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European and Mediterranean Plant Protection Organization
Organisation Européenne et Méditerranéenne pour la Protection des Plantes PM 9/19 (1)

National regulatory control systems
Systèmes de lutte nationaux réglementaires

PM 9/19 (1) Invasive alien aquatic plants

Specific scope

This Standard describes procedures for control of invasive alien aquatic plants. This Standard focuses on invasive alien aquatic plants in freshwaters and wetlands, *i.e.* invasive alien plants having specialized adaptations for growing and reproducing in freshwaters. This Standard does not cover algae, nor plants of marine or brackish environments.

Specific approval and amendment

First approved in 2014-09.

Introduction

Many alien plants are intentionally introduced into EPPO countries, e.g. for the horticultural trade (see for instance Heywood & Brunel, 2009). Some of these plants have been identified as posing an important threat to biodiversity or as having other potential negative economic or social impacts in the EPPO region. It is recognized that, from some perspectives it is deemed desirable to import alien plants for research, breeding, horticultural, commercial and other purposes. However, when such plants are known or suspected to be invasive, their intentional import may present a risk to the importing country, should they accidentally escape or be voluntarily released into the environment.

Freshwater rivers, lakes, aquifers, and wetlands provide vital resources for humans, deliver ecosystem services and are rich and unique environments (Strayer & Dudgeon, 2010). Freshwater ecosystems (in particular surface freshwaters such as lakes, reservoirs, and rivers) are among the most extensively altered and endangered ecosystems on Earth (Carpenter *et al.*, 2011). Declines in biodiversity are far greater in freshwaters than in the most affected terrestrial ecosystems (Sala *et al.*, 2000; Dudgeon *et al.*, 2006).

Freshwater ecosystems are particularly vulnerable, and the impacts of invasive alien aquatic plants can be major, including threats to biodiversity by direct competition, changes in physico-chemical characteristics and in water flow, blockage of irrigation canals and of recreation areas, etc. Furthermore, few management measures are available for invasive alien aquatic plants, as in some countries no herbicides are authorized for use in the aquatic environment.

This Standard presents the basis of a national regulatory control system for the prevention, monitoring, early warning, eradication and containment of invasive alien aquatic plants and describes:

- General concepts concerning prevention and the main pathways of introduction for invasive alien aquatic plants;
- Elements of the monitoring programme that should be conducted to detect new infestations or to delimit an infested area;
- Measures aiming to eradicate pest populations (including incursions);
- Containment measures to prevent further spread in a country or to neighbouring countries from areas where eradication is no longer considered feasible.

Regional cooperation is important and it is recommended that countries communicate with their neighbours to exchange views on programmes in order to achieve regional goals of preventing further introduction and spread of invasive alien plants. This is particularly relevant considering the transboundary nature of many watercourses and surface-freshwater ecosystems across EPPO countries (e.g. see Espoo (EIA) Convention[1]). Invasive alien aquatic plants do not recognise political boundaries. Thus potentially effective management of an invasive alien aquatic plant in one

[1]Convention on Environmental Impact Assessment in a Transboundary Context (Espoo, 1991) - the 'Espoo (EIA) Convention' (http://www.unece.org/env/eia/about/eia_text.html) adopted in 1991 and entered into force on 10 September 1997 establishes procedures to manage transboundary impacts. According to the Espoo Convention (art. 1), a transboundary impact is any impact, not exclusively of a global nature, within an area under the jurisdiction of a Party caused by a proposed activity the physical origin of which is situated wholly or in part within the area under the jurisdiction of another Party. The Environmental Impact Assessment (EIA) process is a planning tool applied in many countries including the European Union.

area may be undermined by absence of a complementary program of management in an adjacent area (Mitchell, 1996).

Contingency plans aim to ensure a rapid and effective response to an outbreak of a pest which has been assessed as likely to cause a major economic and⁄or environmental impact. They can help the organizations involved in eradication of an outbreak to be prepared, especially when several parties need to cooperate. Adjustment of contingency plans following the evaluation of eradication campaigns enables the response to an outbreak to be improved. In addition, contingency plans represent a concrete opportunity to raise awareness on the plant being managed and to involve partners.

For the most efficient implementation of monitoring and control at the national level, cooperation with all the relevant public bodies (e.g. NPPOs, Ministries of Environment, Ministries in charge of water management), as well as with other interested bodies and stakeholders (e.g., private sector, associations, professionals) should be established.

Definitions and a description of existing legislative frameworks is provided in Appendix 1.

Target audience and context in which to use this Standard

This Standard is directed to NPPOs and competent authorities and organizations involved in the management of aquatic plants. Collaboration between institutions is necessary, at the local or national scale. Lists of invasive alien aquatic species are provided by EPPO; some of these species are recommended for regulation[2] (information available on the EPPO website). To consider whether a species represents a threat for a given area, the EPPO prioritization process for invasive alien plants (EPPO, 2012) may be used, as well as the EPPO Decision-support scheme for quarantine pests (EPPO, 2011). As a majority of plants, including aquatic plants, are introduced for ornamental purposes, actions involving the plant industry (plant importers, producers, sellers, landscapers) should be undertaken in order to implement good practices, for example through a Code of conduct (see EPPO, 2009 and Heywood & Brunel, 2009).

[2]As of May 2014, the following invasive alien aquatic plants are recommended for regulation and registered on the A2 list: *Crassula helmsii* (Crassulaceae), *Eichhornia crassipes* (Pontederiaceae), *Hydrocotyle ranunculoides* (Apiaceae), *Ludwigia grandiflora* and *L. peploides* (Onagraceae). Additional species are registered on the EPPO List of invasive alien plants for which countries should take measures to prevent the introduction and spread of these species: *Alternanthera philoxeroides* (Amaranthaceae), *Cabomba caroliniana* (Cabombaceae), *Egeria densa* (Hydrocharitaceae), *Elodea nuttallii* (Hydrocharitaceae), *Hydrilla verticillata* (Hydrocharitaceae), *Hygrophila polysperma* (Acanthaceae), *Lagarosiphon major* (Hydrocharitaceae), *Myriophyllum aquaticum* (Haloragaceae), *Myriophyllum heterophyllum* (Haloragaceae), *Pistia stratiotes* (Araceae) and *Salvinia molesta* (Salviniaceae).

Background information on invasive alien aquatic plants

Characteristics of aquatic plants

On the basis of biological characteristics as well as life history strategies, different growth form types have been characterized (see e.g., Arber, 1920; Sculthorpe, 1967; Mäkirinta, 1978; Margalef, 1983; Den Hartog & Van der Velde, 1988).

For the purpose of this Standard, aquatic plants are divided in three groups: floating plants, submerged plants, and emergent plants. These three categories have been chosen to describe species as other definitions of aquatic are not necessarily harmonized, such as hydrophytes, macrophytes, helophytes, etc.

Floating plants

Floating plants drift on the surface or in the water without being attached to the sediments. The species belonging to this group are dependent on the nutrients available in the water body, as they cannot use nutrient reserves in the soil/sediment. They are usually well equipped to capture high to very high nutrient levels. Plants belonging to this growth model are competitive in capturing dissolved nutrients and have a very fast vegetative reproduction. Examples include *Azolla filiculoides* (Salviniaceae), *Ceratophyllum submersum* (Ceratophyllaceae), *Lemna minuta* and *Lemna minor* (Araceae).

Submerged plants

These species are rhizophytes with leafy stems or with rosettes of leaves. They have a more or less extensive root system and can take various portions of their nutrient requirement (e.g., N and P) up from the sediments. The reproductive parts of these plants may be above water. Some submerged plants have a massive build-up of biomass, allowing them to become highly invasive. Examples include *Crassula helmsii* (Crassulaceae), *Egeria densa* (Hydrocharitaceae), *Elodea canadensis, Elodea nuttallii* (Hydrocharitaceae) and *Lagarosiphon major* (Hydrocharitaceae).

Emergent plants

These plants float in the water or are rooted in the sediments, often in shallow sections of the water body, with some parts emerging above the surface. Their emergent tissues may be adapted to their aerial existence in various ways. Examples include *Myriophyllum aquaticum* (Haloragaceae) and *Ludwigia grandiflora* (Onagraceae). Their emergent leaves may be adapted to their aerial existence in various ways and differ from the submerged leaves (leaf dimorphism). Species that root in the water but lack leaves adapted to the submerged state (e.g., *Arundo donax*, *Phragmites* spp., *Typha* spp.) do not fall under this category and are not treated in this Standard.

Major pathways of introduction and spread of invasive alien aquatic plants

Van Valkenburg & Pot (2008) demonstrated that alien aquatic plants are arriving in larger numbers and at higher frequencies than in the past due to increased movement in trade and of people. Indeed, thousands of ornamental aquatic plant specimens are being imported into the EPPO region every month (see Brunel, 2009 for further detail). Those imported aquatic plants may be used directly in ponds and lakes or may escape into the wild.

Plants are also introduced to improve fisheries (most often trout fisheries), for instance *Ranunculus* species.

Aquatic species may also be used as aquarium plants, and the dumping of the contents of aquaria is considered to have released some invasive alien plants in the wild (e.g. *Cabomba caroliniana, Crassula helmsii*) (Verbrugge *et al.*, 2011). Invasive alien aquatic species may also be introduced as contaminants of other non-invasive imported aquatic plants (Maki & Galatowitsch, 2004).

Some aquatic plants may also be introduced as contaminants of crops, such as rice and cotton. For instance *Eclipta prostrata* entered Sardinia (IT) as a weed of rice (Brundu *et al.*, 1998), and *Potamogeton pennsylvanicus* is considered to have entered Yorkshire (GB) as a contaminant of cotton (Arber, 1920).

Another introduction pathway is use in phytoremediation. Some plants such as *Eichhornia crassipes* are considered to hyper accumulate heavy metals and have been used for the treatment of industrial effluents and sewage waste water (Rahman & Hasegawa, 2011; Patel, 2012).

Once introduced into a river catchment, aquatic plants may then be spread by water currents or floods, by animals or human activities. Aquatic plants may indeed be spread through fishing material as well as through machinery. Water birds also convey aquatic plants from place to place (Arber, 1920; Guppy, 1893).

Impacts of invasive alien aquatic plants

Invasive alien aquatic plants may have indirect impacts on crop yield due to water losses (e.g. *Eichhornia crassipes* in Argentina, Lallana *et al.*, 1987). Their management also incurs high costs for the cleaning of canals and draining as they build up large biomasses during critical periods (Van Valkenburg & Pot, 2008).

Invasive alien aquatic plants may also have detrimental impacts on crops through competition such as in rice (e.g. *Eichhornia crassipes* in Portugal, Moreira *et al.*, 1999), and they may also be alternate hosts of other pests. By outcompeting wetland grasses, some invasive alien aquatic plants can reduce grazing space for livestock in wet meadows, as is the case for *Ludwigia grandiflora* (Dutartre, 2004).

Invasive alien aquatic plants have huge detrimental impacts on aquatic ecosystems. By building up a large biomass, they locally replace native plants, some of which may be rare and threatened and have impacts on fauna including fish and water fowl, as has been observed for *Ludwigia grandiflora* and *L. peploides* in France (Dandelot, 2004).

The dense monospecific stands formed by invasive alien aquatic plants reduce light to submerged species, thus depleting oxygen in aquatic communities (Ultsch, 1973). The resultant lack of phytoplankton (McVea & Boyd, 1975) alters the composition of invertebrate communities (Hansen *et al.*, 1971), ultimately affecting fisheries in the case of invasions by *Eichhornia crassipes* (see also Schultz & Dibble, 2011). Drifting mats choke vegetation, destroying native plants and wildlife habitats which are often of nature conservation value (Habitat Directive 92/43/EEC). Higher sediment loading also occurs under invasive alien aquatic plants mats due to increased detritus production and siltation, as is the case for *Eichhornia crassipes*.

Invasive alien aquatic plants cause significant changes in ecological processes and structures in the following way:

- The high biomass production leads to the slowing of waters, leading to changes of floral and faunal communities;
- The high biomass production may lead to high sedimentation of detritus and may influence the course and the speed of successions;
- Reduction in oxygen concentrations results in severe deoxygenation which is harmful to the aquatic fauna;
- Decreases in pH may be observed due to the suppression of aquatic photosynthetic processes;
- Changes in hydrological regimes may lead to increased risks of flooding.

Invasive alien aquatic plants therefore cause negative impacts on ecosystem services, in particular negative social impacts (affecting the quantity and quality of potable waters), by impeding the use of recreational areas (e.g. swimming, boating impeded by the invasion of *Eichhornia crassipes* in Spain, Cifuentes *et al.*, 2007 and by *Cabomba caroliniana* in the Netherlands, Van Valkenburg & Rotteveel, 2010), by threatening the production of electricity through hydropower generation or by creating suitable environments for the vectors of diseases e.g. snails, mosquitos (e.g. *Eichhornia crassipes* in Africa, Navarro & Phiri, 2000).

Caution against invasive alien aquatic plants

Caution must be exercised so as not to introduce an alien pest into a new country, region or habitat. It is recommended that an appropriate risk analysis be performed by the NPPOs of each country before introducing a new species through trade, aquaculture or cultivation programmes (Wersal & Madsen, 2012). A pest-specific management plan should include a section which provides important summary information on the pest and its biology and in particular information on its geographical distribution, quarantine status (listed by EPPO or in national legislation), morphology and identification, biology and ecology, habitats, pathways of entry and spread, impacts and control options together with references to sources of further information.

Monitoring of invasive alien aquatic plants

Regular delimiting surveys (according to the ISPM no. 6 *Guidelines for surveillance*, IPPC, 1997) are necessary to determine the geographical distribution of (invasive) alien aquatic plants and their incidence (see Baker *et al.*, 2012). These may be annual or with lower or higher frequency, according to the cases and availability of resources. Information on distribution is necessary to evaluate priorities between different species (see EPPO, 2012), to determine control measures, and to geographically locate countries or regions at risk of invasion. Control strategies need to be adjusted on a case-by-case basis according to the density and occurrence of the (invasive) alien aquatic species within a country.

Priority areas to survey are therefore ponds, lakes, rivers, canals, reservoirs for irrigation, etc. A focus can be put on waters rich in nutrients (Van Valkenburg & Pot, 2008) as they represent the most likely habitats of invasive alien aquatic plants. Indeed, excessive concentrations of phosphorus is the most common cause of freshwater 'eutrophication' which is characterised by a proliferation in the growth of problematic algal blooms and an undesirable disturbance to aquatic life (EEA, 2010[3]). This includes most inland waters subject to periodic management activities (regular disturbance), as well as nature development projects which create additional disturbance (Van Valkenburg & Pot, 2008). Another option is to monitor protected areas in order to avoid aquatic habitats of conservation value being invaded. In both cases, the whole water surface should be monitored, but particular attention should be paid along the shoreline and amongst vegetation (e.g. within *Arundo donax* or *Phragmites australis* stands).

As many invasive alien aquatic plants are still poorly recognized by those carrying out surveys, a publicity campaign dealing with particular aspects of invasive alien aquatic plants is required. User-friendly identification tools must be made available to the general public and field staff should be trained in identifying the species. For example, a field guide for invasive alien aquatic plants has been developed for the Netherlands (Van Valkenburg, 2011). Identification sheets were also developed in the framework of the EUPHRESCO DeCLAIM[4] project, as well as an interactive identification tool for invasive alien aquatic plants for the Netherlands.

[3]EEA (European Environment Agency) Freshwater quality - SOER 2010 thematic assessment (http://www.eea.europa.eu/soer/europe/freshwater-quality).

[4]The outcomes of the EUPHRESCO DeCLAIM projects are available in the Q-bank database http://www.q-bank.eu/Plants/

Furthermore, citizen science is gaining increased attention for the surveillance and reporting of pests including invasive alien plants. As monitoring emerging species requires enormous resources which are lacking, citizens are increasingly invited to provide data on the presence of particular invasive alien species which are already present in Europe and are sufficiently conspicuous and easy to identify. National projects have also been implemented with success (e.g. in Belgium, the United Kingdom, Norway and Sweden). In the United Kingdom, the project 'Plant Tracker'[5] launched an iPhone application to track the locations of three invasive alien plants and in particular of the aquatic *Hydrocotyle ranunculoides*. All aggregated data, once the verification is made, are then displayed on a map at the scale of the United Kingdom. Such initiatives not only allow the collection of original distribution data for important invasive alien species, but also raise awareness among the general public. Remote sensing can also be used for the monitoring of invasive alien aquatic plants, as has been done for mapping the spread of *Azolla filiculoides* in Spain by using hyperspectral sensors (Bustamante *et al.*, 2009), or *Eichhornia crassipes* and *Urochloa mutica* using SPOT 5 satellite imagery in Australia (Schmidt & Witte, 2010).

Taking decisions on eradication and containment actions

As invasive alien aquatic plants usually reproduce very vigorously and spread rapidly through water currents, eradication and containment may only be successful when undertaken at an early stage of invasion. Indeed, control actions undertaken may be costly with no satisfactory outcomes, as, due to rapid regeneration of some aquatic species, recolonization is very difficult to avoid within weeks.

The EUPHRESCO DeCLAIM project considered that the level of risk of an outbreak is determined according to the number of the patches, how widespread the species distribution is across different parts of a channel, the connectivity of the infested channel to other water bodies, as well as the activities on-going on the watercourse such as navigation and fishing as these may further spread the species. Other factors such as the availability of resources and the coordination of different actors are crucial in the success of a control action.

The decision-support scheme (DSS) for action on outbreaks developed under PRATIQUE (Enhancements of Pest Risk Analysis Techniques) which brings together a set of guidance and tools can be used for invasive alien aquatic

[5]The project 'Plant Tracker' has been launched by the University of Bristol and the Centre for Ecology and Hydrology who developed an iPhone application to track the locations of *Fallopia japonica, Hydrocotyle ranunculoides and Impatiens glandulifera* (http://planttracker.naturelocator.org/).

plants. The DSS is initiated by the collation of key information on the current outbreak situation, and then compares candidate measures in order to derive a strategy for action and/or contingency. This tool aims to assist National Plant Protection Organizations (NPPOs) in addressing and justifying eradication and containment campaigns effectively as well as in making priorities among actions (Sunley *et al.*, 2012).

When it has been decided that eradication or containment action should be undertaken, contingency plans can be elaborated to ensure a rapid and effective response to an outbreak of a pest assessed as likely to cause a major economic and/or environmental impact. Contingency plans can help the organizations involved in the eradication of an outbreak to be prepared, especially when several parties need to cooperate. Adjustment of existing contingency plans following the evaluation of eradication campaigns enables the response to an outbreak to be improved.

Stakeholder's involvement

It is strongly recommended that stakeholders be listed and involved during the elaboration of contingency plans for specific invasive alien aquatic plants. The involvement of affected stakeholders (e.g., landowners, natural areas managers, municipalities, etc.) in the preparation of a contingency plan promotes awareness of the invasive alien aquatic plants threats, encouraging vigilance together with good quarantine and hygiene practices (e.g. cleaning of vehicles, of material that may be contaminated with propagules of the invasive alien aquatic plants). It also helps to ensure that stakeholders are engaged and fully aware of what will happen if an outbreak occurs. Nursery industry professionals and aquatic species trade associations need to be involved to discourage them from selling or advertising invasive alien aquatic plant. This can be done through the development of a Code of conduct (see Heywood & Brunel, 2009). Indeed, as the main pathway of entry of invasive alien aquatic plants is trade for aquaria and ponds, an efficient preventive action consists of proposing alternative non-invasive aquatic species to replace invasive alien aquatic plants in trade. As an example, the UK organization 'Plantlife' has proposed a list of alternative plants to invasive alien aquatic plants to oxygenate garden ponds[6]. The Belgian project 'Alter IAS' implementing the Code of conduct on horticulture and invasive alien plants also proposed a list of alternative non-invasive plants[7]. Any collection of plants from the wild may be subject to national regulation.

Eradication of invasive alien aquatic plants (more details are given in Appendix 2)

According to ISPM no 5 (IPPC, 2013), eradication is defined as the application of phytosanitary measures to eliminate a pest from an area.

Any eradication programme for an invasive alien aquatic plant in the case of recently detected populations (including an incursion) should be based on the delimitation of an area within the country (or region) and the application of measures to both eradicate and prevent further spread of the pest. The feasibility of the eradication of a species depends on the size of the area infested, the type of the water body, the density of the population and the characteristics of the invasive alien aquatic plant including its reproductive strategy.

Some general recommendations can be found in Champion & Clayton (2002). The feasibility of physical removal is largely dependant on the extent of the infestation, and for plants that reproduce via clonal fragments on the frequency of their fragmentation. The eradication of invasive alien aquatic plants should take into account the biological characteristics of the species (see Appendix 2).

The success of habitat manipulation by drainage is largely dependent on whether it is possible to isolate the infestation and on the costs of collateral damage. Chemical control in Europe in an aquatic environment is highly controversial and tightly regulated.

The effective success of an eradication action and the good return on investment of such an operation requires a commitment of repeated operations for the necessary number of years and to monitoring activities for at least the duration of the seed bank of the species of concern.

Containment of invasive alien aquatic plants (more details are given in Appendix 3)

According to ISPM no 5 (IPPC, 2013), containment is defined as the application of measures in and around an infested area to prevent spread of a pest.

When eradication fails, the containment of an aquatic plant in the case of established populations is based on the application of measures to prevent further spread of the pest in the country or to neighbouring countries, to mitigate the negative impacts.

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[6]According to Plantlife, these alternative species are proposed: *Callitriche stagnalis* (Plantaginaceae), *Ceratophyllum demersum* (Ceratophyllaceae), *Eleocharis acicularis* (Cyperaceae), *Fontinalis antipyretica* (Fontinalaceae), *Hottonia palustris* (Primulaceae), *Hydrocharis morsus-ranae* (Hydrocharitaceae), *Myriophyllum spicatum* (Haloragaceae), *Myriophyllum verticillatum* (Haloragaceae), *Nuphar lutea* (Nymphaceae), *Nymphaea alba* (Nymphaceae), *Potamogeton crispus* (Potamogetonaceae), *Ranunculus aquatilis* (Ranunculaceae) (Plantlife & Royal Horticultural Society, 2010).

[7]The following alternative species to invasive alien plants have been proposed in the framework of the Alter IAS project (alter IAS Website http://www.alterias.be/en): *Callitriche palustris* (Plantaginaceae), *Caltha palustris* (Ranunculaceae), *Ceratophyllum demersum* (Ceratophyllaceae), *Myriophyllum spicatum* (Haloragaceae), *Nuphar lutea* (Nymphaceae), *Potamogeton natans* and *P. lucens* (Potamogetonaceae), *Ranunculus aquatilis* (Ranunculaceae) and *Sagittaria sagitifolia* (Alismataceae) (Branquart, Undated).

The containment of invasive alien aquatic plants should take into account the biological characteristics of the species (see Appendix 3). In addition to the management options consisting of manual, mechanical and chemical control, hydrological and integrated controls represent other long term options. Biological control of invasive alien aquatic plants may offer chances for the reduction of populations (Gassmann *et al.*, 2006) which have not yet been explored within a European context.

Communication and awareness raising

In order to increase awareness among stakeholders to prevent the entry, establishment or spread of invasive alien aquatic plants, a communication plan should be prepared by the relevant institutions covering aspects such as the impacts of the species and the measures to be taken to minimize the risk of introduction. Communication may also be needed in the event of an outbreak to highlight the measures being taken and ways to prevent further entry and spread of the pest.

Suitable publicity material (such as leaflets, posters, press releases, lakeside notifications, information on the internet, identification guide on invasive alien aquatic plants) could be developed and made available to stakeholders. Such communication and engagement is particularly important to the success of any management action in areas frequented by the general public. Communication may be done through the involvement of the general public and of stakeholders, in the monitoring of the species through citizen sciences (see Monitoring of aquatic alien invasive plants). The involvement of anglers and boaters may be especially useful as they can report sightings of the invasive alien aquatic plants, and as the cleaning of their material is indispensible to prevent the spread of these species.

Stakeholder or public participation in the decision making may represent an important part of the contingency plan. The development of a contingency plan may itself involve stakeholders and the general public, and covers communication needs in the event of an outbreak. Public participation can be defined as a continuous, two-way communication process which involves promoting full public understanding of the process, as well as a mechanism through which environmental problems and needs are investigated and solved by the responsible agency. The public would then be kept fully informed about the status of the invasion, the progress of action, policy formulation and verification of eradication or containment efficacy, but could also be solicited to provide their opinions and perceptions (Canter, 1996).

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Appendix 1 – Definitions and legislative frameworks

Freshwaters are defined as having a low dissolved solid concentration, usually less than 1 000 milligrams per litre (mg L^{-1}), most often salt[8]. In many national legislations freshwaters are defined as all waters of rivers, streams, lakes, ponds[9], lagoons, wetlands, impoundments, canals, channels, watercourses, or other bodies of water whether naturally occurring or artificially made. The term specifically excludes seawater and brackish water. Inland waters[10] are sometimes used as synonym for freshwaters. A number of key terms are generally used in international water law including, e.g. watercourse, term used in the UN Convention[11] to refer to a river, stream, or lake, as well as many types of aquifers.

According to the Habitat Directive (92/43/EEC), the following habitats are concerned: 3. freshwater habitats (31. Standing water and 32. Running water – sections of water courses with natural or semi-natural dynamics (minor, average and major beds) where the water quality shows no significant deterioration).

The Ramsar Convention[12] provides a framework for the conservation and wise use of wetlands. Wetlands are therewith defined as areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres. Ramsar sites may also incorporate riparian (banks of a stream, river, pond or watercourse) and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands.

A large *corpus* of legally binding and non-legally binding laws establish obligations to protect water resources,

[8]This upper limit of freshwater is based on the suitability of the water for human consumption. Brackish waters can be defined as those having a total dissolved-solids concentration of 1 000 to 35 000 mg L^{-1}. The upper concentration limit for brackish water is set at the approximate concentration of seawater (35 000 mg L^{-1}). Reference: Barlow P (2003) Ground water in fresh water-salt water environments of the Atlantic Coast. Circular 1262. US Department of the Interior. US Geological Survey. http://pubs.usgs.gov/circ/2003/circ1262/pdf/circ1262.pdf

[9]The term 'lake' or 'pond' as part of a waterbody name is arbitrary and not based on any specific naming convention. In general, lakes tend to be larger and/or deeper than ponds. Ponds are small and shallow, natural or man-made water bodies defined as wetlands by the Ramsar Convention. Ponds are small (1 m² to about 5 ha), man-made or natural shallow waterbodies which permanently or temporarily hold water (De Meester *et al.*, 2005). Reference: De Meester L, Declerck S, Stoks R, Louette G, Van de Meutter F, De Bie T, Michels E & Brendonck L (2005) Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. *Aquatic Conservation: Marine and Freshwater Ecosystems* **15**, 715–726.

[10]According to article 2 Directive 2000/60/EC (WFD), 'Inland water' means all standing or flowing water on the surface of the land, and all groundwater on the landward side of the baseline from which the breadth of territorial waters is measured.

[11]The United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention).

[12]Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971. UN Treaty Series No. 14583. As amended by the Paris Protocol, 3 December 1982, and Regina Amendments, 28 May 1987. [Article 1 - *For the purpose of this Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres*]. See also Shine C & de Klemm C (1999) Wetlands, Water and the Law. Using law to advance wetland conservation and wise use. IUCN, Gland, Switzerland, Cambridge, UK and Bonn, Germany. xvi + 330 pp.

achieve sustainable development[13], maintain and improve water quality conditions[14], etc. (see Iza, 2004).

EU water policies comprise a large body of legislation covering areas as diverse as flood management, bathing-water quality, chemicals in water, clean drinking water, groundwater protection and urban waste water. The EU Water Framework Directive (WFD[15]), adopted in 2000, was introduced to streamline the EU's large body of water legislation into one over-arching strategy.

The WFD has the ambitious objective to reach 'good status' for all water bodies in the EU in 2015 by establishing a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. Other Directives, such as the Birds Directive (BD[16]) and Habitats Directive (HD[17]), similarly set objectives for the conservation and enhancement of wetlands and their flora and fauna. These policies make cross-references to each other, in particular by ensuring that the protected areas established through the Natura 2000 network[18] are integrated into river basin management and marine strategies.

The EU Water Framework Directive (WFD) creates uniform legislation for water protection in Europe. The Directive demands the assessment and monitoring of all surface waters by the use of various biological quality elements, instead of relying primarily on chemical measurements. Following the Directive, river ecological quality assessment is to be based on four groups: phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna. The quality elements outlined in the WFD for macrophytes consist of taxonomic composition and abundance (EC, 2000). Macrophytes considered by the WFD are a heterogeneous group of plants (helophytic, and hydrophytic (including floating leaved) vascular plants, bryophytes and charophytes).

Herbicides are plant protection products (PPPs) used to control plant species that harm agricultural crops[19] and the environment. Aquatic ecosystems may be contaminated with PPPs as a result of spray-drift, leaching, runoff, and/or accidental spills, and when aquatic ecosystems contain species related to the target organisms of PPPs, undesirable side effects may occur (Brock *et al.*, 2006). In the EU Guidance Document on Aquatic Ecotoxicology (SANCO, 2002[20]), a document provided in support of Directive 91/414/EEC, procedures are described for prospective higher-tier testing to evaluate the ecological risks of PPPs before their marketing. However, besides Regulation 1107/2009 which repeals Directive 91/414/EEC, other EU legislation exists that deals with the derivation of Environmental Quality Standards (EQS) for chemicals in surface waters, such as the above cited WFD.

EPPO provides recommendations for regulation for invasive alien aquatic plants on the basis of Pest Risk Analysis to NPPOs, and the Bern Convention also provides recommendations to M inistries of the environment on invasive alien species.

Appendix 2 – Eradication programme

The eradication process involves four main activities:
(1) Surveillance to fully investigate the presence of the pest;
(2) Containment to prevent the spread of the pest;
(3) Treatment and/or control measures to eradicate the pest when it is found;
(4) Verification of pest eradication.

1. Surveillance

A delimitation survey should be conducted to determine the extent of the pest distribution (see the paragraph 'Monitoring of invasive alien aquatic plants'). Specific monitoring programmes may be planned to be part of contingency

[13]Convention on the Protection of the Rhine (New Rhine Convention) Bern, 12.4.1999. Sustainable development of the Rhine ecosystem on the basis of a comprehensive approach, taking into consideration the natural wealth of the river, its banks and alluvial areas.

[14]Convention on Cooperation for the protection and sustainable use of the Danube River (The Danube River Protection Convention) (DRPC). Sofia, 29.06.1994.

[15]Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. See also related acts (e.g. The Groundwater Directive 2006/118/EC developed in response to the requirements of Article 17 of the Water Framework Directive, Common Implementation Strategy).

[16]Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds.

[17]Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

[18]The Natura 2000 network is an EU wide network of nature protection areas established under the 1992 Habitats Directive. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats. It is comprised of Special Areas of Conservation (SAC) designated by Member States under the Habitats Directive, and also incorporates Special Protection Areas (SPAs) which they designate under the 1979 Birds Directive.

[19]According to Regulation 1107/2009, plant protection products are products, in the form in which they are supplied to the user, consisting of or containing active substances, safeners or synergists, and intended for one of the following uses: (a) protecting plants or plant products against all harmful organisms or preventing the action of such organisms, unless the main purpose of these products is considered to be for reasons of hygiene rather than for the protection of plants or plant products; (b) influencing the life processes of plants, such as substances influencing their growth, other than as a nutrient; (c) preserving plant products, in so far as such substances or products are not subject to special Community provisions on preservatives; (d) destroying undesired plants or parts of plants, except algae unless the products are applied on soil or water to protect plants; (e) checking or preventing undesired growth of plants, except algae unless the products are applied on soil or water to protect plants.

[20]SANCO Santé des Consommateurs (2002) Guidance document on aquatic ecotoxicology in the context of the Directive 91/414/EEC. European Commission, Health & Consumer Protection Directorate-General, SANCO/ 3268/2001 rev. 4 (final). Brussels (BE).

plans in case of invasion outbreaks. Infested areas and adjacent areas, especially downstream, that might receive seed or vegetative reproductive parts, should be monitored.

Monitoring programmes should be established at country, region or catchment levels to assess new infestations in inland waters. Monitoring could be prioritised according, e.g., to the proximity to potential introduction/escape foci, according to the environmental value of the inland water.

2. Containment

The biology of the species and its seasonality need to be carefully considered. Understanding the biology of the species is essential to allow effective management decisions. The entry and spread pathways of the species need to be carefully considered in order to apply the necessary preventive measures to stop additional entry or further spread of the invasive alien aquatic plant.

Management measures such as manual removal or chemical treatment should preferably be undertaken at the beginning of spring when populations are still small. As aquatic plants often have the capacity to regrow from fragments, the mechanical removal of the plant including topsoil should be preferred to manual removal which may leave some fragments behind.

Measures are suggested according to invasive alien aquatic plants biology[21].

If the species is sensitive to shading, such as *Cabomba caroliniana* and *Myriophyllum aquaticum*, sunlight should be blocked, suggested measures include covering flowing waters or drainage channels with opaque floating material, and using dyes in still waters.

If the plant is rooted in topsoil such as for example *Ludwigia grandiflora*, suggested measures include mechanical control using excavators to remove plant material and topsoil. The depth of the excavation depends of the depth of the roots of the plant (e.g. the plant is shallow rooted, and an excavation of 10 cm of top soil would remove the majority of plant material). The removed soil may be stockpiled to avoid escape of fragments or seeds (if the species produces viable seeds), and contaminated topsoil may be buried.

If the plant is floating, the removal of topsoil is not necessary if viable seeds are not produced.

If fragments of the plant including roots may regenerate new individuals, such as for *Cabomba caroliniana, Hydrocotyle ranunculoides, Ludwigia grandiflora* and *Myriophyllum aquaticum,* mowing, cutting, dredging and re-profiling should be avoided particularly in spring and summer when species are usually in a growing phase (generally, such measures should be avoided between the middle of March and the end of May, and these activities are not recommended between June and the middle of July in the EPPO region, to avoid impacts on other plant and animal species). Such measures may not be efficient for a high biomass production plant, and may even assist its spread. If the species is able to resprout from roots, biomass removal that does not eliminate the root system or that is not done in conjunction with herbicide treatment may result in re-growth of the plant. Filters should be applied to avoid the spread of the species downstream. Measures should be undertaken to inform the users so that recreational activities (e.g. boating, fishing, swimming) and usual management activities (e.g. mowing of river banks) cannot spread the species.

If buoyant stems can float and spread as is the case for *Cabomba caroliniana,* management equipment should be washed out carefully (this can be done with a hydro-jet), fragments should be collected and destroyed (they should be buried, dried and burnt, or be given to cattle when palatable and when there is no risk of seed dispersal). Filters should be applied to avoid the spread of the species downstream.

If the species has a high biomass production, as for instance *Hydrocotyle ranunculoides*, when either chemical control or mechanical removal actions are undertaken, the risk of deoxygenation is very high, particularly in late summer-start of autumn when the plant has built up dense populations. Treated patches should therefore be separated by the same length of an untreated section, usually 500 m maximum, to avoid deoxygenation of the watercourse.

3. Treatment and control programme

Whatever the technique used, once cleared, sections of the water body should be isolated to prevent further invasion.

For any management measures, decaying plant material in stagnant water bodies (without removing biomass) leads to an increase biochemical oxygen demand and subsequently a decreased dissolved oxygen and increases in nutrient loads. Managed plant material needs to be removed but this should be done in a way to minimize disturbance.

Manual removal

This technique should be used when patches are new and/or small, in areas that are sensitive to disturbance such as nature areas and as a follow up technique after mechanical or chemical control later in the season. It is an essential part of an eradication campaign as control cannot be achieved by either gross mechanical removal or by herbicides alone.

Mechanical removal

Mechanical control consists either of using machinery to cut and collect the plant material. Manual hand picking may follow any mechanical control technique.

[21]Recommendations for *Cabomba caroliniana*, *Hydrocotyle ranunculoides*, *Ludwigia grandiflora* and *Myriophyllum aquaticum* in a northwest European setting are given in the office guides from the EUPHRESCO DeCLAIM project (Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011a-d).

Several machine types can be used for cutting and collecting plant material (Matthews *et al.*, 2012), as for instance:

- Passive cut with the use of a blunt V-blade towed behind a boat (see Fig. A1). This technique has been used to remove *Lagarosiphon major* in Ireland. Divers were required to assess the effectiveness of the V-blade, and this equipment was considered to have removed about 95% of *L. major*. One disadvantage of the method is that the collecting of plant biomass is only partially possible and spread is stimulated.
- Active cutting boat: boats are equipped with cutter bars with hydraulic control of the depth and angle of the cutter bar in the water (see Fig. A2). Plants are cut more efficiently than with cutting boats using a V-blade. They have the same disadvantage concerning collecting plant biomass and spread.
- Harvesting boat: small boats with a hydraulic controlled rack on the front that can collect plants floating and present on the banks. Collecting plant biomass is only partially possible and spread is not prevented completely.
- Mowing basket: a steel bucket with cutter bar attached to a hydraulic arm of a tractor or excavator that can be lowered in drainage channels, small rivers and ponds, and cut and collect plant material very efficiently. Loss of collected plants is minimal and this machine is highly suitable to prevent spread of the removed plants.

Nevertheless, in the Netherlands, regular dredging to get rid of *Cabomba caroliniana* did not result in a permanent removal of this and other macrophytes, even when applied twice a year. A major cause of this lack of success is the influx of fragments of invasive alien aquatic plants and the absence of competition from other waterplants (Plant Protection Service *et al.*, 2011b).

Another technique consists of removing the vegetation in a watercourse by using a powerful water jet to re-suspend the vegetation as well as the soft sediment, after which the loose material is removed (see Fig. A3). This technique was quite successful when tested to control *Cabomba caroliniana* in the Netherlands (Plant Protection Service, 2011b).

Continuous efforts should be made to remove plants after such operations and as soon as they reappear. Consideration should also be given to disposal of collected plant material. Removal to dry bunded areas is acceptable for temporary storage, but deep burial or drying and burning are considered more effective long term disposal options (Plant Protection Service *et al.*, 2011a). The treated areas should also be fenced off to prevent the downstream spread of the managed invasive alien aquatic plant. In addition, mechanical removal of above-ground plant material from shallow wetlands can create substantial disturbances and should ideally be minimized (Plant Protection Service *et al.*, 2011d).

An experiment had also been attempted in the Netherlands using liquid nitrogen to kill the invasive alien aquatic plants. The method will not be repeated as it did not provide satisfying results (Plant Protection Service *et al.*, 2011c).

Blocking sunlight

The surface of a watercourse or its bottom when it is dredged can be covered with black geotextile. Stretches of geotextile need to alternate with open spaces so as not to asphyxiate the entire flora and fauna of the watercourse. An experiment using this technique was conducted for *Cabomba caroliniana* in the Netherlands (Fig. A4). Blocking the sunlight on the surface killed all underwater vegetation, but the effect over the long term is not clear as it is expected that after reopening, regrowth of macrophytes will occur, including of invasive alien aquatic plants. The coverage of the sediments at the bottom of the watercourse did not result in the suppression of *Cabomba caroliniana* in the Netherlands. Sedimentation occurred on the top of the geotextile, resulting in a recolonisation of the invasive alien aquatic plant (Plant Protection Service, 2011b).

Fig. A1 V-blade used to cut *Lagarosiphon major* in Rinerroon Bay, Ireland (Caffrey & Acavedo, 2007). © Photo reproduced with permission of J. Caffrey, Inland Fisheries Ireland.

Fig. A2 A weed cutting boat with adjustable mowing gear used to manage invasive alien aquatic plants in the Netherlands © R. Pot.

Fig. A3 Dredging using a powerful water-jet in the Netherlands. On the picture, the water jet is raised above water to illustrate its operation. © L van Kersbergen.

Such a method was also used in Ireland to control *Lagarosiphon major*, and the effectiveness of the operation was dependent on whether the targeted plants in the treated area were cut prior to textile placement (Fig. A5).

The use of dyes has also been tested in the Netherlands. In a newly created shallow pond, several methods to control *Crassula helmsii* were deployed simultaneously after complete drainage appeared not to be feasible and physical methods for shading the entire pond were not possible. Treatment with a mixture of soluble red and black dyes, commercialized for the control of invasive alien aquatic plants and phytoplankton, started in January 2013. Biomass of submerged vegetation was recorded prior to dye treatment in October 2012 and again in October 2013. Measurement of photosynthetically active radiation at different water depths showed that prolonged light limitation was unlikely to have occurred even in the deepest part of the pond. Although pond morphology and water-level changes made application more complicated in this particular case, effective control of *Crassula helmsii* by 'shading' with dyes appears unlikely given the extreme growth plasticity of this species (Van Valkenburg & De Hoop, 2013).

Chemical treatment

Extensive literature is available on the use and efficacy of herbicides on individual invasive alien aquatic plants. Availability of herbicides and related legislation varies significantly from country to country. Options for use of herbicides in aquatic environments are very limited in most EPPO countries. EPPO recommends that only products registered in a country for a given purpose be used. All products should be used following the label instructions.

When considering the application of glyphosate in aquatic systems for example, it is important to assess the impact on non-target species. The use of glyphosate in enclosed waters is to be undertaken below certain concentrations, and such products should not be used in sites used for drinking water and fishing.

In the European Union, before the ban of use of many herbicides in aquatic environments, glyphosate, 2,4-D amine, imazapyr, triclopyr and diquat were the most used active substances to chemically control invasive alien aquatic plants. For example, *Hydrocotyle ranunculoides* has been successfully controlled with the use of glyphosate (in conjunction with the use of adjuvants TopFilm™ or Codacide Oil after August) or 2,4-D amine (Plant Protection Service, 2011c). *Ludwigia grandiflora* and *L. peploides* have also been controlled with good results in the UK with glyphosate, triclopyr and diquat (Plant Protection Service *et al.*, 2011d). *Myriophyllum aquaticum* was also successfully controlled in the UK with glyphosate (used at 1.9 kg. a.s. per ha with the adjuvant TopFilm™ at 600 mL per ha) (Jonathan Newman, CEH Wallingford, unpublished, cited in Plant Protection Service, 2011a).

Fig. A4 Surface of a watercourse covered with black geotextile to control *Cabomba caroliniana* in the Netherlands. © Johan Van Valkenburg, Dutch NPPO.

Fig. A5 Application of a geotextile at the bottom of a lake in Ireland to manage *Lagarosiphon major*. © Johan Van Valkenburg, Dutch NPPO.

The density of the canopy is an important factor in limiting the success of herbicide application, in particular glyphosate, and herbicides should be applied before the invasive alien aquatic plant reaches a considerable biomass (i.e. June or July for *Ludwigia grandiflora* according to the Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011a) to get the best canopy penetration leading to more effective control.

Chemical treatments may be undertaken from early spring to summer when the aquatic plants are present at the surface of the water, and such chemical treatment may be coupled with mechanical control. Retreatment would usually be necessary.

Although initial assessments may give the impression that herbicide treatment has been successful, the ability of dormant nodes to produce new shoots should not be underestimated. Often regrowth from apparently dead mats of plant material occurs within 6–8 weeks after treatment, requiring retreatment or mechanical removal of dead mats. Continuous monitoring should occur in the first year of treatment, followed by monitoring of any regrowth in the following spring and summer. Overwintering of untreated material should be avoided, as this results in very rapid spread within a catchment (Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011ab).

Adjuvants may increase the efficacy of chemical treatments. TopFilm™ absorbs the herbicide and sticks it to the leaf surface for up to 3 weeks, resulting in excellent rain fastness and a long slow release pattern. This prevents the herbicide being excreted rapidly and results in better control early in the season (before mid August). After August, better control is achieved by using Codacide Oil, a vegetable oil that rapidly dissolves the waxy leaf cuticle and results in very rapid absorption of the herbicide, overwhelming the plant's ability to excrete the herbicide, and a disruption of the ability to regulate transpiration by the leaves, resulting in fairly rapid cell necrosis and plant death (Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011b).

4. Verification of pest eradication

Any control activity should be conducted until there is no sign of the invasive alien aquatic plant targeted. For a species to be declared eradicated, follow up monitoring should not find any sign of the species for at least the duration of the longevity of its seeds or vegetative reproductive propagules.

Appendix 3 – Containment programme

In the case of an established population, eradication is difficult to achieve and the objective is the suppression of the plant. Containment measures aiming to prevent further spread of the pest to endangered areas or to neighbouring countries should be applied.

As for eradication, measures to prevent spread from an infested area should be applied (see Appendix 1, eradication programme). Manual, mechanical and chemical control (as described in Appendix 1) may be implemented to suppress populations of invasive alien aquatic plants. However, management using manual/mechanical removal, suction dredging and herbicides have the disadvantage of being costly, ineffective over the long term especially for established populations and to have potential detrimental environmental impacts. Other methods are therefore described below.

1. Hydrological control

Reducing the water level of impoundments to desiccate invasive alien aquatic plants may have a limited effectiveness. Plants, fragments of plants or seeds may well survive in mud, and a re-growth or germination would occur when refilling. In addition, such a measure is difficult to implement as it requires the removal of large volumes of water and is likely to have drastic consequences for the other species living in the ecosystem.

The hydrological regime of wetlands and watercourses (e.g. moist, saturated, partial or complete inundation) may influence the biology (e.g. growth and resilience) of a target invasive alien aquatic plant. Experiments have been conducted on the invasive alien aquatic plant *Juncus ingens* (Juncaceae) invading wetlands in Australia. A moist hydrological regime (soil held at field capacity) resulted in the most vigorous seedlings, while saturated conditions (flooding maintained level with the soil surface) resulted in the most vigorous mature *J. ingens*. Furthermore, seedling mortality was greatest under complete and prolonged inundation (Mayence *et al.*, 2010).

Some invasive alien aquatic species preferring river banks, such as *Ludwigia grandiflora* and *L. peploides,* may be susceptible to flooding if water levels are increased substantially early in the year for an extended period of time, resulting in prolonged periods of very low oxygen concentration at the growing points (Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011a). Such a technique has proven successful in managing *L. grandiflora* and *L. peploides* in natural areas in the Camargue (FR) (Jonathan Newman, CEH Wallingford, pers. obs., 2013) as well as other *Ludwigia* species in rice fields in Southeast Asia (Naples, 2005 in Dutch Plant Protection Service & Centre for Ecology & Hydrology, 2011a).

Hydrological control may be used in conjunction with other methods such as mechanical removal of plants, but a good knowledge on the biology of the targeted invasive alien aquatic plant and in particular its response to changes in hydrological regimes are required.

Experiences with salt management have proven successful. In the Lymington-Keyhaven Nature Reserve located in the estuarine area of Hampshire County in England, an ancient system of salt pans separated by low dykes is still in place although no longer used for producing salt. After a first record of a small patch of *Crassula helmsii* in 2007, a serious infestation of the species was observed in 2008. Spraying this invasive alien aquatic plant with herbicides or mechanical control were no longer feasible options to control the plant. Located on a coastal grazing marsh separated from the sea by a seawall, the ancient salt pans were inundated with salt water. Following the salt water treatment in July, the pans filled up with rainwater the following autumn, diluting the salt. In 2009, a 99% kill of *Crassula helmsii* was observed, the plant only surviving on places that could not be reached by the salt water. After 2 years the level of salt had reduced down to less than two parts per thousand. The method has been applied at other sites in the reserve with equally good results. While the salt has largely left the system at these sites, the original flora has not yet returned. It has been replaced by mud flats that attract a variety of wading birds that were not there before, thereby enriching the fauna of the nature reserve (Durnell P, pers. comm., 2014).

In France, *Ludwigia* spp. have also been managed with salt in Camargue and in Brière, and this method proved to be more efficient when coupled with the removal of the water and manual or mechanical removal (Dandelot *et al.*, Undated).

2. Environmental control

Several environmental methods may be used, none of which represents a complete solution.

Many invasive alien aquatic plants are favoured by high nutrient levels. As an example, Coetzee & Hill (2012) highlighted that water nutrient status was more important than herbivory by biological control agents for *E. crassipes* growth in South Africa. An important step in a sustainable *E. crassipes* control programme or any species favored by high levels of nutrients should therefore be to reduce the nutrient status (nitrogen and phosphorus) of the water body. Nutrient management efforts should focus on limiting the amount of runoff from agricultural areas, sewage systems, and managed turf areas (e.g., lawns, golf courses) (Rizzo *et al.*, 2009). To optimize such an action, the sensitivity of the targeted invasive alien aquatic plants to nutrient levels may provide useful information. For instance, the critical value below which *Myriophyllum aquaticum* is stunted is approximately 1.8 mg L^{-1} of nitrogen, while reducing water column phosphate does not appear to limit the growth of the plant (Sytsma & Anderson, 1993 in Plant Protection Service, 2011a).

Shade may be an effective method of control if the invasive alien aquatic plant does not establish well in shaded conditions, and is best achieved by planting trees on the south side of waterbodies, as was done to control *Hydrocotyle ranunculoides* in the Netherlands (Plant Protection Service, 2011c).

As some species do not grow well in water deeper than 50 cm (e.g., *Myriophyllum aquaticum*), deepening channels or the margins of lakes and ponds may reduce regrowth of the species. This needs to be coupled with other control activities (Plant Protection Service, 2011a).

The presence of invasive alien aquatic plants such as *Ludwigia grandiflora* and *L. peploides* may also be associated with wetland degradation: thick sediments in shallow, slow-moving, nutrient-rich waters in full sun. The long term control of such invasive alien aquatic plants would then benefit from restoration of riparian areas, improved water quality by reducing nutrient loads and sedimentation and possible channel modifications (including sediment removal) to encourage higher-quality habitat development (Plant Protection Service *et al.*, 2011d). All actions enhancing ecosystem resilience would therefore be beneficial, although there is a lack of available publications to concretely implement such operations.

3. Integrated control

Integrated control consists of a combination of several management options, and this is usually the option carried out in the field. For instance, mechanical and manual removal in combination with environmental management options is considered promising for a new control programme against *Hydrocotyle ranunculoides* in the Netherlands (Plant Protection Service, 2011c). Several studies of wetlands suggest that coupling mechanical control with flooding can also be an effective management option (Mayence *et al.*, 2010).

4. Mechanical containment

When any management measure is undertaken, floating barriers and filters should be used to avoid the spread of the species downstream (Fig. A6), as has been used in Spain for *Eichhornia crassipes*.

5. Biological control

Biological control represents in some cases the most appropriate tool for permanent ecological management of invasive alien plants, in particular when they are widespread and difficult to manage. The release of biological control agents is subject to specific procedures in countries and in the European Union, and requires researches on useful agents, and risk analysis to ensure the absence of impacts on non-target species. Sheppard *et al.* (2006) made a review of the best candidates for classical biological control in Europe, based on their invasiveness, distribution in Europe, history of biological control against the species,

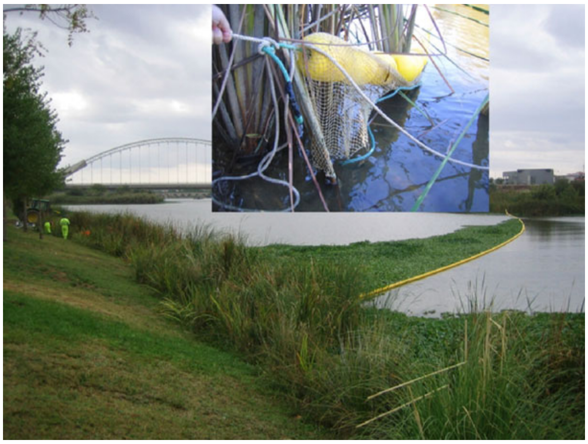

Fig. A6 Booms used to prevent the spread of *Eichhornia crassipes* on the Guadiana river in Spain. © Nicolás Cifuentes.

taxonomic isolation from European natives to limit non-target damage, likelihood of suitable natural enemies. They identified some invasive alien aquatic plants as candidates for management by biological control agents. These species are: *Azolla filliculoides* (Salviniaceae), *Crassula helmsii* (Crassulaceae), *Elodea canadensis* (Hydrocharitaceae), *Hydrocotyle ranunculoides* (Apiaceae), *Ludwigia grandiflora* (Onagraceae), and *Myriophyllum aquaticum* (Haloragaceae). Additionally, biocontrol agents have been used for the control of other species such as *Lagarosiphon major* (Hydrocharitaceae) (Baars *et al.*, 2010) or *Eichhornia crassipes* (Pontederiaceae) (Julien *et al.*, 2001).

Grass carp (*Ctenopharyngodon idella*) may also be used to control several invasive alien aquatic plants. Though, experiments in New Zealand had shown that only carp over 500 g were eating large quantities of *Lagarosiphon major*, when they had no other choice (Edward, 1974). Although grass carp is already present in the EPPO region, further introductions of this alien species would need to be considered with care as this fish is a non-discriminate grazer which may have an impact on the ecosystem.

Gassmann *et al.* (2006) consider that free-floating and emergent aquatic plants with genus-specific species of chrysomelid and curculionid beetles should represent the most promising options for biological control programmes in Europe. As many invasive alien aquatic plants do not have congeneric species in Europe, the risk is therefore minimal in Europe. This suggests that there is therefore considerable potential for safe biological control for invasive alien aquatic plants.