DOI: 10.1111/epp.12784

PM 9/8 (2) *Pontederia crassipes*

Specific scope: This Standard describes the control procedures aiming to monitor, contain and eradicate *Pontederia crassipes*.

Specific approval and amendment: First approved in 2009–09 as PM 9/8 (1) *Eichhornia crassipes*. Revision approved in 2021–09.

Authors and contributors are given in the Acknowledgements section.

1 | INTRODUCTION

Water hyacinth has for a long time been known as *Eichhornia crassipes*, but more recently its accepted name is *Pontederia crassipes* (Pellegrini et al., 2018; WCSP, 2020). This is the preferred name in the EPPO Global Database (EPPO, 2021).

Details on the biology, distribution and economic importance of *P. crassipes* (Pontederiaceae) can be found in Coetzee et al., (2017) and EPPO (2021).

P. crassipes is an introduced pest alien to the EPPO region and originating from South America. This species is considered one of the worst invasive aquatic plants worldwide. The plant has detrimental environmental and economic impacts: it is a threat to agriculture, plant health, the environment, public safety, recreation activities, water quality and quantity, and human health. *P. crassipes* has negative impacts on agricultural production worldwide. The most important impacts of the plant on crop yield are caused by water loss and increasing irrigation costs. It can also have positive impacts like nutrient reduction in water bodies or the use of plant material as compost, fodder or for manufacturing furniture and paper (Coetzee et al., 2017; Kleinschroth et al., 2020).

P. crassipes is an EPPO A2 pest recommended for regulation as a quarantine pest. The species is regulated under EU Regulation 1143/2014 as a species of Union concern. The species is also regulated in specific EPPO countries. In Georgia, Jordan and Turkey it is included on the A1 List of regulated pests.

In the EPPO region, established populations of *P. crassipes* occur in France (Corsica), Israel, Italy (including Sardinia), Jordan, Morocco, Portugal, Spain (including the Balearic Islands) and Turkey. It also occurs as a casual species (e.g. in Belgium, the Czech Republic, mainland France, the Netherlands and the United Kingdom). In Hungary and Germany, the species occurs in thermally abnormal waters [see EPPO (2021) for a distribution map]. The main pathway of introduction is as an ornamental plant for ponds and for aquaria.

This plant is well adapted to survive the existing procedures usually used for aquatic weed management, such as the killing and removal of plants, and draw down (lowering of the water level). *P. crassipes* is a free-floating and mobile macrophyte on variable water levels. It tolerates some degree of desiccation; its flowers and seeds can be produced within 12 weeks after germination. Reproduction is both vegetative, via daughter plant production, and by seeds. Daughter plants are spread through wind and wave action. In the Guadiana river in Spain, doubling time varied between 10 and 60 days (Ruiz-Téllez et al., 2008). Seeds are produced in very large numbers and persist in the seed bank for up to 20 years (Gopal, 1987).

Countries with areas at risk may wish to regulate this plant at the national level to prevent introduction into non-invaded areas and to manage infested areas.

EPPO member countries at risk are advised to prepare a contingency plan for the surveillance, eradication and containment of this pest.

This EPPO Standard presents the basis of a national regulatory control system for the monitoring, eradication and containment of *P. crassipes* and describes:

- Elements of the monitoring programme that should be conducted to detect a new infestation or to delimit an infested area
- Measures aiming at eradicating recently detected populations (including an incursion)
- Containment measures to prevent further spread in a country or to neighbouring countries in areas where the pest is present and eradication is no longer considered feasible.

Regional cooperation is important and it is recommended that countries should communicate with their neighbours to exchange views on the best programme to implement to achieve the regional goal of preventing further spread of the pest. This is particularly important in the case of 'international' river and freshwater systems.

For the efficient implementation of monitoring and control at a national level, cooperation between the relevant public bodies (e.g. NPPOs, ministries of environment, ministries in charge of water management), as well as with other interested bodies (private sector, associations) should be established.

2 | MONITORING OF *P. CRASSIPES*

Staff of organizations in charge of the monitoring of the species should be trained to recognize the plant at all stages in its lifecycle, even when present as small populations. This may include staff of NPPOs, botanists, managers of water reserves, nature conservation managers and municipal authorities.

An annual delimiting survey (according to FAO, 2018) is necessary to determine the geographical distribution of the plant and its prevalence. Such information is necessary to determine control measures. Control strategies need to be adjusted on a case-by-case basis according to the density and occurrence of the plant within a country.

Priority areas to survey are ponds, lakes, rivers, canals, water tanks, etc., with a focus on waters rich in nutrients. The whole water surface should be monitored, but particular attention should be paid to the shoreline and amongst riparian vegetation.

Remotely sensed imagery (Sentinel-2, drones) and derived indices (e.g. the Normalized Difference Vegetation Index, NDVI) can be very effective in monitoring and quantifying the invaded surfaces, in particular in difficult sites to scout (Datta et al., 2021).

3 | ERADICATION OF *P. CRASSIPES*

The eradication programme for *P. crassipes* in the case of recently detected populations (including an incursion) is based on the delimitation of an area within the country and the application of measures to both eradicate and prevent further spread of the pest. The feasibility of eradication for *P. crassipes* depends on the size and accessibility of the area infested and the density of the plants. These measures are described in Appendix 1.

4 | CONTAINMENT OF *P. CRASSIPES*

The containment programme for *P. crassipes* 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. These measures are described in Appendix 2.

5 | COMMUNICATION AND COLLABORATION

Professional (administrations, in particular managers of water reserves, etc.) should be informed by NPPOs, ministries of environment and forests and ministries in charge of water management about the threat of *P. crassipes* to natural and managed water bodies, and about preventive measures. This species is very easily recognizable and professionals (administration, managers of water reserves, etc.) as well as the public (e.g. in schools, public places, etc.) should be informed about its threats (see EPPO, 2014). A wide public could take part in monitoring the species (see Nang'alelwa, 2008) and can be involved in citizen science projects. As water hyacinth management may have undesired side effects on mosquito control, measures against the weed and against mosquitos should be coordinated (Portilla & Lawler, 2020).

ACKNOWLEDGEMENTS

This Standard is a revision of PM 9/8(1). The Standard was updated by Mr U. Starfinger (DE), Mr G Brundu (IT) and Mr van Valkenburg (NL). The Panel on Invasive Alien Plants reviewed the Standard.

REFERENCES

Albano Pérez E, Ruiz Téllez T, Ramos Maqueda S, Casero Linares PJ, Vázquez Pardo FM, Rodriguez Medina PL, Labrador Moreno J, López Gallego F, González Cortés J & Sánchez Guzmán JM (2015). Seed germination and risks of using the invasive plant Eichhornia crassipes (Mart.) Solms-Laub. (water hyacinth) for composting, ovine feeding and biogas production. *Acta Botanica Gallica*, 162, 203-214.

Barrett SCH (1989) Waterweed invasions. *Scientific American* 260, 90–97.

Brundu G, Stinca A, Angius L, Bonanomi G, Celesti-Grapow L, D'Auria G, Griffo R, Migliozzi A, Motti R & Spigno P (2012) *Pistia stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms.: emerging invasive alien hydrophytes in Campania and Sardinia (Italy). *EPPO Bulletin* 42, 568–579. https://doi.org/10.1111/epp.12004.

Center TD, Dray FA Jr, Jubinsky GP & Grodowitz MJ (1999) Biological control of water hyacinth under conditions of maintenance management: can herbicides and insects be integrated? *Environmental Management* 23, 241–256.

Coetzee J & Hill M (2008) Biological control of water hyacinth (*Eichhornia crassipes*) – the South African experience. *Bulletin OEPP / EPPO Bulletin* 38, 458–463.

Coetzee JA, Hill MP, Ruiz-Téllez T, Starfinger U & Brunel S (2017) Monographs on invasive plants in Europe N° 2: *Eichhornia crassipes* (Mart.) Solms. *Botany Letters* 164, 303–326.

Datta A, Maharaj S, Prabhu GN, Bhowmik D, Marino A, Akbari V, Rupavatharam S, Sujeetha JARP, Anantrao GG, Poduvattil VK, Kumar S & Kleczkowski K (2021) Monitoring the spread of water hyacinth (*Pontederia crassipes*): challenges and future developments. *Frontiers in Ecology and Evolution*. https://doi.org/10.3389/fevo.2021.631338.

Duarte L. (2017) Water Hyacinth Invasion on Guadiana River. Some Number, Facts and Thoughts. Steemit. Biology-Blogs. https://steemit.com/biology/@liliana.duarte/water-hyacinth-invasionon-guadiana-river-some-numbers-facts-and-thoughts. Accessed June 15, 2017.

EPPO (2006) EPPO Standard PM 3/66(2) Guidelines for the management of plant health risks of biowastes of plant origin. *Bulletin OEPP / EPPO Bulletin* 38, 4–9.

EPPO (2014) PM 9/19 Invasive alien aquatic plants. *EPPO Bulletin* 44, 457–471.

EPPO (2021) EPPO Global Database. https://gd.eppo.int/

EU (2014) *Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management* *of the introduction and spread of invasive alien species*., http://data.europa.eu/eli/reg/2014/1143/oj. Retrieved 21 October 2020.

FAO (2018) *ISPM 06 Surveillance*., https://www.ippc.int/static/media/files/publication/en/2019/02/ISPM_06_2018_En_Surveillance_2018-05-20_PostCPM13.pdf. Retrieved 30 November 2020.

Gopal B (1987) *Water Hyacinth*, 471 pp. Amsterdam (NL), Elsevier.

Gutirrez Eric, Huerto R, Saldaa P & Arregun F (1996) Strategies for waterhyacinth (*Eichhornia crassipes*) control in Mexico. *Hydrobiologia* 340, 181–185.

Harley KLS, Julien MH & Wright AD. (1996) Water hyacinth: a tropical worldwide problem and methods for its control. In: *Proceedings of the Second International Weed Control Congress Volume II* (Ed. Brown H, Cussans GW, Devine MD, Duke SO, Fernandez-Quintanilla C, Helweg A, Labrada RE, Landes M, Kudsk P & Streibig JC), pp. 639–644. Copenhagen (DK).

Hill MP & Olckers T. (2001) Biological control initiatives against water hyacinth in South Africa: constraining factors, success and new courses of action. Biological and Integrated control of water hyacinth, *Eichhornia crassipes*. In: *Proceedings of the Second Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth* (Eds Julien MH, Hill MP, Center TD & Ding J), pp. 33–38. Beijing, China, 9–12 October 2000. ACIAR Proceedings No. 102.

Hussner A, Stiers I, Verhofstad Mjjm, Bakker Es, Grutters Bmc, Haury J, van Valkenburg Jlch, Brundu G, Newman J, Clayton Js, Anderson Lwj & Hofstra D (2017) Management and control methods of invasive alien freshwater aquatic plants: a review. *Aquatic Botany* 136, 112–137.

Jones RW (2001) Integrated control of water hyacinth on the Nseleni / Mposa rivers and lake Nsezi, Kwa Zulu-Natal, South Africa. In: *Proceedings of the 2nd Meeting of the Global Working Group for the Biological and Integrated Control of Water hyacinth* (Ed. Julien MH, Hill MP, Julien MH & Center TD), pp. 123–129. Beijing, China, 9–12 October 2000. Australian Centre for International Agricultural Research, Canberra, Australia.

Jones RW & Cilliers CJ (1999) Integrated control of water hyacinth on the Nseleni / Mposa rivers and lake Nsezi, Kwa Zulu-Natal, South Africa. In: *Proceedings of the First IOBC Global Working Group Meeting for the Biological and Integrated Control of Water Hyacinth* (Eds. Hill MP, Julien MH & Center TD) pp. 160–167. 16–19 November 1998, Zimbabwe, Plant Protection Research Institute, Pretoria (ZA).

Julien MH & Griffiths MW (1998) *Biological Control of Weeds: A World Catalogue of Agents and their Target Weeds*, 4th edn. CABI Publishing, CAB International, Oxon (GB).

Julien MH, Griffiths MW & Wright AD. (1999) *Biological control of water hyacinth. The weevils* Neochetina bruchi *and* N. eichhorniae*: Biologies, host ranges, and rearing, releasing and monitoring techniques for biological control of* Eichhornia crassipes. Monograph No. 60, 87 pp. Australian Centre for International Agricultural Research (ACIAR), Canberra.

Kleinschroth F, Winton RS, Calamita E, Niggemann F, Botter M, Wehrli B & Ghazoul J (2020) Living with floating vegetation invasions. *Ambio* 50, 125–137.

Nang'alelwa F (2008) Public awareness activities on *Eichhornia crassipes* in the Victoria Falls world heritage site, Livingstone, Zambia. *Bulletin OEPP/ EPPO Bulletin* 38, 464–469.

Pellegrini MOO, Horn CN & Almeida RF (2018) Total evidence phylogeny of Pontederiaceae (Commelinales) sheds light on the necessity of its recircumscription and synopsis of *Pontederia* L. *PhytoKeys* 108, 25–83.

Portilla MA & Lawler SP (2020) Herbicide treatment alters the effects of water hyacinth on larval mosquito abundance. *Journal of Vector Ecology* 45, 69–81.

Ruiz-Téllez T, López EM, Granado G, Pérez EA, López RM & Sánchez Gurzmán JM (2008) The water hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain). *Aquatic Invasions* 3, 42–53.

Sushilkumar RP & Pandey AK (2008) Deleterious effects of herbicides on water hyacinth biocontrol agents *Neochetina bruchi* and *Alternaria alternata*. *Biocontrol Science and Technology* 18, 523–533.

Wright AD & Purcell MF (1995) *Eichhornia crassipes* (Mart.) Solms-Laubach. In *The Biology of Australian Weeds* (eds. Groves RN, Sheperd RCH & Richardson RG), pp. 111–121. R.G and F.J. Richardson, Melbourne (AU).

WCSP (2020) 'World Checklist of Selected Plant Families. Facilitated by the Royal Botanic Gardens, Kew. Published on the Internet; http://wcsp.science.kew.org/ Accessed 21 October 2020.'

APPENDIX 1 – ERADICATION PROGRAMME

The eradication process involves four main activities:
1. Surveillance to fully investigate the distribution of the pest
2. Containment measures 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.

Eradication depends on effective surveillance to determine the distribution of the pest and containment to prevent spread while eradication is in progress. Any eradication measures must be verified by surveillance to establish if attempts and measures have been successful. Staff in charge of the control of the plants should be trained for working in and around water.

1. Surveillance
A delimitation survey should be conducted to determine the extent of the pest distribution (see Monitoring). Infested areas and adjacent areas, especially downstream, that might receive seed or vegetative reproductive parts should be monitored.

2. Containment
Preventive measures include the prohibition of planting of *P. crassipes*, in particular in close proximity to sensitive areas, and prohibition of its release both into the natural environment and in human irrigation infrastructures and phyto-purification facilities. In the EU, the species is listed as an invasive alien species of Union concern and may not be traded, bred, kept etc. (EU, 2014). Unintentional transport of seeds or reproductive vegetative parts through water currents, flooding, fishing equipment, machinery and boats should be avoided. Equipment and machinery should be cleaned to remove mud before moving to an uninfested area. In water, fences (that extend into the substrate under shallow water) could be placed to prevent the spread downstream of the plant. Booms and cables can be used to prevent *P. crassipes* from entering hydro-power coolant intakes, fishing areas, drinking water intake areas, etc. The weight of mobile mats of aquatic plants, when pushed by wind or flow, or through growth expansion, can break booms and fences.

3. Treatment and control programme
Treatment should start early in the growing season and continue as long as regrowth is noted. Chemical and mechanical controls are the two most effective treatment measures for eradication.

Eradication is only possible if there are small and accessible populations of *P. crassipes*. A combination of mechanical and chemical control may give better results (see Appendix 2).

Mechanical control
Manual control can be done through hand-pulling or using pitch forks. This method is widely used in developing countries and can be an employment creation exercise. However, it is very labour intensive and only effective for small infestations. Operators should be warned not to spread the plant by leaving some parts in the water, and to remove mud from their footwear.

Mechanical control aims at removing biomass of the plant and should be used in conjunction with fences or barriers to prevent the plant from spreading. It is also used to prevent the plant from entering some areas, e.g. to prevent *P. crassipes* clogging water supply systems and hydroelectricity turbines. The remoteness and difficult accessibility of many infestations makes mechanical control unfeasible.

In Spain, crane trucks equipped with a grapple, backhoes with buckets and 35 m boom cranes were used (Ruiz-Téllez et al., 2008).

Mechanical control includes a wide range of equipment to collect and remove the plant: bulldozers, grapple buckets swung from shore or from boats, self-propelled collecting machines that pick the plant up then dump their load on shore via conveyors, dump trucks, etc. Mechanical control can be very costly but inefficient. For example, in the Guadiana river in Spain, a total of 26 million EUR was spent for management in the period 2005 to 2015 but during this period the plant increased its area of infestation (Duarte, 2017). Mechanical control requires repeated follow-ups as regrowth is very fast even from limited residual fragments (Brundu et al., 2012).

P. crassipes mats are usually quite heavy when fresh, as the plant contains around 95% water. Calculations must be made to determine how much wet weight of material can be removed per unit of time, since collecting boats have been known to sink (e.g. in Lake Victoria in East Africa). Plants pulled out should be put into waste disposal, or dried and then burnt (requirements for the treatment of biowaste of plant origin to ensure its phytosanitary safety are presented in PM 3/66 *Guidelines for the management of plant health risks of biowaste of plant origin*; EPPO, 2006). The use of plant material as sheep fodder is also considered safe. Composting and biogas fermentation, however, result in some viability of seeds after the process and are not recommended (Albano Perez et al., 2015).

Chemical control
Herbicides have been widely used to control small to medium size populations of *P. crassipes* that are accessible. The remoteness and difficult accessibility of many infestations makes chemical control unfeasible. Chemical control has the advantage of being quick and temporarily effective but must be regularly and frequently reapplied (Center et al., 1999). *P. crassipes* is very susceptible to 2,4-dichlorophenoxyacetic acid (2,4-D), diquat and

glyphosate (Gopal, 1987). These herbicides have resulted in successful control in small, single-purpose water systems such as irrigation canals and dams of around 1 ha in size (Wright & Purcell, 1995).

It should be noted that all products should be used following the label instructions and in line with the relevant plant protection product regulations. For applying 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 generally prohibited, and such products should not be used in sites used for drinking water and fishing.

In the EU, glyphosate and 2,4-D presently have registered aquatic uses. Availability varies significantly from country to country and the current product approvals are subject to change under the EU review process for plant protection products.

Glyphosate and other herbicides have been applied against the weed in China. While they have proven effective in killing the plant, they did not sustainably reduce the populations. Chemical control often involves treating areas that can be reached from land or by boat, since the cost of using hovercraft, fixed-wing planes or helicopters is prohibitive or restricted by national legislation.

4. Verification of pest eradication

Chemical or mechanical measures should be conducted until there is no sign of *P. crassipes*. Since the seeds can survive for many years in the soil (Gopal, 1987), follow-up monitoring should be undertaken for approximately 20 years.

5. Habitat restoration

After killing large masses of plants, the dead biomass should be removed to facilitate the restoration of the water body. For lasting success, artificial water eutrophication should be reduced (Hussner et al., 2017).

APPENDIX 2 – CONTAINMENT PROGRAMME

1. Surveillance

A delimitation survey should be conducted to determine the extent of the distribution of *P. crassipes*.

2. Containment measures

In the case of an established population, eradication is difficult to achieve and often 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.

3. Treatment and control

Chemical control

As for eradication, measures to prevent spread from an infested area should be applied (see Appendix 1). Chemical and mechanical control (as described in Appendix 1) may be implemented to suppress populations of *P. crassipes*. Applying a combination of different measures may prove more effective, as was the case in Mexico, using the herbicide 2,4-dichlorophenoxyacetic acid and machinery for removal (Gutierrez et al., 1996), where reasonably successful results were obtained.

Hydrological control

Reducing the water level of impoundments to desiccate *P. crassipes* is generally limited in effectiveness. In most situations, it is not possible to remove the large volume of water needed to cause the plant to desiccate. Plants must be collected as they survive well on mud. In addition, seed-bank germination can occur with refilling and negative effects on non-target organisms must be considered (Barrett, 1989). Floods can be effective in controlling the pest in areas where the pest would enter the sea or where the water salinity kills the plant (Coetzee et al., 2017).

Biological control

In tropical countries biological control is considered to be the most successful method and offers economical and sustainable control of the pest (Harley et al., 1996). In temperate areas (e.g. Southern Africa, the USA and China) acceptable levels of control have either not been achieved through this method or biological control is perceived to be too slow acting. In tropical areas, establishment of an efficient biological control for *P. crassipes* under ideal conditions can last 3–5 years (Julien et al., 1999). To date, biological control agents have been released in at least 33 countries (Julien & Griffiths, 1998). The most widely used agents throughout the world are the weevils *Neochetina bruchi* Hustache (Coleoptera: Curculionidae) and *N. eichhorniae* Warner, the moth *Niphograpta albiguttalis* (Warren) (Lepidoptera: Crambidae) and the mite *Orthogalumna terebrantis* (Acarina: Galumnidae) (Coetzee et al., 2017). It should be stressed that the release of biological control agents may be subjected to specific procedures nationally.

Integrated control

In areas where frost can cause high mortality of the biological control agents, but the plant is able to survive during winter, an integrated management approach is followed. This includes a combination of biological control, herbicide applications, manual removal and possibly most importantly, the reduction of nutrients entering the aquatic ecosystem (Hill & Olckers, 2001). Communication and citizen awareness may also be involved. Jones and Cilliers (1999) and Jones (2001) described an integrated management programme for the Nseleni River system in the more tropical region of South Africa. The key elements of this approach were primarily the appointment of one individual or organization to drive the control programme, the involvement of all interested and affected parties on the river system, the division of the river system into management units and the implementation of appropriate control methods for each of these management units. Using this integrated approach, some 19 km of river that was previously 100% covered by *P. crassipes* was initially cleared using mainly herbicide application and is maintained at 5% weed cover through biological control with occasional follow-up herbicide application around sensitive sites (water extraction localities) when necessary. This control operation occurred between 1995 and 2000 (Jones, 2001), and represents an example where a river has been returned from being heavily impacted by *P. crassipes* to a fully functioning aquatic ecosystem through appropriate management (Coetzee & Hill, 2008). Nevertheless, the use of herbicide may have deleterious effects on biological control agents such as *Neochetina bruchi* (Sushilkumar & Pandey, 2008) and on non-target organisms.