PONTEDERIA CRASSIPES MART. (PONTEDERIACEAE): ITS BIOLOGY AND SOCIO-ECOLOGICAL IMPACTS IN THE PHILIPPINES

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Abstract: The *Pontederia crassipes* Mart. (Pontederiaceae) is an invasive aquatic herb included in the world's worst weeds. The rapid proliferation of this species is due to its ability to propagate through seeds and stolon and its free-floating habit. Its infestation has caused problems to communities, economy, and ecosystems. This paper aims to discuss biology, current problems, and actions addressing the problems of *P*. *crassipes* in the Philippines. A literature review was done by sourcing published scholarly journals and government articles, news releases, citizen science, and personal observations. The taxonomy of *P. crassipes* has recently been re-circumscribed based on old molecular and new morphological data analysis. As a result, the former nomenclature, *Eichhornia crassipes,* has been placed as a synonym and the genus *Pontederia* has three subgenera. The *P*. *crassipes* is the sole species in the subgenus *Oshunae*. The Philippines has been dealing with the infestation caused by this plant up to this day, most notably in Laguna Lake, Pasig River, and Rio Grande de Mindanao. Manual and mechanical means were the primary actions to control this species. Fortunately, it provided additional income to small-scale fisherfolks. However, due to the difficulty of eradicating the plant, alternative ways of utilization were studied and developed, such as phytoremediation in polluted waterways, fibers for textiles, handicrafts, biofuel, and animal feeds. Further studies are recommended for its medicinal value, safety as an organic fertilizer, as well as on commercial viability of other alternative uses, potential biocontrol agents, herbicides, and the efficacy of phytoremediation in wastewater *in situ.*

Keywords: ecological impacts, invasive plants, *Pontederia crassipes*, social impacts, water hyacinth, weed management

Introduction:

The *Pontederia crassipes* Mart. (Pontederiaceae) is a perennial aquatic herb originally from Amazon, South America. It has been introduced to many countries worldwide as an ornamental plant for botanical ponds due to its striking inflorescence until it reached the Philippines in 1912 (Backer 1951). The distribution of water hyacinth as an ornamental plant has become detrimental because it rapidly spread

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and became noxious, it is even considered to be one of the world's worst weeds as it causes significant social, cultural, economic, and ecological problems (Coetzee et al. 2009; Valencia 2012; Teves 2019). It has been included in the top 10 world's worst weeds since the 70s (Holm et al. 1977; Chandrasena and Narayana Rao 2017) and recognized in the top 100 of the world's worst invasive alien species by the International Union for Conservation of Nature (IUCN) (Lowe et al. 2000).

The *Pontederia crassipes* is commonly known as 'water hyacinth' but sometimes as 'water lily'. The species is called a water hyacinth because of the resemblance of its inflorescence to a terrestrial hyacinth *Hyacinthus* from the family Asparagaceae. People consider flowering plants that 'float' on the water as 'water lily'. However, for the sake of clarity of this research, the scientific nomenclature *Pontederia crassipes* is used for the rest of the paper as an emphasis on one specific species.

This paper aims to study the socio-ecological and environmental impacts of *P. crassipes* in the Philippines. Specifically, the objectives are as follows: a) discuss the biology of *P. crassipes*, b) examine current problems of *P. crassipes* and c) identify strategies in addressing the *P. crassipes* problems in the Philippines.

Materials and methods:

Literature review was done and had been sourced from scholarly published articles using the keywords: *Pontederia crassipes*, *Eichhornia crassipes*, water hyacinth, water lily, and Philippines. The data for the distribution of water hyacinth was acquired from research grade iNaturalist observations, government press reports, news outlets, and research studies. Citizen science sightings were acquired through Facebook groups such as Philippine Biodiversity Net: Digital Library of Species, and Co's Digital Flora of the Philippines. Records on the existence of water hyacinths in the area are dated from 2010 up to the most recent information. Personal observations were also included.

Results and discussion:

Biology of *Pontederia crassipes*

The *Pontederia crassipes* Mart. (Pontederiaceae) – it is the current accepted scientific nomenclature of water hyacinth. It was discovered and described in 1823 and has been known as *Eichhornia crassipes* (Mart.) Solms since 1883 when it was placed under the genus *Eichhornia* (Téllez et al. 2008) to group the species with trilocular ovaries and numerous seeds (Simpson and Sanderson 2002). However, the re-examination of the phylogeny of the family Pontederiaceae based on old molecular and new morphological data analysis made known that the *Eichhornia* lineage has diverged into three lineages. Re-circumscription of *Eichhornia* resulted in changing its taxonomic rank from genus level to sub-genus level under Pontederia. This was done because sinking the *Eichhornia* into a broader, but morphologically cohesive *Pontederia* (monophyletic) genus is more taxonomically stable (Pellegrini et al. 2018).

Despite these changes in the taxonomy at the genus and subgenus level, the *P. crassipes* has always maintained its status as a species. It is a unique member in the family because it is the only one with this combination of characteristics: free-floating habit, stems produce stolons, flabellate ligules, and inflated petioles. Other combined characteristics include spirally alternate petiolate leaves, perianth loosely enveloping the fruit, and a nectar guide consisting of a sole spot. In fact, in the three lineages of *Eichhornia* (polyphyletic), the *P. crassipes* diverged separately. Hence, in the new taxonomy of the family, the *P. crassipes* is the sole species in the subgenus *Oshunae* (Pellegrini et al. 2018).

According to the Unified Species Concept by De Quieroz (2007), the only defining attribute that makes an organism a species is that it must evolve from other lineages. The

P. crassipes has met this criterion as mentioned above. Further validation is given by other pieces of evidence gathered from various species concepts (when they were treated as important properties of species) such as being phenetically distinguishable, diagnosable in terms of fixed character states, and ecologically divergent (De Queiroz 2007) further validates the species status of *P. crassipes*. As a result, the first binomial nomenclature of *P. crassipes* has regained its status as the accepted name, while the *E. crassipes* has been placed as a synonym.

The current widely accepted plant classification system, the Angiosperm Phylogeny Group IV (2016), also known as APG IV, classifies plants based on morphology but mostly molecular-based. Moreover, they also do not follow the taxonomic hierarchy ranks above order such as class, phylum, and kingdom, instead it uses the term 'clade' to indicate the position of the taxon in the phylogenetic tree (Stevens 2001 onwards). The updates on the taxonomy of the water hyacinth since Pellegrini et al. (2018) have been incorporated in the Angiosperm Phylogeny Website (Stevens 2001 onwards). Hence these changes were already recognized in the APG IV 2016.

Pontederia crassipes belongs to the clade Monocots or Monocotyledons or Monocotyledoneae or Lilianae based on the combination of morphological, molecular, and physiological characteristics, such as herbaceous, rhizomatous, growth sympodial, CYP716 triterpenoid enzymes 0, benzylisoquinoline alkaloids 0, stomata oriented parallel to the long axis of the lead, leaf blade linear, main venation parallel, leaf margin entire, inflorescence terminal racemose, and one cotyledon. It belongs to clade Commelinids, which is under the Monocots, mostly based on physiological characteristics, such as unlignified cell walls with >3.5 mg/g ferulate, primary and secondary cell walls mostly with (glucurono)arabinoxylans, and tapetum invasive or amoeboid. The next classifications are following the taxonomical hierarchal ranks. It belongs to Order Commelinales mostly based on physiological characteristics such as the lack of mycorrhizae, and seed coat testal and tegmic. Under Commelinales, the water hyacinth belongs to the family Pontederiaceae based on morphological and physiological characteristics such as leaves bifacial, broad blade, petiolate, leaf initially surrounding petiole of an older leaf, flowers sessile, pollen 2- or 3-sulcate, endotestal cells narrow, and cotyledon linear (Stevens 2001 onwards). The genus and species level were in the earlier part of the discussion.

In weed science, classification is based on morphology and life cycle. *Pontederia crassipes* is classified as a broadleaf based on morphological characteristics such as leaves being fully expanded with parallel veins (for monocots) (Donayre et al. 2019). It is also a perennial plant based on its life cycle (Donayre et al. 2018).

Current problems of water hyacinth in the Philippines

Pontederia crassipes have been widely distributed in many countries worldwide along the tropical and subtropical climate regions due to the introduction by a human fascination with its striking inflorescence. It became invasive, difficult to control, and brought devastating effects on the environment resulting in social, economic, and ecological impacts. Its invasiveness is not only attributed to its biology, being able to propagate sexually through its free-floating seeds and asexually through stolons (Barrett 1977; Datta et al. 2021), but also to its ecology wherein it thrives in any aquatic environment due to its tolerance to pollutants (Lituañas 2014), namely heavy metals such as cadmium, chromium, copper, lead, mercury, and nickel (Lituañas 2014; Madrid et al. 2014; Puzon et al. 2014; Napaldet and Buot 2019), and other contaminants such as ammonia, nitrate, and phosphate (Lituañas 2014; Acero 2019; Napaldet and Buot 2019). These contaminants were results from agricultural, aquacultural, industrial, and domestic wastes from the surrounding communities and infrastructures

(Ebol et al. 2020; Legaspi et al. 2015; Sacdal et al. 2021) and were absorbed and accumulated in the root and stolon tissues of the *P. crassipes* (Development Academy of the Philippines 2019).

The infestations in bodies of water pose the following problems: blockage of canals and rivers, obstruction of major waterways, a hindrance to water transport, clogging of irrigation and water supply intakes, micro-habitats for disease vectors, aquaculture-related problems such as fish kill incidents, waste direction flow, and the general decrease in littoral macroinvertebrate diversity (Coetzee et al. 2009; Ndimele et al. 2011; Dersseh et al. 2019; Teves 2019; Department of Environment and Natural Resources (DENR) 2020; Kleinschroth et al. 2021). In the Philippines, the *P. crassipes* is widely distributed in almost (if not all) bodies of water (Fig. 1, Annexes). Table 1 (Annexes) shows some of the reported problems caused by the infestation of *P. crassipes* in the bodies of water such as bay, creek, estuary, lake, marsh, specific rivers, and river systems. Most of these areas have fishing communities or were near agricultural lands.

The socio-ecological impacts of water hyacinth stem largely because of lakes and tributaries being heavily contaminated. Domestic and agricultural activity present along these areas often contributes to the increase of nutrient and pesticide discharge. In the case of Laguna Lake, concentrated levels of pollutants have exceeded the recommended level for a single pesticide in drinking water (Varca 2012; Cinco 2017). Other large waterways, such as Lake Mainit in Mindanao, also have high levels of pollutants and heavy metals, such as cadmium, lead, and mercury (Ebol et al. 2020), providing an environment that allows water hyacinth to spread.

The problems posed by water hyacinths are especially aggravated during monsoon season (Cinco 2017) when residents of nearby coastal communities are at an increased risk of disease vectors like mosquitoes because of wind-driving water hyacinths near said communities. Additionally, water hyacinth populations obscure waterways and block transport, such as small boats, and compromise the livelihoods of these coastal communities. As a result, addressing water hyacinth infestations has become a priority at local and regional levels in the Philippines (DENR 2021; Cabrera 2021).

Addressing *Pontederia crassipes* problems in the Philippines

There are three different methods of controlling the presence of water hyacinth: mechanical control, where the water hyacinth population is removed by hand or with instruments; chemical control, where herbicides such as 2, 4-D dimethyl amine 58% (4 kg ha-1) are used; and biological control, where fungus (i.e., Talaromyces), and insects are used (Ndimele et al. 2011; Catahay et al. 2017). In the Philippines, mechanical control is the only used method with varying instruments combined with the manual collection (Tab. 2). It is practical, however costly in terms of money, labor, and energy, and it is not a long-term solution.

Many studies have existed intending to promote proactive and sustainable solutions in mitigating infestation issues brought by the *P. crassipes* (Sierra-Carmona et al. 2022) which minimizes its negative impact while taking advantage of its potential social, economic, and environmental benefits (Kleinschroth et al. 2021). Analyses of the elemental and chemical properties of *P. crassipes* reveal that it is comprised of the following elements: carbon, oxygen, sodium, magnesium, aluminum, zinc, potassium, calcium, iron, potassium, and sulfur, with carbon and oxygen having the highest percentages (Ayanda et al. 2020). Due to the phytoaccumulation properties of this plant and with the increasing water pollution issues, phytoremediation studies have been extensive in many countries, as well as in the Philippines (Tab. 3, Annexes).

The phytoremediation capability of *P. crassipes* is one of the foundations of the Aquatic Macrophyte Biosorption System (AMBS) Technology developed by Zafaralla

(2010). The design is to establish a barrier made of short bamboo poles across a knee-deep river, stream, or creek, that holds the mat of bio-accumulating plants, such as *Pontederia crassipes*, to filter solid and chemical wastes. It was first applied in Molawin Creek in Los Baños which improved the water quality and once again became breeding sites of aquatic fauna such as tilapia. It is currently operational in bioparks in Tanay, Rizal and Lipa, Batangas (Sarian 2016; Villafuerte 2023).

Table no. 2 The different mechanical instruments used to collect *Pontederia crassipes* from the infested bodies of water in the Philippines

Instrument	Description	Reference
Boats and barges	Used in manual collection where the collectors use the boat to navigate the water to collect the plants and transport the collected plants to the shore. It also serves as an additional storage and transport vessel for the machine-collected plants. It is the most used instrument.	Valencia 2012; personal communication, January 12, 2019
Harvester I	It is a prototype of a locally fabricated dredger able to mechanically collect free-floating *P. crassipes* up to 25 kilograms per load. It was developed by the DOST-MIRDC and first deployed in 2012.	Valencia 2012
Harvester II	Also known as the High-Capacity Water Hyacinth Harvester. It is an improved model of Harvester I which is faster, more stable, has complete control gauges, has better scooping, and tripled the storage capacity of its predecessor up to 12.5 cubic meters. It was developed by DOST-MIRDC and first deployed in 2013.	Cortez 2013
Excavator	There were two kinds of excavators used in harvesting the *P. crassipes* in rivers, the amphibious excavator, and the normal excavator either on a bridge or on a floating or extended platform. This is mostly used in rivers, creeks, and estuaries, and shallow parts of the lake.	Dalan 2020; DPWH 2020
Trash skimmer	This instrument looks like the harvester but has one less mechanism. The DOST fabricated harvesters have a rotating reel at the front of the vessel to scoop the *P. crassipes* into the conveyor belt, while the trash skimmer does not have the rotating reel. Large trash skimmers have storage in the vessel, and smaller models do not have storage.	Dela Cruz 2020; DPWH 2020

Other alternatives and sustainable benefits of the water hyacinth have been explored in various studies in the country for the past decade (Tab. 4). While the water hyacinth cannot beeaten fresh like other edible green vegetables (Ndimele et al. 2011), it has the potential for use as aquafeeds and ruminant feeds for fish and shrimp, (Hontiveros and

Serrano 2015; Chavez et al. 2016), and livestock, such as dairy cows (Tumambing et al. 2019). Aquafeeds and ruminant feeds can be made especially viable given the significance of aquaculture in the Philippines. In 2021, total harvests from aquaculture farms reached 2,246.32 metric tons, contributing as much as 52.8 percent to the total fishery production in the country (Philippine Statistics Authority 2021). Among these, tilapia and shrimp are two of the most popular species currently farmed.

Table no. 4 Scholarly published studies on the alternative and sustainable uses of water hyacinth in the Philippines

Use	Findings	References
Antibiotic	The secondary metabolites, functional groups, and Total Flavonoid Content (TFC) of water hyacinth (WH) methanolic extract have the potential to inhibit Quorum sensing-controlled virulence factors of *Pseudomonas aeruginosa.*	Bautista et al. 2021
Aquafeeds	Water hyacinth leaf protein concentrate (WHLPC) can replace 25% of soybean meal protein in the formulated diets of white shrimp *Litopenaeus vannamei* (Boone) postlarvae.	Chavez et al. 2016
	WHLPC is a potential source of protein for the Nile tilapia.	Hontiveros and Serrano 2015
Biocompost	Nutrients (nitrogen, phosphorus, and potassium) in sundried compost and fresh compost in the soil have increased from medium to high levels with the addition of WH.	Bondoc 2020
Bioenergy	Polypyrrole-coated WH-polyester blended fabrics exhibited promising characteristics as super-capacitor electrode material.	Alzate et al. 2022
	WH converted into charcoal briquette with molasses as binding agent showed ignition time for 2-3 minutes.	Carnaje et al. 2018
	Hybrid process of bioelectricity generation using plant-microbial fuel cell (PMPC) and phytoremediation of Ni^{2+} from WH.	Pamintuan et al. 2018
Construction	Pulverized water hyacinth (PWH) as an admixture for concrete, 0.5% PWH may serve as a concrete accelerator which increases the setting time of concrete in cold weather while 1% PWH can be concrete retarder which reduces setting time of concrete in hot weather. Both resulted to increased compressive strength compared to a normal concrete cylinder.	Abana et al. 2021
Fiber	Mixed fibers containing 50% paper pulp and 50% WH fiber with 60% tearing resistance as a potential alternative trashbag.	Marces and Dapadap 2020
	WH pulps with long fibers replacing 25% to 75% of the abaca pulp or wastewater pulp as component of handmade paper had animproved tensile property suggesting better formation and bonding of fibers.	Mari 2012
Ruminant feeds	WH can be fed at 10%-40% inclusion rate to the Napier grass feed to Holstein Friesian x Sahiwal dairy cows and calves without affecting the rumen metabolism, serum metabolites, urine oxalate concentration, and milk yield and quality.	Amit 2019; Tumambing et al. 2019
	Ensiled WH is a best potential substitute to mature Napier grass.	Celeste et al. 2020

In Mindanao, the water hyacinth has already been used as organic fertilizer in North Cotabato (Sarmiento 2012) and biocompost in Lake Sebu. Bondoc (2020) found out in his study that the nutrient levels of the composts were increased with the addition of water hyacinth. Since it has phytoaccumulation properties that enable it to absorb heavy metals, it raised some concerns about its safetyin its use in agriculture (Ilo et al. 2020). However, some studies have addressed this concern that establishing water hyacinth as a biocompost or organic fertilizer is not dangerous to humans. Earthworms, such as *Eisenia fetida*, in vermicompost, could reduce heavy metals in soils as they are able to accumulate in their gut and skin (Turgay et al. 2011; Ilo et al. 2020) but proper management should still be observed (Guzman et al. 2020). Some microorganisms are capable of bioremediation or bacteria-assisted phytoremediation (Henao and Ghneim-Herrera 2021; Sondang et al. 2021).

The potential use of water hyacinth for bioenergy, especially using it as a biofuel, has been the sustainable goal of a start-up company in the Philippines called HiGi energy (est. 2015). This company provided livelihood to locals in Taytay, Rizal for collecting the water hyacinth. Despite the process of making the *P. crassipes* charcoal briquettes was not disclosed, they ensured that the products are relatively smokeless and can provide heat for as long as 90 minutes (The Good Energy 2019). The *P. crassipes* charcoal is also commercially available as compact briquettes in other shops in the Philippines mixed with coconut shell and husk which is claimed to be smokeless and can burn up to three hours (Casa de Lorenzo n.d.).

The Philippines is ranked third as the world's greatest plastic generator (Jambeck et al. 2015), and finding alternatives to plastic, apart from reducing single-use plastics, is another contribution to helping the environment. Fibers of water hyacinth did not only exhibit excellent results in bioenergy, as discussed earlier, but it has also been tested for its efficiency as a paper and launched as a textile (Mari 2012; Valencia 2012; DOST-Philippine Textile Research Institute 2014; Marces and Dapadap 2020).

The drying technology of water hyacinth has also been subject to some studies to ensure that the raw materials will not accumulate molds and will maintain its good quality as a raw material for handicrafts (Opiña 2008; Casas et al. 2012). Handicrafts using water hyacinth as raw materials have been long established in the Philippines. In fact, it has already been commercialized for this purpose. The Department of Trade and Industry (DTI) and Forest Products Research and Development Institute (FPRDI) have supported micro, small, and medium enterprises (MSMEs) in the processing of raw materials using the locally fabricated water hyacinth dryer (Martin 2013; Carmelo 2014; Araral 2015) and in training on making various designs of handicrafts (Technical Education and Skills Development Authority (TESDA) 2011; Araral and Decena 2017; Philippine Commission on Women 2019) which are export quality. As a support of the government to the MSMEs, there were shared service facilities (SSF) established in many provinces to promote the use of water hyacinth as a raw product for eco-friendly and sustainable handicrafts and biofuel (Martin 2013). There were also private companies that promoted the sustainable use of water hyacinth and sold their products commercially locally and internationally.

Conclusions:

Given its inclusion and as one of the world's worst weeds (Holm et al. 1977), the effects of the *Pontederia crassipes*, or commonly known as the water hyacinth, are well understood in terms of environmental, ecological, social, and cultural impact (Coetzee et al. 2009; Valencia 2012; Teves 2019). However, various studies have shown it is possible to mitigate the presence of water hyacinth by converting and processing it into commercialized water hyacinth scrapes and handicrafts. It may be concluded that despite its socio-ecological impact, *P. crassipes* shows potential in addressing different needs across various industries, as well as supplementing the livelihoods of coastal and swamp communities suffering from regular infestations.

Given this, the following studies are recommended:

- A study assessing the commercial viability of the current existing sustainable methods of mitigating the destructive effects of water hyacinth;
- A study for potential biological control agents efficient in the Philippine tropical ecosystem;
- Assessment studies on herbicides for *P. crassipes* control and biosafety;
- Additional studies on the potential medicinal value of *P. crassipes*;
- Additional studies on its safety as an organic fertilizer in agriculture;
- Additional studies on the efficacy on the use of water hyacinth for bioremediation in contaminated waterways and tributaries *in situ* in the Philippines.

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Rezumat:

PONTEDERIA CRASSIPES MART. (PONTEDERIACEAE): BIOLOGIA ȘI IMPACTUL SOCIO-ECOLOGIC ÎN FILIPINE

Pontederia crassipes Mart. (Pontederiaceae) este o plantă acvatică invazivă inclusă printre cele mai rele buruieni din lume. Proliferarea rapidă a acestei specii se datorează capacității sale de a se propaga prin semințe și stoloni dar și felului său de a pluti liber. Invazivitatea sa a cauzat probleme comunităților, economiei și ecosistemelor. Această lucrare își propune să discute despre biologia speciei, situația actuală și acțiunile care abordează problemele speciei *P. crassipes* în Filipine. O revizuire a literaturii a fost realizată prin aprovizionarea cu reviste academice publicate și articole guvernamentale, comunicate de presă, știință comunitară și observații personale. Taxonomia *P. crassipes* a fost recent recircumscrisă pe baza analizei moleculare vechi și a datelor morfologice noi. Drept urmare, în fosta nomenclatură, *Eichhornia crassipes* a fost plasată ca sinonim, iar genul *Pontederia* are trei subgenuri. *P. crassipes* este singura specie din subgenul *Oshunae*. Filipine s-a confruntat cu infestarea cauzată de această plantă până în prezent, în special în Lacul Laguna, Râul Pasig și Rio Grande de Mindanao. Mijloacele manuale și mecanice au constituit acțiunile principale de control a răspândirii acestei specii. Din fericire, a oferit venituri suplimentare pescarilor la scară mică. Cu toate acestea, din cauza dificultății de eradicare a plantei, au fost studiate și dezvoltate modalități alternative de utilizare, cum ar fi fitoremedierea pe căi navigabile poluate, fibre pentru textile, artizanat, biocombustibil și hrana animalelor. Sunt recomandate studii ulterioare pentru valoarea sa medicinală, certitudinea ca îngrășământ organic, precum și viabilitatea comercială a altor utilizări alternative, potențiali agenți de biocontrol, erbicide și eficacitatea fitoremedierii în apele uzate *in situ*.

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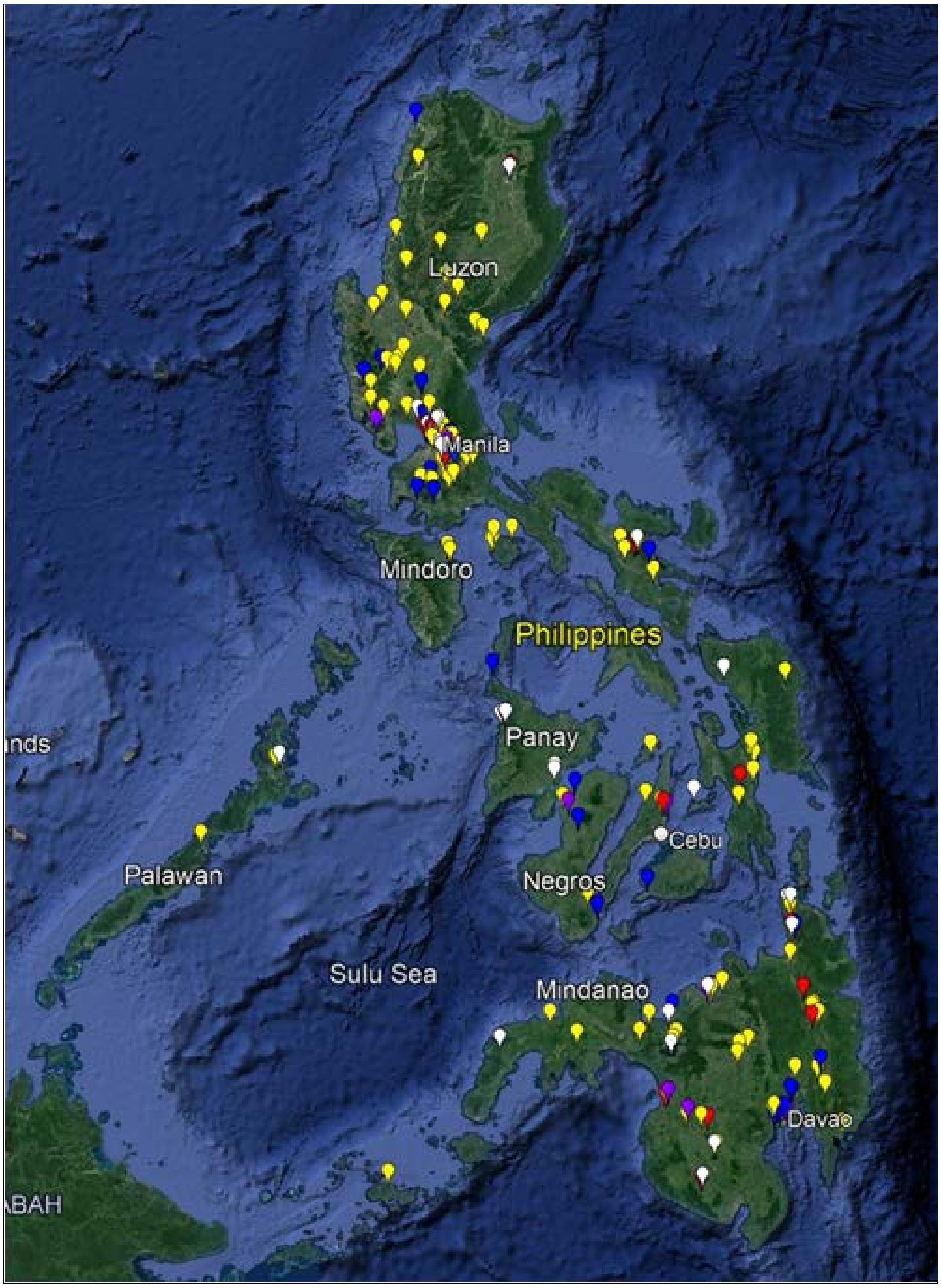
Annexes:

Figure no. 1 Distribution map of *Pontederia crassipes* in the Philippines



Note: blue – research grade iNaturalist observations, red – government press releases, white – published research articles, purple – news outlet releases, yellow – citizen science sightings.
Generated using Google Earth by J.A. Basilio (2023).

Table no. 1 Infestation of *Pontederia crassipes* in water bodies in the Philippines reported in the last 10 years.

Body of Water	Problem	Locality	Reference
Bay	Plastic and organic wastes thrown casually into the estuary and creeks drifted to the bay with the free-floating *P. crassipes*. In addition, it ruins the aesthetics of the Dolomite beach.	Manila Bay, Manila	Philippine News Agency (PNA) 2019; DENR 2022
Creeks and estuaries	The *P. crassipes* with plastic wasters and other debris clogged the waterflow in the creeks and waterways in the city.	Casili, Laoag City	Adriano 2019
Lake	The unmitigated proliferation of the *P. crassipes* has become a major obstruction in the navigation of boats for public transport and fisherfolks. It has also threatened the aquatic biodiversity and general ecosystem of the lake.	Laguna Lake, Laguna	Teves 2019; DENR 2021
	The *P. crassipes* has formed thick mats that covered the entire surface of the lake blocking light penetration, a breeding area for disease vector arthropods such as mosquitoes and causing oxygen depletion. Therefore, affecting the health of aquatic flora and fauna, and the nearby communities, as well as the income of the fisherfolk.	Pagalungan Lake, Cagayan de Oro	Inodeo 2014
	Impedes water flow in irrigation and lake outlets, one of the factors causing *kamahong* (fish kill), obstruction to water transport sometimes damaging propellers of motorized boats.	Lake Sebu, Lake Seloton and Lake Lahit in Lake Sebu, South Cotabato	personal communication, January 12, 2019; Sumagaysay 2019
	The *P. crassipes* caused a massive fish kill due to its contribution to oxygen depletion. It also blocked light penetration affecting the deeper aquatic flora and fauna. As a consequence, it degrades water quality. It also clogs waterways.	Lake Buhi, Camarines Sur	Department of Science and Technology (DOST)-Science and Technology Information Institute (STII) 2015; Eboña 2019
Lake	Thick mats of *P. crassipes* become a nuisance to communities near the lake. It also impedes navigation, entangled in fish nets, and clogs waterways.	Permanent lakes in Agusan del Sur	Isorena 2016
Marsh	The *P. crassipes* from the marsh drifted, accumulated, and clogged the downstream portions of the river channels. This resulted to raised river water level and flooding in the low-	Liguasan Marsh, Maguindanao	University of the Philippines Los Baños (UPLB)-College of Forestry and Natural

	lying areas in Cotabato City and Sultan Kudarat.		Resources (CFNR) 2016; Japan International Cooperation Agency (JICA) 2019
River	The main river where the *P. crassipes* from the Liguasan marsh have accumulated caused massive floods in Cotabato City and Sultan Kudarat. Most notable in 2011 wherein 500 families from 30 barangays were affected. In 2022, the same occurrence happened again as an aftermath of Bagyong Paeng but substantial increase in water level was mitigated due to advanced removal of the plant in the river.	Rio Grande de Mindanao, Cotabato City	Department of Public Works and Highways (DPWH) 2019; Mamasainged 2022
	The *P. crassipes* from the Rio Grande de Mindanao drifted to many tributaries including Taviran River. The plant accumulated in the river reaching above human height and destroyed houses in the communities near the river.	Taviran River, Maguindanao	Fernandez 2022
River Systems	Influx of *P. crassipes* especially at the choke points of the river system impedes the water flow and trap floating solid wastes especially in Napindan Channel, the major waterway connecting Laguna Lake and Manila Bay through Pasig River. Clogged rivers are polluted, increases risk of flooding in low lying areas, and pose health risk as it becomes a breeding site for disease vector arthropods. It halted water transport especially in the Pasig River, and fishing activities affecting their source of income.	National Capital Region: PAMARISAN (Pasig-Marikina-Rizal-San Juan), MUNTIPARLAS PIZAP (Muntinlupa-Parañaque-Las Piñas-Zapot, and MANATUTI (Malabon-Navotas-Tullahan-Tinajeros) River Systems	DPWH 2019; Allanigue 2021; DENR 2021; DENR- National Capital Region (NCR) 2021a, 2021b; DENR 2023

Table no. 3 Scholarly published studies on the phytoremediation of *Pontederia crassipes* in the Philippines

Chemical Element/Compound	Findings	References
Ammonia and phosphorus	Lowered the ammonia-N mg/L, phosphorus mg/L, and pH in the wastewater from Estero de San Miguel in Manila.	Acero 2019
Heavy metals- As, Cd, Cu, Fe, Hg, Mn, Pb, and Zn	One of the most effective metal hyperaccumulators to reduce the acidity and the heavy metals (As, Cd, Cu, Fe, Hg, Mn, Pb, and Zn) from the acid mine drainage in constructed wetlands at the Canatuan sulfide mine in Zamboanga del Norte.	James et al. 2009
Lead, Cadmium, Nitrogen, and Phosphorus	Live specimens and dried biomass were tested as a component of aquatic microphytes biofiltration system in Laguna de Bay. Both are capable of phytoremediation of heavy metals (lead and cadmium) and eutrophying nutrients (nitrogen and phosphorus) but the dried biomass adsorbed more HM than the living specimens.	Lituañas 2014
Cu^{3+}, Cr^{3+} and Pb^{2+}	Radiation-induced grafting and subsequent chemical modification of WH fibers into amine-type adsorbents improved its Cu^{3+}, $Cr^{3+,}$ and Pb^{2+} sorption behavior.	Madrid et al. 2013, 2014
Cr^{6+}	WH as a potential phytoremediator of a heavy metal contaminant, Cr^{6+}, in industrial wastewaters, with optimal efficiency of 12 days contact.	Maulion et al. 2015
NO_3 and PO_4	WH had an impressive reduction efficiency across different parameters, especially of NO3 and PO4, and is still efficient at 7 days of hydraulic retention time (HRT). WH had an optimal HRT of 3 days for reduction of TSS, NO3, PO4, and fecal coliform; HRT of 4 days for BOD; and HRT of 5 days for total coliform. Mercury and lead were also significantly reduced in the constructed wetlands experiment.	Napaldet and Buot 2019
Pb^{2+}	Partially deproteinated water hyacinth roots (DWHR), a by-product after obtaining water hyacinth cationic proteins (WHCP). It was used in the removal of lead (Pb^{2+}) in aqueous systems in simulated lead-contaminated wastewaters based on metal concentrations of water effluents in lead-battery manufacturing industries. DWHR is a potential alternative low-cost material in the phytoremediation of heavy metals.	Nieva et al. 2020
Hg^{2+}	Hg^{2+} was detected in the leaves without affecting the WH's photosynthetic integrity, indicating its tolerance to mercury-induced stress.	Puzon et al. 2014

Cd^{2+}	High levels of Cd^{2+} were detected in the protoplasts of young and mature laminae of WH. The higher levels of S_2 and SH- containing compounds in the young protoplasts indicated its role in the chelation and sequestration.	Puzon et al. 2008; Rivero et al. 2009