Ludwigia grandiflora, L. peploides. © *Marcia Stefani. CC BY 2.0.*

The management of water-primrose (*Ludwigia grandiflora*) and floating primrose-willow (*Ludwigia peploides*)

Measures and associated costs

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Scientific name(s)	*Ludwigia grandiflora* (Michx.) Greuter and Burdet and *Ludwigia peploides* (Kunth) P.H. Raven
Common names (in English)	Water-primrose
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Common names for *Ludwigia grandiflora*

BG Голямоцветна лудвигия
HR Velecvjetna močvarna mekčina
CZ Zakucelka velkokvětá
DA Uruguay ludwigia
NL Waterteunisbloem
EN Water-primrose
ET Suureõieline ludviigia
FI Lauttarusolehti
FR Ludwigie à grandes fleurs
DE Großblütiges Heusenkraut
EL Μαγνόλια του Νότου
HU Nagyvirágú tóalma
IE –
IT Porracchia a grandi fiori
LV –
LT Stambiažiedė liudvigija
MT –
PL –
PT Florzeiro
RO –
SK –
SL Velikocvetna ludvigija
ES Ludwigia
SV Storblommig ludwigia

Common names for *Ludwigia peploides*

BG Пеплисовидна лудвигия
HR plutajuća močvarna mekčina
CZ zakucelka plazivá
DA krybende ludwigia
NL kleine waterteunisbloem
EN floating primrose–willow
ET vaipludviigia
FI loikorusolehti
FR jussie rampante
DE Flutendes Heusenkraut
EL –
HU sárga tóalma
IE –
IT porracchia plepoide
LV –
LT gulsčioji liudvigija
MT –
PL –
PT –
RO –
SK ludvigia
SL plazeča ludvigija
ES onagraria
SV krypludwigia

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

Ludwigia grandiflora and *Ludwigia peploides* (hereafter the term *Ludwigia* spp. is used throughout the text) are perennial macrophytes native to South and Central America. These plants have been intentionally introduced into the EU as ornamentals. They can invade a variety of habitats, particularly ponds, lakes, wetlands, ditches and other watercourses. They primarily spread by clonal growth and vegetative fragments, but they can also spread via seeds. Both species form dense mats that exclude native biodiversity, increase flood risk and siltation, and degrade watercourses for users of these sites.

As *Ludwigia* spp. are showy and attractive plants with ornamental values, it is extremely important to decrease the instances of intentional introduction from existing to uninvaded sites by raising awareness with the general public that *Ludwigia grandiflora* and *Ludwigia peploides* are regulated under the EU IAS Regulation and a major threat to biodiversity. To prevent secondary spread, it is important to implement biosecurity measures (best practices) on water bodies to limit the unintentional spread of fragments by human activities (through equipment and boats of fishermen, hunters, and people using pleasure boats etc.).

Small and/or newly established populations can be eradicated by manual, mechanical or chemical control methods. In most EU countries, the application of herbicides is restricted in aquatic and wetland habitats and there is a reluctance of managers to use chemicals, which are also negatively perceived by the public. For very small infestations, manual control by hand-pulling and/or digging with hand tools is preferred. If the infestation is more established, mechanical control (excavation of the plants and of the sediments by a digger), followed by manual removal in order to extract the remaining plants is the most effective measure to eradicate the species. Removed plant material must be stored in a dry environment, to ensure their drying and decomposition. They can also be sent to an approved waste disposal site.

For the long-term control or containment of large and widespread populations, manual control is less cost-effective and chemical control would likely have serious negative side-effects. Therefore at this scale, a combination of mechanical and manual control is the most cost-effective measure, and has been largely applied in western France. This involves managing larger populations with mechanical means (excavators or boats equipped with a shovel) and completing the work with the manual removal of the remaining individuals as well as other small populations. Environmental control by shading (along river banks), by limiting eutrophication and by controlling water level and salt concentration can also be efficient in combination with curative measures. For terrestrial forms in wet grasslands, there are currently no effective solutions. Finally, *Ludwigia* spp. have been identified as good candidates for biological control but in Europe, the biological control programme is still at the beginning of the experimental phase.

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 *L. grandiflora and L. peploides.*

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.

Unintentional introductions.

MEASURE DESCRIPTION

There are no records of Unintentional introduction of *Ludwigia* spp. into a new territory (introduction in the sense of entry) (EPPO, 2011a, 2011b). Once introduced in a country, there might be Unintentional spread through human-mediated dispersal of fragments of *Ludwigia* spp.

These aspects are addressed in the following section on secondary spread.

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

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

Public awareness campaigns.

MEASURE DESCRIPTION

All wild populations of *Ludwigia* spp. in Europe are the results of either: i) intentional introduction into the wild, ii) garden escapes or iii) non-intentional spread of fragments by human activities (EPPO, 2011a, 2011b). As *Ludwigia* spp. are showy and attractive plants with ornamental values, it is extremely important to decrease the instances of intentional introduction from existing to uninvaded sites. Although there is now a ban on trading the species under the EU IAS Regulation, people can pick up individuals of the species in the wild and plant it in their garden or in another wild site because they consider the flowers of *Ludwigia* spp. are beautiful (intentional secondary spread). Moreover, *Ludwigia* spp. easily produce stem fragments that are easily transportable (Dandelot, 2004). It is extremely important to decrease the instances of accidental secondary spread by addressing humans as a vector.

Both of these mechanisms of secondary spread can be addressed by a single measure, through awareness raising activities with different stakeholder groups. By increasing awareness on the impact and risks posed by *Ludwigia* spp., and on measures that can be taken on how to properly clean equipment used in wetlands or waterbodies (boots, boats, …), and how to dispose of garden ponds or aquarium water, it is likely that instances of intentional and accidental transportation and release will decrease.

The objective of the measure is to support the implementation of the EU IAS Regulation beyond the ban of trading the species, by engaging i) with the public that may still cultivate individuals in their garden ponds, to raise awareness of the regulated status of the species and its potential impacts and provide guidance on how to remove it appropriately, ii) with the public that use waterbodies invaded by *Ludwigia* spp. (fishermen, hunters, people using pleasure boats, etc.) to raise awareness of the risk of unintentional fragments dispersal and the adoption of simple biosecurity practices.

The following actions are included in this measure:

At the scale of the Union:

- raise awareness with the general public that *Ludwigia* spp. are regulated IAS and a major threat to biodiversity etc.,
- provide guidance on how to remove *Ludwigia* spp.from their garden ponds (with a protocol describing manual removal and how to dispose of the plant material following removal),
- provide guidance to limit unintentional spread of fragments for people using infested waterbodies.

At the scale of water bodies in response to new infestations, awareness activities with relevant stakeholder groups could help limit the spread of fragments by undertaking simple biosecurity practices:

- maintain haul-out areas without *Ludwigia* spp. (and other aquatic weeds) reducing the likelihood that fragments are attached to the boat,
- systematically picking up all visible plant fragments from equipment especially boats and trailers,
- storing the boat on dry land for a certain amount of time in order to dry the plant fragments attached to the boat (Hussner, 2017).

Such campaigns, targeting aquatic invasive plants and animals in general, already exist within the EU for example the UK's Check Clean Dry[1] or Be Plant Wise[2].

SCALE OF APPLICATION

This measure should be applied at the scale of the whole Union, but probably implemented at a national level so that whole waterbodies and catchments where the species has

1 http://www.nonnativespecies.org/checkcleandry/index.cfm?
2 http://www.nonnativespecies.org/beplantwise/

been detected can be targeted through engagement with relevant stakeholder groups.

EFFECTIVENESS OF MEASURE

Effective.

It is expected that once people are aware of the legal status and potential impacts of the species, they will be more inclined to remove the species from their garden ponds and dispose of it responsibly. Therefore, if garden ponds are connected to river systems (garden ponds near natural streams), there is a significant probability that removing these cultivated individuals will avoid new established populations. Raising awareness could also strongly limit the collection of the plant in the wild and its intentional introduction to new sites.

The adoption of biosecurity practices (such as, cleaning of equipment and correct disposal) is an effective measure to limit unintentional dispersal of *Ludwigia* spp. and other invasive aquatic plants in general. However, it has to be taken in mind that the success or failure of the measure will depend on various parameters, for example the minimum size of fragments needed for regeneration, the resistance of fragments to desiccation and heating (Hussner, 2017).

EFFORT REQUIRED

In order to significantly prevent secondary spread of *Ludwigia* spp., these measures must be applied for the long-term.

RESOURCES REQUIRED

The resources required include means of communication to reach the general public (posters, leaflets, information meeting, inserts in the press, advertising, videos, and website). To reach people using water bodies, these measures require the installation of infrastructure near the waterbodies access, such as information boards as well as equipment to collect or kill plant fragments.

Nets can also be installed to create weed free haul-out areas in water bodies infested with *Ludwigia* spp.

The efficacy of the measure will increase if there is staff time to raise awareness and help people cleaning their equipment after being used. The cost of advertising the presence of the species could be shared with similar measures for other invasive aquatic plants of Union (or national) concern (at least: *Elodea nuttallii*, *Hydrocotyle ranunculoides*, *Lagarosiphon major*, etc.).

SIDE EFFECTS

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

Environmental effects: this measure provides a form of education to the general public that could help with understanding the issue of invasive species in general and result in more positive action with other invasive species. It can also prevent the spread of other invasive aquatic plants (for example, *Cabomba caroliniana*,*Elodea nuttallii*, *Hydrocotyle ranunculoides*, *Lagarosiphon major, Myriophyllum aquaticum*,and *Myriophyllum heterophyllum*).

Social effects: None to detail.

Economic effects: None to detail.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

This measure should be positively perceived by the majority of the general public, though there may be some objections by those that like the ornamental value of the species. The measures will also impact water sports and other water recreational activities. However, the inconvenience caused by these biosecurity measures is less important than the impacts caused by heavy infestations of *Ludwigia* spp.

ADDITIONAL COST INFORMATION

Implementation cost for Member States: Funding are required to produce communication material detailing the negative impacts of the species, why it should not be transported and introduced in new wild sites or cultivated in garden ponds, how to eradicate it safely and how to prevent unintentional dispersal of fragments. It is estimated that the cost for an awareness raising campaign could be up to EUR 10,000 per year for each Member State (Tanner, 2017). However, sectors of society may bear some of these costs themselves.

Cost of inaction: due to high cost for eradication and management of *Ludwigia* spp. (see below), the cost of inaction is higher than the cost of preventive measures. However, if all the measures (information campaign, biosecurity measures on waterbodies) are implemented in all areas where the species is already established, the cost for the preventive measures should be considered as high.

cost-effectiveness of the measure: Preventive measures such as mounting a public campaign or implement biosecurity measures for boats and other equipment is usually considered as low cost compared to management activities, resulting in a cost-effective measure (Simberloff *et al.,* 2013).

Socio-economic aspects: Negative socio-economic impacts would include a loss of *Ludwigia* spp. for people who appreciate this species in their garden ponds and in the wild.

LEVEL OF CONFIDENCE*

Established but incomplete.

An "Established but incomplete" rating has been chosen as a general agreement in the literature has been found, although only a limited number of studies exist on this measure with no comprehensive synthesis and no specific studies that address the question for *Ludwigia* spp.

* See Appendix

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

Citizen-science.

MEASURE DESCRIPTION

Visual detection of plants in the field is the only feasible early detection method for new occurrences of *Ludwigia* spp. in the Union. It is possible to identify both species (*Ludwigia grandiflora*, *Ludwigia peploides*) in the field with very little training, as there are no look-a-like species in the European flora. There are two other species of *Ludwigia*, which can be easily distinguished by their opposite leaves, the native species, *Ludwigia palustris* has small flowers with no petals, and the additional non-native *L. natans* has small yellow petals that do not persist long (Fried, 2017).

Ludwigia spp. are perennial macrophytes with two growth forms. Early growth consists of rosette-like clusters of rounded leaves on the water surface. During this first growth stage, the plant produces smooth or sparsely pubescent stems that grow horizontally over the soil or water, rooting at nodes and producing white, spongy roots. During the second stage, shoots begin to grow vertically, emerge over the water surface, and leaves lengthen to a lanceolate or elliptical shape. Both species have bright yellow flowers (2–5 cm diameter) with 5 petals. Flowers are on solitary stalks that are approximately 2.5 cm long. The fruit of *L. grandiflora* is a capsule of 1–3 cm long and 3–4 mm wide with 5 loculi containing 40-50 seeds 1-1.5 mm long. *Ludwigia* spp. can grow up to 3 m deep in water, and up to 80 cm above water level.

A significant network of stakeholders is required to monitor all potential areas where *Ludwigia* spp. may occur, though sites most at risk are aquatic habitats (ponds, lakes and other water bodies, rivers, waterways and wetlands including wet grasslands). The area surrounding known infestations (for example, up and downstream of a river) could be specifically targeted in a first phase. The staff involved could come from government agencies and/or citizen scientists.

SCALE OF APPLICATION

This measure can be undertaken at the catchment level, but needs to be applied over the area of the Union where *Ludwigia spp.* are not yet present but has a high probability of establishment according to bioclimatic modelling (EPPO, 2011a, 2011b).

Priority should be given to the monitoring of areas near established populations (especially if hydrologically connected) and within these areas in habitats most at risk such as ponds, lakes and other water bodies, rivers, waterways and wetlands including wet grasslands (EPPO, 2011a, 2011b).

EFFECTIVENESS OF MEASURE

Effective.

The different stages of *Ludwigia* spp. are relatively easy to identify making it suitable for a broad network of trained and amateur naturalist stakeholder groups (for example through established citizen-science programmes) to easily identify. Readily available field guides (for example Fried, 2017) and numerous identification leaflets available on the internet (for example from the GB Non-native Species Secretariat[3], University of Florida[4]) can be used to identify the species. While it can sometimes be difficult to distinguish *Ludwigia peploides* and *Ludwigia grandiflora*, particularly at the vegetative stage, it is difficult to confuse with another aquatic species because of its large yellow flowers with five petals.

Visual detection is commonly used by amateur and professional botanists and naturalists for currently recording *Ludwigia* spp. in the field.

EFFORT REQUIRED

Surveillance should be applied over the long term for Member States where it is not yet established as part of the surveillance system of invasive alien species of Union

3 GB NNSS L. grandifoliahttp://www.nonnativespecies.org/downloadDocument.cfm?id=861
4 University of Florida Ludwigia spp. https://plants.ifas.ufl.edu/wp-content/uploads/files/caip/pdfs/LudwigiaIDGuide.pdf

Ludwigia grandiflora, L. peploides. © *Eugene Zelenko. CC BY-SA 4.0.*

concern required by Article 14 of the EU regulation No 1143/2014 on invasive alien species.

The period of surveillance is from spring to autumn with more intensive surveillance during summer and autumn when the plant has been fully developed (such as flowering stage) and thus, is more easily detectable.

RESOURCES REQUIRED

Resources would involve staff time and travel costs. Actual costs of a monitoring programme will depend on the area surveyed. Efforts could be shared with the monitoring of other invasive alien species of Union concern requiring similar surveillance in aquatic habitats, for example, *Elodea nuttallii*, *Hydrocotyle ranunculoides*, *Lagarosiphon major,* etc. If citizen-science programmes are utilised, stakeholder engagement activities will need to be undertaken, ID guides provided, and a reporting system put in place for example online or smartphone applications (which may already exist for other alien species).

SIDE EFFECTS

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

The surveillance of *Ludwigia* spp. can lead to the detection of other invasive alien aquatic plant species (for example, *Cabomba caroliniana*, *Elodea nuttallii*, *Hydrocotyle ranunculoides*, *Lagarosiphon major, Myriophyllum aquaticum*, *Myriophyllum heterophyllum*). The measure per se has low environmental impact and low cost to implement, especially if existing citizen-science programmes can be used. Obtaining access to discrete areas of land may, however, be problematic with the division of land ownership. Thus, despite intensive surveys, if the species is not controlled at a catchment scale, seeds or fragments of remaining undetected populations can become incorporated into the waterbody and spread to colonise new areas.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

The visual detection of *Ludwigia*spp. is likely to be acceptable to stakeholders and no significant side effects of this measure are envisaged. Informing the public and providing smartphone applications to non-scientists will increase acceptance of Early Detetction and Rapid Response (EDRR) methods compared to curative control measures (Hussner, 2017). However, it should also be noted that local stakeholders may choose not to report findings on private land to avoid associated management costs (Tanner, 2017).

ADDITIONAL COST INFORMATION

Implementation cost for Member States: There is no information available on the costs of surveillance actions for *Ludwigia* spp. Depending on the area to survey, the implementation costs will vary considerably. For example, in southern France, 80 km of a river have been surveyed to detect the riparian invasive vine *Humulus scandens* in 2012 and 2014, for a total cost of EUR 13,000 (Fried, 2018). Engagement with the local environmental NGOs, citizen scientists and utilization of volunteer networks can partly reduce these costs. Finally, some regional training workshops would probably be needed to train stakeholders in identification, management and safety aspects. It is estimated that each training workshop may cost EUR 3,000 (Tanner, 2017).

Cost of inaction: Regular surveillance can lead to detection of small populations that are easy to control at very low cost. Thus, inaction at this stage will lead to increase later cost of control when the population is well established.

cost-effectiveness of the measure: This measure has the potential to be very cost-effective if Member States can cooperate with local natural history or botanical societies and utilize their expertise. Regional funding should be made available to local NGOs to monitor all potential invasive alien plants. The monitoring of *Humulus scandens* on the Gardon river (Occitanie region, South of France) by a team of two people has been estimated at EUR 167/km to survey (Fried, 2018).

Socio-economic aspects: There are no socio-economic aspects to detail for this measure.

LEVEL OF CONFIDENCE*

Established but incomplete.

Few documents exist but the information provided is consistent.

* See Appendix

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

Manual control with hand tools.

MEASURE DESCRIPTION

For small infestations at the beginning of the invasion, individuals of *Ludwigia* spp. can be carefully pulled by hand or digging with spades. Because *Ludwigia* spp. have thick and long rhizomes, digging may be more effective than hand pulling. Manual removal efficacy is also improved if other vegetation is cut back to allow good access and inspection (Renals, 2017). Due to high regeneration capacity by fragments (Dandelot, 2004), it is important to remove the whole root system with hand tools and dispose of waste material by composting or burying away from aquatic habitats.

The objective of the measure is to eradicate a newly established population and prevent its further spread. If working on a river, it is advised to use a containment net placed around the treatment area (RAPID, 2018). It could also be a geotextile and a layer of sand, which inhibit the spread of plant fragments but which allow water to pass through.

SCALE OF APPLICATION

Manual control is best suited for small infestations < 10m^2 (Beck and Thibault, 2004; Hussner *et al.*, 2016; Renals, 2017). In Germany, about 28 kg/m^2 of fresh biomass of a dense *Ludwigia grandiflora* stand on an area of 1.5 m^2 has been removed during one single hand pulling operation. In four other sites, in which the individuals were more scattered in areas ranging between 3.5 and 30 m^2, *Ludwigia grandiflora* was successfully eradicated by hand pulling after three years (Hussner *et al.*, 2016). In the UK, eradicated sites by manual control ranged between 2 and 20 m^2 (Renals, 2018).

Depending on the resources and time available, it can be used for larger infestation but mechanical methods or combination of several methods are preferred for larger scale (see below).

EFFECTIVENESS OF MEASURE

Effective.

Based on reports from several eradication programmes, when applied in optimal conditions and at a relevant scale (<10m^2), manual control is very effective (Hussner *et al.*, 2016; Renals, 2017).

In a site in Germany, hand weeding was successfully applied for the eradication of the plants in 5 sites of varying size (1.5-30 m^2) with varying density of *Ludwigia grandiflora* (Hussner *et al.*, 2016). Within 3 days, more than 99% of the biomass (25 tonnes) was harvested. However, plant regrowth re-occurred in one extremely muddy site, where mechanical control was therefore applied in addition. Similarly, in a lake at Watton, Norfolk (UK), a small infestation of 2 m^2 detected at an early stage in 2010 has been eradicated by successive hand removal between 2010 and 2012 (Renals, 2018).

In Switzerland, an outbreak of *Ludwigia grandiflora* was found in the Cavoitanne pond in Laconnex, near Geneva in 2002. Four distinct mats of *L. grandiflora* colonized a total of ca. 120 m^2, while the total pond surface was 900 m^2. All the *Ludwigia grandiflora* individuals were removed manually and put in bags before being incinerated. The pond was monitored, and the same operation was undertaken again in 2003 and in the following years. In 2009, the species was considered eradicated in Switzerland (EPPO, 2011a).

Manual control is a tedious operation that requires a lot of care (Beck and Thibault, 2004). Therefore, it has a more limited efficacy on larger sites, or where the plant is well-rooted or established amongst dense vegetation (Renals, 2017).

EFFORT REQUIRED

While most of the biomass of a small infestation can be removed in one operation, a subsequent monitoring of the area is always necessary because forgetting a single piece of rooted rhizome or floating stem will allow recovery of the plant (Beck and Thibault, 2004). Based on examples provided above in Germany, Switzerland and the UK, between 3 and 7 years are required for a complete eradication of a small infestation.

In Germany, four persons during three days were required for the first stage of the hand pulling operation representing 120 working hours. Three persons representing 72 additional working hours undertook follow-up management measures over three years (Hussner *et al.*, 2016).

In Norfolk (UK), a small infestation of 2 m² detected at an early stage in 2010 has been eradicated through 3 years of manual removal (Renals, 2018). Another infestation of 20 m² in the Gloucestershire (UK) has been eradicated by manual removal over a six year period. A minimum of 5 years of post-eradication monitoring is necessary to assess for regrowth or new seedlings.

RESOURCES REQUIRED

In Germany, hand-pulling eradication of *Ludwigia grandiflora* during three consecutive years required a total of 232 human working hours (for both preparation and the hand weeding).According to the estimated hourly labour costs in the EU countries, the cost of such manual removal would range from EUR 1,330 to EUR 10,700. The costs for removal of the plant biomass and burning in a power plant were EUR 980.

Equipment may include boats, dry suits, wheelbarrows, forks, rakes. Vehicle and trailer if not disposing at site. Stop-nets and sweep nets (RAPID, 2018).

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Positive
Economic: Positive

Environmental effects: *Ludwigia* spp. often occur in sensitive aquatic habitats, and therefore any treatment method can have negative side-effects on the environment. Compared to chemical treatments or mechanical control, manual control of plants represents the method with the smallest risk of impact on non-targeted species. However, digging up the plants does disturb the soil so that some minor non-intended effects should still be expected.

Socio-economic effects: eradication operations can have positive socio-economic effects. If they are carried out by volunteers, this can create a sense of cohesion among the local population and help to raise awareness on environmental issues and the issue of invasive species. For larger infestations of *Ludwigia* spp., this can also be achieved through small contracts that can provide temporary employment to some people.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.

Manual control would be perceived as more environmentally acceptable to stakeholders compared to chemical treatments, especially for environmental NGOs involved in management actions but also for the general public.

ADDITIONAL COST INFORMATION

Implementation costs for Member States: Among the available methods for eradication, manual control is more expensive ranging from about EUR 1,000 to EUR 10,000 for small sites due to person working hours (Hussner *et al.*, 2016).

Cost of inaction: It is much easier and more effective to try to control this plant at the beginning of the invasion process when it has just established. Small populations are effectively controlled by hand, before significant clonal expansion (Hussner *et al.*, 2016). The cost of managing large and established populations will increase dramatically.

Cost-effectiveness: Manual control is a labour intensive and time-consuming method but it is often the best-suited method for controlling *Ludwigia* spp. in sensitive habitats. Eradication at an early stage of invasion can be very cost-effective as shown by the case reported for Germany (~ 10,000 EUR) (Hussner *et al.*, 2016) compared to control of widespread populations in France estimated to at least at EUR 340,000 per year in one region (Lambert *et al.*, 2009).

Socio-economic aspects: None to report.

LEVEL OF CONFIDENCE*

Well established.

All the numerous reports and published studies give consistent information (for example, Beck and Thibault, 2004; Hussner *et al.*, 2016; Renals, 2017; Renals, 2018).

* See Appendix

Mechanical control.

MEASURE DESCRIPTION

Mechanical control includes different options that vary according to the local conditions in the sites, including the site accessibility for digger or smaller excavators, soil type, and the possibility of emptying the invaded water bodies. If the water level can be controlled (for example in a pond, a small lake or a canal), it is recommended to first drain water from the waterbody. A digger can then be used to scrap off the *Ludwigia* spp. stands plus an approximately 5-40 cm-thick layer of sediments. The extraction of sediment intends to limit regrowth due to the possible presence of cuttings or seeds in the soil. A containment net should be set around the managed area, particularly if working in river systems. The containment net must be regularly maintained to remove fragments of *Ludwigia* spp. Post-control assessment is essential both immediately after the control operations to assess the need for further control, and additionally at least annually. Further control such as hand removal or application of herbicides may be required.

Seeking a suitable disposal option is often the most problematic and costly aspect of this method and must be undertaken before the start of the removal operation. Contaminated topsoil with fragments and plants have to be buried at least 1 m deep.

Note that this approach is only feasible if there is access for a digger, a suitable site for waste disposal, and the capacity to bury or otherwise dispose of the arising plant material. Mechanical removal must be undertaken in a methodical fashion with great care to prevent fragmentation, dispersal and further spread (Biosecurity measures described in the *Prevention of secondary spread of the species* section for boats must also be applied to vehicles used in the mechanical operations).

The objective of the measure is to eradicate a newly established population and prevent its further spread when the size of infestation make it impossible to be controlled manually.

SCALE OF APPLICATION

Mechanical control for rapid eradication can be applied at relatively large scale. In France, it has been successfully applied to a 1,850 m² pond covered two-thirds by *Ludwigia grandiflora* (Sarat and Béguin, 2015). Mechanical control has also been successfully applied on two ponds of 6,000 and 12,500 m² (Guillemot *et al*., 2017).

Mechanical control is best suited as soon as infestations exceed 100 m².

EFFECTIVENESS OF MEASURE

Effective.

Where the site condition allows (accessibility of digger, excavator) it is considered as an effective method.

In France, it has been successfully applied to ponds ranging from 1,850 m² to 12,500 m² highly invaded by *Ludwigia grandiflora* (Sarat and Béguin, 2015; Guillemot *et al*., 2017). In the Netherlands, *L. peploides* was successfully removed from an infestation covering several hundred square meters in 2007, and regrowth has not been observed since (June 2010) (EPPO, 2011b).

EFFORT REQUIRED

The mechanical operation can be done in one single stage but has to be followed by several manual removal efforts (or chemical treatments), and at least five years of post-eradication monitoring are usually advised (RAPID, 2018)

RESOURCES REQUIRED

A harvester, a transporter to store the harvested plant material and transport it to the shore, a conveyor to elevate the harvested biomass to a truck and a suitable disposal site is required (Gettys *et al*., 2014). The cost for the management of free floating plants with a harvester depends on the population size, the time for transporting, disposal costs and the accessibility of the water (Gettys *et al*., 2014; Laranjeira and Nadais, 2008) (see *Management* sections: *Mechanical control below* for costs).

For all activities from boats, personal floatation devices, skills in boat handling are mandatory for the safety of the operator (de Winton *et al*., 2013).

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Neutral or mixed
Environmental effects: mechanical control often implies draining water from ponds, lakes or canals which dramatically alter the abiotic conditions for fauna and flora of these habitats. Moreover, the use of heavy machines (diggers, tractors with trailers, excavator) compact the soil and the excavation of *Ludwigia* spp. with a layer of 5-40 cm sediments has a significant impact on non-target species.
Socio-economic effects: none to report.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

In some countries, such as in the UK, there are reluctances for using mechanical control in natural areas due to soil disturbances and related impact on non-target species (van Valkenburg, pers. comm., 2019). The use of large machinery (excavators, tractors) in natural areas can be considered as unacceptable by land managers, private owners or the public. However, the views can be more balanced according to the size of gear used (based on author's experience.). When manual control is not possible, mechanical removal remains the preferred method of management in Europe, where the use of herbicides in or near water is much more restricted.

ADDITIONAL COST INFORMATION

Implementation costs for Member States: The cost of mechanical control for eradicating populations of *Ludwigia* spp. ranged from EUR 6,800 to EUR 77,500. It is difficult to give an average cost per ha or per volume extracted, costs between different places may greatly vary due to different conditions (population size, site accessibility, pond, waterway or river) (EPPO, 2011a).

Cost of inaction: It is much easier and more effective to try to control this plant at the beginning of the invasion process when it has just established. Medium-size populations and dense stands in restricted areas are effectively controlled by mechanical means. The cost of managing larger populations connected to other populations in the catchment will increase dramatically (for example, control of widespread populations in France have been estimated to at least EUR 340,000 per year in one region (Lambert *et al.*, 2009)).

Cost-effectiveness: Mechanical control is the preferred control option for dense stands for which cost are much lower than for manual control (see the *Management* section for an attempt at comparison of cost per ha).

Socio-economic aspects: None to report.

LEVEL OF CONFIDENCE*

Well established.

All the reports and published studies give consistent information (Sarat and Béguin, 2015; Guillemot *et al.*, 2017).

* See Appendix

Chemical control.

MEASURE DESCRIPTION

Two herbicides are considered as effective against *Ludwigia* spp. in or near water: glyphosate (usually applied with an adjuvant to aid adhesion to leaves) andthe auxin-type herbicide 2,4-D. Availability of herbicides and related legislation varies significantly from country to country (EPPO, 2014). Options for use of herbicides in aquatic environments are very limited in most EU countries. It is important to note that EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

Herbicides are particularly useful to control the terrestrial form of *Ludwigia* spp., thus avoiding deoxygenation problems associated with chemical control of *Ludwigia* spp. in water bodies (see side-effects). Its application could be more suitable for sites that have poor access for mechanical or manual removal, or as a treatment following mechanical removal. Herbicide treatment is most effective in dry conditions (such as, no rain after applications).

SCALE OF APPLICATION

In the UK, eight sites of *Ludwigia* spp. were treated with herbicides. The initial size of the infestation ranged from 5 to 1,100 m². Another eradicated site had an initial infestation size of 3,000 m², but herbicides were applied after three years of manual removal.

EFFECTIVENESS OF MEASURE

Effective.

In the majority of eradicated sites in the UK chemical control has been used: in 8 sites, only herbicides (mostly glyphosate) have been used, in 3 other sites, herbicides have been used followed by manual removal (Renals, 2018). Liquid glyphosate formulations were effective on in reducing biomass of *Ludwigia* spp. when used with an adjuvant. However, this method requires repeated applications over a number of years and often results in tiny fragments surviving in the soil (RAPID, 2018).

It should be noted that glyphosate is effective only on emerging or floating materials (not underwater). Therefore, i) chemical treatments should be undertaken from early spring to summer when aquatic plants are present on the surface of the water, and ii) herbicide treatment may not be appropriate where the water level fluctuates. The density of the canopy is also an important factor that can limit the success of herbicide application, in particular glyphosate. Therefore, herbicides should be applied before *Ludwigia* spp. reaches a significant biomass (such as June or July for *Ludwigia grandiflora,* EPPO, 2011a) to get the best canopy penetration leading to a more effective control.
In summary, chemical control is particularly effective when herbicides are applied in underoptimal conditions (such as *Ludwigia* spp. individuals are emerged, no water levels fluctuation, terrestrial forms, and dry weather).

EFFORT REQUIRED

Depending on the size of the initial infestation, eradication based on chemical control require repeated applications during one to seven years (Renals, 2018). For example, one single spray has been sufficient to eradicate two populations, one of 9 m² and the second of 90 m² in two ponds (Renals, 2018). A stand of *Ludwigia grandiflora* of 700 m² in a farm pond required 8 sprays over 4 years to be completely removed.

RESOURCES REQUIRED

Equipment required include a knapsack sprayer, preferably with a long-lance (RAPID, 2018). The cost of control in the UK between 1998 and June 2010 for a total of 2.38 ha was 27,320 GBP (ca. 30,400 EUR) including method development costs, which is equivalent to 11,467 GBP/ha (ca. 12,700 EUR/ha) (EPPO, 2011a). These costs are ongoing until eradication will be achieved. In the US, the average cost of herbicide treatment during a 3-year project period in California ranged between 300 and 600$/ha (ca. 270 – 540 EUR/ha) (Meisler, 2008).

SIDE EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Positive
Environmental effects: the application of herbicides in aquatic systems can have an impacts on non-target species. For treatments in water, the main risk is deoxygenation, if large decomposing biomass of *Ludwigia* spp. is not removed. If the pond is heavily infested with *Ludwigia* spp. it may be best to treat the pond in sections and let each section decompose for about two weeks before treating another section. Aeration, particularly at night, for several days after treatment may help control the oxygen depletion (RAPID, 2018).
Socio-economic effects: none to report.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

In most EU countries, including the Netherlands and France for *Ludwigia* spp. management, there are strong and increasing reluctances for using chemical control in natural areas or in aquatic habitats. Since 2009, France no longer allows herbicide use for any applications in aquatic habitats due to perceived risks and indirect effects on reduced O_2 concentrations in water (Haury *et al.*, 2010).

ADDITIONAL COST INFORMATION

Implementation costs for Member States: Based on the experiences developed in the UK, the cost of chemical control for eradicating a small newly established populations was about 11 467 GBP/ha (ca. 12,700 EUR/ha) (EPPO, 2011a).

Cost of inaction: It is much easier and more effective to try to control this plant at the beginning of the invasion process when it has just established. Medium-size populations and dense stands in restricted areas are effectively managed by chemical means. The cost of managing larger populations connected to other populations in the catchment will increase dramatically (for example, control of widespread populations in France have been estimated to at least EUR 340, 000 per year in one region (Lambert *et al.*, (2009)).

Cost-effectiveness: herbicides are considered as cost-effective for eradicating small populations of newly established *Ludwigia* spp.

Socio-economic aspects: None to report.

LEVEL OF CONFIDENCE*

Established but incomplete.

All the reports and published studies give consistent information. However, the available data is only from the UK and the US. Depending on available herbicides in other countries, some aspects of the measure (effectiveness, side-effects, costs) may differ.

* See Appendix

Manual control with hand tools.

MEASURE DESCRIPTION

The description of the method is the same as for 'Rapid eradication', only the aim of the measure is different here.

The objective of the measure is the containment of *Ludwigia* spp. in catchments where the species is already widespread. The aim is to contain the species and to limit its ecological and economic impacts by controlling in priority upstream populations, backwaters of rivers (and other areas of high biodiversity importance) as well as parts of the river or lakes used for recreation by the public.

SCALE OF APPLICATION

Manual control for containment of *Ludwigia* spp. has been applied at large scale in France, for example on a 69 km stretch of the Gardon River (Sarat *et al.*, 2016).

EFFECTIVENESS OF MEASURE

Neutral.

Manual control is very effective for the eradication of small populations (Renals, 2017). However, the method is very labour intensive on a large scale and it is difficult to maintain the effort over the long term (Sarat *et al.*, 2016). On the Gardon River, after 6 year of manual control on a linear stretch of 69 km that aimed to control all populations, the strategy has been revised in order to focus only on populations present in sensitive areas (areas where people use the river as a beach, and areas of concern for biodiversity (Sarat *et al.*, 2016)). This change in objective illustrates the difficulty of maintaining this measure on a large scale. Although it may be effective punctually over time, the slightest carelessness in the control operation can lead to major re-infestation. This measure is effective only if significant and sustained effort could be given.

EFFORT REQUIRED

This measure requires permanent effort as long as *Ludwigia* individuals are present in the target areas. On the Gardon River, each year, manual removal was done for about 5 months (from June to October) (Sarat *et al.*, 2016).

RESOURCES REQUIRED

The cost of manual removal along the Gardon River ranged from EUR 224,911 in 2012 to EUR 303,269 in 2014. Teams

Ludwigia grandiflora, L. peploides. © *Nagarazoku. CC BY-SA 2.0.*

of 4 to 10 persons were required for each section of the river. The team walks along the river, assisted by one to two motor boats, and equipped with nets and bags (Sarat *et al.*, 2016).

SIDE EFFECTS

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

Environmental effects: *Ludwigia* spp. often occur in sensitive aquatic habitats, and therefore any treatment method can have some negative side-effects on the environment. However, compared to chemical treatments or mechanical control, manual control of invasive plants represents the lowest risk of impact on non-targeted species. Digging up plants with rhizomes will disturb the soil so that some slight non-intended effects should still be expected. A positive aspect is that by walking along the riverside, teams can detect other invasive aquatic plant species early, which has been the case on the Gardon river for *Pistia stratiotes* or *Elodea nuttallii* (Sarat *et al.*, 2016).

Socio-economic effects: none to report.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Manual control would be perceived as more environmentally acceptable to stakeholders when compared to mechanical methods (for example, excavation) and chemical applications, especially for environmental NGOs involved in management actions but also for the general public. However, the high cost of this method when applied on large spatial-temporal scales can be easily criticized as being too costly and ineffective (Tassin, 2014).

ADDITIONAL COST INFORMATION

Implementation costs for Member States: Based on the experience on the Gardon River in France, the cost of manual control is relatively high ranging between EUR 4,000 to EUR 6,000 per km of river (Sarat *et al.*, 2016).

Cost of inaction: not known

Cost-effectiveness: manual control at large scale is not cost-effective (Sarat *et al.*, 2016).

Socio-economic aspects: none to report.

LEVEL OF CONFIDENCE*

Established but incomplete.

There is only one report for this measure applied on widespread populations (Sarat *et al.*, 2016), but the information is consistent.

* See Appendix

Mechanical and manual control.

MEASURE DESCRIPTION

The objective of the measure is to keep *Ludwigia* spp. at low densities to limit the ecological impacts associated with high densities of the plant (Mazaubert, 2015).

Two types of operations are usually implemented in combination:

- mechanical control followed by manual control on heavily invaded sites with the objective of moving to a management phase based solely on manual control the following years
- manual control in sites previously managed mechanically (during previous years), with two passes each year, in May and in November.

Mechanical control can be done by using an excavator or a boat associated to an amphibious mechanical shovel. In order to prevent spread of the species a number of precautions can be used, tarpaulins during evacuation, protective nets during mechanical work, and sifting of the water from the boat to recover the fragments of *Ludwigia* spp.

SCALE OF APPLICATION

In France, in the Marais Poitevin, this measure has been applied along 1,311 km of shores (Mazaubert, 2015). This is the preferred measure in France once the populations are widespread.

EFFECTIVENESS OF MEASURE

Effective.

The method is considered as effective in relation to the stated objective. Since 1999, the area under control increased (new areas were included in the control programme) while the work time remained identical and the biomass extracted decreased, showing a decrease of *Ludwigia* spp. populations. As a consequence, the number of sites with only manual control increased (Mazaubert, 2015).

EFFORT REQUIRED

This measure needs to be applied for a long period. For example, in France in the Marais Poitevin, this measure has been continuously applied for over 20 years (Mazaubert, 2015).

RESOURCES REQUIRED

For the purpose of carrying out this operation at the scale of the 1,340 km of shores of the Marais Poitevin, 10 contractual technical assistants are required from May to November of each year. In total, human resources represent an equivalent workload of nearly 55 months (10 fixed-term contracts for 5 and a half months) (Mazaubert, 2015).
At a smaller scale, the cost of the same measure for managing 850 m x 13 m of waterways during two years amounted to EUR 27,000 (Blottière and Damien, 2017).

Standard calculation of control costs is extremely difficult as it greatly depends on the characteristics of the sites and of the infestations (Lambert *et al.,* 2009). In the West of France, for the period 1990-2003, the costs were as follows for both L. grandiflora and L. peploides (Lambert *et al.,* 2009):

- Mechanical removal: 51 to 64 EURO per tonnes of fresh biomass removed, for highly invaded sites with very dense biomass.
- Manual removal: 1100 to 1330 EURO per tonnes of fresh biomass removed, for new infestations, and for removal of small isolated patches over larger areas after initial mechanical extraction.

Equipment required: i) an excavator or any other machine to extract the biomass of *Ludwigia* spp. (and sediments), ii) a tractor with trailers or truck with a bucket or any other means to export the biomass to a dedicated place of treatment, iii) protective covers on the ground to prevent the spread of small fragments of *Ludwigia* spp. during the loading of the waste into the skips (for example tarpaulin), iv) means for creating a filtering dam: windbreak synthetic mesh, protective nets.

SIDE EFFECTS

Environmental: Negative
Social: Positive
Economic: Positive
Environmental effects: such long term management could have initial negative impacts related to the use of mechanical means of control (such as digger, tractor, trucks). It is expected that on the long term, the move towards more manual control will decrease the environmental side-effects.
Socio-economic effects: in regions where Ludwigia spp. is widespread, such activities of long-term management can create jobs (Mazaubert, 2015).

ACCEPTABILITY TO STAKEHOLDERS

Neutral and mixed.

For the public the perception is often mixed. On the one hand, the removal of an invasive alien plant impacting socio-economical activities (boating, fishing, hunting) is perceived positively. On the other hand, cost can be very important. In the Marais Poitevin, the annual cost for control since 2000 was EUR 200,000 (EPPO, 2011a).

ADDITIONAL COST INFORMATION

Implementation costs for Member States: at the scale of one region in France (lower part of the Loire-Bretagne water basin), where both L. grandiflora and *L. peploides* are present, the total cost of 66 management actions have been estimated to amount EUR 340,000 for the year 2006 (Lambert *et al.,* 2009). Unit costs vary from a few hundred euros to about EUR 50,000 for one of them. In Belgium, sums of EUR 140,000 and EUR 126,000 were spent in 2005 and 2006 to clear 25 ha invaded by *L. grandiflora*, respectively (De Bruyn *et al.,* 2007).

Cost of inaction: it is difficult to estimate the cost of inaction at this stage.

Cost-effectiveness: the combination of mechanical and manual control is relatively cost-effective for controlling *Ludwigia* spp. at large spatio-temporal scales.

Socio-economic aspects: none to report.

LEVEL OF CONFIDENCE*

Well established.

All the reports are in agreement, so the information provided can be considered as well established (Blottière and Damien, 2017; EPPO, 2011a, Lambert *et al.,* 2009; Mazaubert, 2015).

* See Appendix

Physical methods.

MEASURE DESCRIPTION

The objective of the measure is to reduce the densities of *Ludwigia* spp. at an acceptable level in wet grasslands to avoid impact on agriculture and biodiversity (Ferdandez, 2018; Cazaban, 2018; Bottner, 2017).

Several management measures can be implemented in combination (or alone):

- thermal weeding with the use of a thermal burner (Fernandez, 2018)
- mowing with export of cut plants (Fernandez, 2018; Cazaban, 2018)
- ensilage with export of the biomass (Cazaban, 2018)
- restoration of the grassland with a soil tillage at a depth of 10-15 cm (Cazaban, 2018)
- scraping, soil tillage and sowing of desired grassland species (Bottner, 2017)
- mowing, soil tillage and sowing of desired grassland species (Bottner, 2017)

These measures have only been currently applied in experimental plots to test their effectiveness as part of an integrated approach, and are therefore addressed in one management table.

SCALE OF APPLICATION

These measures have been only tested experimentally in the Barthes de l'Adour (Landes, France) (Fernandez, 2018; Cazaban, 2018) and in the Marais de l'Isac (Loire-Atlantique) (Bottner, 2017). The experimental plots represented around 100 m².

EFFECTIVENESS OF MEASURE

Ineffective.

The results of the experimental trials showed that:

- mowing has a short term effect on the growth and height of *Ludwigia* spp. but not on the cover and there were no significant effect on the longer-term (after three years) (Fernandez, 2018). A positive effect on other non-target species was however observed (more cover)
- thermal weeding had no significant effect on the cover of *Ludwigia* spp. neither on the cover of other species (Fernandez, 2018)
- combination of scraping or mowing with soil tillage and sowing of desired grassland species was ineffective with similar cover of *Ludwigia* spp. in the year following the treatments (Bottner, 2017)

EFFORT REQUIRED

The described experiments have been conducted over 2 or 3 years. It is unknown whether improvement of the measures and its repeated use on the longer-term could have resulted in better efficacy.

RESOURCES REQUIRED

The cost of the different measures were estimated as follows (Cazaban, 2018):

- thermal weeding with the use of a thermal burner: EUR 565/ha
- mowing with disposal of cut plants: EUR 230/ha
- ensilage with disposal of the biomass: between EUR 580 and 750/ha
- combination of mowing and thermal weeding: EUR 557/ha
- combination of ensilage and thermal weeding: between EUR 573 and 659/ha
- restoration of the grassland with a soil tillage at a depth of 10-15 cm : EUR 48/ha

Equipment required include: i) tractor with a thermal burner ii) a tractor with mower, forage harvester and tillage tools.

SIDE EFFECTS

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

Environmental effects: the effect is mixed. In some of the experiments even if the reduction of *Ludwigia* spp. cover was not as high as expected, the cover of native grassland species increased (Fernandez, 2018), Agricultural practices applied (thermal weeding, soil tillage) can be detrimental for other non-target species.

Economic effects: If palatable grassland species recover and the density of *Ludwigia* spp. is reduced, a positive economic effect of the measure is expected for farmers. But at this stage, there is no clear evidence for such a trend.

Social effects: none to report.

ACCEPTABILITY TO STAKEHOLDERS

Neutral and mixed

As the results are not yet conclusive, it is difficult to estimate how this measure will be accepted. However, there is a strong demand from farmers whose grasslands are invaded by *Ludwigia* spp. to find an effective measure of control. In this situation, we can expect that any cost-effective measure will be acceptable by farmers.

ADDITIONAL COST INFORMATION

Implementation costs for Member States: direct cost will be low and mainly borne by farmers.

Cost-effectiveness: not known at this stage.

Socio-economic aspects: none to report.

LEVEL OF CONFIDENCE*

Well established.

Further studies are needed to improve and assess management measures to control terrestrial forms of *Ludwigia* spp. in (agricultural) wet grasslands. The level of confidence is unresolved.

* See Appendix

Biological control.

MEASURE DESCRIPTION

The introduction of a co-evolved, host-specific herbivore from the area of origin of the invasive alien plant can potentially provide sustainable control without affecting non-target indigenous plants.

The objective of the measure is to keep *Ludwigia* spp. at low densities to limit the ecological impacts associated with high densities of the plant.

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

There are no available examples of application of this measure at large scale for *Ludwigia* spp. However, it is acknowledged that biological control represents one of the most appropriate tools for the permanent ecological management of invasive alien plants in general, in particular when they are widespread and difficult to manage using other methods.

EFFECTIVENESS OF MEASURE

Effective.

Sheppard *et al.,* (2006) reviewed the invasive plants that would make the best candidates for classical biological control in Europe, based on their invasiveness, their distribution in Europe, history of biological control against the species taxonomic isolation from European natives to limit non-target damage, likelihood of suitable natural enemies. They identified *Ludwigia grandiflora* as a good candidate for management by biological control agents.

However, studies on the biological control of *Ludwigia* spp. are limited. For example, a field study conducted in the United States in 1994 with replication and pre and post measurements revealed that the introduction of *Lysathia ludoviciana* beetles into a pond significantly reduced the abundance *of Ludwigia grandiflora* (McGregor *et al.,* 1996). The beetles were introduced in July in a one-hectare pond containing *Ludwigia grandiflora*. Changes in *Ludwigia grandiflora* abundance were monitored in six 5 x 10 m pens. When the beetles were introduced into the pond, the abundance of *Ludwigia grandiflora* decreased from an initial average of 61 g / m^2 to an average of 7 g / m^2 between July and September. The average density of flea beetles ranged from 1 to 12 / m^2 during the study.

EFFORT REQUIRED

The biological control agent must establish and persist on the long term so that this measure is effective.

RESOURCES REQUIRED

Developing a biological control programme requires research to identify useful agents, and a risk analysis to ensure the absence of impacts on non-target species, and socio-economics. This is a long process that needs significant funds and research staff for many years.

However, once the biological control agent is released and established, the cost may be very low and consist only in staff time to monitor the impact of the biological control agent on *Ludwigia* spp.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed
Environmental effects: we consider the case where the biological control agent was chosen according to the rules given above (Sheppard *et al.,* 2006), and it is therefore very unlikely that there will be an unintended effect of this measure.
Socio-economic effects: none to report.

ACCEPTABILITY TO STAKEHOLDERS

Neutral and mixed

For the public the perception is often mixed. On the one hand, biological control could be perceived positively because it does not imply using chemical products or heavy machinery in natural areas. On the other hand, some people, especially in Europe, do not trust in biological control and fear non-intended effects associated to the introduction of a non-native species. Information campaigns may be required to limit this negative perception.

ADDITIONAL COST INFORMATION

Implementation costs for Member States: funding are necessary to develop research activities for the medium term (about ten years) for targeting the relevant biological agent, assessing all the risk and testing its efficiency in the field.
Cost of inaction: it is difficult to estimate the cost of inaction at this stage.
Cost-effectiveness: on the long-term, biological control is usually considered as very cost-effective for managing widespread invasive alien plants.
Socio-economic aspects: none to report.

LEVEL OF CONFIDENCE*

Unresolved.
Currently, there are only experiments and the measures have not been tested in the field in Europe.

* See Appendix

Environmental control.

MEASURE DESCRIPTION

All the management measures applied to control and contain widespread populations of *Ludwigia* spp. could be enhanced when combined with environmental control options(for example limit nutrient release at the catchment scale, shading, control of water table level) that aim to reduce suitability of abiotic and biotic site conditions.

Limit nutrient release at the catchment scale:
Nitrogen present in the drainage waters of crops is very favorable to the development and growth of *Ludwigia* spp. At the catchment scale, partnerships with farmers need to be developed to optimize fertilization levels and/or avoid fertilization runoffs from cultivated fields to the river systems. This could reduce eutrophication and limit the development of opportunistic invasive alien plants such as *Ludwigia* spp. whose performance becomes higher than native analogue species when resources become abundant.

Shading:
Ludwigia spp. are heliophilous species that need full light conditions to grow and to display their invasive behaviour. Thus, *Ludwigia* spp. grow less quickly in tree-lined canals and marshes covered with dense vegetation such as reeds. Where the riparian forests have been degraded, replanting trees and shrubs can prevent the establishment of *Ludwigia* spp. (Beck andThibault, 2004).

Control of water table level:
Ludwigia spp. develop in environments characterized by low to zero salinity. From 2 g/l of salt in water, the growth of *Ludwigia* spp. is halved; it becomes very weak beyond 5 g/l. Where possible (for example Camargue/France), allowing the marsh to dry in summer remains the simplest solution to limit the growth of *Ludwigia* spp. (Beck andThibault, 2004). The effectiveness of water stress can be combined with the action of salt. By capillary rise phenomenon, the salt present in the sheet will slow the growth and may even eradicate *Ludwigia* spp.

The objective of these measures could be i) specifically to prevent re-colonization of *Ludwigia* spp.after curative management by mechanical or chemical means, or more generally ii) to prevent establishment of *Ludwigia* spp.in riparian habitats, especially where human activities have degraded the riparian habitats.

SCALE OF APPLICATION

There are no available examples of application of this measure at large scale.

EFFECTIVENESS OF MEASURE

Neutral.
Applied alone these measures are not completely effective. As they are based on environmental conditions, the

Ludwigia grandiflora, L. peploides.

effectiveness is attributed to the heterogeneity of ecological conditions of infested sites. For example in Camargue, the effect of water level vary according to the actual duration of water and salt stress and the nature of the media (salt level, depth of the water table, other feeds water) (Beck and Thibault, 2004). Applied after curative management, this measure is effective and also makes curative measures more effective.

EFFORT REQUIRED

This measure will necessitate a strong initial effort (for example, planting trees in degraded riparian habitats, working with farmers and other stakeholders at the catchment scale to reduce pollutions in the river system) but if actions are successful, this measure does not need to be repeated over numerous years as for curative management. A simple survey to check that *Ludwigia* spp. establishment is prevented would be sufficient during the following years.

Decreasing of the water level to create dry and more salty conditions should be repeated over the years especially in places with little salt in the surface water.

RESOURCES REQUIRED

There is no information available on the cost of this measure.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed
Environmental effects: these measures, especially shading and limiting nutrient release at the catchment scale, will not only have a positive effects for controlling *Ludwigia* spp. and other invasive alien plants but will improve ecosystem services associated with riparian habitats, such as the provision of food, moderation of stream water temperature via evapotranspiration and shading, provision of a buffer zone that filters sediments and controls nutrients, and stabilization of stream banks. It also provides a corridor for the movement of biota (Hood and Naiman, 2000).

Socio-economic effects: although initial investment may be perceived as high, this is the only management measure that does not need to be repeated each year if the restoration of the habitat is achieved. On the medium- to long-term, it has rapidly positive economic effects with the cost of curative management saved. This will be most likely less expensive compared to solely direct management of *Ludwigia* spp..

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.
Public perception of this measure is expected to be positive. However, there may be problems with economic sectors who exploit gravel and disturb riparian habitats (creating sunny conditions favourable to *Ludwigia* spp.), and with the agricultural sector who might be reluctant to regulate the level of fertilisation inputs.

ADDITIONAL COST INFORMATION

Implementation costs for Member States: there is no available information for the cost of ecological management and restoration measures.
Cost of inaction: inaction (such as, leaving the habitat degraded, prone to re-infestation or new invasion) will increase the duration and therefore the cost of curative management measures.
Cost-effectiveness: Ecological control is very cost-effective when managing large populations over large scale. Moreover, it will be efficient for regulating several other invasive aquatic alien species.
Socio-economic aspects: none to report.

LEVEL OF CONFIDENCE*

Established but incomplete.
Although there are few case studies of environmental control so far, and no specific examples for *Ludwigia* spp., the confidence level of the information provided is established but incomplete.

* 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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