröm
IE	–
IT	–
LV	–
LT	Vėlyvoji gvajulė
MT	–
PL	Partenium ambrozjowate
PT	Coentro-do-mato
RO	–
SK	–
SL	Ameriški ščetinasti vratič
ES	–
SV	Flikpartenium

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

Parthenium hysterophorus L. is an annual plant originating from the Americas. It is a major invasive alien plant in almost all continents and its deleterious impacts on agriculture, environment, human and animal health are extensively documented (see Adkins and Shabbir, 2014; EPPO, 2014). *P. hysterophorus* is only known to occur in the EU from rare records in Belgium (Tsiamis *et al*., 2017) and Poland (Mirek *et al*., 2002), but climate niche modelling indicates that substantial areas in the EU are at risk of invasion—even more so under climate change scenarios (Kriticos *et al*., 2015).

PREVENTION OF UNINTENTIONAL INTRODUCTIONS AND SPREAD

P. hysterophorus could be unintentionally introduced to the EU via multiple pathways, comprising two categories, in which the species would be a contaminant or a hitchhiker, respectively. Arguably, the highest risk pathway for the unintentional introduction and spread of *P. hysterophorus* is as a contaminant of seeds intended for planting, as seeds will be sown under conditions that favour the establishment of both beneficial plant and weed. Since relatively low volumes of seed for sowing are involved, it would be feasible to establish a sampling procedure to ensure that the presence of *P. hysterophorus* does not exceed a critical level. The weed may also be a contaminant of imported grain and/or feed, where the large volumes concerned would make inspection impractical. Here, a certification scheme would be recommended. Routine inspection and cleaning of imported used machinery and equipment would be required to minimise the risks associated with this introduction pathway. As regards the hitchhiker pathways for unintentional introduction, inspection of passengers from outside the EU is considered disproportionate to the risk of introduction (cf. van Valkenburg, 2018) and hitchhiking on fruits, vegetables, timber, soil and packaging material is considered unlikely (Brunel *et al*., 2014).

PREVENTION OF SECONDARY SPREAD

The pathways by which secondary spread of *P. hysterophorus* would occur are similarto those that enable its unintentional introduction. Dispersal of this species is largely human-mediated. Mandated cleaning of vehicles, machinery and equipment (VME) that have been used in agriculture, road works and other situations in which *P. hysterophorus* is known to occur will assist in the prevention of spread. Properly enforced certification schemes should significantly reduce the potential for spread of this species in commodities such as seed for planting, grain, growing media, hay and fodder, and livestock. Another option, requiring a lower investment to ensure compliance, is a legally required vendor declaration concerning the absence or presence of *P. hysterophorus* in any product (including VME). Employed in Australia, 'weed hygiene declarations' enable a receiver of goods to make an informed decision, taking precautions to prevent new infestations when appropriate. Water is the only significant natural dispersal vector for *P. hysterophorus*, highlighting the importance of controlling this weed along watercourses and in floodplains.

MEASURES TO SUPPORT EARLY DETECTION

Early detection of *P. hysterophorus* will rely upon reporting of new occurrences through active monitoring ('structured' or 'active' surveillance) of high-risk sites, such as ports and grain processing facilities, and the involvement of an informed public ('unstructured' or 'passive' surveillance). Early detection measures for *P. hysterophorus* could be included in a general active surveillance program concerning other invasive alien plant species that might be introduced by the same pathways, invade similar habitats and spread along corridors such as roadside verges and disturbed land. Citizen science programs can be used to support passive surveillance. A public campaign designed to create awareness of the hazards posed by *P. hysterophorus*, especially the risk posed to human health, would be very useful in this regard. Critically, owing to its rapid life cycle, 'early detection' of *P. hysterophorus* must occur within a more restricted timeframe than for other IAS having longer juvenile periods.

RAPID ERADICATION OF NEW INTRODUCTIONS

There is little by way of documentation concerning *P. Hysterophorus* eradication. The single documented successful eradication effort targeted a small infestation, with a treated area comprising 0.25 ha. The gross area (such as the area over which the species was distributed) is unknown, but is likely to have been less than 5 ha. Two characteristics of the species reduce its eradication feasibility: 1) a rapid life cycle (seeds can be produced as early as 4 weeks post emergence); and 2) a persistent seed bank, especially if seeds become buried. Eradication feasibility can be expected to decrease markedly with increasing infestation area, highlighting the importance of early detection. Hand pulling is not recommended as a control measure, owing to the risk of acute allergic reactions. Small infested areas should be sprayed with either 2,4-D or a mixture of 2,4-D+ picloram for a degree of residual control. The combination of staggered germination and rapid reproduction in *P. hysterophorus* mean that infested sites will need to be visited relatively frequently to prevent seed production.

MANAGEMENT OF ESTABLISHED POPULATIONS

Because *P. hysterophorus* is a serious weed elsewhere, there is a wealth of information concerning its management.

Controlling *P. hysterophorus* in cropland requires selective herbicide use and/or crop rotations. Herbicides commonly employed include glyphosate, metsulfuron-methyl, 2,4-D and diuron. In the horticultural context, diuron, metribuzin, bromoxynil and glyphosate have been used. Glyphosate resistance has developed in *P. hysterophorus* as a result of regular use in some horticultural situations. In pastures, *P. hysterophorus* is susceptible to several herbicides when these are applied at high volume (such as 2000 l/ha), for example, 2,4-D (4 kg a.i./ha), picloram (0.8 kg a.i./ha) dicamba (1 kg a.i./ha), and diuron (2 kg a.i./ha). Metsulfuron-methyl, 2,4-D amine, 2,4-D + picloram, 2,4-D ester and dicamba are employed to control *P. hysterophorus* in Australian pastures. Because this weed readily invades disturbed areas, controlling grazing pressure is a key component of its management in pastures. Competitive pasture swards will be more easily maintained in high rainfall areas than in those prone to drought, either seasonally or long-term. In other non-crop situations (including commercial and industrial areas, roadsides and rights-of-way), high-volume applications of dicamba or picloram + 2,4-D are generally the most cost-effective alternatives. Other herbicides (or herbicide mixtures) recommended for non-crop situations include metsulfuron-methyl, aminopyralid + metsulfuron-methyl and triclopyr + metsulfuron-methyl. Herbicide selectivity is not particularly important in these non-crop situations, but in natural environments, off-target damage is a major consideration and care must be taken not to affect desirable species. Classical biological control is another option for the management of established populations of *P. hysterophorus*. Multiple agents have been tested and approved for release elsewhere. It is likely that other, currently widely established, species on the IAS list would be targeted for biological control prior to *P. hysterophorus*. Such activity would be expected to “pave the way” for the implementation of biological control against this species. The effective management of established populations could ultimately involve biological control in combination with several other management tools.

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, breeding, growing, and cultivation, as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *P. hysterophorus.*

MEASURE DESCRIPTION

As the species is listed as an invasive alien species of Union concern, the following measures will automatically apply, in accordance with Article 7 of the EU IAS Regulation 1143/2014:

Invasive alien species of Union concern shall not be intentionally:

(a) brought into the territory of the Union, including transit under customs supervision;
(b) kept, including in contained holding;
(c) bred, including in contained holding;
(d) transported to, from or within the Union, except for the transportation of species to facilities in the context of eradication;
(e) placed on the market;
(f) used or exchanged;
(g) permitted to reproduce, grown or cultivated, including in contained holding; or
(h) released into the environment.

Also note that, in accordance with Article 15(1) – As of 2 January 2016, Member States should have in place fully functioning structures to carry out the official controls necessary to prevent the intentional introduction into the Union of invasive alien species of Union concern. Those official controls shall apply to the categories of goods falling within the Combined Nomenclature codes to which a reference is made in the Union list, pursuant to Article 4(5).]

Therefore measures for the prevention of intentional introductions do not need to be discussed further in this technical note.

Inspection of potentially contaminated imported seed for planting.

MEASURE DESCRIPTION

The objective of this measure is to minimise the risk of unintentional introductions of *P. hysterophorus* via contamination of imported seed that is intended for planting. This is arguably the highest risk pathway for the unintentional introduction and spread of *P. hysterophorus*, since seeds will be sown under conditions that favour the establishment of both beneficial plant and weed.

P. hysterophorus was introduced to central Queensland, Australia via contaminated pasture seeds (grass) imported from Texas; to Africa, Asia and Oceania in cereal and grass seed shipments from the USA; to Shandong Province in China via the importation of soybean seeds from the USA; and to areas of Sri Lanka as a contaminant of onion seed from India (see references in EPPO, 2014). Thousands of tonnes of seeds of field crops and vegetable crops are imported annually to EU countries, although much of this trade is within the EU itself (EPPO, 2014).

EPPO has recommended that *P. hysterophorus* be regulated as a quarantine pest in the national phytosanitary regulations of EPPO Member Governments (https://gd.eppo.int/taxon/PTNHY/documents), which would enable the establishment of maximum levels of contamination, as well as inspection regimes to ensure compliance.

SCALE OF APPLICATION

EU wide.

EFFECTIVENESS OF MEASURE

Effective.

In Australia, *P. hysterophorus* was listed as contaminant of pasture seed imported from Texas in 1958 (Everist, 1976). Had the significance of this contamination been appreciated at the time, a serious weed invasion could have been averted. *P. Hysterophorus* was listed as a quarantinable pest in Proclamation 86P of the Australian Quarantine and Inspection Service (Walton and Parnell, 1996), some years after the unintentional introductions of this biotype and another, previously introduced, biotype of *P. hysterophorus* (Navie *et al*., 1996). No evidence exists for further unintentional introduction following regulation of the species.

EFFORT REQUIRED

This measure would need to be put in place permanently, or until *P. hysterophorus* was so widely established that its imposition was no longer justifiable.

RESOURCES REQUIRED

If *P. hysterophorus* were to be appropriately inspected, the resources required should already be in place in all EU Member States to implement Regulation (EU) 2016/2031 (applicable from 14 December 2019) and Directive 2002/32/EC.

SIDE EFFECTS

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

Environmental, social or economic side effects are difficult to postulate.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

There has never been stakeholder opposition to the prohibition and inspections of *P. hysterophorus* in imports to Australia. For the EU, a public awareness campaign concerning the potential impacts of this weed if it became widespread (see *Surveillance to support early detection*, below) would enhance stakeholder support.

ADDITIONAL COST INFORMATION

Preventing the unintentional introduction of a potentially serious weed, such as *P. hysterophorus*, could be the most cost-effective management strategy—depending upon the effectiveness and cost of post-invasion management measures (Epanchin-Niell, 2017). If *P. hysterophorus* were to become established because of inaction, the costs incurred from further attempts to limit its spread and impacts could greatly exceed the costs of implementing preventative measures.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Elsewhere, weeds have been designated as quarantine or prohibited species in seeds for planting, with associated compliance procedures in place (for example Walton and Parnell, 1996; Wilson *et al*., 2016). *P. hysterophorus* has been designated as such in Australia for decades (Walton and Parnell, 1996).

1 See Appendix

Certification of *P. hysterophorus* freedom in grain prior to import.

MEASURE DESCRIPTION

The objective of this measure is to minimise the risk of unintentional introduction of *P. hysterophorus* via contamination of imported grain that is intended for animal and human consumption. The risk of introducing weeds to new areas through grain intended for processing or consumption is considered less than that from seed for planting. However, weed risk varies significantly within the range of end uses for grain and needs to be addressed (Wilson *et al.*, 2016).

Contaminated grain has proved to be an effective pathway for the unintentional introduction of *P. hysterophorus* over large areas of the world (see EPPO, 2014 for documentation supporting the following elaboration). In India, *P. hysterophorus* was most likely introduced through large scale import of infested wheat and other cereals from the USA under a grant to counter food shortage. Through public distribution of these infested cereals, *P. hysterophorus* ultimately spread over 35 million ha of the Indian sub-continent via various spread pathways. It is suspected that *P. hysterophorus* was introduced into Ethiopia through infested grain from the USA, and entered Maputo harbour in Mozambique through grain imports, possibly as food aid. *P. hysterophorus* was accidentally introduced into Israel in 1980, probably through import of infested grains from the USA for use as fish food in ponds.

Thousands of tonnes of wheat, sorghum and maize are imported each year in EU countries (EPPO, 2014).

In the EU, there is no specific regulation on this for *P. hysterophorus*, but there is regulation on the infestation of grain from *Ambrosia* species (Commission Regulation (EU) No 574/2011), which requests that the grain be clean from *Ambrosia* spp. seeds. However, owing to marked differences in seed size between *Ambrosia* spp. and *P. hysterophorus*, this regulation would not prevent the infestation of grain with *P. hysterophorus* (EPPO, 2014). Furthermore, listing of *P. hysterophorus* in Regulation No. 574/2011 would, in principle, address contamination of grain intended for animal feed, but would not address the issue of contaminated grain intended for human consumption.

SCALE OF APPLICATION

EU wide.

EFFECTIVENESS OF MEASURE

Neutral.

The seeds of *P. Hysterophorus* are very small (2-3 mm). While inspection of imported grain is technically feasible, imposition of this measure would not be realistic given the tonnages involved (EPPO, 2014). Tillage and cultivation and the extensive use of herbicide have limited the abundance of *P. hysterophorus* in the USA (Reddy and Bryson, 2005). Although management practices, especially the use of herbicides, limit the prevalence of *P. hysterophorus*, they may not totally remove the species from crops and therefore from the commodity, as indicated by control percentages achieved through the application of different herbicides (Reddy and Bryson, 2005). However, in-crop control is a valuable measure when used in combination with others, for example post-harvest cleaning (EPPO, 2014).

EFFORT REQUIRED

This measure would need to be put in place permanently, or until *P. hysterophorus* was so widely established that its imposition was no longer justifiable.

RESOURCES REQUIRED

Staff would be required for certification activities prior to export. Such activities could include crop inspection and monitoring of post-harvest cleaning.

SIDE EFFECTS

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

Environmental, social or economic side effects are difficult to postulate.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Producers exporting grain would need to consider the costs of compliance relative to the potential value of their commodities in the EU.

ADDITIONAL COST INFORMATION

See additional cost information under *Inspection of potentially contaminated imported seed for planting.*

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Elsewhere, weeds have been designated as quarantine or prohibited species in imported grain, with associated compliance procedures in place (for example Walton and Parnell, 1996; Wilson *et al.*, 2016). *P. hysterophorus* has been designated as such in Australia for decades (Walton and Parnell, 1996).

1 See Appendix

Inspection and cleaning of imported used machinery and equipment.

MEASURE DESCRIPTION

The objective of this measure is to minimise the risk of unintentional introduction of *P. hysterophorus* via contamination of imported used machinery and equipment.

P. hysterophorus can enter new territories as a contaminant, either on machinery (for example seeds lodged on the radiators and grills of automobiles) or as seeds in soil attached to machinery (see EPPO, 2014 for documentation supporting the following elaboration). *P. hysterophorus* is considered to have entered Bangladesh and Pakistan from India, most probably through transport vehicles, and the species is thought to have entered Papua New Guinea through second-hand vehicles imported from Australia. The first reported record of *P. hysterophorus* in Australia was attributed to the movement of aircraft and machinery parts into Australia during the Second World War. Farmers in eastern Ethiopia believe that *P. hysterophorus* has been introduced to their area by army vehicles during the Ethiopian-Somalian war.

Volumes of used machinery that are transported are difficult to estimate (EPPO, 2014). Sale of second-hand harvesters sometimes occurs between EU and other countries, especially via the internet, though this is likely to be infrequent. Vehicles circulate freely within European countries, and circulate as well among other countries, so the volume of vehicles to potentially spread *P. hysterophorus* would be high. The potential involvement of military equipment will be related to future geopolitical developments (EPPO, 2014).

In Norway, when used machinery and equipment intended to be used in agriculture, forestry or horticulture is imported, an official statement must accompany the consignment stating that it has been thoroughly cleaned and, if necessary, disinfected, and that it is free from soil, plant remains and contamination from pests. The country of export's plant inspection service, or an equivalent official agricultural authority, shall issue this certification (Regulations of 1 December 2000 no. 1333 relating to plants and measures against pests) (EPPO, 2014).

Annex IV of Directive 2000/29/EC (repealed by Regulation (EU) 2016/2031, which is applicable from 14 December 2019) has recently been amended by Implementing Directive (EU) 2019/523, now requiring that "Machinery and vehicles which have been operated for agricultural or forestry purposes, imported from third countries other than Switzerland - Without prejudice to the provisions applicable in Annex IV(B)(30), official statement that machinery or vehicles are free from any soil and plant debris". Furthermore, an ISPM Standard, no. 41 (IPPC, 2017), has been drafted and adopted on 'International movement of used vehicles, machinery and equipment'. This focuses on reducing the risks of transporting contaminants (soil, seeds, plant debris, pests) associated with the international movement (either traded or for operational relocation) of vehicles, machinery and equipment (VME) that may have been used in agriculture, forestry, as well as for construction, industrial purposes, mining and waste management, and the military. For those VMEs that represent a contaminant risk, the phytosanitary measures recommended are detailed in the ISPM and cover cleaning, prevention and disposal requirements. These include cleaning using pressure washing or compressed air cleaning, chemical or temperature treatments, storing and handling VMEs that prevent contact with soil, keeping vegetation short around storage areas of ports.

The information in the following sections has largely been taken from a similar note on measures and related costs in relation to *Ambrosia confertiflora* DC. (van Valkenburg, 2018). *A. confertiflora* is closely related to *P. hysterophorus* and both species are likely to be transported through the same pathways for unintentional introduction.

SCALE OF APPLICATION

The measure would need to be applied across the EU, as once VME have been imported into the EU they could be moved to high risk areas.

EFFECTIVENESS OF MEASURE

Neutral.

It is difficult to assess when VMEs present a risk, and therefore when to apply the relevant phytosanitary measures (IPPC, 2017). The ISPM provides a number of elements to consider when assessing risk: distance of movement (shorter distances are a lower risk), complexity of VME structure (more complex are a higher risk), origin and prior use (VME in close proximity to vegetation are a higher risk), storage (VME stored outside near vegetation are a higher risk), intended location or use (VME for use in agriculture, forestry, or close proximity to vegetation are a higher risk). In addition, the inspection, cleaning and treatment will normally take place in the exporting country to meet import requirements, but there are no EU regulations on phytosanitary requirements for imports of VMEs. Therefore, for the measure to be effective, either regulations need to be developed to regulate VME imports, or inspections and phytosanitary measures would need to be applied at EU ports, as well as at EU/non-EU border facilities.

Parthenium hysterophorus *plant flowers 4-8 weeks after germination. © Jean-Marc Dufour-Dror.*

The measure could be highly effective if procedures can be applied to all high risk VME being imported.

EFFORT REQUIRED

This measure would need to be put in place permanently, or until *P. hysterophorus* was so widely established that its imposition was no longer justifiable.

RESOURCES REQUIRED

Facilities required for the inspection, cleaning, and treatment of VME may include: surfaces that prevent contact with soil, including soil traps and wastewater management systems – temperature treatment facilities –, fumigation or chemical treatment facilities (IPPC, 2017). In addition, trained staff are needed to undertake the inspections and impose phytosanitary measures, and suitable disposal facilities are needed, especially if implemented within the EU. As such, the cost of cleaning exported/imported equipment could be substantial.

SIDE EFFECTS

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

There would likely be economic impacts to operators involved in moving VME into the EU, but no social side effects are expected with this measure. Mixed environmental side effects are anticipated. A positive effect could result from the measure removing additional potential IAS. If suitable disposal facilities are not installed, however, there is a risk of environmental impacts, for example through local establishment of *P. hysterophorus*, or to freshwater systems in the local area from cleaning and treatment processes.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Stakeholders may be resistant to implementing such measures, depending on the associated costs and location of cleaning facilities, which might introduce transportation costs. Costs should not be prohibitive, although disposal of wash water may require construction of specialised facilities, so that water can be transported to wastewater treatment facilities or be treated onsite.

ADDITIONAL COST INFORMATION

See additional cost information under I*nspection of potentially contaminated imported seed for planting*.

LEVEL OF CONFIDENCE[1]

Unresolved.

While there are observations on the use of this measure in relation to post-introduction spread prevention, little is known about it in the context of introduction prevention.

1 See Appendix

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

Certification of *P. hysterophorus* contamination status in commodities moving within the EU.

MEASURE DESCRIPTION

In contrast to weeds of natural ecosystems, where spread occurs via essentially uncontrollable natural vectors (for example wind, water and wild animals), *P. hysterophorus* is, for the most part, dispersed via human-mediated vectors (Panetta, 2012; Panetta and Cacho, 2012; Brunel *et al*., 2014). The objective of the proposed certification scheme is to provide information on the contamination status (including freedom) regarding *P. hysterophorus* in a range of potentially contaminated commodities in order to prevent the secondary spread of the species in the EU. Such commodities include seed for planting, grain, growing media/soil, animal manure, hay and fodder, and livestock.

For example, *P. hysterophorus* is considered to spread locally as a contaminant of potting mix/soil associated with the ornamental plant trade in Pakistan (Naveed, 2015). The species has also been reported to enter Kashmir in India from Poona (where it was initially observed) along with some Jasmine rooted cuttings. Movement of plants for planting with adherent soil exists among EPPO countries (EPPO, 2014).

In Queensland, Australia, a "Weed Hygiene Declaration" provides information on whether any product is contaminated or free of *P. hysterophorus*. The receiver can then make an informed decision and take precautions to prevent new infestations. A written notice is required prior to selling, giving or supplying any 'thing' (for example machinery, stock, fodder, soil, water, gravel, grain, and vehicles) that may contain *P. hysterophorus* or several other specified weeds. If a written notice is not given, a penalty of up to AUD30, 000 can apply (Department of Local Government, Planning, Sport and Recreation, 2007).

This scheme would not prevent the movement of *P. hysterophorus* per se, but it would alert the receiver of the potential presence of the weed and allow for its rejection (in the case of seed for planting) or the institution of compensatory measures, such as sequestration of contaminated livestock for a withholding period. Infestations around yards can be easily spotted and controlled, whereas infestations can develop unnoticed in larger areas.

SCALE OF APPLICATION

The scale of application of this measure would depend upon the distances over which commodities would be transported. Land-based human-mediated dispersal can potentially operate over distances up to hundreds of kilometres. In Queensland, Australia, the mandated use of vendor declarations has applied to commodities transported over such distances.

EFFECTIVENESS OF MEASURE

Unknown.

A legal requirement for transported commodities to be free of *P. hysterophorus* would, in principle, reduce the potential for secondary spread, but there would be a need to demonstrate that the benefits of this higher degree of regulation would outweigh the increased requirement for resources to ensure compliance. This would be easiest to do when such an obligation was imposed in conjunction with an eradication effort - less so if *P. hysterophorus* were relatively well established.

It should be noted that *absolute* containment (such as stopping spread) of weeds is very rarely observed—the more common management outcome is *relative* containment, corresponding to a slowing of weed spread (Panetta, 2012; Panetta and Cacho, 2012).

EFFORT REQUIRED

This measure would need to be in place permanently.

RESOURCES REQUIRED

If there were a legal requirement for a weed hygiene declaration, the only resources required would be those for ensuring compliance. These could be minimal if the measure was generally well received. An obligation for transported commodities to be free of *P. hysterophorus* would reduce the potential for secondary spread but would substantially increase the resources required to ensure compliance.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed
Environmental, social or economic side effects are difficult to postulate.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.
The acceptability to stakeholders would be a function of the costs of compliance, which would vary according to the specifics of the measure.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE[1]

Established but incomplete.
Even where a measure such as a "weed hygiene declaration" has been employed, there is no information available on outcomes.

1 See Appendix

Cleaning of vehicles, machinery and equipment (VME) that have been used in agriculture, road works and other situations in which *P. hysterophorus* is known to occur.

MEASURE DESCRIPTION

New infestations of *P. hysterophorus* in New South Wales, Australia have been attributed to the combined movement of contaminated grain harvesters and vehicles/trucks and other machinery. In the Shandong Province, China, harvesters are also reported as a vector of spread. In Pakistan, it is believed that *P. hysterophorus* was spread from Islamabad with the movement of military vehicles (EPPO, 2014).

For imported VMEs that represent a contaminant risk, the phytosanitary measures recommended are detailed in ISPM Standard, no. 41 (IPPC, 2017). Such measures include cleaning using pressure washing or compressed air, both of which would be central to the prevention of secondary spread of *P. hysterophorus* following its introduction. For example, Bajwa *et al.,* (2018) calculated that a typical roadside wash down facility can remove ca. 6,700 *Parthenium* weed seeds per week in Queensland, Australia.

See measure description under *Inspection and cleaning of imported used machinery and equipment* for additional information.

SCALE OF APPLICATION

This measure has been successfully employed at a scale of 100s of kilometres in New South Wales (NSW), Australia, following the legislation of inspection and cleaning standards for grain harvesters entering NSW from central Queensland, where *P. hysterophorus* had become widely established (Blackmore and Johnson, 2010).

EFFECTIVENESS OF MEASURE

Effective.

In Australia, *P. hysterophorus* was first recognised as a serious weed in Queensland in the 1970s (Navie *et al.*, 1996). It was first detected in NSW, bordering Queensland on the south, in 1982. Since its first detection in NSW, it became clear that the incidence of establishment of *P. hysterophorus* was a function of the amount of seeds introduced from Queensland infestations via human activity (Blackmore and Johnson, 2010). Most (> 70%) detections occurred on roadsides or in the vicinity of clean-down facilities, as opposed to private properties (Blackmore and Johnson, 2010). An analysis of the probable source of outbreaks for the 64 new infestations that were detected between 1982 and 2004 indicated that grain harvest machinery was the principal source (nearly 60%) (Blackmore and Johnson, 2010). Other pathways associated with human mediated dispersal (for example hay and silage making machinery, earthmoving machinery, livestock and livestock transports, cars and caravans, hay, grain and seed) had been assessed repeatedly, but had not been considered of sufficiently high risk to be actively regulated (Panetta, 2012).

Attempts to prevent this weed from becoming widely established in NSW were enhanced in 1997 by the inspection and cleaning standards that were legislated for grain harvesters entering NSW from Queensland (Blackmore and Johnson, 2010). A consistently high level of surveillance effort in NSW led to the detection of infestations, generally at a stage when these consisted of a low number of plants (Panetta, 2012). An overall decline in the number of new detections of this species in NSW over time, such as from 26 in 1999 to three in 2010, demonstrates the effectiveness of this containment measure at a large scale (Panetta, 2012).

EFFORT REQUIRED

The measure would need to be in place permanently. Awareness of the importance of weed seed hygiene is likely to vary between different sectors in the EU (see Graham *et al.*, 2016 for Australian data) and should be linked to surveillance measures to support early detection (see *Surveillance measures to support early detection* below).

Cleaning should occur prior to movement of VMEs and care should be taken to ensure that cleaning does not lead to further local spread. Adherence to vehicle hygiene standards would be encouraged through establishment of a requirement for a weed hygiene declaration (see *Certification of* P. hysterophorus *contamination status in commodities moving within the EU* above).

RESOURCES REQUIRED

Wise *et al.,* (2007) estimated the economic costs of the measures for controlling long distance dispersal of *P. Hysterophorus* (including wash-down facilities for vehicles, mandatory inspections and adoptions of codes of practice by agribusiness) in Queensland and New South Wales as ranging from USD4.667, 000 per year to 6.426,000 per year in 2006 dollars. In 2000, grain harvesters in Queensland estimated that a single clean-down of their machinery cost about AUD2, 000, mostly due to the time required (1.5 days) (Agriculture and Resource Management Council of Australia and New Zealand, Australian and New Zealand Environment and Conservation Council and Forestry Ministers, 2001).

SIDE EFFECTS

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

Environmental side effects are in the main neutral but could be negative if *P. hysterophorus* seeds removed during the cleaning process are not contained, potentially leading to local infestation and spread. Approximately 4% of the new infestations detected in New South Wales were in wash down areas (Blackmore and Johnson, 2010). It is difficult to postulate social and economic side effects.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

While the aggregated costs associated with this measure could be large, costs to individual operators would not be excessive and, at least in some cases, could be passed on to clients.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

This measure has been employed in Australia as a means of reducing the spread rate of *P. hysterophorus*. The costs of its implementation and potential degree of acceptance by stakeholders in the EU are unknown.

1 See Appendix

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

Reporting of new occurrences through active and passive surveillance.

MEASURE DESCRIPTION

The objective of this measure is to promote the detection of incursions of *P. hysterophorus* when they are small enough to be eradicable. Early detection of *P. hysterophorus* will depend upon reporting of new occurrences through active monitoring (such as active or structured surveillance) of high-risk sites, plus contributions by an informed public (such as passive or unstructured surveillance). Early detection measures for *P. Hysterophorus* could be included in a general active surveillance program targeting a selected group of invasive alien plant species that might be introduced by the same pathways, invade similar habitats and spread along corridors such as roadside verges and disturbed land (van Valkenburg, 2018).

Additionally, citizen science programs can be used to support unstructured surveillance for *P. hysterophorus*. The identification of new occurrences through citizen science and the general public should be supported by awareness raising activities. Reports from the community about new incursions can lead to significant cost savings when early detection results in shorter management programs (Hester and Cacho, 2017). However, not all community surveillance is equal: some information from the public may arise from chance encounters, other from stakeholders from a particular industry, and other data may be reported by groups of volunteers organised on the basis of citizen science activities (Hester and Cacho, 2017). Involvement with international networks in the reporting of new incursions may also be beneficial. For example, the International Parthenium weed Network (iPaWN) was established in 2009, with the aim of documenting new outbreaks of *P. hysterophorus* and recommending strategies to reduce further spread (https://apwss.org/apwss-ipawn.htm). This network consists of more than 150 members (mostly weed scientists, researchers and extension workers) that represent more than 50 countries (see Shabbir, 2017).

SCALE OF APPLICATION

The scale of application of this measure will be a function of the distribution of unintentional introduction pathway endpoints. Across the EU, such sites would include, for example, ports, transport corridors and grain processing facilities.

Areas subjected to recent disturbances, such as road maintenance or construction sites, are likely to be colonised early, especially if equipment, construction materials, or landscaping materials (for example, soil, mulch, and gravel) are transported from infested areas.

EFFECTIVENESS OF MEASURE

Neutral.

Because *P. hysterophorus* has a distinctive appearance when flowering and occurs in pastures, crops and disturbed sites in readily accessible areas, there is considerable scope for the detection of this weed through both active and passive surveillance (Panetta and Cacho, 2012). However, detection of the largest infestations on private property in New South Wales, Australia (Blackmore and Johnson, 2010) indicate the need for ongoing investment in public awareness programs to support timely detection through passive surveillance (Panetta and Cacho, 2012).

Once people are familiar with the appearance of *P. hysterophorus*, they can quickly locate new populations and the measure can be highly effective. However, owing to its rapid life cycle, early detection of *P. hysterophorus* must occur within a tighter timeframe than for species that have longer juvenile periods. Failure to locate even small populations of only a few individuals can result in large infestations in subsequent years, because of the very high reproduction rate of this weed (Navie *et al.*, 1996).

EFFORT REQUIRED

The effort required would be a function of the effectiveness of the measures employed to prevent the unintentional introduction and spread of *P. hysterophorus*. If its unintentional introduction were a rare event and measures to prevent secondary spread were generally effective, there would be a low requirement for targeted surveillance, as opposed to the general surveillance proposed by van Valkenburg (2018). Given repeated unintentional introductions of *P. hysterophorus* and largely unimpeded secondary spread, surveillance measures would have to be in effect until such time that *P. hysterophorus* had become widely established in the EU.

RESOURCES REQUIRED

If a general surveillance effort were in place, there would be a need for a number of staff and vehicles to implement this measure on the ground. Furthermore, public awareness programs can be expensive. For example, during an eradication program targeting the red imported fire ant in south-eastern Queensland, Australia, AUD1 million was invested in public engagement activities over the five years between 2006 and 2010 (Cacho *et al*., 2012). However, this is likely to exceed what was invested to increase public awareness of *Ambrosia artemisiifolia* in Eastern Europe, where between 10 and 15% of the population developed allergic reactions to this species (Kiss, 2007).

SIDE EFFECTS

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

While the direct effect of effective surveillance against *P. hysterophorus* would be positive across all dimensions, the side effects of the measure would be neutral in the case of the environment and economy. These would be, on the one hand, negative in the case of social effects, because of the possible allergic responses for some individuals involved in surveillance of this species; however, social effects of citizen science programs are positive, as they increase public awareness (and reporting) of other invasive alien species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

To the extent that stakeholders are aware of the benefits that accrue from the proactive management of pest species, there should be little opposition to this measure.

ADDITIONAL COST INFORMATION

While the resources, activities and effort required to encourage different types of community surveillance are known to differ, very little is known of the relationships that determine surveillance effectiveness, and hence the level of investment that would be required to encourage a level of reporting (Hester and Cacho, 2017). The only known attempt to estimate the monetary value of community engagement to enhance passive surveillance is that of Cacho *et al.,* (2012), who estimated the savings in active surveillance that were achieved through reports from the public in the Red Imported Fire Ant eradication program in Queensland, Australia. They estimated that the AUD1million invested in public engagement activities had resulted in AUD60 million saved in active surveillance costs—a return on investment of $60 per $1 invested in community engagement.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

The effectiveness of active surveillance in relation to *P. hysterophorus* has been documented (see Blackmore and Johnson, 2010). Passive surveillance effectiveness has been demonstrated for professionals (see above), but how amenable the species might be to public awareness campaigns is unknown.

1 See Appendix

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

Application of plant protection products (PPP).

MEASURE DESCRIPTION

The objective of this measure is to achieve consistently a very high level of control of *P. hysterophorus* plants, such that seed production is prevented. Hand pulling of individual *P. hysterophorus* plants is not recommended because of the health risk, such as the potential for acute allergic reactions (Navie *et al.*, 1996).

PPP can be applied with hand pump sprayers, backpack sprayers, or CO_2 or gas-powered sprayers mounted on ATVs or trucks. Any PPP should be applied according to manufacturer's instructions and in accordance with EU and national regulations. It is important not to over apply these products and to be as selective with applications as possible. In this document, information on the use of PPP to control *P. hysterophorus* elsewhere in the world is confined to active ingredients whose use is permitted according to Regulation (EC) No. 1107/2009.

In Queensland, Australia, 2,4-D amine, 2,4-D + picloram, 2,4-D ester, metsulfuron-methyl and dicamba are commonly employed to control *P. hysterophorus*. Small infested areas should be sprayed with either 2,4-D or a mixture of 2,4-D + picloram for a degree of residual control.

EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

SCALE OF APPLICATION

Data on successful eradication efforts targeting *P. hysterophorus* are scant. The one documented successful effort involved a net area (area to which treatment was applied) of only 0.25 ha (Table S1 in Panetta and Cacho, 2014). The gross area (roughly the area over which the species was distributed) is unknown but is likely to have been less than 5 ha. Eradication feasibility can be expected to decrease markedly with increasing infestation area, highlighting the importance of early detection.

EFFECTIVENESS OF MEASURE

Neutral.

As for many weeds, eradication is possible only if infestations are detected when very limited in extent (Panetta, 2015). However, *P. hysterophorus* has two features that increase the difficulty of its eradication. Firstly, it is an annual species that is capable of producing seeds rapidly (its pre-reproductive period can be as short as 4 weeks post emergence). Only when detected relatively early post emergence can seed production be prevented. If plants are not detected and controlled in a timely manner, they will add seeds to the soil seed bank. Secondly, seeds that achieve burial may persist for years (Navie *et al.*, 1998; Tamado *et al.*, 2002) — Navie *et al.,* (1998) reported a half-life of 6 years for *P. Hysterophorus* seeds buried at 5 cm. Panetta (2015) identified eight weed eradication syndromes, based upon time to maturity, seed bank persistence and dispersal characteristics. According to this scheme, *P. hysterophorus*is a member of the syndrome characterised by the lowest eradication feasibility.

Attempts at eradicating *P. hysterophorus* in Australia have been generally unsuccessful, although very small infestations are believed to have been eradicated in New South Wales and the Northern Territory (Blackmore and Johnson, 2010; Wingrave, 2010) and in parts of India (Ramachandra Prasad *et al.*, 2010; Sushilkumar and Varshney, 2010). Eradication would only be possible given timely detection of isolated and small (< 5 ha) infestations, where sustained resourcing could be anticipated.

EFFORT REQUIRED

Control measures will need to be employed in a manner that prevents seed production in an infestation for enough years to ensure exhaustion of the *P. Hysterophorus* seed bank. The size of the seed bank will depend, among other factors, upon the degree of seed burial (Navie *et al.*, 1998) and the time for which the infestation has existed undetected. In the absence of reproductive escape (Panetta, 2007), the minimum period over which control effort is required is likely 5 years. A combination of staggered germination and rapid reproduction means that infested sites will need to be visited frequently to prevent seed production (Panetta, 2007). Should plants produce seeds at any time, a longer period of control could be needed. The duration of control will need to be determined on a case-by-case basis, depending on observed patterns of *P. hysterophorus* seedling emergence.

RESOURCES REQUIRED

A primary determinant of a weed eradication program's cost is its duration. This, in turn, will depend upon how effective control efforts are in preventing reproduction. For a given infestation, several staff, spray equipment and herbicide will be required. An additional cost will be associated with travel to and from the site.

SIDE EFFECTS

Environmental: Neutral or mixed

Social: Neutral or mixed

Economic: Negative

Owing to its biological and ecological characteristics, *P. hysterophorus* is a species that is particularly difficult to eradicate. Eradication should be attempted only against very small infestations—at this scale of operation, the environmental side effects would be minimal. There may be small health costs arising from allergenic effects on workers. However, by controlling *P. hysterophorus*, the potential for the general population to develop acute allergic reactions to this weed is reduced. If the infestation occurs on an agricultural property and measures need to be imposed to prevent spread from the property, this could have a negative economic effect.

Parthenium hysterophorus *grows in a wide range of habitats, including degraded and disturbed lands, banks of streams and rivers. © Jean-Marc Dufour-Dror.*

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Stakeholder acceptability will depend upon the habitats in which *P. hysterophorus* is detected. The greatest challenge to acceptability may occur when the weed occurs on private property. There may be a need to gain permission to enter and conduct control measures. Furthermore, farmers may require compensation if an eradication program interferes with their ability to market their products.

ADDITIONAL COST INFORMATION

Eradication is generally a very cost-effective management strategy, if successful (Simberloff, 2003). However, eradication success against *P. hysterophorus* will likely be constrained to very small infestations (< 5 ha). If infestations of a suitable size are the only ones targeted, and eradication programs are well resourced and managed, the cost-effectiveness of this measure could be high.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

The biological and ecological characteristics of *P. hysterophorus*, and their relationships to eradication feasibility (Panetta, 2015), are well understood. Eradication attempts targeting large infestations have not been successful.

1 See Appendix

Application of plant protection products (PPP) in crops and fallows.

MEASURE DESCRIPTION

P. hysterophorus has been recorded as occurring in many dryland crops, and in both annual and perennial irrigated crops (EPPO, 2014).

The objective of this measure is to reduce the abundance and biomass of *P. hysterophorus*, so that its impact on crop production or crop quality is at an acceptable level. PPP can be applied with hand pump sprayers, backpack sprayers, or CO_2 or gas-powered sprayers mounted on ATVs (all-terrain vehicles) or trucks. Any PPP should be applied according to manufacturer's instructions and in accordance with EU and national regulations. It is important to not over apply products and to be as selective with applications as possible.

EU/national/local legislation on the use of plant protection products and biocides needs to be respected

SCALE OF APPLICATION

This measure would need to be applied at the scale of the crop concerned.

EFFECTIVENESS OF MEASURE

Effective.

Crops. Controlling *P. hysterophorus* in cropland requires selective herbicide use, cultivation and/or crop rotations (DEEDI, 2011). A range of herbicides has been used to control *P. hysterophorus*. In Queensland, metsulfuron-methyl is commonly employed at stages of the cropping cycle (DEEDI, 2011) and glyphosate is often used for fallow weed control. 2,4-D has been used to control *P. hysterophorus* in sorghum and maize (Dutta *et al.*, 1976) and diuron has successfully controlled *P. hysterophorus* in lucerne (*Medicago sativa*) (Zanbrana and Corona, 1973). Campbell *et al.,* (2019) recently reviewed the information available on chemical and cultural control of parthenium weed.

Crop rotation may be an important component of *P. hysterophorus* management (Department of Agriculture and Fisheries, 2016), for example by including a cereal crop as a basis for obtaining the selectivity afforded by herbicides that are effective against broad-leaved weeds. Rotation of winter and summer crops will also help to break the weed cycle; for example, introducing a cool season crop in temperate regions may disfavour the germination and growth of *P. hysterophorus*.

Fallows. In Australia, glyphosate and metsulfuron-methyl are employed in fallow situations (DEEDI, 2011).Also employed are dicamba (Department of Agriculture and Fisheries, 2016) and 2,4-D + picloram (Navie *et al.*, 1996).

Horticulture. Since *P. hysterophorus* is a major weed in horticultural crops (EPPO, 2014), the most chemical options are available for this land use. Examples include diuron in orchards (Gupta and Sharma, 1977; Crane *et al.*, 2006), metribuzin in potato and tomato, and diuron in grapes and pineapple (Gupta and Sharma, 1977). Bromoxynil has given good control of *P. hysterophorus* in onions, if applied when the weed is young (Menges and Tamez, 1981). Low rates of glyphosate have controlled *P. hysterophorus* in coffee (Njoroge, 1989). However, glyphosate resistance has developed in *P. hysterophorus* in horticultural situations as a result of regular use of this herbicide (Crane *et al.*, 2006; Vila-Aiub *et al.*, 2008). The need to manage herbicide resistant populations could increase costs of control for the species.

EFFORT REQUIRED

The measure would be applied seasonally, as required.

RESOURCES REQUIRED

The resources required for *P. hysterophorus* control in crop would include a single operator, appropriate equipment and machinery, including personal protective equipment (PPE) and herbicide. In some circumstances, general broad-leaved weed control operations, including cultivation, would control *P. hysterophorus* as well as other weeds, so that its presence in a crop would not impose additional costs.The level of control required to prevent agricultural product contamination (see *Prevention of secondary spread*, above) would be considerably higher than that needed to reduce production losses (Yokomizo *et al.*, 2009), imposing higher control costs specific to *P. hysterophorus*.

In 2012, cropping industries in central Queensland incurred costs of AUD6 million per annum from additional herbicides and cultivation in order to control *P. hysterophorus* (Australian Weeds Committee, 2012).

There may be additional costs if research is required to adapt control methods employed elsewhere to EU conditions. Whether the measure becomes part of standard crop management practice will depend upon its cost-effectiveness.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

In some circumstances, control operations for *P. hysterophorus* would control other noxious weeds. Furthermore, by controlling *P. hysterophorus*, the potential for the general population to develop acute allergic reactions to this weed is reduced.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

As for most agricultural practices, this measure would be adopted only if an economic benefit is anticipated. The stakeholders most immediately affected (such as crop producers) will make decisions that they perceive to be favourable to their business. If *P. hysterophorus* is controlled sufficiently by current cropping practices, there will be essentially no decision to make. If contamination of crop products by *P. hysterophorus* becomes an issue, producers will do what they need to in order to be able to market their product. The public perception of this measure should not be different to that for any other in-crop weed management matter.

ADDITIONAL COST INFORMATION

The cost of inaction should be inversely related to the degree to which uncontrolled *P. hysterophorus* reduces product quantity and quality. The socioeconomic aspects are likely to be minimal.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Research related to the application of PPP to *P. hysterophorus* is extensive. However, whether and the extent to which, this weed will impose additional costs in cropping situations is unknown.

1 See Appendix

Application of plant protection products (PPP) in pastures.

MEASURE DESCRIPTION

As mentioned before, PPP can be applied with hand pump sprayers, backpack sprayers, or CO_2 or gas-powered sprayers mounted on ATVs or trucks. Any PPP should be applied according to manufacturer's instructions and in accordance with EU and national regulations. It is important not to over apply the products and to be as selective with applications as possible.

The two main objectives of this measure are: 1) to reduce the impact of *P. hysterophorus* upon pasture and animal production and 2) to reduce the potential for contamination of plant and animal products. Where *P. hysterophorus* infestations attain high densities and biomass, substantial production losses result from reduced carrying capacity and live weight gains (Chippendale and Panetta, 1994). *P. hysterophorus* is reported to reduce the species diversity in pasture communities (Nguyen *et al.*, 2017). *P. hysterophorus* is toxic to animals and is usually avoided by stock, but at high weed densities cattle may consume sufficient quantities to suffer adverse effects (Navie *et al.*, 1996). Fisher (1996) (cited in Sushilkumar and Varshney, 2010) indicated that *P. hysterophorus* was found to cause clinical signs in animals, such as salivation, onset of diarrhoea, anorexia, pruritus, alopecia and dermatitis on the face, muzzle, neck, eyes, thorax, abdomen and brisket region in calves. Stock animals, especially horses, suffer from allergic skin reactions while grazing infested paddocks (Dhileepan, 2009). Sheep appear to be more resistant to this species' toxic effects, but consumption may result in tainted meat; tainting of cow's milk has also been reported (Tudor *et al.*, 1982; Navie *et al.*, 1996).

Control of *P. hysterophorus* in pastures is also important for reducing its spread potential. The spread of *P. hysterophorus* is largely human-mediated, but water is the most important natural dispersal vector for this species (Panetta, 2012; Panetta and Cacho, 2012). An additional objective of this measure would be to reduce spread of *P. hysterophorus* by reducing its seed production, especially in sites that are prone to flooding, such as stream banks and floodplains.

SCALE OF APPLICATION

The scale of application would need to take into account the spatial distribution of *P. hysterophorus*. In Queensland, *P. hysterophorus* has been controlled by PPP in native pastures over hundreds of hectares following widespread invasion (Holman, 1981). If *P. hysterophorus* is managed proactively (see below), spot spraying during the earliest stages of invasion would markedly reduce the scale of application.

EFFECTIVENESS OF MEASURE

Effective.

Trials in Australia have shown that *P. hysterophorus* is susceptible to a number of herbicides when these are applied at high volume (such as 2000 l/ha) (Navie *et al.*, 1996). The plant can be killed by 2,4-D (4 kg a.i./ha), picloram (0.8 kg a.i./ha) dicamba (1 kg a.i./ha), and diuron (2 kg a.i./ha) (Haseler, 1976). Often 2,4-D amine, 2,4-D + picloram, 2,4-D ester, metsulfuron-methyl and dicamba are employed to control *P. hysterophorus* in pastures (DEEDI, 2011). Dicamba is used to control the weed selectively in grass pastures. The presence of picloram in the 2,4-D + piclorammixture will provide residual control (New South Wales Department of Primary Industries, 2008). Research in Pakistan has demonstrated the effectiveness of metribuzin and glyphosate in managing *P. hysterophorus* in degraded pasture, with all herbicides tested being more effective against rosette plants than those that had bolted (Khan *et al.*, 2012). Dense infestations will often require herbicide treatment in conjunction with pasture management (see *Grazing management* section below) to attain effective long-term control (Department of Agriculture and Fisheries, 2016).

EFFORT REQUIRED

If a proactive approach (Panetta and Gooden, 2017) is taken for the management of *P. hysterophorus* in pastures, the weed could be maintained at a density and biomass below which it would cause significant production losses. This would involve periodic spot spraying, using herbicide products and rates of application that are unlikely to cause damage to beneficial species. It will be more difficult to control dense *P. hysterophorus* infestations, in which case careful grazing management may be also required (see *Grazing management in pastures*, below). Because *P. hysterophorus* will not be extirpated, this measure would have to be applied indefinitely. In some situations, the predicted economic returns may be so low that herbicide application would not be warranted.

RESOURCES REQUIRED

The resources required for *P. hysterophorus* control in pasture would include a single operator, appropriate equipment and machinery (including Personal Protective Equipment - PPE) and herbicide.

SIDE EFFECTS

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

Regarding environmental effects, the amount of damage to non-targeted pasture species caused by this measure will depend upon the level of *P. hysterophorus* infestation, the choice of herbicide and the method of its application.

Allergic responses in humans increase with the degree of exposure to *P. hysterophorus*. McFadyen (1995) reported that in Australia, after 1-10 years of exposure to *P. hysterophorus*, some 10-20% of the human population will develop severe allergic reactions to this weed. In Queensland, 73% of persons sampled presented a positive allergy risk to *P. hysterophorus* (Goldsworthy and Austin, 2009). The sample in the latter study included people from rural towns, as well as farmers and graziers. By controlling *P. hysterophorus*, the potential for the general population to develop acute allergic reactions to this weed is reduced. With the use of appropriate PPP, the risk to operator health should be minimal.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

This measure should be acceptable by all stakeholders, as it would decrease the potential adverse effects caused to both livestock and humans.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Research related to the application of PPP to *P. hysterophorus* is extensive, but productivity gains from the use of PPP have not been documented.

1 See Appendix

Application of plant protection products (PPP) in non-agricultural areas.

MEASURE DESCRIPTION

The objective of this measure is to reduce the social and environmental costs resulting from the presence of *P. hysterophorus*. The social impacts of this species in the EU are likely to far outweigh its environmental impacts. *P. hysterophorus* has incurred significant social costs from its effects upon human health where it has become prevalent (EPPO, 2014). Humans who have continued exposure to *P. hysterophorus* can develop allergic eczematous contact dermatitis (Navie *et al.*, 1996). The pollen of the plant is also allergenic, causing rhinitis (EPPO, 2014). Cross-sensitivity with other plants, particularly other members of the Asteraceae, may occur, causing patients to react to plants to which they previously had not been sensitive (Rodriguez *et al.*, 1977). Since *Ambrosia artemisiifolia* is already a major allergenic problem in the EU, cross-sensitivity with *P. hysterophorus* could amplify the effects on human health.

P. hysterophorus is an opportunistic invader that responds positively to disturbance (see above under "Grazing management" section). In urban settings, it would be most prevalent in disturbed habitats, such as along roadworks, in construction sites and vacant lots. In natural environments, the nature of the impact of *P. hysterophorus* on species diversity may vary, since its invasion has been associated with both decreases and increases in the abundance of native plant species (EPPO, 2014). Its abundance is highly correlated with levels of disturbance and its potential impact on native species populations has been rated as low to medium (EPPO, 2014).

SCALE OF APPLICATION

The measure would be applied at the scale of *P. hysterophorus* infestations. If a proactive approach to management were taken to managing *P. hysterophorus* in natural ecosystems, small areas (less than several hectares) would need to be treated. Roadside infestations could be linear and patchy, extending over kilometres. Vacant lots and building sites would generally be less than a few hectares.

EFFECTIVENESS OF MEASURE

Effective.

In non-agricultural situations, including commercial and industrial areas, roadsides and rights-of-way, high-volume applications of dicamba or picloram + 2,4-D are probably the most cost-effective alternatives (Parsons and Cuthbertson, 1992). Other herbicides (or herbicide mixtures) recommended for non-crop situations include metsulfuron-methyl, aminopyralid + metsulfuron-methyl and triclopyr + metsulfuron-methyl (Department of Agriculture and Fisheries, 2016). In these non-crop situations, herbicide selectivity is not particularly important.

In natural environments, however, off-target damage is a major consideration (Panetta *et al.*, 2019) and care must be taken not to affect desirable species.

A degree of selectivity may be obtained, for instance by using herbicides that are specific to broad-leaved weeds (for example dicamba, MCPA and fluroxypur) in a grass-dominated habitat, or by using herbicide rates that are effective against *P. hysterophorus* but not overly damaging to surrounding species. This would need to be determined on a case-by-case basis.

EFFORT REQUIRED

This measure would have to be applied seasonally.

RESOURCES REQUIRED

In Queensland, the cost of herbicide per hectare (such as not including cost of labour and machinery) for roadside control of *P. hysterophorus* with metsulfuron-methyl (4.2 g a.i) in 2005 was AUD2.28 (Brooks, 2005). Labour and equipment costs would be additional.

SIDE EFFECTS

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

In conservation areas, the selection of herbicide, rate of application and application method can minimise damage to non-targeted species, which has to be carefully taken into consideration (Panetta *et al.*, 2019). There may be small health costs arising from allergenic effects on workers who apply this measure, but the potential for the general population to develop acute allergic reactions to this weed is reduced. No economic side effects of this measure can be anticipated.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

One of the most detrimental effects of *P. hysterophorus* is its impact on human health, observed both in India and Australia (Sharma and Sethuraman, 2007). A case would need to be made that control of *P. hysterophorus* would have significant public health benefits (this would be an essential part of a public awareness program—see *Surveillance methods to support early detection*, above), but stakeholder acceptance could be anticipated.

In natural environments, the use of herbicides is considered less favourably than mechanical control by conservation practitioners (Olszańska *et al*., 2016), but the potential human health effects associated with hand-pulling of *P. hysterophorus* should mitigate against that bias.

ADDITIONAL COST INFORMATION

In India, Sushilkumar and Varshney (2010) reported that more than USD18.4 million were spent annually for the treatment of medical problems arising from exposure to *P. hysterophorus.* It is likely that the impacts on human health in the absence of control of *P. hysterophorus* in the EU would not be as great, since the population here would be relatively less exposed—for example, manual control of the species is commonly practised in India. On the other hand, however, the prevalence of *Ambrosia artemisiifolia* in the EU could exacerbate the negative impacts through the effects of cross-sensitivity.

LEVEL OF CONFIDENCE[1]

Well established.

Research related to the application of PPP to *P. hysterophorus* is extensive. Impacts of this weed on human health are also very well documented.

1 See Appendix

Grazing management in pastures.

MEASURE DESCRIPTION

The objective of this measure is to manage grazing pressure in pastures, in order to suppress the numbers and biomass of *P. hysterophorus* individuals through competition from desirable pasture plants.

P. hysterophorus is rarely a problem in pastures that are healthy and in good condition (Chamberlain and Willcocks, 1996; cited in O'Donnell and Adkins, 2005). In a glasshouse experiment, O'Donnell and Adkins (2005) found that grasses were generally stronger competitors against *P. hysterophorus* than were pasture legume species. Similar results were found under simulated grazing conditions in the field (Khan, 2011; Khan *et al*., 2014), but testing under natural grazing conditions has not been undertaken (Dhileepan *et al*., 2019). As there is a negative relationship between invasion by *P. hysterophorus* and pasture vigour (Navie *et al*., 1996), management of grazing pressure is an important component of the management of this weed. High grazing pressure increases both the likelihood of invasion by *P. hysterophorus* and the severity of existing infestations. Stocking rates must be carefully adjusted according to season and rainfall in order to maintain the dominance of pasture grasses (Navie *et al*., 1996).

SCALE OF APPLICATION

This measure would be applied at the scale appropriate for pastures in the EU. Native pastures in Australia are generally considerably larger than those in the EU.

EFFECTIVENESS OF MEASURE

Neutral.

Grazing management seems to be generally effective in controlling *P. hysterophorus* and the weed would be more readily managed in pastures in higher rainfall areas. The measure has been shown to be less effective as a tool to control *P. hysterophorus* in the semi-arid rangelands (<500 mm annual rainfall) of Australia, as vegetation tends to be relatively sparse and prone to weed invasion when rainfall is above average or following flood events (Australian Weeds Committee, 2012). This suggests that grazing management may be less effective in controlling *P. hysterophorus* in drier areas of the EU.

EFFORT REQUIRED

No effort should be required beyond that to sustain good pasture management practice, for example adjusting stocking rates to the amount of herbage on offer. This could be achieved by either rotational grazing practice or destocking.

RESOURCES REQUIRED

The fencing required to support rotational grazing may already be in place in higher rainfall regions of the EU, where grazing management would be effective in controlling *P. hysterophorus*. Mustering costs will be incurred from moving stock between different pastures or for moving them to transport to the market.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

The practice of adjusting grazing pressure to the amount of available herbage is ecologically sound and, besides reducing the invasion and impacts of *P. hysterophorus*, would promote productivity of beneficial plant species. Maintaining *P. hysterophorus* at low abundance and biomass would also have positive effects on farmworker and animal health. Mixed economic effects would arise from potential short-term losses of animal production, likely to be compensated by higher productivity over the long term.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

This measure could be more difficult to impose in lower rainfall environments, where *P. hysterophorus* would likely be more invasive and have a greater impact on both pasture and animal productivity. Whether farm managers in these areas would be willing to alter (or would need to alter) their current practices owing to the presences of *P. hysterophorus* is unknown.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Information on the field performance of *P. hysterophorus* in relation to grazing management is largely observational. Field trials related to the competitiveness of other pasture species under actual (as opposed to simulated) grazing are needed.

1 See Appendix

Biological control.

MEASURE DESCRIPTION

The objective of this measure is to reduce the impacts of *P. hysterophorus* through the establishment of classical biological control agents that have been subjected to host-specificity testing and approved for release.

The most extensive use of classical biological control against *P. hysterophorus* has occurred in Australia, where 11 agents (nine insects and two fungi) were released and subsequently established. Less advanced programs are underway in India, South Africa and a few other countries (Dhileepan *et al.*, 2019).

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

This measure would need to be applied EU wide, in areas that are suitable for *P. hysterophorus* (see Kriticos *et al.*, 2015). This measure has been used successfully across thousands of km^2 in Queensland, Australia (Dhileepan *et al.*, 2019).

EFFECTIVENESS OF MEASURE

Effective.

The implementation of biological control is most advanced in Australia, therefore its effectiveness there is described herein. *P. hysterophorus* is primarily a weed of grazing areas, so biological control efforts have focused on grazing areas. In Queensland rangelands, biological control has had a significant negative impact on this weed and its soil seed banks (Dhileepan *et al.*, 2019). The economic benefit of this measure is expected to be higher if classical biological control is combined with effective grazing management (Shabbir *et al.*, 2013); see above, under *Grazing management*.

EFFORT REQUIRED

Once biological control agents are established, they are likely to persist indefinitely. Their impact on *P. hysterophorus* over time would largely be a function of their population dynamics.

RESOURCES REQUIRED

Access to funding has been one of the three major impediments to the implementation of biological control in Europe (Sheppard *et al.*, 2006). There will be a need to support facilities that are currently available for agent rearing and additional host specificity testing, plus staff to undertake these activities. The highest cost-benefit ratios will be delivered by projects with agents that have been subjected to biocontrol studies and host range testing elsewhere (Shaw *et al.*, 2011), which is clearly the case for *P. hysterophorus* (Dhileepan *et al.*, 2019).

Considerable cost-sharing between countries impacted by *P. hysterophorus* could be anticipated. "In Europe, at present, weed biological control is very much a concern at the national level and there is a lack of coordination when it comes to any regional work. Research is currently carried out by teams on behalf of their host nations in some countries that have the necessary quarantine facilities and experience to do the work safely, such as the UK, Portugal, Ireland, Switzerland, and France and, to some extent, Italy and Greece. A sensible next step would be for work to commence on [the species of European concern in the EU Regulation on Invasive Species] with the affected countries sharing the costs and conducting the research in collaboration with experienced research groups that have established quarantine facilities" (p. 342 in Shaw *et al.*, 2018).

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Positive

In order to be approved for release, classical biological control agents must undergo rigorous host specificity testing (must be demonstrated to be highly host specific), plus basic biological studies. As such, any agents that are released, establish and prove effective against *P. hysterophorus*, are likely to have indirect positive effects on associated species. In some situations, implementation of biological control will lessen the need for chemical control. Major cost savings in human health, as well as substantial increases in plant production, have been achieved as a direct result of biological control in Queensland, Australia (see *Additional cost information* section below).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

The biggest current challenge to classical weed biological control is ensuring that it is given due consideration by decision makers who are inherently risk averse, or unaware, of the technique. It is anticipated that, over time, biological control will gain the confidence of regulators and politicians in Europe, as well as their advisors in the ecology and conservation communities (Shaw *et al.*, 2018). There are several widespread weeds on the IAS list that would probably be prioritised over *P. hysterophorus* for biological control research and implementation. Should

No natural enemies of P. hysterophorus *are known to occur within the EPPO region. © Jean-Marc Dufour-Dror.*

P. hysterophorus be considered as a target in the EU, it is likely that any opposition to this technique would by then be minor.

ADDITIONAL COST INFORMATION

In 1995, the benefit from increased grass production due to biological control of this weed was estimated to be AUSD1.25/ha/year in Central Queensland and AUD1.19/ha/year in North Queensland (Adamson and Bray, 1999). Biological control of *P. hysterophorus* was estimated to save AUD8 million annually in health costs for the treatment of allergic dermatitis and asthma in workers in parthenium weed-infested areas, giving an overall benefit/cost ratio for the biological control program of 7.2 and a net present value (in 2005) of AUD33.3 million for a total cost of AUD11 million (Page and Lacey, 2006). Because additional agents have established since, an evaluation based on the current state of agent establishment and abundance would likely show a higher economic benefit to the Queensland beef industry.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

The countries in which biological control agents targeting *P. hysterophorus* have established are relatively few. Further studies are needed concerning the effectiveness of these agents where they are well-established.

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:** comprehensive meta-analysis or other synthesis or multiple independent studies that agree. *Note:* 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 that may 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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