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RESEARCH ARTICLE

Review article on *Alternanthera philoxeroides* (Mart.) Griseb (alligator weed); an invasive plant species in Sri Lanka and its control measures

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Abstract: Alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb) is an invasive weed in different countries of South America, North America, Australia and Asia. It can grow in range of habitats from aquatic to terrestrial environments. It is one of the non- native plants which was invading natural and agricultural eco systems in Sri Lanka and has recorded as a threat to the native species and thereby to the plant bio diversity. It was an accidental introduction to Sri Lanka due to misidentification as a commonly cultivated leafy vegetable *A. sessilis* (Mukunuwenna). So it is highly possible to include *A. philoxeroides* in the market samples of leafy vegetables due to this similarity. *A. philoxeroides* can propagate through vegetative fragmentation and these vegetative propagules can be dispersed by water in aquatic habitats. An over view of all aspects of *A. philoxeroides* including its geographical distribution and spread in the world, morphology and ecological aspects, environmental impacts, success of the management options used and present status of this weed in Sri Lanka is presented by this article. Management of alligator weed through chemical, biological, and mechanical means are effective up to some extent in Sri Lanka but it is still a problem in many areas Therefore well-planned, long-term mechanism to evaluate the role of different factors which is responsible for rapid infestation is essential to control the weed. Future research should be focused more on integration weed management approaches in both natural and agricultural ecosystems and to identify the weed from its congener, *A. sessilis*.

***Keywords**: Alternanthera philoxeroides, A. sessilis, Alien invasive species, Sri Lanka*

Taxonomic position

Scientific name: *Alternanthera philoxeroides* (Mart.) Griseb.

Kingdom: Plantae, Phylum: Spermatophyta, Sub phylum: Angiospermae, Class: Dicotyledoneae, Order: Caryophyllales, Family: Amaranthaceae, Genus: *Alternanthera*, Species: *A. Philoxeroides*

Common names: English: alligator weed. Sri Lanka: Bata pala, Wal mukunuwenna

Global distribution and spread of the weed

Alligator weed is one of the worst weeds in the world and also it is the world's first aquatic weed (Tanveer et al., 2018). Its native range is South America but it has also been recorded from North America, Central America, Caribbean, Australia, New Zealand and many Asian countries including Bangladesh, China, India, Indonesia , Japan, Laos, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Singapore, Taiwan, Thailand and Vietnam (EPPO Bulletin, 2016).

In the USA, the presence of *A. philoxeroides* has been recorded since 1897 (Kay & Haller, 1982; Zeigler, 1967) and it has been found at significant level since 1960s (Buckingham, 1996; Spencer & Coulson, 1976). In Australia, *A. philoxeroides* was first observed in the 1940s (Hockley, 1974; Julien & Bourne, 1988; Julien & Broadbent, 1980) and it is still present as very dense monospecific stands in New South Wales (Van Oosterhout, 2007). In

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Australia. *A. philoxeroides* is a Weed of National Significance and has been declared as a noxious weed in all of their states (Australian Government, 2003). *A. philoxeroides* was first recorded in 1906 in New Zealand (Roberts & Sutherland, 1989) as *Telanthera philoxeroides* and now it can be found invading many wet habitats across the country (Bassett et al., 2012; EPPO Bulletin, 2016). It also has been listed as an unwanted plant under the Biosecurity Act (1993) and also included on the National Pest Plant Accord List preventing the sale, propagation and distribution the plant throughout New Zealand (EPPO Bulletin, 2016). This alligator weed was observed in Europe in 1971 from France (Dupont, 1984). This plant has also been recorded as invasive along the Arno River from Signa to Florence (Iamonico et al., 2010; Iamonico & Pino, 2015). *A. philoxeroides* is listed as invasive in USA, France, Italy, India, Sri Lanka, China, Indonesia, Taiwan, Singapore, Myanmar, Australia and New Zealand (Chandra, 2012; DAISIE, 2016; Ewald Weber et al., 2008; USDA-ARS,2016; Weeds of Auatralia,2016). In Lazio, *A. philoxeroides* is considered as an invasive plant (Iamonico & Iberite, 2014).

This weed is widespread and problematic in some Asian countries. It is causing serious impacts on aquatic habitats in China (Flora of China Editorial Committee, 2016). Liu et al. (2017) has predicted that *A. philoxeroides* has a high potential for further spread and expand from South to North range in China. In India, *A. philoxeroides* was reported across Assam, West Bengal, Andhra Pradesh, Karnataka, Delhi, Bihari, Punjab and in the largest freshwater lake, Wular (Masoodi & Khan, 2012). In 1995, it was found that alligator weed has been growing in home gardens of Sri Lankan community in Australia as a vegetable by mistake and later it has been introduced accidentally to Sri Lanka (Gunasekara & Bonila, 2001; Gunasekera & Adair, 1999). However, it was first observed in Sri Lanka in 1998 (Bambaradeniya, 2000). Once established, it has the capability to totally disrupt natural aquatic, semi-aquatic ecosystems and terrestrial environments behaving as an aggressive invader (ISSG, 2016).

Status of Invasive Alien species in Sri Lanka

According to the Convention of Biological Diversity (CBD), the Invasive alien species (IAS) are defined as "Invasive Alien Species (IAS) are species whose introduction and/or spread outside their natural past or present distribution threatens biological diversity."

Sri Lanka which is an island with a very rich biological diversity is now under a threat of alien invasive biota. Many species of alien plant species have been introduced to Sri Lanka when the island was subjected to colonial rule. Few economical important plants such as tea, rubber and coconut are examples for such exotic plants. Some other introduced species have invaded natural ecosystems as well as agricultural ecosystems in the country resulting rapid losses of the biodiversity. Therefore this issue was highly concerned and several attempts have been made to identify this invasive biota in Sri Lanka and to generate public awareness on their impacts on biodiversity (Bambaradeniya, 1999).

Sri Lanka has now recognized invasive alien species (IAS) as a major threat to the native biodiversity (IUCN Sri Lanka and the Ministry of Environment and Natural Resources, 2007). However, a small proportion of intentional or accidental alien introductions have become serious problems due to their invasiveness in natural and agricultural eco systems (Marambe & Gunawardena, 2010). These threats are becoming increased with the implementation of some economic policies facilitating international trade, travel and transportation movement. According to the IUCN Invasive Species Specialist Group's (ISSG), 82 potentially invasive species are present on the island in their Global Invasive Species Database and 40 out of them are plants. Few studies have been focused on this invasive alien flora (Marambe, 2002, 1999, 2000) and no formal risk assessment process has been undertaken to determine their invasiveness. There are many introduced plant species in cultivated lands, roadsides or in natural habitats but it is very difficult to draw a sharp line between IAS and weed species. If the new species has the ability to attack existing environment and spread successfully in the new habitat it may be a sign of invasiveness. When it becomes established in such area, it is able to invade

new habitats and may alter the composition of the ecosystem. In addition, a species become an invasive species when it shows high tolerance levels to diverse conditions. For example, *Pinus caribaea* generally grows in temperate biomes and not spread naturally in Sri Lanka but it is now showing an invasive behavior in Knuckles region (Medawatte et al., 2008). According to the 2015 risk assessment, *A. philoxeroides* was not in national alien invasive plant species list (MMD&E, 2015). Most of the IAS will be unaffected by the microclimatic changes or fluctuations. Phenotypic plasticity to microclimatic variations has been recognized as a critical trait of *A. philoxeroides* contributing to its invasiveness (Geng et al., 2006; C. Zhang et al., 2006). Most of the IAS identified in Sri Lanka has higher growth rates than that of native species and therefore they can occupy easily in the ecosystems. For instance, *A. philoxeroides* has a higher biomass compared to *A. sessilis* and therefore *A.philoxeroides* is a good competitor under varied environmental conditions than *A. sessilis* (Sun et al., 2010). Climate is the key driver of diversity of life in ecosystems. Changes in the climate would not only alter the spatial distribution of species but also facilitate some of the non-native species to become invasive (Iqbal et al., 2014). Sri Lanka has considerable experience where deliberate introduction of alien plants has finally ended to be invasive or weedy (Wijesundera, 1999). Several organizations such as Department of Wildlife Conservation, Forest Department and Department of Agriculture actively participate on IAS related issues in Sri Lanka. However, it is vital to coordinate such action by a specific organization. Therefore, in collaboration with different sectors in Sri Lanka, control efforts have been made for many IAS flora including *A. philoxeroides*. However proper coordination, continuous monitoring and evaluation plans have to be developed.

Alernanthera phioxeroides in Sri Lanka

According to Bambaradeniya, 2002, 59 Alien invasive species (AIS) have been identified in Sri Lanka. *A. philoxeroides* which was first observed in Sri Lanka in 1998 (Bambaradeniya, 2000), was an accidental introduction due to misidentification as a commonly cultivated leafy vegetable, *A. sessilis* and it has been invaded more than 200 ha of lands in Southern province of Sri Lanka and then it has been spread from the Southern Province to the Western Province (Marambe et al., 2001). This rapid spread of the plant may be mainly due to human intervention. This plant was identified in the Western and Southern provinces of Sri Lanka in 1999 (Jayasinghe, 2008) and was recorded in the central province of Sri Lanka in 2004 at high altitudes (over 2500 m a.s.l.) (Gunasekera L., pers. comm., 2015). It seems that the problem has come back to light within green leafy vegetable cultivations in Southern Sri Lanka as patches (Figure 2) and also in many abandoned areas close to those green leafy cultivations (Figure 4). Therefore it is highly possible to include this weed to the market samples and thereby to consume this noxious weed unknowingly by the people.

In Sri Lanka, *A. philoxeroides* is considered as one of the non- native plant which is invading natural as well as agricultural eco systems. In Sri Lanka, now it is becoming a threat to the native species, particularly in leafy vegetable cultivations and thereby to the plant biodiversity. *A. philoxeroides* is also in the list of Alien invasive flora in natural ecosystems of the different bioclimatic zones of Sri Lanka (Bambaradeniya, 2002; Bambaradeniya et al., 1999). In addition, it was in the common invasive alien list in Sri Lanka showing that it is present in up and low country wet zones. (Wijesundara, 2010).

The state Department of Agriculture has taken measures to eradicate the plant from cultivated land with the assistance of the farming community (Marambe, 2001). Although the Department of Agriculture is taking measures to control the weed but again the weed has resurfaced and recently become problematic in waterways as reported for some other IAS such as Water Hyacinth [*Eichhornia crassipes* (Mart.) Solms.] and Salvinia (*Salvinia molesta* D. S. Mitchell) (Perera & Dahanayake, 2015).

Habitats and morphology of the plant

Julien & Bourne (1988) has listed many habitats for this species as freshwater habitats, coastal areas, wetlands, agricultural lands, disturbed areas, river banks, urban habitats and forests. *A. philoxeroides* can tolerate relatively high levels of salinity than a

freshwater plant (10–30% that of sea water) (Global Invasive Species Database, 2010). Therefore this tolerance to salinity may be one of the reasons that it is adapted to aquatic habitats. Also it can adapt to low light conditions (E. Weber, 2003). It is an emergent stoloniferous aquatic or semi- aquatic perennial herb which can live even under terrestrial environments. It often grows at the interface of these two environments. It has a hollow, creeping stem which may sprout up to about 1M in length. This weed produces large mats forming a blanket over the surface of water. Also it grows as a prostrate plant with thin stems and thick roots which contain extensive stores of carbohydrate in moist terrestrial habitats . *A. philoxeroides* has opposite leaves and the shape of the leaf is little bit variable but usually orbicular to ovate with entire margins .These leaves are also seems to be hairless (i.e. glabrous) and have a somewhat waxy appearance. It blooms from May to November, but rarely produces viable seeds. Each flower has five small, white petals with five yellow stamens and is characterized by whitish, papery appearance with stalks and may turn straw-coloured as they mature.

A. philoxeroides can be confused with some other *Alternanthera* species. There are four species of *Alternanthera* species in Sri Lanka as *A. pungens*, *A. sessilis*, *A. paronichioides* and *A. bettzickiana* (Dassanayake & Fosberg, 1980). However, *A. sessilis* (L.) R.Br. ex DC .is the very closely related congener to *A. philoxeroides*.

Figure 1: Commercial cultivations of *A. sessilis* in Southern Province, Matara District, Sri Lanka

Reproduction and dispersal

A. phioxeroides spreads by seeds but seeds are generally produced in areas of its native distribution range. In much of the invasive range, seed production is not observed (Van Oosterhout, 2007). When the seeds produced in many invasive species, those are usually not viable (Julien, 1995). However, this species has been recorded to set seeds in China (Zhang et al., 2004). In Sri Lanka, it has been observed flowering in the field around May but not produces viable seeds. *A. philoxeroides* can spread commonly and quickly by vegetative propagation mainly through fragmentation (ISSG, 2016; Julien (ed.), 1992; Weeds of Australia, 2016). So the spread is predominant from axillary buds at each nod or any piece containing a node. Detachment of small parts of distal ramets with stolons may be very effective in spreading the weed in the field (Bi-Cheng et al., 2012). Those fragments have ability to float along the water currents. According to Zhou et al. (2017), fragmentation of this invasive plant decreases its growth but not its competitive effect. It has been revealed that application of the herbicide glyphosate

results in the production of many stem fragments which are viable and capable of colonization (Dugdale et al., 2010).

Figure 2: *A. Philoxeroides* present as patches in *A. sessilis* cultivations, Southern Province, Sri Lanka.

Figure 3: *A. Philoxeroides* plant taken from *A. sessilis* cultivation in Matara District, Sri Lanka

Figure 4: *A. Philoxeroides* which grows in abandoned wet muddy areas close to *A.sessilis* cultivations in Matara District, Sri Lanka (after flowering occurs)

Impacts on vegetation

As a dense mats floating their clusters of stems on water, it blocks the natural flow of water in some irrigation systems. This invasive species competes with the native vegetation for available resources mainly the solar energy, space, nutrients and water. It also limits the amount of light which penetrates to the interior of water bodies and thereby reduction of the available light for submerged vegetation in such water bodies. It also negatively effect on the quality of the water due to increasing the sedimentation of water in aquatic bodies. *A. philoxeroides* has been shown to provide breeding grounds for snails and mosquitoes in Asian countries and thereby impacts on livestock, food production and human health (EPPO, 2012; Global Invasive Species Database, 2010). In addition, it may function as a habitat for vectors of some diseases increasing vector populations. The final outcome with all of these impacts is the narrowing down of native biological diversity in the areas which they invaded.

Natural enemies to the weed

Agacicles. hygrophilla, commonly called alligator flea beetle has been reported as a bio-agent for the control of alligator weed (Chandrasena & Pinto, 2007), but *A. hygrophila* is not considered as a bio control agent when the weed is widely spread. (Hayes, 2007; Stewart et al., 1999; Winks, 2007). Y*ogtia malaoi (a moth species), laying their eggs on the apical leaves and Amimothrips andersoni (a thrip species) causing limited damage to the apical leaves* are used as promising biocontrol agents to control *A. philoxeroides* (Buckingham, 1996; Pomella et al., 2006). No literature is found using bio control agents to control the weed in Sri Lanka.

Other impacts of the weed

Green leafy vegetables play a significant role in the Sri Lankan diet due their low cost, easy availability, high nutritional value and medicinal properties. However some of them shows toxic effect rather than nutritional values. Long-term application of agrochemicals may increase the heavy metal accumulation in soil in Sri Lanka. A major issue of *A. philoxeroides* is that it can absorb heavy metals and can accumulate at high levels in the plant tissues. Those may be hazardous to the people who consume these plants as a leafy vegetable in their diet. *A. philoxeroides* has been shown a higher level of Cr tolerance without a considerable growth reduction compared to *A. sessils* which is a nutritional leafy vegetable commonly used in Sri Lanka and therefore consuming this as a green leafy vegetable gives a health risk with the accumulated Cr (Siriwardhana & Rathnayake, 2018).

It has been reviewed that Grazing of *A. philoxeroides* by Cattle and horses in terrestrial pasture land has been associated with photosensitivity and skin lesions (EPPO, 2015).

In contrast, this ability of heavy metal absorption may be very useful in phytoremediation to remove heavy metals from polluted lands (http:// www.pdn.ac.lk/ cjsbs/cjsps/text/text35.14.pdf.) It is also suggested that *A. philoxeroides* biochar is a low-cost adsorbent for heavy metals and it may give great ecological and environmental significance for removing Pb (II) in contaminated water. (Yang et al., 2014). Also some research have focused on the potential of lead and arsenic uptake by *A. philoxeroides* under laboratory conditions indicating that metal concentration of the plant tissue is proportional to the metal concentration in the solution.

Control measures

There should be a mean to regulate the flow of potentially invasive organisms. The most effective way is to prevent their introduction to the country. Although the quarantine authorities are so vigilant to prevent the entrance of many alien species to the country (De Silva, 2001; De Silva et al., 2005, 2006), those may have not completely succeeded in preventing importation of the plant parts which comes by some unethical methods. As an example, airline passengers may bring some plant parts in their luggage without authorization. *A. philoxeroides* is an example for an accidental introduction due to misidentification. Accordingly, the leafy vegetable farmers in Sri Lanka have started to grow this weed in their farming lands because of their higher growth rate and considering that it is one of the better variety of *A. sessilis* (Mukunuwenna).

A. philoxeroides is difficult to control because a part with a node has ability to form a new plant (Sainty et al., 1998). Considering this alligator weed, physical removal of the plant is time-consuming and expensive because all fragments of the plant should be removed to avoid any regeneration of the weed population. In addition, it is very difficult to remove the below ground plant parts when the population had been established for a longer period. Dugdale & Champion (2012) has revealed that the effectiveness of herbicides for management of *A. philoxeroides*. However there is no registered herbicide to control this alligator weed but glyphosate and metasulfuron with some organosilicone penetrant have been used to control the weed (Chandrasena & Pinto, 2007; EPPO Bulletin, 2016; Gunasekara & Bonila, 2001). Application of glyphosate, metsulfuron-methyl, dichlobenil, fluridone, hexazinone, triclopyr amine, dimethylamine, imazapyr, diuron, and amitrole

herbicides have been found most effective in controlling this weed in different habitats (Clements et al., 2014; Gunasekera & Adair, 1999; Langeland, 1986; Tanveer et al., 2018). In Australia, they have used the herbicide depending on the associated plants which are associated with alligator weed when grown in home gardens. Dichlobenil at 60 kg/ha-1 was used and was successful and they have treated all naturalized sites associated with water with glyphosate at the rate of 3.24kg/ha-1 in two monthly intervals for three times (Gunasekara & Bonila, 2001). In New Zealand, glyphosate, metasulfuron and imazapyr were used to control the weed and imazapyr was most effective than glyphosate (Deborah & Champion, 2010) as reported by some others in the literature (Allen et al., 2007; Langeland, 1986; Tucker et al., 1994) showing that imazapyr provides better results in the field.

Department of Agriculture in Sri Lanka has launched awareness programs for publics in addition to the chemical control programs to eradicate the weed (Amarasinghe, 2001). After that leafy vegetable farmers did not grow this in their fields but it was seen in water ways arising predominantly around those cultivated areas. It is also observed in the wet muddy areas around the growing lands in Southern province of Sri Lanka (figure 4). Therefore there is a high possibility to survive the weed and spread back to the agricultural lands. So it is urgently needed to do physical removal of the weed in these patches.

Future areas of the research

Research works have been explored on limited aspects of invasive plant species in Sri Lanka during the last decade and therefore many opportunities are existing for future works. Jayarathna & Ranwala, 2014 have revealed that the average rate of publications on IAP in Sri Lanka during 1999-2008 was 12 publications per year. Further, the total number of publications per year neither became consistent nor gradually increased. They also have identified that publications on IAP were limited to only 22 plant species up to 2008 indicating that some species have not studied in detail. According to their list, no detail studies have been conducted on *A. philoxeroides*. In addition, priority has been given mainly on control measures and ecological & economic aspects of the species during the past but not on some areas such as assessment of distribution using any mapping system or geographical information systems and the potential threat by new invasive plant species.

Although the DOA has taken many control measure to eradicate this species, the problem has still on the surface. So all the weed scientists and relevant authorities should pay more attention on this non-native weed which gives a major threat to the bio diversity. The management of the weed through chemical, mechanical or using bio agents may be effective but it is essential to do a well-planned, long term field research works to evaluate the role of various other factors which are responsible for its regeneration after the application of herbicides, their infestation and its spread in high soil fertility or in soil disturbances such as deep ploughing and grazing by buffaloes and cows. These should be focused on various ecological regions with regards to both aquatic and terrestrial ecosystems.

It is still consumed with misidentification to the *A. sessilis*; a green leafy vegetable even though not at a significant level (Dissanayake et al., 2015) and that contamination also should be avoided. This can be done by conducting education and awareness programmes regularly to publics, farmers, secondary and higher education level students using media such as TV programmes, seminars, newspaper articles. Doing projects at under graduate or post graduate level is also useful to study the plant well and thereby developing some packages for control of the weed. Therefore further researches are necessary to eradicate this species using integrated weed management. As there is very few studies on the possibility of absorption of heavy metals by this plant, more works should be carried out to elucidate this process also.

In addition it may be useful to look forward the ability of this plant to remove heavy metals from polluted wet lands, in phytoremediation process.

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