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A Review For Water Monitoring Based on Invasive Aquatic Plants

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Abstract: Invasive aquatic plant is non-native aquatic plant species which be prone to grow more rapid than the original native species even in habitats that have low resources, due to its high level of adaptation when accompanied with an absence of common predators. The aquatic invasive plants have been introduced in many new habitats intentionally and unintentionally. These plants easily reproduce and increase its population starting from small fragments. The invasive plants which classified in three groups which are emergent, free-floating, and submerged aquatic plants are successfully invades to new habitats and causes various impacts towards socio-economy, freshwater ecosystem and water quality. The physical, biological and chemical control methods are considered for managing the aquatic invasive plants. Few researchers have studied the water quality parameters with the presence of aquatic invasive plants. This review summarizes information about the categories of aquatic invasive plants, the process and factors of successful invasion, the impacts of invasive plants management methods to control aquatic invasive plants, the relationship between water quality parameters and the presence of invasive aquatic plants.

Keywords: Aquatic Plant, Impact, Water Quality

1. Introduction

Invasive aquatic plant is non-native aquatic plant species which be prone to grow more rapid than the original native species even in habitats that have low resources [1]. The traits of aquatic invasive aquatic plants are their high level of adaptation when accompanied with an absence of common predators, fast proliferation, and phenotype versatility [2]. Other than that, increase in nutrient levels in water and alteration of flow regime are other factors of strengthening the growth and spread of the aquatic invasive plants [3]. The invasive aquatic plant species transported to differents places in the world including Malaysia due to the growing worldwide trade and cross boundaries activities. Examples

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of common aquatic invasive plant species that can be found worldwide and also in Malaysia are water hyacinth, *Lemna* and hydrilla, and water lettuce [2]. They causes various impacts towards socio-economy, freshwater ecosystem and water quality as well [4]. To control the aquatic invasive plants effectively, several management methods need to be taken properly to minimize the management cost [5]. Thus, this review aims to summarize information about the 1) categories of aquatic invasive plants, 2) the process and factors of successful invasion, 3) the impacts of invasive plants management methods to control aquatic invasive plants, and 4) the relationship between water quality parameters with the presence of invasive aquatic plants.

2. Categories of aquatic invasive plants

Aquatic invasive plants grow in different forms which are classified to emergent, free-floating and submerged species as shown in Figure 1[5]. The emergent aquatic invasive plant species grow in shallow areas such as along the river banks. These species are rigid which can stand on their own without support of water [2] because they are rooted in the sediments [6]. The most common and dominant emergent aquatic invasive plants species are *Nelumbo nucifera* (Lotus) (Figure 2), *Nymphaea nouchali* (Water lily) (Figure 3), *Althernanthera philoxeroides* (Alligator weed), *Pandanus helicopus* (Pandan) and Neptunia oleracea (Water mimosa) [4].

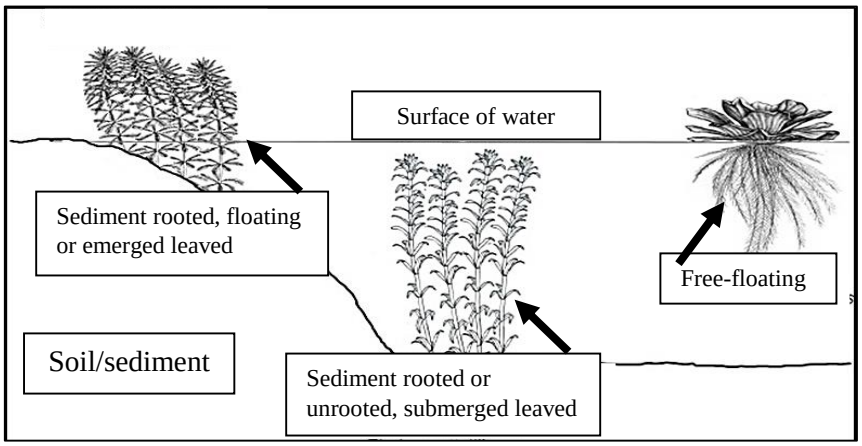

Figure 1: Growth forms and species of aquatic invasive plants [5]

Figure 2: *Nelumbo nucifera* (Lotus) [7]

Figure 3: *Nymphaea nouchali* (Water lily) [7]

The free-floating aquatic invasive plants can be seen on the surface of water which their roots are not attached to the bottom sediment of water or the water bed [2]. The free-floating aquatic invasive plants which are dominant in rivers are *Eichhornia crassipes* (Water hyacinth), *Salvinia molesta* (Water fern), *Pistia stratiotes* (Water lettuce), *Azolla imbricate* (Mosquitofern), *Lemna minor* (Duckweed), *Spirodela polyrhiza* (Giant duckweed) and *Polygonum amphibium* (Water smartweed) [4].

Figure 4: *Eichhornia crassipes* (Water hyacinth) [7]

Figure 5: *Salvinia molesta* (Water fern) [7]

Besides emergent and free-floating aquatic invasive plants, the submerged aquatic invasive plant species grow completely underwater and they have root system in water bed. They are physically supported by water [2]. The most common submerged aquatic invasive plant species that can be found are *Hydrilla verticillate* (Hydrilla), *Najas indica* (Guppy grass), *Ottelia alismoldes* (Duck lettuce), *Cabomba caroliniana* (Fanwort), *Ceratophyllum demersum* (Coontail), *Potamogeton* (Pondweed) and *Myriophyllum spicatum* (Eurasian watermilfoil) [4].

Figure 6: *Hydrilla verticillate* (Hydrilla) [7]

Figure 7: *Najas indica* (Guppy grass) [7]

3. Process and factors of successful invasion

The steps and stages of successful invasion of invasive aquatic plants are illustrated in Figure 8. The invasion process of invasive plants starts with first step which is immigration of invasive plant species that led the presence of the species in new habitat which the plant to complete the first stage 'presence of invasive plants in new area'. It reaches the second stage which is spontaneous establishment when the species go through second step when it starts to grow independently and start to reproduce. The invasive plants considered reached the third stage, the permanent establishment by the third step where the population of the species has reached minimum viable population (MVP) at the new habitats securing an opportunity for endurance. After the forth step, the complete possession of the new habitat, the last stage is achieved where the spread of invasive plant species in introduced habitat is completed [8].

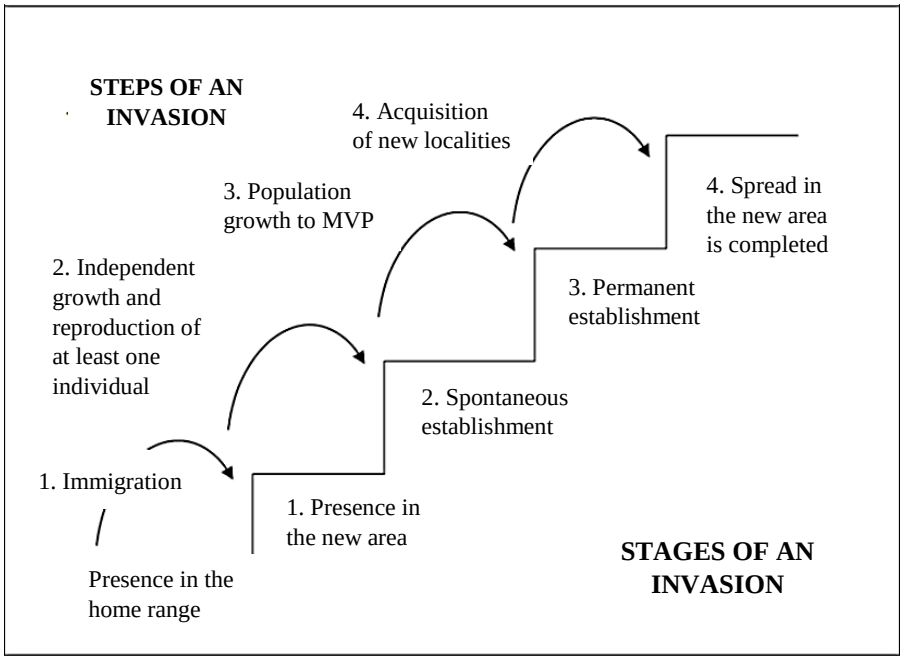

Figure 8: Invasion Process of aquatic invasive plants [8]

The main factor of successful invasion is because of human activities [5]. They intentionally introduced some species of aquatic invasive plants as ornamentals, aquarium decorations and as souvenirs [9]. Some species were introduced unintentionally by human when their boats are contaminated with invasive plant's small fragments which can easily survive and reproduce [9]. Species like water hyacinth was brought in as food for the hogs [2].

Invasive aquatic plants have higher competitive ability which becomes another factor of successful invasion. They grow vigorously and compete with the native species for the habitat which then they outcompete the native aquatic plant species. The free-floating aquatic invasive plants compete with native aquatic plants to get sunlight and limit the light penetration into water for the native aquatic plant species to carry out photosynthesis process [10].

Another factor for the aquatic invasive plants' successful invasion is the lack of their natural predators. The native animals and fishes in water consume native aquatic plants and algae compared to the invasive aquatic plants [11]. Some native herbivore's growth is restricted in the habitats where massive volume invasive plants can be seen. Hence the population of the herbivores decrease which led the invasive aquatic plant to grow massively it invaded habitat [10].

Phenotypic plasticity is another factor of invasion; enables invasive aquatic plants to adapt with the environment changes. They able to adapt the changes of environment conditions such as temperature and light. *Elodea canadensis* was the earlier colonizer which promotes its invading ability due to its high plastic responses towards temperature [12]. High phenotypic plasticity with ability of adaptation in environment changes caused invasive plant have higher competitive advantage compared to native species. For example, the invasion of *Alternanthera philoxeroides*, especially in resource-rich habitats is due to the plasticity of the species [10].

4. Impacts of invasive aquatic plants and the management methods

Aquatic invasive plants become biggest concern in environment. There are lots of impacts caused by the aquatic invasive plants towards various aspects such as the socio-economy and the river water transportation including boat navigations. This effect was due to the vigorous growth of thick mats of free-floating and emergent aquatic invasive plants which covers the surface of river water [4]. Hence, ecotourism related to water activities has been affected since boat transportations have been obstructed [13]. Hydrilla also obstructs water flow, which may clog irrigation systems and cause flooding during tropical storms, hurricanes, and other severe weather [9]. Other than that, hydropower generations also affected when the aquatic invasive plants clog the hydropower dams and turbines [5]. Moreover, the thick mats of aquatic invasive plants become as the breeding medium for mosquitos and other insects. Hence, it causes increase in vector diseases such as dengue fever and malaria which impacts the socio-economy [14], [15].

The freshwater ecosystem is highly affected by aquatic invasive plants [16]. The aquatic invasive plants modify the habitat of native flora and fauna by altering the growing ability of native aquatic plants [15]. Invasive aquatic plant species such as *Myriophyllum aquaticum, Eichhornia crassipes* and *Alternanthera philoxeroides* impact other species growth by forming large stands in freshwater body. Other than that, aquatic invasive plants cover the surface of water and reduces the penetration of sunlight into water which is required by native species for photosynthesis [4]. They also highly affect the growth of algae which consequetly reduce the food sources for the fishes [15]. Hence the aquatic invasive plants disturb the whole food webs in rivers [3].

Water quality is also highly affected due to infestation of aquatic invasive plans. Mainly, aquatic invasive plants change the hydrological regime of rivers. The water clarity is highly affected and the turbidity of the water is increased [15]. This is because the aquatic invasive plant species increase the siltation and total suspended solids (TSS) in river water content [14]. Since the aquatic invasive plants cover the surface of water, they reduce the amount of oxygen molecules dissolve in water which decreases the dissolved oxygen (DO) content in river water [15]. Aquatic invasive plants grow rapidly due to high nutrient concentration in water [3]. Hence heavy metals and nutrient concentration amount in water with aquatic invasive plants is agreed to be lower compared to nutrient concentration amount in water without aquatic invasive plants due to its uptake capability of nutrients [14].

There are several methods which are effective in managing the aquatic invasive plants. The most relevant and cost-effective methods are physical control methods [5]. Mechanical harvesting is the common method which can be done by cutting and removing the aquatic invasive plants using machineries [5]. The mechanical harvesting usually carried out using cutter boat in Europe [17] and using weed harvesters in USA [9]. Rotovators are used in Pacific Northwest to mechanically manage the submerged aquatic invasive plants [18]. Although it can increase the plants fragments and biomass in water, pre-planned harvesting with proper removal of the fragments would not give much effects on water turbidity and biomass content. Mechanical excavation is another method which can be used to control the overgrown aquatic invasive plants [5]. Removing the aquatic invasive plants using water jets are another method used for successful control of emergent species such as *Cabomba caroliniana* and *Myrtophyllum heterophyllum* where this method is used to wash out the aquatic invasive plants from the sediments including the root system [17]. Hand-weeding are much needed in small water

channels and irrigation channels although it is costly compared to other physical control methods [19]. Dredging and deepening the ponds and lakes or shallow shoreline area are another effective method of controlling and limiting the aquatic invasive plants [19].

Biological control methods are also effective in controlling aquatic invasive plants. Insects species such as *Coleoptera* (Chrysomelidae, Curculionidae), *Lepidoptera* (Arctiidae, Crambidae, Noctuidae) or *Diptera* (Chirono-midae, Ephydridae) and fish species such as *Procambarus clarki* (red swamp crayfish), *Cyprinus carpio* (common carp), *Scardinus erythrophthalmus* (rudd), *Rutilusrutilus* (roach) and tropical fishes *Tilapia spp* (tilapia) and *Metynnis spp* (silver dollar fish) which consume aquatic invasive plants are used as biocontrol agents [5]. However, the biocontrol agent species such as grass carp can increase its population vigorously and cause biodiversity imbalance in the water ecosystem. Hence, infertile grass carps are being introduced for the purpose of controlling the aquatic invasive plants [20]. The introduced biocontrol agents should be removed once the mission to eliminate the aquatic invasive plant is completed because they consume all the native and invasive aquatic plants and can affect the restoration of native aquatic plants [5].

Chemical control method which is most common is using herbicides to control invasive aquatic plants [5]. Since the herbicide could become toxic to the native aquatic plants and fishes, this method is not recommended to be used to control the aquatic invasive plants. However, at some situations this will be the only practical method to be applied [20]. Establishing this method need to be consulted and decided by the government and legislations [5]. The licensed herbicide products that have been used around the world are consists of active ingredients such as 2,4-D, bispyribac-sodium, carfentrazone-ethyl,copper, dichlobenil, diquat, endothall, flumioxazin, fluridone,glyphosate, haloxyfop-R-methyl, imazapyr, imazamox, metsul-furon methyl, penoxsulam, terbutryn and triclopyr [5]. Salt can be used as natural herbicide to control some of the invasive aquatic plants such as *Ludwigia spp* and *E. crassipes*. This method will not harm the environment and the water quality [21].

5. Relationship between water quality parameters with the presence of invasive aquatic plants

Table 1 showed the water quality parameters being monitored from lake or river invaded with invasive aquatic plant. It seems that parameters such as pH, turbidity, temperature, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved solids (TDS), Total suspended solids (TSS), Ammoniacal Nitrogen, Total Nitrogen and Total Phosphorus always being monitored.

Table 1: Parameters related to aquatic invasive plants

Parameter	References
pH	[2] [14] [15] [22] [23] [24] [25]
Turbidity	[14] [15] [22] [23] [25]
Temperature	[15] [22]
Biochemical oxygen demand (BOD)	[22] [23] [24] [25]
Chemical oxygen demand (COD)	[15] [22] [23] [25]
Dissolved oxygen (DO)	[2] [15] [22] [24] [23] [25]
Total dissolved solids (TDS)	[14] [15] [22]
Total suspended solids (TSS)	[2] [22] [24] [25]
Ammoniacal nitrogen	[15] [22] [23] [25] [26]
Total nitrogen	[3] [14] [15] [24] [25] [26] [27]
Total phosphorus	[3] [14] [15] [23] [25] [26] [27]

A study carried out by Wan [27] on the effects of phosphorus on the competitive ability of invasive aquatic plant (*Solidago canadensis*) with the native aquatic plant in which the growth of the invasive plant was experimented in three different conditions including phosphorus addition under surrounding nitrogen condition, high phosphorus and nitrogen condition, and surrounding phosphorus and nitrogen condition (Control). The finding showed that phosphorus addition reduces the ability of invasive plant to compete with native species.

Keller [3] studied the impact of invasive aquatic plants on ecosystem in Wular Lake, India. Environmental changes due to the growth of invasive plants in the lake have been observed. The total area of the lake has been seen decreased and resulted in large increase in nutrient level. The phosphorus and nitrogen concentration in the lake have been increased. [15] studied the relationship between water hyacinth with the water quality in tropical reservoir. The physico-chemical water variables were sampled at 32 locations at both covered and non-covered area by the water hyacinth. The results of the study show that only turbidity differed significantly between different sample sites which one of them is with the presence of water hyacinth and another is without water hyacinth.

Several researchers had monitored the water quality for a period to make a correlation with the presence of aquatic invasive plant and the findings of previous study was tabulated in Table 2.

Table 2: Water quality with the presence of aquatic invasive plants

Parameter	Changes	Related aquatic invasive plant species	Reference
Temperature (°C)	27.86 – 27.37	*Eichhornia crassipes* (Water hyacinth)	[15]
pH	7.35 – 7.11		
TDS ($mg.L^{-1}$)	0.05 – 0.04		
DO ($mg.L^{-1}$)	8.04 – 7.22		
Turbidity (FTU)	5.20 – 3.66		
pH	8.46 – 8.23	*Azolla pinnata* (Mosquitofern)	[25]
TSS ($mg.L^{-1}$)	24.81 – 16.37		
DO ($mg.L^{-1}$)	10.8 – 11.46		
Turbidity (FTU)	2.57 – 2.16		
COD	15.18 – 16.8		
BOD	13.97 – 5.96		
TP	4.32 – 3.18		
TN	295.09 – 224.23		
NH_3N	2.59 – 1.29		

6. Conclusion

Aquatic invasive plants categorized in three groups which are emergent, free-floating and submerged plants. They introduced to new habitats intentionally and unintentionally which associated by their higher competitive ability, phenotypic plasticity and lack of natural predators which may cause negative impacts to fresh water ecosystems. Several management methods including physical, biological and chemical methods are taken to control the overgrowth of aquatic invasive plants. Besides that, water quality parameters are being monitored with the presence of aquatic invasive plants. The findings from this research can be useful for the future research particularly for the organizations that took serious about managing the growth of excessive aquatic invasive plants which may lead to better environmental qualities in Malaysian rivers. This study can help in enhancing the environmental management systems.

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