Cortaderia jubata *is a perennial grass with long leaves arising from a tufted base, known as a tussock. © Krzysztof Ziarnek, Kenraiz. CC BY 4.0.*

The management of purple pampas grass (*Cortaderia jubata*)

Measures and associated costs

Scientific name(s)	*Cortaderia jubata* (Lemoine ex Carrière) Stapf Bot. Mag. 124: t. 7607. 1898
Common names (in English)	Purple pampas grass
Other designation	Other sources indicate this species as *Cortaderia selloana* subsp. *jubata* (Lemoine) Testoni & Villamil
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Common names

BG	–
HR	Andska pampas trava
CZ	Kortaderie
DA	Lilla pampasgræs
NL	Hoog pampagras
EN	Purple pampas grass
ET	Andi pamparohi
FI	Rusopampaheinä
FR	Herbe de la pampa pourpre
DE	Pampasgras
EL	Γρασίδι της Πάμπας
HU	–
IE	Féar pampas corcra
IT	Cortaderia a fiori rosa
LV	–
LT	Karčiuotoji kortaderija
MT	Il-ħaxix tal-pampa r-roża
PL	–
PT	–
RO	Iarbă de Pampas
SK	Kortadéria hrivnatá
SL	Andska pampaška trava
ES	Hierba de pampa púrpura
SV	Andinskt pampasgräs

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

Purple pampas grass, *Cortaderia jubata* (Lemoine ex Carrière) (Poaceae), is a perennial grass species native to Argentina, Chile, Bolivia, Ecuador, Peru and Colombia (Testoni and Villamil, 2014). It can grow up to 4 m in height and has large, serrated leaves and a tall, fluffy inflorescence (sometimes referred to as a plume) (Clayton, Vorontsova, Harman and Williamson, 2006 onwards). This species is currently not known to occur in the EU, but was trialled as an ornamental in the late 1800s in France, Ireland, and Switzerland (Carrière, 1878; Hooker, 1898) and more recently at two nurseries in the UK (Royal Horticultural Society, 2009). In the regions where this species has become invasive (Australia; New Zealand; South Africa; USA: California, Hawaii, Oregon), this species invades a wide range of habitats, but is most common in disturbed environments such as roadsides, disturbed vegetation, forestry plantations and recently burnt vegetation (Edgar and Connor, 2000; Parsons and Cuthbertson, 2004; Robinson, 1984; Starr, Starr and Loope, 2003).

Purple pampas grass outcompetes native plants in areas in which it invades, and can form monotypic stands (CABI, 2018; Daehler, 2006; Lambrinos, 2000; Queensland Government, 2018; Peterson and Russo, 1988). These invasions can cause reductions in the abundance and diversity of arthropods and rodents (Lambrinos, 2000). When purple pampas grass invades plantations, forestry operations are hampered and become much more expensive (Gadgil, Knowles and Zabkiewicz, 1984).

A common problem across all of the measures proposed in this note is that purple pampas grass and the closely related *C. selloana* are morphologically extremely similar (Testoni and Linder, 2017) and are easily confused with one another (Lambrinos, 2000; Robinson, 1984). Even taxonomic descriptions of these species are very variable (for example Edgar and Connor, 2000; Robinson, 1984; Testoni and Linder, 2017), probably because the two species represent a species complex: *C. selloana* is octoploid (2n=72) and *C. jubata* is duodecaploid (2n=108), and *C. selloana* is gynodioecious (the species has female and hermaphroditic plants) while *C. jubata* is apomictic (flowers do not require fertilisation to form seeds). These two aspects of the ecology of these two species suggest that *C. jubata* is derived from *C. selloana* (Testoni and Linder, 2017). Indeed, Testoni and Linder (2017) assign *C. jubata* to subspecies status of *C. selloana.* However, these species appear to be genetically distinct and are easily distinguished using genetic barcoding (Houliston and Goeke, 2017). *C. selloana* is already common across much of the EU (DAISIE European Invasive Alien Species Gateway, 2008) and it is possible that populations of *jubata* grass have been misidentified as *C. selloana*. This uncertainty makes it difficult to determine whether purple pampas grass has already established within the EU using taxonomic characters alone. Both species also have similar impacts (DiTomaso, 2010). If both species are listed as IAS of Union concern, many of the measures proposed here could be applied to both species and, to some degree, without much concern for the accurate identification of the species.

Prevention: The most appropriate measure for preventing entry of purple pampas grass into a Member State is a *Ban on keeping, importing, selling, breeding and growing* of this species. Seeds are the most likely life stage to be introduced and should be banned, but live plants also have the potential to be introduced for horticultural purposes and also should be banned. *Phytosanitary measures* are likely to be ineffective for preventing entry via the principal pathways through which this species could be moved.

Early detection: A *Survey of known introduction sites and a sample of* C. selloana *populations* will help a great deal for determining whether purple pampas grass is already present in the EU. This measure is particularly important though as a surveillance measure and to support *Early detection.* Surveys are recommended for the four known introduction sites in France, Switzerland and the UK, and a number of *C. selloana* populations in the EU, with a search radius of at least 50 km due to the possibility of seed dispersal (New Zealand Plant Conservation Network, 2018). A reassessment of the identity of any *Cortaderia* plants within the survey area will be required.

The use of *Citizen-science and resource managers' data* is another important surveillance measure for *Early detection*. This is a low-cost option for early detection because these types of IT infrastructure and monitoring programmes already exist. Purple pampas grass is easy to detect because of its distinctive appearance, but data collected through these networks will need to be carefully inspected for the correct species identification.

Rapid eradication and management: Measures for *Rapid eradication for new introductions* and *Management* of widespread invasions are the same for purple pampas grass, with physical control more feasible for smaller invasions and younger plants, and chemical control more cost-effective and practical for larger invasions and difficult to reach plants (DiTomaso *et al.*, 2010; Gosling, Shaw and Beadel, 2000; Popay, Timmins and McCluggage, 2003), but often a combination of both methods has been used in eradication and management programmes (Gosling *et al.*, 2000; Penniman, Buchanan and Loope, 2011).

The effectiveness of these measures is largely dependent on locating and destroying purple pampas grass plants before they flower, because this species' seeds are able to disperse such large distances. However, the short viability of these seeds in the soil seedbank makes eradication and management easier if reproductive plants can be controlled. *Biological control* is currently not an option, with very little research having been done on control agents. *Grazing* has only been suggested as an effective control method in New Zealand (Gadgil *et al*., 1984; Gosling *et al*., 2000) and Australia (NSW Government, 2018), but is probably limited in its effectiveness because of the difficulties of managing grazing (Gadgil *et al*., 1984; Gosling *et al*., 2000), and because *C. jubata* still successfully invades even under high grazing pressure (Lambrinos, 2006). *Oversowing* of pasture species, especially nitrogen-fixing plants, in timber plantations has also only been suggested as an effective control method in New Zealand, and only in combination with grazing (Gadgil *et al*., 1984; Gosling *et al*., 2000).

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 keeping, importing (pre-border measure), selling, breeding and growing as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *C. jubata.*

MEASURE DESCRIPTION

The principal pathway for intentional introductions of this species is via horticulture and horticultural plantings (CABI, 2018), although this species has also been (rarely) used as a forage plant (see references below). This measure therefore will seek to prevent the introduction and spread of *C. jubata* via these pathways.

Although there is no evidence that *C. jubata* is promoted as an ornamental plant within the EU, this species has been historically planted as an ornamental in the late 1800s in France, Ireland, and Switzerland (Carrière, 1878; Hooker, 1898) and more recently was trialled as an ornamental at two nurseries in the UK (Royal Horticultural Society, 2009). In Australia (Queensland Government, 2017), California (Costas Lippmann, 1977; Peterson and Russo, 1988), Hawaii (Starr *et al.*, 2003), New Zealand (Houliston and Goeke, 2017) and South Africa (Robinson, 1984) this species is currently, or was recently, planted as an ornamental.

Seeds of this species can also be purchased from online suppliers from outside of the EU (for example, from https://www.amazon.com/PAMPAS-GRASS-Cortaderia-jubata-seeds/dp/B00480KMME). The large inflorescences of this species (and more so of *C. selloana*) were historically used for decorative purposes, principally in California (Costas Lippmann, 1977), and it seems that the inflorescences of at least *C. selloana* are available for floral bouquets (https://www.etsy.com/uk/market/pampas_grass), although the use of *C. jubata* for these purposes cannot be excluded.

C. jubata has been planted as a forage plant in California (Peterson and Russo, 1988) and New Zealand (Gadgil *et al.*, 1984). There is no evidence that the species is promoted as a forage plant within the EU.

This measure would need to be applied across the EU, but with a focus on areas at high risk of invasion (for details see EPPO, 2018).

EFFECTIVENESS OF MEASURE

Ineffective.

No specific information is available on the effectiveness of preventing intentional introductions through banning the keeping, importing, selling, breeding and growing of *C. jubata*. In addition, there is little evidence to suggest the species is currently found in the ornamental trade, though this could change in the future. However, there is good scientific support for producing positive net economic benefits from banning the import and introduction of potentially invasive ornamental plant species (for example, Keller, Lodge and Finnoff, 2007).

It is however possible that *C. jubata* is already established in the EU. *C. selloana* (commonly found in trade within the EU; DAISIE European Invasive Alien Species Gateway, 2008) and *C. jubata* can be easily confused and therefore one species may be misidentified for another, even by experts (Lambrinos, 2001; Robinson, 1984). Moreover, *C. jubata* is recorded from historical and recent horticultural trials within the EU (Hooker, 1898; Royal Horticultural Society, 2009). Therefore, **this measure is likely only to be effective if the same measures are applied for *C. selloana***, and even then this measure could possibly only be effective in limiting future introductions and subsequent re-invasion of *C. jubata* within the EU.

This measure would require high administrative efforts to ensure compliance and would need to be applied indefinitely due to the risk of introductions from elsewhere in the world. This measure would require a large budget to finance many well-trained staff to monitor and ensure compliance (Kettunen *et al.*, 2014).

SIDE EFFECTS

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

Although this species has been planted as an ornamental in places such as Australia, California, Hawaii, New Zealand

and South Africa (but only trialled as an ornamental within the EU), it is currently not widely sold as a horticultural species anywhere in the world, with *C. selloana* seeming to be the favoured species in this regard (Starr *et al.*, 2003). Therefore, this measure is unlikely to have a negative economic side effect on the horticultural industry if only *C. jubata* (and not *C. selloana*) were to be banned.

There will be no positive or negative environmental or social side effects to this measure.

ACCEPTABILITY TO STAKEHOLDERS

It seems unlikely that this measure will be unacceptable to the horticultural industry or to the public. The only potentially significant use of *C. jubata* is for horticultural purposes, and even for this purpose this species seems to have little popularity. In recent trials conducted in the UK, *C. jubata* was grown at two nurseries, but neither nursery selected this species for further commercialisation (the species is not listed as available on their websites: http://www.dinglenurseryandgarden.co.uk, http://www.knollgardens.co.uk; the species was not given an Award of Garden Merit; Royal Horticultural Society, 2009).

However, due to the difficulty of distinguishing between *C. jubata* and *C. selloana*, this measure is only likely to be effective if both species are banned. Due to the popularity of *C. selloana* as an ornamental species, a ban of this species is likely not to be acceptable to the horticultural industry.

ADDITIONAL COST INFORMATION

Implementation costs for Member States will be dependent on the cost of enforcing such a ban, but figures are not readily available in the public domain (Kettunen *et al.*, 2014), which suggests that costs for this type of measure will be relatively high.

The **cost of inaction** of preventing intentional introductions of this species can be estimated based on costs of controlling invasions in other regions around the world. In California, the most cost-effective control method is glyphosate application (see *Management* section for details) which costs USD 2,800 (ca. EUR 2,441) per hectare (DiTomaso, Drewitz and Kyser, 2008), and in New Zealand aerial application of herbicide can cost NZD 3,885 (ca. USD 2,500 / EUR 2,219) per hectare (Popay *et al.*, 2003).

Another approach to estimating the **costs of inaction** of implementing this measure can be derived from estimates based on management and control of *C. selloana*, which is already widespread and invasive in the EU. In Spain, *C. selloana* was found to be the 6th most widespread invasive species and had the 13th highest amount of money spent on its control in the last decade (EUR 8,600 in 8 of Spain's 17 autonomous communities; this estimate is likely to be a gross underestimate of the true amount spent on this species' management (Andreu, Vila and Hulme, 2009).

It is unknown whether this measure would be **cost-effective**. It has been suggested that because of the high costs of implementation and the high administrative burden, bans such as those suggested by this measure are highly unlikely to be cost-effective (Kettunen *et al.*, 2014). However, theoretical models suggest that there are major net positive economic benefits to preventing the entry of invasive species (Keller *et al.*, 2007). There are, however, no known cost-benefit studies specific to *C. jubata*.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is a large body of literature (not specific to *C. jubata*) that supports a ban on keeping, importing, selling, breeding and growing an alien species that is found in trade. However, there is no information specific to *C. jubata* to support this measure, either in the EU or in third countries.

1 See Appendix

Public awareness raising campaigns to reduce unintentional movement of seeds of the species.

MEASURE DESCRIPTION

Phytosanitary inspections, in particular related to the movement of garden waste, animals and soil, including soil on vehicles and machinery.

A number of aspects of the biology of *C. jubata* are likely to influence the specific details of phytosanitary inspections for this species (see *Surveillance measures to support early detection* for further details on this species' biology). This species usually flowers from mid-summer to early autumn (CABI, 2018; DiTomaso *et al*., 2010; Edgar and Connor, 2000; Robinson, 1984). Much of the invasive potential of pampas grass arises from its ability to produce thousands to millions of wind-dispersed seeds per year (up to 338,000 germinable seeds per year; Drewitz and DiTomaso, 2004), but most seeds only disperse within a small radius of the parent plants (Saura-Mas and Lloret, 2005) and are viable for only up to four months under winter (wet) field conditions (Drewitz and DiTomaso, 2004). While seeds are the primary mode of dispersal, this species is also able to resprout or re-establish from the upper rootstock (Drewitz and DiTomaso, 2004).

C. jubata has the potential to be introduced as a contaminant of garden waste, animals and soil, including soil on vehicles and machinery (CABI, 2018; University of Queensland, 2018). However, there are no quantitative measures of the extent and probability of such introductions occurring. Moreover, *C. jubata* may not even occur within the region (unless there are populations that have been misidentified as *C. selloana*; see *Summary* for details). Therefore, the likelihood of this species being unintentionally introduced via the movement of garden waste, animals and soil, including soil on vehicles and machinery within the EU is very low. Unintentional introductions of *C. jubata* with the importation of these materials/objects from areas outside of the EU where this species already occurs (see *Summary* for details) is possible, but has a low probability given that there are no documented cases of introductions into new countries via these pathways, this species has very short-lived seed viability, and previous introductions of this species into new countries were seemingly intentional (for horticulture).

It is only recently that 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 and forestry, as well as for construction, industrial, mining waste management, and military purposes.

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, and keeping vegetation short around storage areas or ports.

Phytosanitary inspections of these different materials/objects would vary and need to be developed or aligned with current phytosanitary measures.

SCALE OF APPLICATION

This measure would need to be applied across the EU, but with a focus on movement of these materials/objects from areas of known introductions of *C. jubata*, both within and outside of the EU.

No phytosanitary measures currently exist for this species, or for the similar *C. selloana* in the EU.

EFFECTIVENESS OF MEASURE

Ineffective.

Identification of *C. jubata* seeds and root material is impossible without genetic barcoding, or when found together with the large inflorescences. Distinguishing between *C. jubata* and *C. selloana* is, therefore, difficult and, as such, this measure would require the banning of both species to have any measure of effectiveness.

It is difficult to assess whether VMEs present a risk, and therefore when to apply the relevant phytosanitary measure (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 is a higher risk), origin and prior use (VMEs in close proximity to vegetation are a higher risk), storage (VMEs stored outside, near vegetation are a higher risk), and intended location or use (VMEs 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. However, 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 and also at EU/non-EU border facilities.

EFFORT REQUIRED

This measure would have to be applied indefinitely due to the possibility of viable rootstock being imported, and because this species has a long flowering period (summer to autumn) that together with its occurrence in both Northern and Southern Hemispheres means there would be an all-year-round possibility of viable seed being introduced.

RESOURCES REQUIRED

Phytosanitary inspections require trained staff and identification material for accurate identification of *C. jubata*. Visual identification would require inflorescences to be present (Testoni and Linder, 2017), but other plant material could potentially be identified by barcoding (it is genetically distinguishable from *C. selloana*; Houliston and Goeke, 2017).

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, and fumigation or chemical treatment facilities (IPPC, 2017). In addition, trained staff are needed to undertake the inspections and phytosanitary measures, and suitable disposal facilities are required, especially if implemented within the EU.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Positive
Inspections would have an economic cost to those undertaking it, which may include both government and the private sector. There would also be economic costs associated with cleaning/treating infected materials, and with any delays in the transport of high risk materials due to inspections.

There will be no positive or negative environmental or social side effects to this measure, apart from the cases where cleaning and treatment of high risk VMEs would address additional invasive alien species.

ACCEPTABILITY TO STAKEHOLDERS

Due to the measure being ineffective, it is likely this measure would be seen as unacceptable, especially by those sectors involved in the transport of high-risk materials.

ADDITIONAL COST INFORMATION

Implementation costs for Member States will be high because of the need for trained staff and long-term implementation of this measure, but figures are not readily available in the public domain.

For **costs of inaction**, see above section, *Prevention of intentional introductions and spread*.

This measure is unlikely to be **cost-effective** because of the high costs of implementation, but there are no studies specific to *C. jubata* to support this.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Inconclusive.
There is limited evidence to support or reject the use of phytosanitary measures to prevent unintentional introductions of *C. jubata*. This is largely because of uncertainty as to whether the species is already present in the EU, whether seed or rootstock is actually transported in these materials/objects, and whether it would be cost-effective to implement such a measure.

1 See Appendix

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

Removal and destruction of any and all *C. jubata* plants in gardens and ornamental trials.

MEASURE DESCRIPTION

C. jubata spreads naturally primarily by wind dispersal of its seeds as these are small and light and have long fine hairs that assist with long distance dispersal (Bellgard *et al.*, 2010). Ornamental plantings of the related *C. selloana* have been found to be the primary sources of invasions in California (Okada, Ahmad and Jasieniuk, 2007). Dispersal distances as great as 50 km have been reported (New Zealand Plant Conservation Network, 2018). Inflorescences of this species can bear over 100,000 seeds (Drewitz and DiTomaso, 2004), making this species extremely fertile. However, on the positive side from a management perspective, seeds generally are viable for only a short time (up to four months under winter (wet) field conditions; Drewitz and DiTomaso, 2004).

Seeds may also be transported by water or on animals (Queensland Government, 2018).

The stems of Cortaderia jubata *are generally twice as long or more as the tussock. © Forest and Kim Starr. CC BY 3.0.*

The removal and destruction of all plants of this species in gardens and ornamental trials will prevent the secondary spread of this species, particularly via wind dispersal. This can only be achieved through preventing their intentional introduction (see *Prevention of intentional introductions and spread* section), and rapid eradication of established populations (see *Rapid eradication for new introductions* section).

SCALE OF APPLICATION

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

EFFECTIVENESS OF MEASURE

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

EFFORT REQUIRED

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

RESOURCES REQUIRED

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

SIDE EFFECTS

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

ACCEPTABILITY TO STAKEHOLDERS

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

ADDITIONAL COST INFORMATION

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

LEVEL OF CONFIDENCE[1]

See *Prevention of intentional introductions and spread*, and *Rapid eradication for new introductions* sections.

1 See Appendix

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

By surveying of the sites.

MEASURE DESCRIPTION

Survey of known introduction sites and a sample of *C. selloana* populations.

C. jubata has only been recorded as being introduced into a very limited number of sites in the EU, including very early introductions in the late 1800s at Belgrove, Cork (Ireland. However, these plants were killed by frost; Hooker, 1898), Zurich Botanical Gardens (Switzerland), Nancy (France) (Carrière, 1878), and later in the UK at Dingle Nurseries and Garden and Knoll Gardens (Royal Horticultural Society, 2009).

C. jubata is easily confused with the closely related *C. selloana* (Lambrinos, 2001; Robinson, 1984), which is already common across much of the EU (DAISIE European Invasive Alien Species Gateway, 2008). Many of the measures proposed in this note are dependent on knowing whether *C. jubata* is already present in the EU. Therefore the objective of this measure would be to determine if *C. jubata* has escaped cultivation and whether perhaps it has been mistaken for *C. selloana* in areas currently thought to only have *C. selloana* and not *C. jubata.*

The following factors would need to be taken into consideration for designing a survey for the early detection of *C. jubata*:

- Seed dispersal of this species has been recorded up to a maximum of 50 km (New Zealand Plant Conservation Network, 2018), although it is likely that seeds of this species, like those of *C. selloana*, mostly only disperse up to within 40 m of the parent plant (Saura-Mas and Lloret, 2005).
- *C. jubata* invades a wide variety of habitats. It is particularly known for invading disturbed/ruderal areas such as roadsides, logged forests/plantations and recently burnt vegetation (Edgar and Connor, 2000; Parsons and Cuthbertson, 2004; Robinson, 1984; Starr *et al.*, 2003).

Therefore, it is advisable that a minimum of a 50 km search radius around the survey sites be included in any surveys (with particular attention being paid to disturbed areas), but extensive field surveys probably only need be close (within a few hundred metres) to where the plants were grown. The U.S. Fish and Wildlife Service provides useful guidelines on survey design (https://www.fws.gov/invasives/staffTrainingModule/assessing/inventory.html).

In Maui (Hawaii), aerial surveys have been suggested as an effective method of detecting flowering mature plants in difficult to reach locations (Starr *et al.*, 2003), and this could be considered for conducting the broader survey (paying attention to the flowering time of this species). Alternatively, satellite remote sensing imagery has been successfully used to detect large *C. jubata* plants in California (Underwood, Ustin and DiPietro, 2003); although this may not be as useful for early detection, as detected plants would probably already have been reproducing for a number of years before their detection. Moreover, the difficulty in distinguishing between *C. jubata* and *C. selloana* might make this impractical.

The nurseries in the UK at which this species were recently grown may have kept the plants in greenhouses. This would have limited the chances of wind dispersal of this species and it would therefore only be necessary to enquire whether plants were disposed of in a manner that would prevent their spread via rootstock. If spread via rootstock was possible, locations at which plant material was disposed of would need to be inspected, but if not, then no further surveys will be required.

SCALE OF APPLICATION

This measure would need to be applied at the four known introduction sites of this species, within a search radius of at least 50 km of these locations. In addition, a sample of *C. selloana* populations across the EU should similarly be surveyed. Published surveillance strategies are available and would require a more in-depth analysis to design an optimal surveillance strategy (Epanchin-Niell *et al.*, 2012; Hauser and McCarthy, 2009).

EFFECTIVENESS OF MEASURE

Neutral.

C. jubata has a very distinctive growth form and is also a large plant, both of which make it an easy to detect species. In Maui, roadside and aerial surveys have been successfully used for early detection of both *C. jubata* and *C. selloana* (Penniman *et al.*, 2011; Starr *et al.*, 2003).

However, the difficulty in distinguishing between *C. jubata* and *C. selloana* reduces the effectiveness of this measure. Surveyors will be required to be very familiar with the morphological differences between these two species, or be able to use DNA barcoding, in order to ensure this measure is effective.

EFFORT REQUIRED

The only figures available on the search effort for this species come from Maui where 9884.45 ha were surveyed over a period of 3,063 hours in 2012, with 3,910 plants being detected and controlled (HISC Established Pests Working Group, 2013). However, one cannot calculate survey effort from these figures because the total time includes survey and control efforts.

Surveys would need to be conducted during the flowering period of *C. jubata* (such as, mid-summer to autumn) to ensure accurate identification and easy detectability of the species. Based on the phenology of *C. jubata* and *C. selloana* elsewhere in the world, particularly in California, *C. jubata* could be distinguished from *C. selloana* if flowers are already present in July. However, later in summer (August onwards) there is likely to be overlap in the flowering period of these two species (DiTomaso *et al.*, 2010).

RESOURCES REQUIRED

Surveying of these sites will require trained professionals with knowledge of the identification of *C. jubata* and *C. selloana*. For the identification of *C. jubata* and *C. selloana*, easy-to-use identification guides (for example, Cal-IPC, 2018; DiTomaso *et al.*, 2010; Testoni and Linder, 2017), or DNA barcoding (Houliston and Goeke, 2017) will be required. Surveyors will need access to vehicles to explore the survey area. If aerial surveys are to be conducted, the use of a helicopter or UAV (drone) will be needed. There are no published guidelines for the number of surveyors needed to effectively detect *C. jubata* plants within any given area.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Negative
Economic: Positive

There could be negative social (incl. safety) side effects for surveyors if surveying needs to be conducted in difficult to reach locations (for example, cliff faces).

Surveys could provide positive side effects through the creation of employment opportunities.

ACCEPTABILITY TO STAKEHOLDERS

Surveys will almost certainly need to be conducted on privately owned land, and this may not be acceptable to the relevant landowners. Moreover, there may be resistance on the part of any landowners found to possess this species to have it removed. On Catalina Island in California, landowners appear more willing to have a species removed if a native species is offered in replacement (Parish, 2017).

ADDITIONAL COST INFORMATION

Implementation costs for such a survey are not readily available in the scientific literature. The budget for early detection roadside surveys of all invasive species in Hawaii was estimated at USD 100,000 per year per county (such as USD 500,000 for all counties; Hawaii Department of Transportation, 2011). Given a total road length of ~15,500 km in Hawaii (U.S. Department of Transportation Federal Highway Administration, 2013), this equates to ~USD 32.30 (ca. EUR 28.2) per km surveyed.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes from gardens or field trials.

To determine the **cost-effectiveness** of surveying for *C. jubata* around the known introduction sites, one would need to conduct a formal analysis using knowledge of this species, for example, its detectability, probability of occurring in the landscape, potential benefits of detection and eradication, population establishment and growth rates, and costs of surveying and management (Epanchin-Niell *et al.*, 2012; Hauser and McCarthy, 2009). However, based on general findings from studies of survey cost-benefits, it seems likely that given the high detectability of *C. jubata* and the high potential costs of invasions, surveys would be cost-effective.

Socio-economic aspects include the potential loss of revenue to the two nurseries that have been growing *C. jubata*, but this seems minor given that neither nursery selected this species for further commercialisation.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is a substantial amount of evidence to suggest that *C. jubata* was only trialled at a limited number of locations in the EU. However, there is always the potential that there are more localities that are not reported in the scientific or grey literature and that *C. jubata* has been introduced under the false assumption that it is *C. selloana*.

1 See Appendix

Early detection monitoring by citizen-scientists.

MEASURE DESCRIPTION

Use citizen-science and resource managers' data for early detection.

The objectives of this measure would be (1) to promote *C. jubata* as a target for identification to invasive species citizen-science platforms, and (2) to provide citizen-scientists and resource managers with the knowledge to identify this species and thereby support its early detection.

Citizen-science locality data has been shown to be very useful for the early detection of invasive species (Gallo and Waitt, 2011; Maistrello *et al.*, 2016). Numerous such databases currently exist, including EASIN (https://easin.jrc.ec.europa.eu/), which is the official EU platform for reporting alien species occurrences and the accompanying smartphone application. However, *C. jubata* does not currently feature in EASIN. There are also a number of other European and national IAS awareness and citizen-science IAS monitoring programmes into which *C. jubata* could be incorporated, which are important resources for environmental agencies, resource managers and decision makers (Genovesi *et al.*, 2010).

SCALE OF APPLICATION

This measure would need to be applied across the EU, but countries/regions with high climatic suitability should be particularly prioritised (see EPPO, 2018 for details).

EFFECTIVENESS OF MEASURE

Ineffective.

While the effectiveness of citizen-science programmes as an early detection measure for this specific species is unknown, citizen-science locality data has been shown to increase the likelihood of success of arthropod eradication programmes, and the authors suggest that awareness campaigns were pivotal in this regard (Tobin *et al.*, 2014). However, as the species can be easily confused with the widespread *C. selloana*, the effectiveness of citizen-science programmes as an early detection measure that would lead to eradication success is unlikely to be high. Moreover, citizen-scientists may lose interest in trying to detect *C. jubata* if they continually misidentify *C. selloana* and *C. jubata* is indeed not present in the EU.

EFFORT REQUIRED

Citizen-science programmes need good quality assessment of the data collected, well designed and standardised methods of data collection, an explicit goal or hypothesis (such as, in this case, the early detection of *C. jubata*), feedback to participants on their contributions as a reward for their participation (Silvertown, 2009). One area that would require significant effort would be the peer review of data to ensure that any *C. jubata* records are not *C. selloana*.

RESOURCES REQUIRED

This measure will require a well-designed and supported citizen-science platform and ideally smart phone application. The use of EASIN and established national systems for this purpose is possible, but the promotion of recording *C. jubata* will be required.

Accurate identification of *C. jubata* will need to be supported through easy-to-use identification guides (for example, Cal-IPC, 2018; DiTomaso *et al.*, 2010; Testoni and Linder, 2017), as *C. jubata* is easily confused with the closely related *C. selloana* (Lambrinos, 2001; Robinson, 1984), which is already common across much of the EU (DAISIE European Invasive Alien Species Gateway, 2008). New records of *C. jubata* identified by citizen-scientists and invasive species managers will need to be verified by taxonomists or DNA barcoding, due to the difficulty of distinguishing *C. jubata* and *C. selloana*.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

A positive environmental side effect might be the detection of new *C. selloana* localities.

A positive social side effect might be increased awareness of the problem of invasive alien species and European environmental legislation.

ACCEPTABILITY TO STAKEHOLDERS

The public is likely to perceive a citizen-science measure favourably. Participants in citizen-science programmes report having an increased appreciation of the natural world, and greater scientific knowledge, among other benefits (Toomey and Domroese, 2013). However, it has been noted that participation in citizen-science programmes is often limited to wealthier segments of society (Toomey and Domroese, 2013). Resource managers would probably welcome information on (potentially) invasive species.

ADDITIONAL COST INFORMATION

Implementation costs of setting up and running citizen-science databases and awareness raising programmes are large (Genovesi *et al.*, 2010), but databases and programmes like these are already running and funded by the EU (for example, EASIN) and individual Member States.

Therefore, additional costs for promoting the collection of *C. jubata* records, and raising awareness of this species, are likely to be minimal.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

Cost-effectiveness of citizen-science programmes is well established and justified elsewhere (for example, Gallo *et al*., 2011; Genovesi *et al*., 2010; Maistrello *et al*., 2016; Tulloch *et al*., 2013).

There are no known additional **socio-economic aspects** to consider.

LEVEL OF CONFIDENCE[1]

Well established.

There is considerable evidence to support the use of citizen-science for early detection of invasive species (see Measure description).

1 See Appendix

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

Physical control.

MEASURE DESCRIPTION

There are no recommended measures for rapid eradication of new introductions specific to *C. jubata*, or to *Cortaderia* species in general. Moreover, given that this species is thought not to have established within the EU, these measures will largely be the same as for *Management* (section below).

Physical control

Small seedlings can be pulled by hand, but larger plants will require digging up by spade, axe, hoe, having a chain tied around them and pulled out by a vehicle, or even dug up with the use of a digger (DiTomaso *et al*., 2010; Gosling *et al*., 2000).

SCALE OF APPLICATION

There are no specific recommendations for the largest scale at which physical control is possible. However, numerous authors note that physical control is only practical and economical for small invasions of a few plants (DiTomaso *et al*., 2010; Gosling *et al*., 2000; Schmalzer and Hinkle, 1987). This suggests physical control is suitable for rapid eradication for new introductions.

On Moloka'i in Hawaii, *C. jubata* was successfully eradicated from an 11 ha area over a period of seven years of control and monitoring (Penniman *et al*., 2011), probably using only physical control as there were only six plants.

EFFECTIVENESS OF MEASURE

Effective.

Physical control is an extremely effective method of controlling *C. jubata*, with a 98-100% success rate (DiTomaso *et al*., 2008), although it can disturb surrounding vegetation and encourage the re-establishment of *C. jubata* seedlings (Gosling *et al*., 2000). Other considerations to improve the effectiveness of the measure include removing all the inflorescences and destroying these to prevent seed dispersal, and pulling up the majority of roots to prevent resprouting from rootstock (DiTomaso *et al*., 2010).

This measure can only be effective if *C. jubata* can be accurately distinguished from individuals of *C. selloana*. However, physical control of both species would ensure the effectiveness of this measure.

EFFORT REQUIRED

It is not known exactly how long physical control would need to be implemented to ensure a successful eradication. Managers generally declare a species eradicated after five years of no detections, although there are more quantitative methods of determining the optimal amount of time to continue searching for a species before declaring a successful eradication (for example, Regan *et al*., 2006). *C. jubata* has a short-lived seed bank under natural conditions (Drewitz and DiTomaso, 2004), and therefore eradication is possible within a time period as short as a year as long as all reproducing individuals of *C. jubata* are located and removed. However, an eradication programme in Hawaii was only declared successful after seven years of monitoring (Penniman *et al*., 2011).

RESOURCES REQUIRED

Depending on the size of plants, different resources will be required. All plant sizes will require manual labour. Small seedlings can be removed by hand pulling, so labour is probably the only resource required for follow-up treatments of *C. jubata* invasions. Medium-sized plants will require tools (spades, axes or hoes) and even larger plants will require machinery (vehicles and chains or diggers).

There are almost no cost estimates specific to *C. jubat*a (or even for *C. selloana*) available for these methods. In New Zealand physical control was estimated to cost NZD 150 p.ha^{-1} in 1983 (ca. USD 325 / EUR 283 p.ha^{-1} at current prices) (Gadgil *et al*., 1984).

SIDE EFFECTS

Environmental: Negative
Social: Negative
Economic: Positive

This measure can have negative environmental effects in that physical control using machinery can damage surrounding vegetation, and it can encourage germination of *C. jubata* seeds (Gosling *et al*., 2000).

ACCEPTABILITY TO STAKEHOLDERS

This measure is likely to be acceptable for rapidly eradicating new introductions because of the cost-effectiveness of physical control in controlling small invasions of *C. jubata*. However, factors that could lead to this measure being less acceptable include the potential for physical control to damage surrounding vegetation, and to provide opportunities for the re-establishment of *C. jubata.* The difficulty in distinguishing between *C. jubata* and *C. selloana* could also make this measure less acceptable.

ADDITIONAL COST INFORMATION

Implementation costs are uncertain, but see best estimates from New Zealand above.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of physical control for rapid eradications of this species is unknown, but probably high due to the efficacy of the method and the high costs of inaction. For invasive plants in general, the economic effects are likely to be positive overall because the potential impacts of an invasive species outweigh the costs of its control at the early stages of an invasion (for example, Leung *et al.*, 2002).

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Established but incomplete.
There is adequate evidence to support the use of physical control to eradicate new introductions of this species. However, there is no readily available information on the costs of using such an approach.

1 See Appendix

Chemical control.

MEASURE DESCRIPTION

The use of glyphosate, imazapyr, fluazifop-P-butyl, quizalofop, hexazinone, amitrole, dalapon, and sethoxydim have either been trialled or recommended for use on *C. jubata* (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000; Schmalzer and Hinkle, 1987). However, only a few of these have been tested using experimental field trials (DiTomaso *et al.*, 2008). Glyphosate is generally the recommended chemical of choice for controlling *C. jubata* (DiTomaso *et al.*, 2008, 2010; Gosling *et al.*, 2000).

It is important to note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected and authorities should check to ensure chemicals are licensed for use in their respective countries/regions.

SCALE OF APPLICATION

In the case of rapid eradications, chemical control is the only practical control method for difficult to reach invasions of *C. jubata* (Popay *et al.*, 2003), and perhaps also for larger plants for which physical removal is not practical (DiTomaso *et al.*, 2008). Rapid eradications of *C. jubata* are probably only feasible for smaller invasions (lower numbers of plants within a relatively small area) using chemical control, but it is difficult to provide specific numbers. On Tawhiti Rahi Island and Aorangi Island in New Zealand, both *C. jubata* and *C. selloana* were largely eradicated using physical and chemical control from a 272 ha area (only one detection per year in the last two years of a seven-year eradication and monitoring programme) (Coulston, 2002).

EFFECTIVENESS OF MEASURE

Effective.

Chemical control has been shown to be highly effective under certain circumstances. In a Californian trial, spraying of glyphosate at an 8% concentration in early summer was found to be the most cost-effective control method and had a control rate of 99% (however, ropewick application of glyphosate at a 16% concentration in early summer was better for not affecting non-target native species; DiTomaso *et al.*, 2008). In general, glyphosate had a much higher successful control rate than imazapyr, fluazifop and sethoxydim (DiTomaso *et al.*, 2008). The more commonly used spray-to-wet applications of glyphosate (at high concentrations) were as effective as ropewick applications of glyphosate, but even at low concentrations spray-to-wet applications of glyphosate were still more effective than the other herbicides tested (DiTomaso *et al.*, 2008). Larger plants appear to be more likely to survive herbicide control than smaller plants (DiTomaso *et al.*, 2008; Popay *et al.*, 2003).

Hexazinone, a root-absorbed herbicide, has been recommended in forestry plantations in California and New Zealand (DiTomaso *et al.*, 2010; Gosling *et al.*, 2000).

Aerial spraying of haloxyfop from a beer keg from a helicopter has been shown to be quite effective at reducing *C. jubata* growth, but not entirely effective at killing plants. A year after treatment there were numerous new shoots on treated plants and it appears that follow-up treatments are necessary (Popay *et al.*, 2003).

This measure can only be effective if *C. jubata* can be accurately distinguished from individuals of *C. selloana*. However, chemical control of both species would ensure the effectiveness of this measure.

EFFORT REQUIRED

If applied at the correct concentrations, and when the plants are not stressed, chemical control can be very effective, and follow-up treatments can be limited in number and duration, but there are no experimental trials to provide exact recommendations. However, providing high efficacy of herbicide treatments, follow-up treatments will likely only need to focus on the few surviving adult plants, and only on new recruits within the first year after initial treatment as *C. jubata* seeds do not persist for longer than four months in the soil seedbank under winter (wet) conditions (Drewitz and DiTomaso, 2004). In reality herbicide control is not 100% effective and an eradication programme in Hawaii was only deemed successful after seven years (Penniman *et al.*, 2011).

RESOURCES REQUIRED

Herbicide application requires trained staff, equipment (for example, backpack sprayers, ropewicks, spray wands, or in the case of aerial application, a helicopter fitted with a suitable spray device, for example, beer keg), herbicides and surfactants.

The following studies provided cost estimates (all inclusive) of controlling *C. jubata*:

- In California, the most cost effective control method for *C. jubata* was found to be spray-to-wet application of glyphosate, which cost USD 0.28 per 1 m^2 plant (USD 2,800 / ca. EUR 2441 per hectare; DiTomaso *et al.*, 2008).
- Ropewick application of glyphosate, a method less likely to affect non-target plants, was estimated to cost USD 0.80 per 1 m^2 plant (USD 8,000 / ca. EUR 6,975 per hectare; DiTomaso *et al.*, 2008).
- In New Zealand, the cheapest herbicide (haloxyfop) control method using helicopters for inaccessible *C. jubata* infestations was found to cost NZD 3,885 (ca. USD 2,500 / EUR 2,219 per hectare).

SIDE EFFECTS

Environmental: Negative
Social: Negative
Economic: Neutral or mixed

This measure can have negative environmental effects in that chemical control can also affect native species (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000). Glyphosate is a commonly recommended broad-spectrum herbicide recommended for *C. jubata* control, which can also affect neighbouring native plants when applied via sprayers (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000).

For this reason, ropewick application of glyphosate has been recommended (DiTomaso *et al.*, 2008) and is probably a very practical method for controlling a few plants in a new introduction. Hexazinone, which has been used to treat *C. jubata* in plantation forests, can affect native plants in light or sandy soils (Gosling *et al.*, 2000). Haloxyfop is a grass-specific herbicide that has been used in aerial spraying of *C. jubata* in New Zealand and was found to damage the native *Austroderia splendens* (a close relative to *Cortaderia* species), but not other native plants, but was also not completely effective at killing *C. jubata* (Popay *et al.*, 2003).

ACCEPTABILITY TO STAKEHOLDERS

Invasive species managers are likely to favour chemical control because of its ease of use compared to physical control. However, public perceptions of chemical control are often negative (for example, Shindler, Gordon, Brunson and Olsen, 2011). Moreover, chemical control is not always possible or permitted in conservation areas or in riparian areas and wetlands.

ADDITIONAL COST INFORMATION

The best estimates of **implementation costs** are to be found under Resources required above.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of physical control for rapid eradications of this species is unknown, but probably high due to the efficacy of the method and the high costs of inaction. For invasive plants in general, the economic effects are likely to be positive overall because the potential impacts of an invasive species outweigh the costs of its control at the early stages of an invasion (for example, Leung *et al.*, 2002).

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is adequate evidence to support the use of chemical control to eradicate new introductions of this species. However, there are insufficient studies providing guidelines on the duration and number of follow-up treatments required. Moreover, there are no cost-benefit analyses on the use of chemical control of *C. jubata*.

1 See Appendix

Measures for the species' management.

Physical control.

MEASURE DESCRIPTION

Management measures overlap to a large extent with measures for rapid eradication for new introductions, as described in the section above. Probably the largest difference between measures in these two different sections is the scale at which control methods are applied. While both physical and chemical control are possible for both rapid eradication of new introductions and management, physical control is only practical and cost-effective for smaller invasions, while chemical control can be used for both small and large invasions (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000; Schmalzer and Hinkle, 1987).

Given that *C. jubata* is thought not to have established within the EU, management measures are probably not necessary and are provided here for completeness. One consideration though is the similarity in appearance of *C. jubata* to *C. selloana*, and the abundance and wide distribution of *C. selloana* in the EU. This may have prevented the accurate identification of *C. jubata* in the EU and it is plausible that the populations of *C. selloana* in the EU are in fact *C. jubata* and that this species is indeed much more widespread in the EU. This would therefore require the implementation of management measures.

Physical control

Small seedlings can be pulled by hand, but larger plants will require digging up by spade, axe, hoe, having a chain tied around them and pulled out by a vehicle, or even dug up with the use of a digger (DiTomaso *et al.*, 2010; Gosling *et al.*, 2000).

SCALE OF APPLICATION

Numerous authors note that physical control is only practical and economical for small invasions of a few plants (DiTomaso *et al.*, 2010; Gosling *et al.*, 2000). This suggests physical control may not always be possible for management, and may require the additional use (integrated management) of chemical control as has been done in Hawaii (Penniman *et al.*, 2011) and New Zealand (Gosling *et al.*, 2000).

EFFECTIVENESS OF MEASURE

Ineffective.

Physical control is an extremely effective method of controlling *C. jubata*, with a 98-100% success rate (DiTomaso *et al.*, 2008), but is only practical for smaller invasions (DiTomaso *et al.*, 2008; Gosling *et al.* 2000; Schmalzer and Hinkle, 1987) and is therefore assessed as ineffective for managing large-scale invasions.

Other considerations to improve the effectiveness of the measure include removing all the inflorescences and destroying these to prevent seed dispersal, and pulling up the majority of roots to prevent resprouting from rootstock (DiTomaso *et al.*, 2010).

Cortaderia jubata *only produces female flowers, but viable seeds are able to develop without pollination. © Forest and Kim Starr. CC BY 3.0.*

This measure can only be effective if *C. jubata* can be accurately distinguished from individuals of *C. selloana*. However, physical control of both species would ensure the effectiveness of this measure.

EFFORT REQUIRED

As physical control is extremely labour intensive, considerable manpower will be needed to manage larger invasions of *C. jubata*, which may be prohibitively expensive or impractical. As a result, the amount of time required to manage invasions will also be considerably longer than using chemical control. However, the duration of monitoring post-treatment will be the same regardless of the size of invasion because physical control is extremely effective, with a 98-100% success rate (DiTomaso *et al.*, 2008), and *C. jubata* has a very short-lived seedbank (up to four months in winter (wet) conditions; Drewitz and DiTomaso, 2004).

Therefore, eradication is possible within a time period as short as a year as long as all reproducing individuals of *C. jubata* are located and removed. However, an eradication programme in Hawaii was only declared successful after seven years of monitoring (Penniman *et al.*, 2011).

RESOURCES REQUIRED

Depending on the size of plants, different resources will be required. All plant sizes will require manual labour. Small seedlings can be removed by hand pulling, so labour is probably the only resource required for follow-up treatments of *C. jubata* invasions. Medium-sized plants will require tools (spades, axes or hoes) and even larger plants will require machinery (vehicles and chains or diggers).

There are almost no specific cost estimates for *C. jubata* available for these methods. In New Zealand physical control was estimated to cost NZD 150 p.ha^{-1} in 1983 (USD 325 / ca. EUR 283 p.ha^{-1} at current prices) (Gadgil *et al.*, 1984).

SIDE EFFECTS

Social: Neutral or mixed
Environmental: Positive
Economic: Negative

Physical control will have a positive economic side effect in that this species is known to negatively impact forestry operations in New Zealand by competing with forestry trees and making access to plantations more difficult (Gadgil *et al.*, 1984). Costs of clearing *C. jubata* in forestry plantations was estimated to cost NZD 350 p.ha^{-1} in 1983 (ca. USD 760 / EUR 662 p.ha^{-1} at present value) and added 144% to the tending costs of plantations (Gadgil *et al.*, 1984). This measure can have negative environmental effects in that physical control can damage surrounding vegetation, and it can encourage germination of *C. jubata* seeds (Gosling *et al.*, 2000).

ACCEPTABILITY TO STAKEHOLDERS

This measure is unlikely to be acceptable for management because of the high cost of physically controlling large invasions of *C. jubata*. Moreover, physical control has the potential to damage surrounding vegetation, and to provide opportunities for the re-establishment of *C. jubata*. The difficulty in distinguishing between *C. jubata* and *C. selloana* could also make this measure less acceptable. This measure would probably only be acceptable in addition to the use of chemical control.

ADDITIONAL COST INFORMATION

Implementation costs are uncertain, but the best estimates are from New Zealand (see above).

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of physical control for management of this species is unknown, but probably low because of the high cost of controlling large invasions of this species.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is adequate evidence to support the use of physical control for management of this species. However, there is no readily available information on the costs of using such an approach, and on the scales at which it is practical and cost-effective.

1 See Appendix

Chemical control.

MEASURE DESCRIPTION

As noted above for physical control, the use of chemical control for management of widespread *C. jubata* invasions is probably unnecessary due to this species probably not having established yet in the EU (unless *C. selloana* populations have been incorrectly identified).

Chemical control

The use of glyphosate, imazapyr, fluazifop-P-butyl, quizalofop, hexazinone, amitrole, dalapon, and sethoxydim have either been trialled or recommended for use on *C. jubata* (DiTomaso *et al*., 2008; Gosling *et al*., 2000; Schmalzer and Hinkle, 1987). However, only a few of these have been tested using experimental field trials (DiTomaso *et al*., 2008). Glyphosate is generally the recommended chemical of choice for controlling *C. jubata* (DiTomaso *et al*., 2008, 2010; Gosling *et al*., 2000).

It is important to note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected and authorities should check to ensure chemicals are licensed for use in their respective countries/regions.

SCALE OF APPLICATION

Chemical control is the only practical control method for large and difficult to reach invasions of *C. jubata* (DiTomaso *et al*., 2010; Gosling *et al*., 2000; Popay *et al*., 2003). Examples of the scale at which chemical control has been used, include:

- New Zealand (blocks around ~2,000 m^2 in size (Popay *et al*., 2003)
- California. 600 m^2 in Vandenberg Air Force Base (DiTomaso *et al*., 2008)
- Maui, Hawaii. *C. jubata* was "established in numerous areas of rainforest as well as bogs on East and West Maui" and in Haleakala National Park, but has been greatly reduced in number due to an island-wide control campaign (Penniman *et al*., 2011). In 2012 the Maui and Moloka'i Invasive Species Committees controlled 3,910 acres using 3,063 hours of labour (HISC Established Pests Working Group, 2013).
- On Tawhiti Rahi Island and Aorangi Island in New Zealand, both *C. jubata* and *C. selloana* were largely eradicated from a 272 ha area (only one detection per year in the last two years of a seven year eradication and monitoring programme) (Coulston, 2002).

Chemical control therefore seems to be the control method of choice for larger invasions of *C. jubata*, but the dangers of affecting non-target plants should be kept in mind.

EFFECTIVENESS OF MEASURE

Chemical control has been shown to be highly effective under certain circumstances. In a Californian trial, spraying of glyphosate at an 8% concentration in early summer was found to be the most cost-effective control method and had a control rate of 99% (however, rope wick application of glyphosate at a 16% concentration in early summer was better for not affecting non-target native species; DiTomaso *et al*., 2008). In general, glyphosate had a much higher successful control rate than imazapyr, fluazifop and sethoxydim (DiTomaso *et al*., 2008). The more commonly used spray-to-wet applications of glyphosate (at high concentrations) were as effective as rope wick applications of glyphosate, but even at low concentrations spray-to-wet applications of glyphosate were still more effective than the other herbicides tested (DiTomaso *et al*., 2008). Larger plants appear to be more likely to survive herbicide control than smaller plants (DiTomaso *et al*., 2008; Popay *et al*., 2003).

Hexazinone, a root-absorbed herbicide, has been recommended in forestry plantations in California and New Zealand (DiTomaso *et al*., 2010; Gosling *et al*., 2000).

Aerial spraying of haloxyfop from a beer keg from a helicopter has been shown to be quite effective at reducing *C. jubata* growth, but not entirely effective at killing plants. A year after treatment there were numerous new shoots on treated plants and it appears that follow-up treatments are necessary (Popay *et al*., 2003).

This measure can only be effective if *C. jubata* can be accurately distinguished from individuals of *C. selloana*. However, chemical control of both species would ensure the effectiveness of this measure.

EFFORT REQUIRED

If applied at the correct concentrations, and when the plants are not stressed, chemical control can be very effective, and follow-up treatments can be limited in number and duration, but there are no experimental trials to provide exact recommendations. However, providing high efficacy of herbicide treatments, follow-up treatments will likely only need to focus on the few surviving adult plants, and only new recruits within the first year as *C. jubata* seeds do not persist for longer than four months under winter (wet) field conditions (Drewitz and DiTomaso, 2004). In reality, herbicide control is not 100% effective and an eradication programme in Hawaii was only deemed successful after seven years (Penniman *et al*., 2011).

As an example of the effort applied to manage widespread *C. jubata* and *C. selloana* invasions, in 2012 the Maui and Moloka'i Invasive Species Committees controlled 3,910 acres using 3,063 hours of labour (HISC Established Pests Working Group, 2013).

RESOURCES REQUIRED

Herbicide application requires trained staff, equipment (for example, backpack sprayers, ropewicks, spray wands, or in the case of aerial application, a helicopter fitted with a suitable spray device, for example, beer keg), herbicides and surfactants.

The following studies provided cost estimates (all inclusive) of controlling *C. jubata*:

- In California, the most cost effective control method for *C. jubata* was found to be spray-to-wet application of glyphosate, which cost USD 0.28 per 1 m^2 plant (USD 2,800 / ca. EUR 2,441 per hectare; DiTomaso *et al.*, 2008).
- Ropewick application of glyphosate, a method less likely to affect non-target plants, was estimated to cost USD 0.80 per 1 m^2 plant (USD 8,000 / ca. EUR 6,975 per hectare; DiTomaso *et al.*, 2008).
- In New Zealand, the cheapest herbicide (haloxyfop) control method using helicopters for inaccessible *C. jubata* infestations was found to cost NZD 3,885 (ca. USD 2500 / EUR 2,219) per hectare.

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Positive

For the same reasons as *Management: physical control*, chemical control will have a positive economic side effect in relation to lower plantation forestry management costs.

This measure can have negative environmental effects in that chemical control can also affect native species (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000). Glyphosate is a commonly recommended broad-spectrum herbicide recommended for *C. jubata* control, but which can also affect neighbouring native plants when applied via sprayers (DiTomaso *et al.*, 2008; Gosling *et al.*, 2000). For this reason, ropewick application of glyphosate has been recommended (DiTomaso *et al.*, 2008) and is probably a very practical method for controlling a few plants in a new introduction. Hexazinone, which has been used to treat *C. jubata* in plantation forests, can affect native plants in light or sandy soils (Gosling *et al.*, 2000). Haloxyfop is a grass-specific herbicide that has been used in aerial spraying of *C. jubata* in New Zealand and was found to damage the native *Austroderia splendens* (a close relative of *Cortaderia* species), but not other native plants, but was also not completely effective at killing *C. jubata* (Popay *et al.*, 2003).

Negative social side effects can include exposure to toxic substances if adequate precautions are not taken.

ACCEPTABILITY TO STAKEHOLDERS

Invasive species managers are likely to favour chemical control because of its ease of use compared to physical control. However, public perceptions of chemical control are often negative (for example, Shindler *et al.*, 2011). Moreover, chemical control is not always possible or permitted in conservation areas or in riparian areas and wetlands.

ADDITIONAL COST INFORMATION

The best estimates of **implementation costs** can be found under Resources required above.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of chemical control for management of this species is unknown, but probably higher than that of physical control for management.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

There is adequate evidence to support the use of chemical control to manage this species. However, there are insufficient studies providing guidelines on the duration and number of follow-up treatments required. Moreover, there are no cost-benefit analyses on the use of chemical control of *C. jubata*.

1 See Appendix

Grazing.

MEASURE DESCRIPTION

Using domestic livestock to graze *C. jubata* seedlings has been recommended as a control measure in plantation forests in New Zealand (Gadgil *et al.*, 1984; Gosling *et al.*, 2000) and as a temporary control measure in low-risk areas in Australia (NSW Government, 2018).

Fencing, a supply of water for the livestock, and supplementary fodder with high protein are also required for this measure (Gadgil *et al.*, 1984). It has also been suggested that areas invaded by *C. jubata* seedlings be grazed 3 to 4 times a year, and early in the rotation of plantation forestry (Gosling *et al.*, 2000).

SCALE OF APPLICATION

There are no specific recommendations for the scale of application of grazing. Its use in plantation forestry as a control measure suggests that it cannot be used at very broad scales. Moreover, the need for sufficiently high grazing pressure (Gosling *et al.*, 2000; Lambrinos, 2006) also limits its application over large areas.

EFFECTIVENESS OF MEASURE

Ineffective.

Grazing has only been suggested as an effective control method for seedlings of *C. jubata*, and only in New Zealand (Gadgil *et al.*, 1984; Gosling *et al.*, 2000) and Australia (NSW Government, 2018). In California, grazing is not recommended as an effective control method (for example DiTomaso *et al.*, 2010), and in other regions grazing is not mentioned at all.

The effectiveness of grazing is limited because of the difficulties of managing grazing (Gadgil *et al.*, 1984; Gosling *et al.*, 2000), because only seedlings are grazed, and because *C. jubata* still successfully invades even under high grazing pressure (Lambrinos, 2006). Even with high herbivore pressure, *C. jubata* was still able to successfully invade in Californian chaparral, increasing in cover by 20% over 9 years (Lambrinos, 2006).

EFFORT REQUIRED

There is little information available on the effort required. Gosling *et al.* (2000) recommend grazing 3 or 4 times a year, but provide no further details.

RESOURCES REQUIRED

Suitable domestic livestock (cattle, goats or sheep), fencing, water supply, additional high-protein fodder, labour to manage the livestock.

SIDE EFFECTS

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

Grazing in environmentally sensitive areas could damage or kill native plant species, and influence nutrient flows. However, livestock would also eat *C. selloana* seedlings, providing control for both *Cortaderia* species.

Grazing could have positive social and economic side effects through the employment and income generated by allowing grazing in plantations or protected areas, for example. However, there is the potential for issues with animal health, particularly for cattle, if they are allowed to graze extensively on *Cortaderia*. This can lead to the development of “woody tongue” (Maas, 2009).

ACCEPTABILITY TO STAKEHOLDERS

The ineffectiveness of this measure is likely to make it unacceptable to invasive species managers. The possible negative side effects on native species will also make this measure unacceptable to conservation managers.

ADDITIONAL COST INFORMATION

Implementation costs are unknown, but will be linked to the Resources required, as detailed above.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of this measure is unknown.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

Inconclusive.

There do not appear to be any studies experimentally or quantitatively investigating the use of grazing for *C. jubata* (or *Cortaderia* spp. in general) management. Much of the evidence for or against the use of grazing for *C. jubata* control is anecdotal (for example DiTomaso *et al.*, 2010; Gadgil *et al.*, 1984; Gosling *et al.*, 2000; NSW Government, 2018). The only study to scientifically investigate this measure was Lambrinos (2006), but this involved grazing by native herbivores, and also found that grazing was insufficient to prevent the spread of *C. jubata*.

1 See Appendix

Oversowing.

MEASURE DESCRIPTION

In New Zealand, oversowing in timber plantations (or recently felled plantations or sites being prepared for plantations) has been recommended, in conjunction with grazing, as a way of controlling *C. jubata* invasions in timber plantations (Gadgil *et al.*, 1984; Gosling *et al.*, 2000). Nitrogen-fixing species (for example, *Lotus pedunculatus*) were specifically recommended for oversowing in these studies.

SCALE OF APPLICATION

There are no specific recommendations for the scale of application of oversowing. However, its use in conjunction with grazing in plantation forestry as a control measure suggests that it cannot be used at very broad scales.

EFFECTIVENESS OF MEASURE

Ineffective.

Only two references (Gadgil *et al.*, 1984; Gosling *et al.*, 2000) were found mentioning the use of oversowing for the control of *C. jubata*, and even these did not specifically recommend oversowing above other control measures. Moreover, these references are specific to the application of this measure in timber plantations in New Zealand.

A single individual of C. jubata *can produce 100,000 seeds per plume. © Thayne Tuason. CC BY-SA 4.0.*

EFFORT REQUIRED

Immediate control of treated plants can be expected. However, this measure should be followed by measures aimed at preventing regeneration from the rhizome and recruitment from the soil seed bank over an extended period of time (at least 4-10 years; Armstrong, 2008).

RESOURCES REQUIRED

The effort required is unknown.

SIDE EFFECTS

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

Environmental side effects could be both negative and positive. A negative side effect might include the possibility of sowing other invasive species (recommended species include *Lotus pedunculatus*, an alien to New Zealand). A positive side effect might be erosion prevention.

There are no known social or economic side effects.

ACCEPTABILITY TO STAKEHOLDERS

The ineffectiveness of this measure is likely to make it unacceptable to invasive species managers. The possible negative environmental side effects will also make this measure unacceptable to conservation managers.

ADDITIONAL COST INFORMATION

Implementation costs are unknown, but will be linked to the Resources required, as detailed above.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of this measure is unknown.

There are no known **socio-economic aspects**.

LEVEL OF CONFIDENCE[1]

There do not appear to be any studies experimentally or quantitatively investigating the use of oversowing for *C. jubata* (or *Cortaderia* spp. in general) management. All the evidence for the use of grazing for *C. jubata* control is anecdotal and is very specific to plantation forestry in New Zealand (Gadgil *et al.*, 1984; Gosling *et al.*, 2000).

1 See Appendix

Biological control.

MEASURE DESCRIPTION

This measure has received relatively little attention for management of *C. jubata* with papers as recent as 2010 suggesting that biological control had not been investigated at all (for example, DiTomaso *et al.*, 2010). However, recently there appears to be more interest in this measure, particularly in New Zealand. Bellgard *et al.* (2010) conducted a survey of *C. jubata* and *C. selloana* in New Zealand for the presence of native invertebrate herbivores and fungal pathogens. They found the native flax notcher (*Tmetolophota steropastis*) to be the most damaging invertebrate herbivore, and identified a number of damaging fungal pathogens. In a follow-up study, one of these fungal pathogens (*Nigrospora oryzae*), used in conjunction with synthetic herbicides, was found to cause greater dieback of both *Cortaderia* species than when herbicides were applied without an inoculation of this fungus (Bellgard, Probst and Johnson, 2016).

A recent study in Ecuador using a native fungal pathogen (*Ustilago quitensis*) found high infection rates in the inflorescences of *C. jubata* when using this fungus as a biological control agent (Gavilanez Torres and Salazar Andrade, 2016).

It is important to note that the release of macro-organisms as 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

Unknown. No biological control agent has been released as yet.

EFFECTIVENESS OF MEASURE

Ineffective.

No biological control agent has been released or gone through experimental trials yet.

EFFORT REQUIRED

Unknown.

RESOURCES REQUIRED

Unknown, although resources required are likely to be similar to most other biological control agents, for example rearing facilities, trained staff to release/apply biological control agent, etc. The cost of testing and monitoring of a biological control agent is unknown.

SIDE EFFECTS

Environmental: Negative
Social: —
Economic: —

Although highly unlikely if proper testing protocols are followed, there is the potential for a biological control agent to affect a non-target species. There are no native *Cortaderia* species in the EU. No other side effects seem likely.

ACCEPTABILITY TO STAKEHOLDERS

With no biological control agent currently available, it is difficult to judge the acceptability of this measure to stakeholders, which is the reason for giving this a "neutral" rating. However, based on the situation related to other biological control agents, it is possible that the public may perceive any potential biological control agents negatively, and this may influence the political will to use biological control as a management measure (Messing and Brodeur, 2017).

ADDITIONAL COST INFORMATION

Implementation costs are unknown.

Costs of inaction associated with this measure are likely to be similar to those detailed in the *Prevention of intentional introductions and spread* section above, if this species escapes.

The **cost-effectiveness** of this measure is unknown, but biological control is typically ranked as one of the most cost-effective control measures for widespread alien plant species (which *C. jubata* is thought not to be, in the EU) (Barratt, Moran, Bigler and Van Lenteren, 2018).

There are no **socio-economic aspects** as *C. jubata* is not thought to be widespread in the EU, and there are currently no biological control agents available for this species.

LEVEL OF CONFIDENCE[1]

Inconclusive.

Very little research has been conducted on using biological control for *C. jubata* invasions.

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 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 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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