A COMPARATIVE STUDY BETWEEN Pistia stratiotes L. AND Salvinia molesta Mitch. BASED ON LIFE CYCLE AND SALINITY TOLERANCE

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2014

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by

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Thesis submitted in fulfilment of the requirement for the Degree of

Master of Science

AUGUST 2014

ACKNOWLEDGEMENTS

I would like to say Alhamdulillah to Allah for giving me the strength and make me be able to complete my Master of Science from School of Biological Sciences, Universiti Sains Malaysia. For my beloved mom and dad who always support and believe in me throughout my study sessions, thank you so much for being there for me.

My main supervisor, Profesor Mashhor Bin Mansor and wife for always encourage and guide me in completing my thesis. He is one of the best teachers for me, not only in pursuing study but the whole life manners. Dr. Asyraf Bin Mansor, my co-supervisor, thank you for being there and giving your opinion on my study and thesis writing. Your critics on my thesis really work me out.

To all School of Biological Sciences staffs, especially Mr. Rashid, Mr Khairuddin, Mr Abdullah and many more for your assistance and helps throughout my project was conducted. To all my friends, Muzzalifah, Aziera, Nadhirah, Fikri, Nadia, Nazifah, Reen, Truyen and Aisyah thank you for being there for me and sharing the information together.

I would like to express my gratitude to Ministry of Higher Education, Malaysia for sponsoring my study fees under MyMaster Sponsorship Program with the reference number KPT (B) 891023025254 from 1 May 2012 until 30 April 2014.

Thank you!

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	=	Degree Celsius
cm	=	centimetres
Dw	=	dry weight
g	=	gram
L	=	liter
m	=	metres
m^2	=	metres squared
m^3	=	metres cube
mm	=	millimetres
ppt	=	parts per thousand
RGR	=	Relative Growth Rate
t	=	times

SATU KAJIAN PERBANDINGAN ANTARA Pistia stratiotes L. DAN Salvinia molesta MITCH. BERDASARKAN KITAR HIDUP DAN TOLERAN TERHADAP SALINITI

ABSTRAK

Matlamat kajian ini ialah untuk mengkaji persaingan di antara dua tumbuhan rumpai air terapung; *Pistia stratiotes* dan *Salvinia molesta* yang tersenarai di dalam kumpulan rumpai air noksius di seluruh dunia. Kajian ini dijalankan dari 4 September 2012 sehingga 31 Ogos 2013 di dalam rumah tumbuhan di USM. Terdapat tiga objektif utama kajian ini; untuk mengkaji kitaran hidup kedua-dua spesies tumbuhan, untuk mengkaji persaingan di antara kedua-dua spesies tumbuhan dan untuk mengkaji tahap toleransi tumbuhan kajian terhadap saliniti. Kedua-dua spesies tumbuhan kajian diambil dari dalam tangki tumbuhan air di Pusat Pengajian Sains Kajihayat dan kemudian dibersihkan serta ditimbang bagi mendapatkan bacaan berat basah. Kedua-dua spesies tumbuhan ditanam di dalam bekas yang berukuran 33.5 cm x 22 cm x 11.5 cm dimana masing-masing mempunyai enam replikat. Untuk kajian kitaran hidup dan persaingan tumbuhan, gambar untuk setiap perubahan bentuk tumbuhan telah diambil serta kadar pertumbuhan bagi setiap pokok direkodkan setiap hari. Bagi tujuan mengkaji tahap toleransi tumbuhan terhadap saliniti, 50 g tumbuhan ditanam di dalam bekas yang mengandungi air laut pada kepekatan yang berbeza dan setiap perubahan dicatatkan setiap hari. Daripada kajian kitaran hidup, *Pistia stratiotes* dilihat berkemampuan untuk membiak secara penghasilan biji benih dan vegitatif manakala *Salvinia molesta* pula hanya membiak secara vegitatif pada keseluruhannya. Selain itu, dalam kajian persaingan, *Salvinia molesta* telah menyaingi *Pistia stratiotes* dengan nisbah 9:1, *Salvinia* kepada *Pistia*. Untuk kajian tahap toleransi tumbuhan

terhadap saliniti pula *Salvinia molesta* telah direkodkan mampu untuk bertahan di dalam air laut yang berkepekatan 25% manakala *Pistia stratiotes* langsung tidak mampu untuk bertahan di dalam keadaan air laut. Usaha untuk kita mengenali setiap kelakuan tumbuhan adalah penting dan merupakan langkah pertama bagi kita mengawal pertumbuhan pokok-pokok ini sebelum ia membiak sehingga ke tahap yang menganggu dan mengancam keadaan persekitaran. Memandang tumbuh-tumbuhan ini mampu untuk membiak secara agresif, kajian mengenai tumbuh-tumbuhan ini amatlah penting dalam usaha-usaha kita untuk menjaga alam sekitar serta sumber air kita yang utama seperti kolam, tasik, mahupun sungai.

A COMPARATIVE STUDY BETWEEN Pistia stratiotes L. AND Salvinia molesta MITCH. BASED ON LIFE CYCLE AND SALINITY TOLERANCE

ABSTRACT

The aim of this study was to investigate the competition between two floating aquatic weeds; *Pistia stratiotes* and *Salvinia molesta* which are listed as the most noxious aquatic weeds worldwide. This study was carried out from 4 September 2012 until 31August 2013 in the plant house at USM. There were three main objectives of this study; to examine the life cycle of both plant species, to examine the competition between the two plant species and to examine the level of plants tolerance towards the salinity. Both studied plant species were adopted from the water plant tank in the School of Biological Sciences and which then were cleaned and weighed to obtain the wet weight readings. Both plant species were grown in containers measuring 33.5 cm x 22 cm x 11.5 cm where each plant has six replicates. For the life cycle and plant competition study, any plant changes in the form of images were taken and the growth rates for each plant were recorded daily. For the level of plants tolerance towards the salinity study, 50 g plant was grown in containers containing seawater at different concentrations and any changes in plant were recorded daily. From the life cycle study, *Pistia stratiotes* was capable of reproducing through seeds germination and vegetative reproduction while *Salvinia molesta* can only reproduce vegetatively. Moreover, in term of competition study, *Salvinia molesta* had outcompeted *Pistia stratiotes* with the ratio of 9:1, *Salvinia* to *Pistia*. For the level of salinity tolerance study, *Salvinia molesta* was recorded to be able to survive in the seawater with concentration of 25% meanwhile *Pistia stratiotes* was not able to survive in seawater

at all. The attempt for us to know each plant behaviour are essential and it is the first step for us to control the growth of these plants before they multiply to such an extent that interferes and threaten the environment. Since these plants are able to grow aggressively, the study of these plants is vital in our efforts to protect the environment and our water resources such as ponds, lakes, or rivers.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Based on ISI Web of Knowledge index, out of 1,512 studies on aquatic weeds worldwide there were only five intensive studies focusing on the ecology of floating aquatic plant. These studies were conducted by Walsh *et al.* (2013), Galatowitsch (2006), Adams *et al*. (2002), RuizAvila and Klemm (1994) and Harper *et al*. (1990). In addition, based on available literatures there were approximately 235 species of aquatic plants in the aquatic ecosystems of Malaysia (Burkill, 2002).

Lately, the increasing number of invasions by alien species or non-native species was reported to affect the habitats around the world (Vitousek *et al*., 1997). Non-native plant species affect negatively the local plant community composition, ecosystem functions and human uses. Furthermore, most of the non-native species are failed to successfully establish, but some of the species are able to grow and colonise a certain area to nuisance levels (Chapin *et al*., 2000).

Aquatic plants are widely distributed in any water body ranges all over the world. Ten years of field surveys were carried out by Mansor (1996) on various water bodies, rivers, streams and canals in Malaysia. This study covered 28 rivers and five lakes of Peninsular Malaysia, Sabah and Sarawak. Throughout these survey, Mansor (1996) stated that there are four problematic floating aquatic weeds in Malaysia; namely *Eichhornia crassipes, Salvinia molesta*, *Pistia stratiotes* and

Lemna perpusilla. The favourable tropical climate and conducive environment of Malaysia had triggered the massive growth of these weeds.

A study by Marwat *et al*. (2011) from 2005 until 2007 in Dera Ismail Khan District of KPK, Pakistan found that floating weeds have caused serious problems, however they are used for various purposes. The latest research on the invasive alien in Italy was done by Brundu *et al*. (2012) and stated that *Pistia stratiotes* and *Eichhornia crassipes* are invading Campania and Sardinia. These two floating hydrophyte invasions consumed high cost of mechanical removal works and unsuccessful to be utilized in the long term. The introductions of exotic species is one of many factors contribute to the presence of these plants as ornamental plant and used as phytoremediation. A suggestion for the importance of regulation in the trade sector towards the invasive plant species and a set up of national strategy draft on these biological invasions are the priority for Italy. In addition, several specific action plans for aquatic plant species and surrounding habitats, as in the case of inland waters, are also may be required.

Study and documentation on aquatic plant species today, especially free floating plants are still limited and insufficient for reading materials. More research was focused on *Eichhornia crassipes* from Pontederiaceae family and little were done on other family (Perna *et al*., 2012). Intensive research on plant anatomy, plant morphology, plant taxonomy, life cycle, and origin of aquatic plant is needed to supply information for the researcher. From these studies, it is possible to estimate the biodiversity of a given area and further conservation work on that area could be done. As conservation has becomes more politically important, plant identifications works impacts not only on the scientific community, but society as the whole (Knapp, 2010).

It should be noted that not only in Malaysia but the whole world are facing the problems with floating aquatic plant species. Intensive observation is crucial to build knowledge and information not for our society alone but it should be done globally. Since the growth and development of this type of aquatic plant species is connected to water body, it should be handled seriously because water is the base of every living thing and we need to secure our water resources.

1.2 Objectives of study

There are three objectives of this study as listed hereby:

1. To study the life cycle of two free floating aquatic plant species, *Pistia stratiotes* and *Salvinia molesta.*
2. To observe the competition between *Pistia stratiotes* and *Salvinia molesta*.
3. To observe the physiological responses of *Pistia stratiotes* and *Salvinia molesta* under varying degree of salt tolerance, by applying seawater at different salinity.

CHAPTER 2

LITERATURE REVIEW

Aquatic ecosystem is an ecosystem surrounded by water. Organisms that form communities are depending on the environment and interact with each other. Marine ecosystems and freshwater ecosystems are the two main types of aquatic ecosystems (David and Rhodes, 1999). Numerous important environmental functions that performed by aquatic ecosystems such as recycles the nutrient through water cycle, purifying the water source, debilitate floods, revitalize the ground water and equip the habitat for wildlife (Solan *et al*., 2004) and aquatic ecosystems play for human recreation and are very important spot for tourism.

Lately, the health of aquatic ecosystems had been disturbed by various stress results from the human activities, and environmental changes (Keddy, 2010). Stresses on an aquatic ecosystem can be results by the alterations of the environment, either through the physical, chemical or biological changes. Physical alteration includes changes in temperature of the water, water movement and light availability, while chemical alteration includes changes in the bio-stimulatory nutrients loading rates, oxygen consuming materials and toxins. Biological alteration includes the exotic species influx and over-harvesting of commercial species. With the increasing in human populations, excessive stresses on the aquatic ecosystems could be imposed. The usage of synthetic detergent found to kill the aquatic organisms even in a small amount and effect the local environment. Based on a study, six hours exposure of synthetic detergent can kill 70% of aquatic life (Wan Abdullah, 1995).

The alteration of aquatic life forms might collapse the food chain of aquatic and land food web.

Approximately, 71% of the Earth's surface is covered by marine ecosystems and it contain for about 97% of the planet's water. 32% of the world's net primary production is generated by marine ecosystems. Since the presence of dissolved compounds, especially salts in the marine water, they are distinguished from freshwater ecosystems. Eighty five percent from seawater estimated that the dissolved materials are sodium and chlorine. The average salinity of seawater is 35 parts per thousand (ppt) of water and this number may be varies among different marine ecosystems (Pinet, 1996). Whereas, freshwater ecosystems cover 0.80% of the Earth's surface and inhabit only 0.009% of its total water. Three percent of net primary productions have been generated from freshwater ecosystems. 41% of the world's known fish species comes from freshwater ecosystems. There are three basic types of freshwater ecosystems; wetlands, lentic and lotic. Wetlands are areas where the soil is saturated or inundated for at least part of time. Lentic ecosystem is a slow moving water body including pools, ponds and lakes. Next, lotic ecosystem is a faster moving water body, such as streams and rivers (Wetzel, 2001).

2.1 Aquatic Plant

Each of aquatic ecosystems stands in need of aquatic plants because they play a major role by providing food and habitat to aquatic organisms such as fish and wildlife. Plants stabilise sediments, improve water clarity and add diversity to the shallow areas of lakes (Madsen, 2009). Aquatic plants grow completely or partially in water. They are also known as macrophytes or hydrophytes, can be found in the shallow zones of lakes or rivers. This shallow zone is called as littoral zone which is shown in Figure 2.1. This zone receives sufficient light penetrations to the bottom to support the growth of plants.

There are three groups of plants that grow in littoral zones. Emergent plants inhabit the shallowest water with their roots in the sediment and their leaves are extending above the water surface. Common reed, spike rush and cattail are the representative species of emergent plants (Mashhor *et al*., 2002). Floating-leaved plants grow at intermediate depths and some of this species are rooted in the sediment. Water lily is in this group. While others are free floating with roots that hang unanchored in the water column. Water lettuce and water hyacinth are the two examples of free floating aquatic plants (Haller, 2009). Plants that grow their stems and leaves entirely underwater are known as submerged plants**.** Submerged plants display a wide range of plant shapes and grow from near shore to the deepest part of the littoral zone. Submerged plant species are including *Hydrilla*, *Cabomba* and *Egeria* (Haller, 2009).

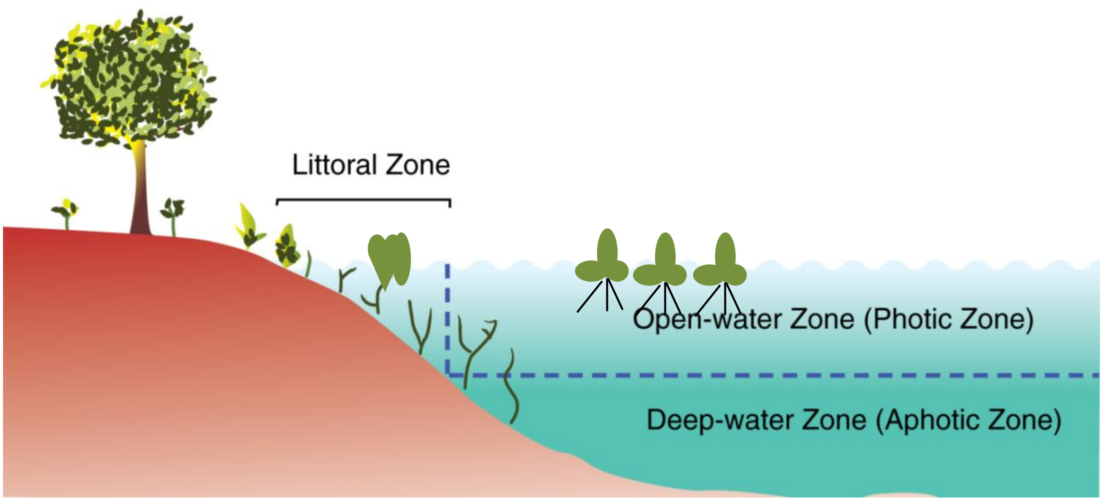


Figure 2.1: The three primary zones of a lake (Source: Ruth, 2010)

2.1.1 The Benefits of Aquatic Plant

Aquatic plants are essentials components of healthy aquatic ecosystems. Plants, whether on land or in or around water photosynthesize using sunlight, carbon dioxide and water to grow, produce new plant tissue and grant us with oxygen through this process. Aquatic plants also play important roles in the aquatic environment (Madsen, 2000). Microscopic plants (algae) or phytoplanktons are essential elements which form the base of aquatic food chain. Aquatic macrophytes provide ideal habitats for big fish and shelter for juvenile fish, organisms as fish food and also provide food for insects, waterfowl and other wildlife. Since all plant, including those that grow underwater produce oxygen after photosynthesis process occur, they are the major source of oxygen for aquatic animal life (Bonvechio and Bonvenchio, 2006).

Rooted plants stabilize shorelines and bottom sediments. They absorbs nutrients and filter pollutant from runoff, which improve water purity. A diverse aquatic plant population adds beauty to the water body. Many people recognize and appreciate the aesthetic value of aquatic vegetation, whether in the backyard fishpond, around the retention pond, or along the shoreline of a lake (Lembi, 2009). Furthermore, the developing technology in producing bio-fuel from the aquatic plant biomass is becoming a major concern nowadays. With consideration of raw material constitutes 40 similar to 80% production costs of bio-fuel, this bio-fuels are made from volatile fatty acids which is derived from waste biomass of aquatic plants has a potential to offers significant economical advantages (Chang *et al*., 2010).

2.1.2 Problems Rises from Excessive Aquatic Plant

Unfortunately, non-native plants that are introduced to new habitats often become a nuisance by hindering human uses of water and threaten the structure and function of diverse native aquatic ecosystems. Simply characterised, invasive plants are those species that easily to prevail over geographic and environmental barriers, fast self establishment, and then expand their numbers and ranges rapidly in the new habitat (Richardson *et al*., 2000). They are often extirpating or displacing populations of indigenous species in this invasion process.

Plants that have been introduced into new regions, either deliberately or inadvertently, by human activities are the highly successful plant invaders (Mack and Lonsdale, 2001). For example, at least 128 of the approximately 5,800 crops or ornamental plants introduced intentionally into the United States have become noxious weeds (Pimentel *et al*., 1989). The most commonly found commercial species was Indian hygrophila (*Hygrophila polysperma* (Roxb.) T. Anderson) later followed by water hyacinth and branched bur-reed (*Sparganium erectum* L.). Misidentification of the plant and inability to recognize the invasive species and also the ignorance of the messages from the websites by many of the hobbyists had becoming the major problem. Much of wetland managers, aquatic plant nursery representatives and dealerships have inadequate knowledge of the aquatic plants that they sell. Leading candidates for this dubious distinction are the floating weeds *Eichhornia crassipes*, *Pistia stratiotes*, and *Salvinia* sp.; submerged weeds *Ceratophyllum demersum*, *Egeria* sp., *Hydrilla verticillata*, *Myriophyllum* sp., and *Potamogeton pectinatus*; rooted, shallow-water plants such as *Ludwigia* sp., *Polygonum* sp., *Typha* sp.; several grass species, and some wetland shrubs and trees (Charudattan, 2001).

To manage these infestations of aquatic weeds, various significant resources are often expended because unchecked growth of these invasive species often interferes with the use of water. This aquatic vegetation could be considered as harmful when its notable growth causes problems for the use of ecosystems, such as navigation, water sports, and fishing activities. The invasive aquatic plant species which affecting the native aquatic plant species, resulting in the need for the controlling methods implementation or management. This marked growth of aquatic vegetation also increases exposure to flash flooding and result in threatened public health conditions (Kay and Hoyle, 2001).

Upon from uncontrolled growth of various aquatic vegetation species in some watersheds, several studies have been conducted with the aim to understand the biology (Antuniasi *et al.*, 2002) and the distribution (Cardoso *et al*., 2002), as well as the plan for management of these species which have assumed holding the status of weeds (Cavenaghi *et al*., 2003).

The three most notorious weeds, *Eichhornia crassipes* (water hyacinth), *Pistia stratiotes* (water lettuce) and *Salvinia molesta* (giant salvinia) cause serious problem in nearly all countries, affecting almost all uses of water bodies such as for aquaculture, commercial and subsistence fishing, drinking and household consumption, hydropower generation, irrigation, transport and recreation (Charudattan, 2001). By replacing the native flora and fauna, these weeds would affect biodiversity and often causing irreversible changes to habitats. With the increase of mosquitoes breeding sites, it would also increase in the insect-borne human diseases count. Another important concern which potential to affect the recreation and tourism is the loss of aesthetic value of waterfront communities due to weed growth. Sedimentation and eutrophication rates will be increased from the dead biomass of large weed and reduces water depth. Floating weeds cause problems by partially or completely forming a thick blanket in large and small water bodies, interfering with the normal access of water. They increase water loss from any water body through the dual actions of evaporation and transpiration (Janes *et al*., 1996). With the evapotraspiration process two times faster than normal, the lake will quickly become shallow. If not treated and managed properly, the man-made lake will not function anymore (Mansor, 1994). Dense mats of aquatic macrophytes, both canopies of free floating species and the sub-canopy species distinct the littoral zone with lower DO concentrations and pH (Frodge *et al*., 1990).

Intensive fisheries industry often involves adding large amounts of commercial feeds and inorganic fertilizers into ponds. Nutrients introduced into the water through feeds and fertilizers often create an ideal environment for aquatic weed growth. Submerge aquatic weeds are particularly undesirable because fish harvesting nets will ride up over the weeds and allow fishes to escape. Pond with highly weed infestations can be impossible to harvest since the weight of the weeds accumulating in the seine can become too great to be pulled (Shelton and Murphy, 1989). In their impact on human society, invasive plants charge economic, social, and medical costs in a number of ways. They compete with food and fiber crops, ornamentals, and other aquatic plants for nutrients and sunlight. They also interfere with water management in agriculture by infesting irrigation ditches and other waterways; reduce incomes from recreational hunting and fishing, and from tourism; restrict access to foreign markets (Culliney, 2005).

For example, *Salvinia molesta* is a free floating aquatic fern native to South America, spreading throughout the tropics and subtropics over half of the twentieth century. The ability to grow very quickly and a dense mats forming over lakes and slow moving rivers could cause wide range of ecological problems and devastating economic loss (Ali *et al*., 2011). For examples, mats of *Salvinia* could block the use of waterways from the commercial and recreational purposes and degrade the aesthetics value of waterside (Johnson *et al*., 2001). Mats of *Salvinia* reduce habitats for some birds' species, limit the access way to a fishing area and probably revise with fisheries, all with negative economic impacts. It also interfere by clog the water intakes of agriculture irrigation, water stock and electrical generation dam (Bravo *et al*., 2012). In some reports, it provides habitats for human diseases vector with serious socioeconomic consequences (Hussner *et al*., 2010). *Salvinia molesta* dense mats provide ideal habitats for *Mansonia* mosquitoes, rural elephantiasis principal vector and other mosquitos' species which is responsible for the transmission of encephalitis, dengue, and malaria (Kweka *et al*., 2012). In developing countries, the mats of *Salvinia* could cause a devastating impact on the use of waterways for transportation, farm lands, and towards communities which depends on fish for local consumption. This species is also known as a weed of paddy field that alters the production by competing for nutrient, water and space (Sinhababu *et al*., 2013).

Flora and fauna depends on open water body to receive sunlight, oxygen and space for nourishment and growth, nest construction, and mating. So, mats of aquatic vegetation could lower the oxygen concentration in the water, necessary for the flora and fauna survivorship (Cilliers *et al*., 2003). Moreover, reducing of sun penetration and oxygen concentration may inhibit the photosynthesis of submerge plant, make the water body high in the carbon dioxide and hydrogen sulphide concentration which will choke out other living organism in the water ecosystems (Richardson and Wilgen, 2004).

As well as *Salvinia molesta*, a dense mat of *Eichhornia crassipes* could reduce the light penetration to submerged plants, thus diminishing oxygen supply in the aquatic community (Martins *et al*., 2008). It gives result in the lacking of phytoplankton densities, hence affecting the fisheries industry by altering the invertebrate community's composition (Turpie *et al*., 2003). Water hyacinth often disturbing and destroy native flora and fauna habitats by competes with the native plants, displacing wildlife habitat and forage (Henderson, 2001). Hanging roots of water hyacinth also traps moving sediment, combine with detrital production and siltation under water hyacinth mats results in higher sedimentation loading (Nel *et al*., 2004). Furthermore, water hyacinth infestation management through mechanical harvesting or herbicidal treatment will cause damages to nearby desirable vegetation such as ornamental plants (Higgins *et al*., 2001).

According to Stuckey and Les (1984) in Florida, *Pistia stratiotes* or water lettuce is one of this invasive floating aquatic weed. Infestation of water lettuce mats able to block navigational channels, impedes water flow in flood control canals and irrigation canals, and disrupting submerge flora and fauna, recorded since 18th century before. Just like water hyacinth, roots of water lettuce, composed of long adventitious roots aligned with extensive lateral rootlets. These extensive infestations accelerate siltation rates as they begun to slow the water velocities in rivers or streams. Consequently, benthic substrates degradation under water lettuce mats resulted in creating unsuitable habitats and nesting sites for many kind of fish species, as well as macroinvertebrate (Görgens and Wilgen, 2004). Likewise, water lettuce has the ability to bioaccumulate noticeable amounts of heavy metals, so the detritus under the water lettuce mats could be highly toxic (Sridhar, 1986).

The total cost imposed solely by invasive aquatic weeds in the United States was estimated to range from $900 million to $14 billion annually (Rockwell, 2003). The Economic Cost of Invasive Non-Native Species to the British Economy suggests that invasive species cost £1.7 billion every year, which includes £251 million in Scotland. For example, with water primrose, a group of South American aquatic weeds which grow rapidly and can block waterways it is estimated that the current timely eradication will cost £73,000 which is significantly less than the estimated £242 million that it would cost if the plant was to become widely established as it has on the continent in countries like France and Belgium (Williams *et al*., 2010). They have badly degraded more than 15 million ha of grazing lands and natural ecosystems in Australia (Glanzing, 2003). Noxious weeds have invaded an estimated 10 million ha in South Africa (van Wilgen *et al*., 2001). This is a critical loss of a resource vital for economic growth. Clearly, invasive plants take an unacceptable toll on agriculture and other sectors of the economy.

2.2 Studied Plant

2.2.1 *Pistia stratiotes* L.

The name *Pistia stratiotes* L., an unique aroid comes from the Greek "pister" meaning hollow trough, in the sense of a drinking through (Mayo *et al*. 1997) or the Greek "pistos" meaning water, and "stratiotes" meaning soldier (Yates, 2005). It was classified in 1943 to its own *Pistiaceae*, but as a result of later research it is now in the *Araceae*, subfamily *Aroideae*, tribe *Pistieae*, and is the only species in the genus *Pistia*. It is a perennial monocot of the *Araceae* family. *Pistia stratiotes* is also known as water lettuce, water cabbage, Nile cabbage or shellflower.

Pistia stratiotes, or water lettuce is an interesting, unique aroid. Glazier (1996) describes *P. stratiotes* as a free-floating perennial of quiet ponds. It is stoloniferous, forms colonies, and has rosettes up to 15cms across. The illustration of *Pistia stratiotes* is shown in Figure 2.2. It has long, feathery, hanging roots. Its leaves are obovate to spathulate-oblong, truncate to emarginate at the apex, and long-cuneate at the base. Leaves are light green and velvety-hairy with many prominent longitudinal veins. Inflorescences are inconspicuous and up to 1.5cms long. Flowers are few, unisexual, and enclosed in a leaf-like spathe. The spathe generally shows a constriction between the groups of flowers male and the female. The spathe below the constriction opens first in the morning hours to expose the wet stigma, whereas the male flower remains enclosed. Some hours later, the spathe opens completely and exposes the part bearing male flowers (Neuenschwander *et al.*, 2009). The inflorescence of this plant is shown in Plate 2.1. Water lettuce does reproduce by sexual and vegetative means. When stolons grow from the mother plant, new daughter plants will be formed and known as seedlings in matured plant.

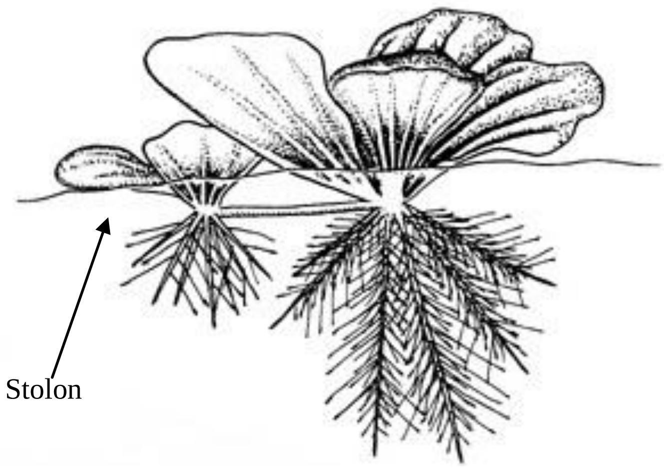
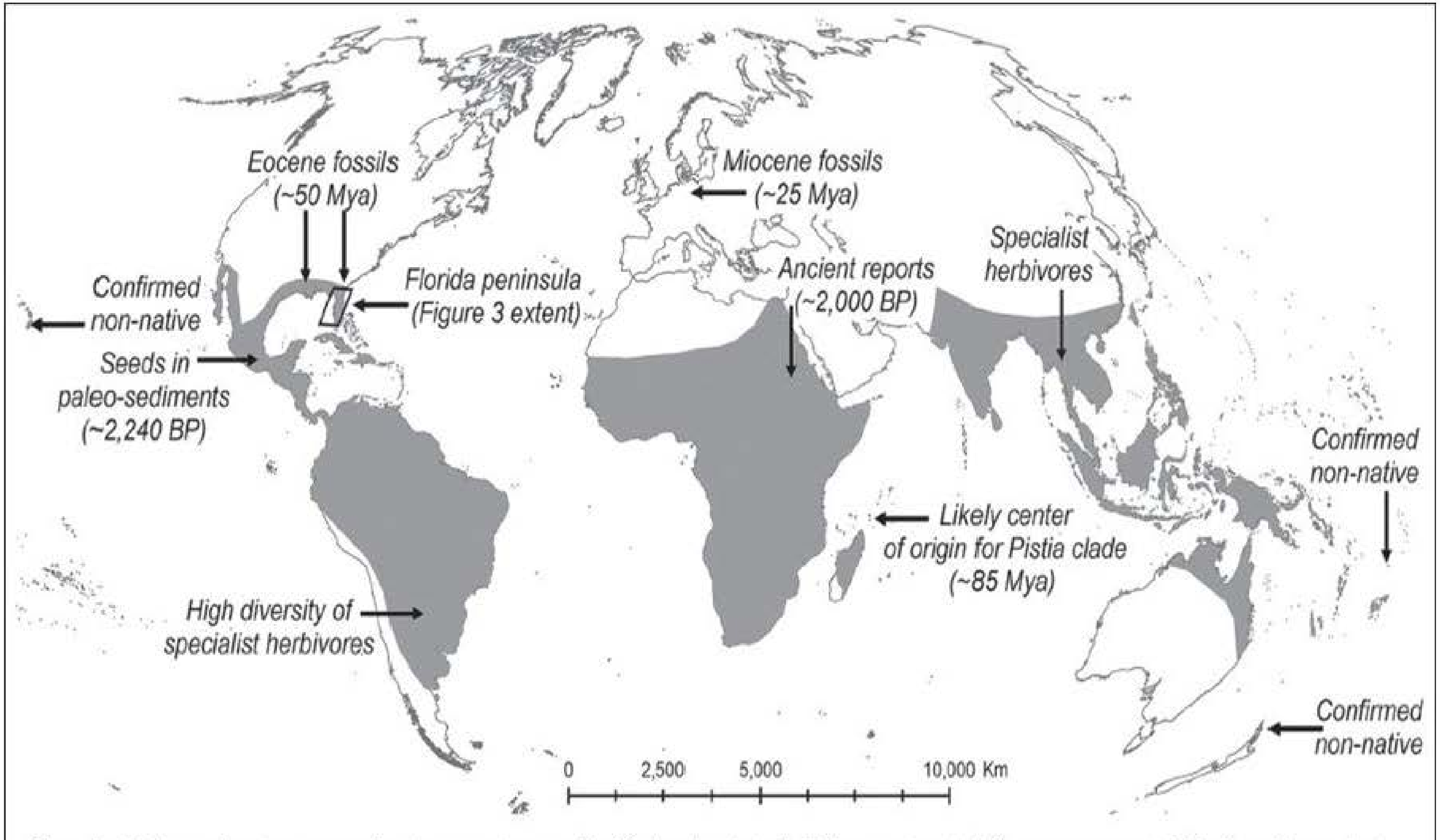


Figure 2.2: Illustration of *Pistia stratiotes* (Source: IFAS, 1990)

Plate 2.1: Inflorescence of *Pistia stratiotes* (in the red circle)

Like any potential invasive species, Yates (2005) also describes that it must be kept in check so it does not become destructive; however, it has valuable properties, as a medicinal, a food source, and environment remediator. There is some confusion about the origin of water lettuce due to its worldwide distribution; however, there is strong evidence that it is native to South America. *P. stratiotes* is now found throughout the tropics and subtropics and is one of the most widely distributed hydrophytes in the tropics (Holm *et al*., 1977). The map on the distribution of *P. stratiotes* is shown in the Figure 2.3. *P. stratiotes* is a popular garden pond plant and is often spread by the dumping of aquarium or ornamental pond plants. It is a free-floating plant that is capable of forming dense mats on the surface of lakes. Fragments or whole plants can spread via boats or fishing equipment from an infested area to a clean body of water. According to Rivers (2002), *P.stratiotes* can cause a severe impact on the environment and economy of infested areas. The dense mats create by connected rosettes of the plant lead to the majority of problems encountered with water lettuce. These mats can drive a negative economic effect by blocking waterways, thus increasing the navigation and hindering flood control efforts. Mats of *P. stratiotes* can also disrupt natural ecosystems. They can lead to a lower concentration of oxygen in covered waters and sediments by blocking air-water interface and root respiration, even extremely thick mats of *P. Stratiotes* can prevent sunlight from reaching underlying water. The cumulative effect of these negative characteristics of the plant is loss of biodiversity in invaded habitats. *P stratiotes* continues to be sold through aquarium supply dealers and through the internet (Ramey, 2001).

In a published study, Pimentel *et al*. (2000) determined invasive aquatic plants species costs $ 10 million in losses and damage and $100 million in control costs in the US. Later in 2002, Dray Jr. and Center estimated expenditures increased to over $1 million dollars annually in Florida by 2002. Although, there are several other aroids considered invasive in various regions, *P. stratiotes* is by far the most insidious one. According to Pimentel *et al*. (2005) *P. stratiotes* among several invasive aquatic plant species, is altering fish and other aquatic rivers and lakes.



Gray shaded area denotes approximate current range for *Pistia stratiotes* L. Map constructed from sources noted in the primary text

Figure 2.3: Phytogeographic highlight of *Pistia stratiotes* L. in the world map. (Source: Evans, 2013)

2.2.2 *Salvinia molesta*

Salvinia molesta is a free floating aquatic fern. It produces a horizontal rhizome lies under water and two types of frond, buoyant and submerged. The mature plant produces egg-shaped spore sacs or sporocarps, containing infertile spores as can be seen in Figure 2.4. It lacks true roots but its submerged fronds function as roots. On their upper surface they have rows of cylindrical papillae. Each papilla has four hairs at its distal end that are joined together at their tips to form what looks like an inverted egg-beater. The cage-like structure of the end hairs is an effective air trap giving the plant buoyancy in the water. The structure of *Salvinia molesta* papillae are shown in Plate 2.2. The papillae, end hairs and upper surface of the plant are water repellent in comparison to the under surface of the leaf, which attracts water. It is this difference in water attraction that maintains the correct orientation of the plant on the water surface. The fronds are light to medium green, often with brownish edges in mature plants, and with a distinctive fold in the center. The plant exhibits great morphological variation depending on the conditions of habitat such as space and nutrient availability, and ranges from a slender floating specimen with leaves less than 1.5cm wide to one with leaves up to 6cm wide (Pieterse *et al* 2003).

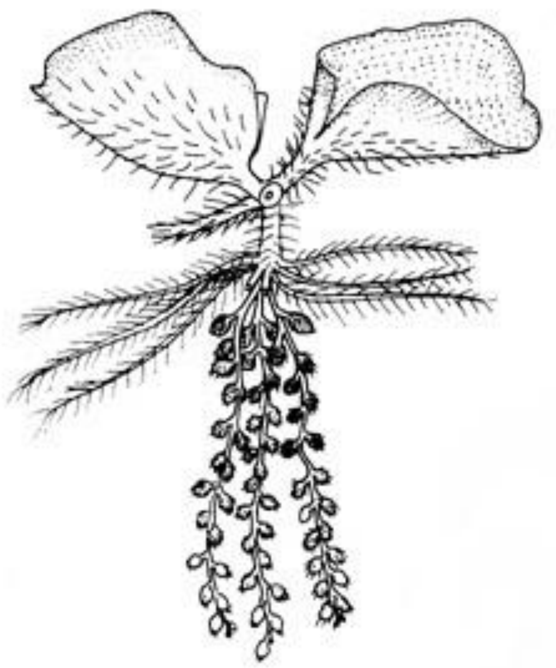


Figure 2.4: Illustration of *Salvinia molesta* (Source: IFAS, 1990)

Plate 2.2: Cage like structure of *Salvinia molesta* papillae (in the red circle)

Salvinia molesta is a floating aquatic fern that thrives in slow-moving, nutrient-rich, warm, freshwater. The map on the distribution of *Salvinia molesta* is shown in the Figure 2.5. A rapidly growing competitive plant, it is dispersed long distances within a water body (via water currents) and between water bodies (via animals and contaminated equipment, boats or vehicles). *Salvinia molesta* is cultivated by aquarium or pond owners and it is sometimes released by flooding, or by intentional dumping. *Salvinia molesta* may form dense vegetation mats that reduce water-flow and lower the light and oxygen levels in the water. This stagnant dark environment negatively affects the biodiversity and abundance of freshwater species, including fish and submerged aquatic plants. *Salvinia molesta* can alter wetland ecosystems and cause wetland loss and also poses a severe threat to socio-economic activities dependent on open, flowing and or high quality water bodies, including hydro-electricity generation, fishing and boat transport (Chamier *et al*., 2012).

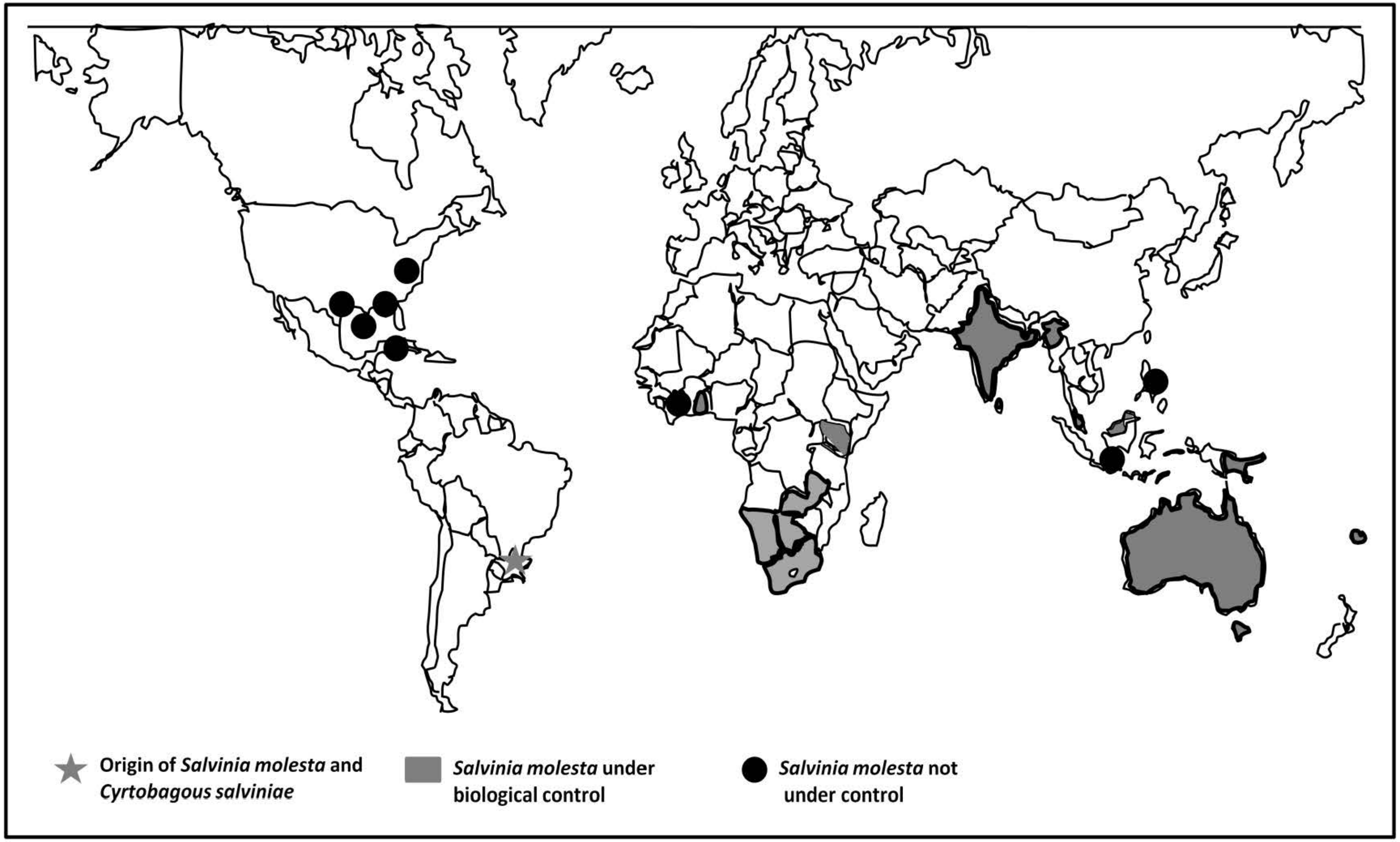


Figure 2.5: Countries where *Salvinia molesta* has been a serious problem in the fresh water systems. (Source: Forno and Harley, 1979)

CHAPTER 3

THE LIFE CYCLE OF *Pistia stratiotes* AND *Salvinia molesta*

3.1 Introduction

Like other floating plants, *Pistia stratiotes* has a notable capacity to build up biomass rapidly (Reddy and De Busk, 1984). *Pistia stratiotes* debris was also used as a biosorbent material to remove metals derived from industrial activities (Miretzky *et al*., 2006) and the living plant is on demand to clear biological waste of water treatment plants (Koné *et al*., 2002; Zimmels *et al*., 2006) or poluted ponds (Vardanyan and Ingole, 2006). Chen *et al*. (2006) stated that *Pistia stratiotes* is also used to reconstruct wetlands or to monitor water quality in rivers.

In most natural situations, *Pistia stratiotes* is a weed because it can quickly overgrow and cover still-water surfaces in a shortest time. Like other floating water weeds, it impedes fishing activities, boat traffic, and flood control, and mats of *Pistia* can threaten hydropower generation dams. By covering water surfaces, it affects habitats and biodiversity (Chamier *et al*., 2012). It blocks out sunlight, affecting native water plants to reduce oxygen movement and thus either displaces or kills native organisms, such as fish.

Consequently, heavy *Salvinia molesta* infestations have negative impact in term of socio-economic because of their potential to ruin industries which depends on clean water bodies. *Salvinia* is also may infest rice fields cultivating area, irrigation channels or entrance to electricity generation stations; hence affect the