Proc. 20th Asia-Pacific Weed Science Soc. Conf., Ho-Chi-Minh City, Vietnam, 121-130.

LUDWIGIA PERUVIANA (L.) HARA AND *LUDWIGIA LONGIFOLIA* (DC) HARA IN SYDNEY: FROM IMMIGRANTS TO INVADERS

Nimal Chandrasena

Ecosystem Restoration

1, Kawana Court, Bella Vista, NSW 2153,
Australia

nimchan@iinet.net.au

Abstract:

Ludwigia peruviana (Primrose Willow; Family: Onagraceae), a native of South America, with a wide geographical distribution in tropical climates, has become a significant aquatic weed in eastern Australia, mainly in the Sydney basin. A second species- *Ludwigia longifolia* (Long-leaf Willow Primrose), first recorded in 1991 as an escapee from nurseries, is also recognised as a significant weed of aquatic habitats in the same region. Until recently, these species have been considered relatively minor weeds or naturalised plants, mainly in the tropics. However, their potential to become major threats to aquatic habitats over a wide geographical area in tropics or sub-tropics needs to be recognised, so that infestations detected early can be managed.

Since 1971, when *L. peruviana* was first recorded in Botany Wetlands in Sydney, it has spread widely from the initial infestation. The magnitude of the infestations in wet habitats, such as wetlands, creek and drains, the rate at which the infestations spread from a Sydney locus indicates how a recently introduced plant (a new ‘immigrant’) could rapidly become an ‘invader’. Although *L. longifolia* is yet to invade so wide a territory, the tenaciousness of its established populations and resistance to control efforts have been noted in several locations.

Issues related to the successful invasion of aquatic habitats by *L. peruviana* and *L. longifolia* are discussed. Case studies are presented, which demonstrate the success, as well as limitations of implementing integrated weed management to locally contain the two species. Whilst recognising that control of biotic invasions becomes most effective when it employs a long-term, ecosystem-wide strategy rather than a tactical approach focusing on individual invaders, it is suggested that, in the case of relatively recent invaders such as *L. peruviana* and *L. longifolia*, an individualist approach appears necessary, if the considerable additional threat posed by these weeds are to be averted.

Containment and/or local eradication strategies should include early detection, early intervention to control individuals reaching maturity and prevention of spread via stormwater runoff, wind and other dispersal mechanisms.

Keywords: *Ludwigia peruviana*, Primrose Willow, *Ludwigia longifolia*, aquatic weeds

INTRODUCTION

Biotic invasions occur when organisms are transported to new, often distant ranges, where their descendants proliferate, spread and persist, establishing successful breeding populations (Mack *et al*. 2000). Such invasions are neither novel nor exclusively human-driven. Nevertheless, the frequency and number of species invading across continents have grown enormously, especially in the last 200 years. This phenomenon is probably a consequence of expanding inter-continental transport of goods and people, with humans serving as both accidental and deliberate dispersal agents.

The establishment of Primrose Willow (*Ludwigia peruviana* (L.) Hara) in Sydney is a classic case of a recent biotic invasion of Australia. The history of its introduction in Sydney, first as a Botanical specimen, and the nature and rate of spread in the region is similar to an invasion, rather than a gentle immigration (an introduction), naturalisation (assimilation) and intermingling with existing vegetation communities.

A second species- Long-leaf Willow Primrose (*Ludwigia longifolia* (DC.) Hara) was first recorded in NSW, Australia in 1991 as an escapee from nurseries. This species is also threatening to become a significant aquatic weed in eastern Australia.

Both *L. peruviana* and *L. longifolia* have not been recorded as major weeds in the world, but are considered as relatively minor weeds and naturalised plants in tropical and sub-tropical countries. However, the threat posed by both species to sensitive aquatic habitats in these areas is much greater than has been recognised.

In this paper, some issues related to the successful invasion of aquatic habitats by *L. peruviana* and *L. longifolia* in eastern Australia are reviewed. Experiences in the control of infestations are also discussed, arguing the case for a possible eradication strategy.

THE INVADERS

Ludwigia peruviana

Ludwigia peruviana, first named by Linnaeus as *Jussiaea peruviana* L, is known by other synonyms, including *Jussiaea grandiflora* L. It is a semi-aquatic, cold-deciduous shrub, which can grow up to 3-4 m height; its flowers are bright yellow, and the plant is a profuse seed setter. A native of the New World, *L. peruviana* occurs widely from southeastern United States, nearly throughout tropical and sub-tropical South America. It has not been regarded a weed in these areas.

According to Raven (1963), introduced in the Old World, the species became naturalised in Asia, South India, Sri Lanka (Ceylon), Singapore, Northern Sumatra and Java. Referring to specimens collected from these countries dating back to mid-1850s Raven (1963) suggested that the spread of genus *Ludwigia* to Australia and Pacific islands might have been relatively recent. The species is regarded s a minor weed in Asia, Indonesia and North America (Ramamoorthy and Zardini 1987).

Specimens in herbaria, such as in Sri Lanka's National Herbarium, are from moist habitats, from 0-1450 m altitude. In Australia, infestations south of Sydney, in Sutherlandshire, latitude $\approx 30^0$ South, are the southern-most limit of its current spread. The pantropical occurrence, across several continents, and tolerance of conditions from sea level to > 1450 m altitude indicates the wide ecological amplitude of the species.

Humans introduced *L. peruviana* to Australia; it was cultivated at the Botanic Gardens in Sydney in 1907 (Jacobs *et al* 1994), possibly after introduction to Australia from South East Asia by botanists. Humans probably moved the species out of the Gardens as well, or humans may have acted as accidental carriers of propagules.

The central locus of first establishment of *L. peruviana* appears to be Botany Wetlands in Sydney (Jacobs et al 1993), less than 10 km south of the Botanic Gardens (Figure 1). This extensive nutrient-rich pond system is historically significant in Australia because they once served as a drinking water supply to early Sydney settlers. First recorded in 1971 as naturalised in Botany Wetlands, *L. peruviana* infestations expanded in the next 20 years and by 1991, dense, mono-specific stands in the ponds covered approximately 30-31% of the Wetlands (Jacobs et al 1993; Chandrasena & Sim 1998) (Table 1).

Infestations in some ponds were so extensive that they covered almost 70% of area, causing large-scale changes to water-flow and vegetation (Figure 2). The potential of *L. peruviana* to spread throughout tropical and temperate Australian waterways and damage other wetlands was recognised with these vast infestations (Jacobs et al 1993).

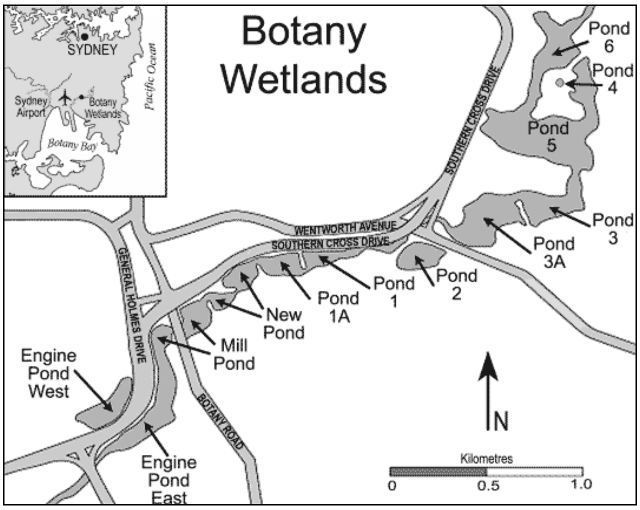

Figure 1.

Botany Wetlands pond system (59 ha) in Sydney's eastern suburbs, where large infestations of *L. peruviana* were first found. By 1990s, 30-31% of pond system was covered by entrenched, dense infestations and floating islands. Note major arterial roads impacting on the Wetlands.

Table 1. Extent of *L. peruviana* infestations in Botany Wetlands (1991).

POND Area (ha)	*L. peruviana* (ha)	Other aquatic weeds & invasive trees (ha)	Open water (ha)
Ponds 6, 5, 4, 3, 3A, 2 (34.1)	6.6	4.5	23.0
Ponds 1, 1A, New Pond (10.0)	7.9	0.7	1.4
Mill Pond & Engine Ponds (15.0)	3.7	7.8	3.5
Total Area (59.1)	18.2 (31%)	13.0 (20%)	28.0 (49%)

Ludwigia longifolia

Ludwigia longifolia (≈ *Jussiaea longifolia* DC.) is also a New World species, whose native range stretches from Brazil to Argentina. Its habitats are also tropical and sub-tropical swamps. The species may look like *L. peruviana*, but its leaves are much narrower, and often have a reddish tinge.

Figure 2. *Ludwigia peruviana* in Pond 3, Botany Wetlands (1991) (a) aerial photograph showing >70% of area was covered (b) 2-3 m tall dense shrubs.

Small *L. longifolia* infestations were first found in New South Wales, Australia, in areas between Sydney and Port Stephens near Newcastle (Gorham 2003). Newcastle is a port city approximately 150 Km north of Sydney on Australia's eastern shoreline. Several large infestations were found in the Mambo Wetlands located in Salamander Bay on the southern foreshore of Port Stephens (Figure 3) (McCall 2004).

In the early 1990s, a few plants of *L. longifolia* were found in the upstream sections (Pond 6) of Botany Wetlands. In 2004, a new infestation was found almost on the same location where the initial patches were found (Figure 4).

FROM IMMIGRANT TO INVADER

Mack et al (2000) suggested that the transformation from an immigrant to an invader entails a long lag phase, followed by a phase of rapid exponential increase, which continues until the species reaches the limits of its new range, and its population growth slackens. The spread and establishment of *L. peruviana* in Sydney fits this model.

It is possible that *L. peruviana* infestations in Botany Wetlands, which existed for nearly 20 years, may have been the source of infestation of the weed for further spread in the Sydney basin. By late-1980s, infestations were found in Heathcote, about 40 km south of Sydney, and in Gosford, about 80 km north of Sydney (Jacobs et al 1993).

The pattern of *L. peruviana* spread in the northwest region of Sydney, along several creek systems, indicates that a now defunct nursery may have been a second source (Peter Gorham, NSW Dept of Primary Industries, *pers. comm.*). Creeks in the northwest drain to the Hawkesbury River- a major river in the Sydney basin. Established populations are regularly encountered on its flood zones and banks.

The species is now widespread in the Sydney basin over a large area and is regarded as a common weed of aquatic habitats. Spread has occurred largely along stormwater drainage creeks, ditches, riverbanks and other wet habitats, where silt accretion occurs.

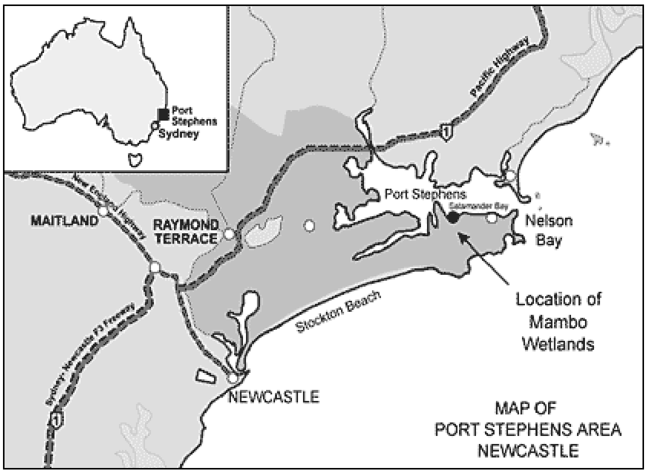

Figure 3. Location of the culturally significant Mambo Wetlands (175 ha), Salamander Bay, Port Stephens, where the largest infestations of *L. longifolia* were first found. Note closeness to the port city Newcastle, north of Sydney. Other infestations found thus far are small and sporadic in occurrence.

Figure 4. *Ludwigia longifolia* in Pond 6 Botany Wetlands (2004). Note reddish tinge in leaves and on young stems.

Ramamoorthy and Zardini (1987) noted the ability of *L. longifolia* also to form floating islands during its late succession stages.

All municipalities in the Sydney basin have now declared *L. peruviana* a noxious plant, to be controlled within their local government areas. The establishment of extremely successful populations in the Sydney basin, over a short space of 30 years, indicates the invasive potential of the immigrant turned ‘invader’ to Australia (Figure 5).

The known extent of *L. longifolia* spread is currently limited to several wetlands and moist locations along the eastern shoreline of NSW between Sydney and Newcastle.

WHY *L. PERUVIANA* AND *L. LONGIFOLIA* ARE PROBLEMS?

The main potential deleterious effect of both species is their ability to supplant native species in wetlands and in riparian zones of waterways, which could result in permanent changes to flora, fauna and ecological diversity in such ecosystems. Dense stands of *L. peruviana* intercepted 93% of incident light (Jacobs *et al.* 1993), which led to dramatic losses of smaller native freshwater wetland plants and a reduction in bird populations.

In the interconnected Botany Ponds, dense *L. peruviana* stands choked water flow between ponds and increased sedimentation.

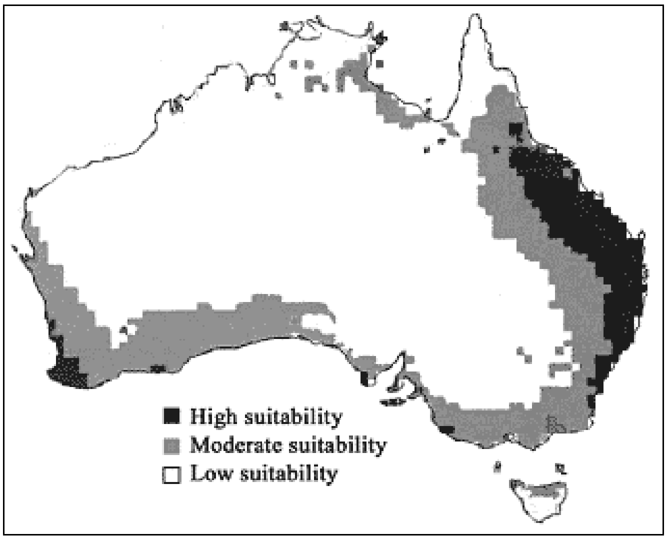

Figure 5.
The CLIMATE computer-generated distribution map for *Ludwigia peruviana* (Source: Dept of Natural Resources, Queensland 2003). Note the vast area of sub-tropical and tropical Australia potentially available to be exploited by the weed.

Reduced water flow increased the risk of flooding of adjacent properties. The addition of vast amounts of organic material, over decades, led to deoxygenation of ponds and wide ranging ecological damage. Recurrent toxic blue-green algal blooms were common in the ponds, which indicated, nutrient enrichment and a breakdown of natural food webs. These adverse changes threatened cultural, social, aesthetic and economic values of the Botany Wetlands (Chandrasena and Sim 1998). Negative social impacts included reduced opportunity for recreational use by the public.

McCall (2004) noted that the near pristine state of the Mambo Wetlands was under threat by *L. longifolia* as it increased the risk of flooding and sedimentation of the Wetlands, and the reduced the Wetlands' recreational values.

It could also be argued that there are other environmental impacts, which could arise due to applying weed control technologies, such as herbicides or mechanical removal. Economic factors affected include costs of such controls, plus increased maintenance costs of stormwater drainage systems, to prevent re-establishment of the weeds.

KNOWLEDGE OF BIOLOGY AND ECOLOGY

Understanding relevant aspects of the invader's biology and ecology is critical to effectively manage the invasions. Such understanding, particularly the invader's strengths and weaknesses, allows strategies to be developed targeting the weaknesses.

Seed production

Seed production is the main reproductive strategy of both species ("r-strategists"). Mature *L. peruviana* stands in Botany Wetlands produced ≈ 450,000 seeds m^{-2} (Jacobs et al 1994). In addition, there were ≈ 65,000 seeds m^{-2} in the soil seed bank and ≈ 300,000 seeds m^{-2} in old fruits, which remained on stems over winter.

Young plants flowered within two years. Within a year, there are two periods of flowering (spring and late summer) in Sydney. Seed viability was extremely high, in the range of 80-99% in the first year, declining significantly within 2 years (Jacobs et al 1993). The small seeds germinate readily in mud throughout spring and summer.

There was some evidence of dormancy, possibly due to the hard-seed component of the seed bank, but this appears to break down after about one year (Jacobs et al 1993).

The seeds of *L. peruviana* are hydrophobic, which make them germinate while afloat or underwater (Jacobs et al 1993). But the seedlings eventually float to the surface for establishment along shorelines, and also allow *L. peruviana* to form floating islands.

McCall (2004) reported that a *L. longifolia* plant, one year old, produced about 5 capsules, equivalent to 35,000 seeds. A more mature plant can average 35 capsules stem^{-1} and with 6–10 stems plant^{-1}, this equates to ≈ 2.45 Million seeds plant^{-1}. Annual seed production of heavily infested sites (10 plants m^{-2}) can reach 25 Million seeds m^{-2}. The seed germination rate of *L. longifolia* over 45 days in this study was 94%. The young plants grew at a growth rate of 125 mm month^{-1}. The sediments had a pH range of 3.6-5.8 and very high levels of aluminium and ferrous.

Seed bank depletion would occur due to germination of those, which germinate, and decay over time of those that are not germinating. Seeds survive by being buried in mud and shallow buried seeds are probably lost by intermittent exposure. Based on flushes of new seedlings, which appear on exposed mud at Botany Ponds, where previous stands occurred, it is evident that *L. peruviana* seeds have moderate long-term longevity.

The primary dispersal agents of seeds are water, wind and birds. Machinery, vehicles, footwear and clothes, which are contaminated with mud or seeds, also cause spread.

Vegetative Reproduction

A major strength of both species is their ability for vegetative propagation, mainly by stem layering. Dislodged branches and stem pieces can take root after dispersal by flood or by machinery during removal and develop new plants. The capacity for vegetative reproduction greatly exacerbates the threat posed, particularly in environments where established small to medium infestations occur.

CONTROL OPTIONS

From the trials conducted at Botany Wetlands (McCorkelle et al 1995) and subsequent on-ground weed management works (Chandrasena et al 2002), a significant amount of information is available on options to control *L. peruviana* infestations. Given that both species are well adapted to exploit the ecological niches left open in environments altered by man, the overall focus of integrating the weed management options should be to create conditions unfavourable to weed establishment and growth, while maintaining suitable conditions for other beneficial vegetation.

The integrated weed management (IWM) strategy implemented at Botany Wetlands combined the following: (a) water level management, (b) herbicides (Biactive® Glyphosate, 2,4-D Amine), (c) mechanical weed clearing, (d) controlled burning, (e) early detection and control of new infestations, and (f) large-scale revegetation. Over 6-7 years (1996-2002), the program reduced the once dominant infestations to negligible levels, with concomitant increases in native vegetation cover (Chandrasena et al 2002).

Preventative Control

Preventative control is strategic weed management. However, to be successful, prevention has to apply to all levels of scale from the whole of Australia down to small areas, creek lines, roadside culverts, private properties, water bodies or paddocks.

To manage invaders such as the *Ludwigia* species, early detection and control of isolated plants is critical. Early interventions have to be applied aggressively to a wider area, region or catchment, and are by far the most effective means of controlling and arresting the invasions of the weed species.

Herbicides

Experiences at Botany Wetlands and other areas in the Sydney basin indicate that both *L. peruviana* and *L. longifolia* can be relatively easily controlled by the non-slective glyphosate and highly selective 2,4-D Amine.

However, treatment efficacy can be sub-optimal, because of poor access to infestations and difficulties in applying herbicides in locations such as wetlands. Therefore, repeat treatments, after some regrowth had occurred, are often required to control mature stands. Biodegradable adjuvants increase the efficacy of treatments (data not presented), and these would ensure that the overall amounts of chemicals needed are reduced.

Lower herbicide rates are often preferred in wetlands, to reduce potential damage to native vegetation. In such situations, split applications with lower rates can be used. Control of seedling flushes can also be achieved with much reduced rates.

Controlled Burning

Ludwigia stands, killed by herbicides, can be removed by burning. This method of weed-clearing has been successful in Botany Wetlands (Chandrasena et al 2002).

Mechanical and manual clearing

Mechanical clearing of *L. peruviana* stands is possible, but this option is only suitable after killing the plants with herbicides. Machinery is also limited by access to sites and potential environmental impacts they may have on adjacent native vegetation.

Seedlings of both species are easily removed by hand pulling, but mature plants are difficult to remove because of extensive root systems embedded in the mud.

Biological Control

Biological control possibilities for the two *Ludwigia* species have not yet been explored. If they were found, the use of any natural enemies of the weeds (parasites, predators and pathogens) would be by far the cheapest method of long-term control.

Revegetation

Reclaiming *Ludwigia*-infested habitats will succeed only if competitive, perennial native macrophytes, including sedges, rushes and grasses, would displace the invaders. Hence, revegetation needs to be an integral component of fighting the invasions.

To ecologically complement wetland plant communities, preference should be for natural regeneration over active replanting. Once the original *L. peruviana* infestations were controlled in Botany Wetlands (Chandrasena et al 2002), the growth of competitive macrophytes drastically reduced recolonisation by the weed.

Supplementing natural regeneration by purposeful planting of a range of wetland species may also be necessary, to maximise species diversity to achieve resilience to future disturbances, resist further weed invasion and enhance ecological values. Local seed sources or propagules should be used in revegetation, to retain genetic resources.

A CASE FOR AN ERADICATION STRATEGY

Eradication of a weed species requires control aimed at destruction of every propagule capable of growing up to a breeding individual, from an area or region, thus preventing re-establishment of a larger population. In contrast, containment is control, which targets prevention of spread, possibly with reductions of the size of populations.

Eradication of a widespread invader has rarely been achieved in any country. However, local eradications of weed infestations are commonly achieved. In general, successful eradication depends more on sustained weed control over a period of time, backed by diligent monitoring, than on the efficacy of any specific control method.

The decision to use eradication as a management strategy is a complex one. It involves assessing the following: (a) long-term impact of the weed species on native ecosystems; (b) the value placed by the public on those vulnerable ecosystems; (c) ease of achieving eradication; (d) costs and benefits of containment control; and possibly (e) the potential environmental disruptions caused by eradication treatments.

In the case of relatively recent invaders in the Sydney basin, like *L. peruviana* and *L. longifolia*, a ‘weed-led’ individualist eradication approach appears necessary, if these species are not to become permanent major weed problems in fragile environments. The main rationale for eradication is that: (a) the existing knowledge on the biology and ecology is sufficient to formulate reasonable management strategies; (b) the species are still rather limited in distribution; (c) the area occupied by the infestations is small in most cases; (d) control methods are relatively well known; and (e) relatively quick and sustained action on small infestations has achieved local eradications.

An effective eradication plan requires legislative backing, which exists in New South Wales with *L. peruviana* classed as a W2 category noxious weed, under the *Noxious Weeds Act*. It also requires a commitment from those involved to stop the invaders.

CONCLUSIONS

Invasive species thrive in new habitats replacing other species, because the newcomer is better suited to exploit the environment. In most cases this occurs not because the newcomer is necessarily ‘environmentally fit’, but because the existing environment has undergone changes due to disturbances caused by humans or by natural causes. The examples of the *Ludwigia* species in Sydney represent the human-disturbance scenario.

Accumulation of nutrient-enriched sediments in urban drainage systems, traceable to human activities, created conditions conducive to the establishment and expansion of the *Ludwigia* species. Absence of natural enemies may have been the main cause, which allowed the new invaders to be successful in their new habitats. Their innate capacity to tolerate a wide range of ecological conditions, combined with ‘r-strategist’ life cycles (enormous reproductive potential involving seed production, rapid growth and vegetative reproduction) allowed them to maintain breeding populations and spread.

In my view, *L. peruviana* and *L. longifolia* represent unwarranted new weed invasions, which pose considerable threats to Australia’s fragile natural ecosystems. The most significant and long-lasting adverse effect of the invaders is the alteration of the integrity of wetland ecosystems, through modification of biological inter-relationships.

As well documented in Botany Wetlands, and probably seen to some extent at Mambo Wetlands, the two *Ludwigia* species altered the floral composition of the wetlands, community structure and stability and along with the above, trophic relationships, natural cycling and productivity. The aggregate effect would be loss of bio- diversity and our inability to protect natural ecosystems and native vegetation communities.

There is a case for weed managers in Australia to adopt eradication as a strategy, rather than containment, to deal with both *Ludwigia* species in the Sydney basin, based on the previously discussed rationale. Where there are still small infestations, there should be quick action focused on eradication; where there are relatively large infestations, sustained action is needed, complemented by monitoring.

The tools required for a successful eradication campaign- integration of biological information into management and control options, are well established. The need is really for a change of mindset, early detection of new infestations, and a commitment of resources to cause local eradication through a systematic, co-ordinated approach.

LITERATURE CITED

Chandrasena N. and Sim R. 1998. Managing entrenched weed problems in Botany Wetlands- an urban stormwater basin in Sydney. Proceedings of 11th IWSA-ASPAC Regional Conference, Sydney, 364-370.

Chandrasena N., Pinto L. and Sim R. (2002) Reclaiming Botany Wetlands, Sydney through integrated management of *Ludwigia peruviana* and other weeds. Proceedings of 13th Australian Weeds Conference, Perth, 134-137.

Jacobs S. W. L., Perrett F., Brock M., Bowmer K. McCorkelle G., Rawling J., Stricker J. and Sainty G. R. 1993. *Ludwigia peruviana*- Description and Biology. Proceedings of 14th Asian-Pacific Weed Science Society Conference, Brisbane, 225-228.

Jacobs S. W. L., Perrett, F., Sainty G. R., Bowmer K. H. & Jacobs B. J. 1994. *Ludwigia peruviana* (Onagraceae) in the Botany Wetlands: Sydney, Australia. Journal of Marine and Freshwater Research 45: 1481-1490.

Mack R. N., Simberloff D., Lonsdale W. M., Evans H., Clout M. and Bazza F. A. 2000. Biotic invasions: Causes, Epidemiology, Global consequences and Control. Ecological Applications. 10: 689-710.

McCall S. 2004. Monitoring *Ludwigia longifolia* at Mambo Wetlands. Investigation of a potentially invasive new weed incursion for Port Stephens Council. University of Newcastle, Australia- Placement Study (Unpublished Report).

McCorkelle G., Sainty G. and Bowmer K. 1995. Management of aquatic plants in the Botany Wetlands. III. Field evaluation of herbicides for the control of *Ludwigia peruviana* and revegetation strategies. CSIRO Division of Water Resources, Report No. 95/29. pp. 47.

Ramamoorthy T. P. and Zardini E. M. 1987. The systematics and evolution of Ludwigia sect. Myrtocarpus sensu lato (Onagraceaea). Monographs in Systematic Botany. Missouri Botanic Gardens. Pp. 120.

Raven P. H. 1963. The old world species of *Ludwigia* (including *Jussiaea*) with a synopsis on the genus (Onagraceae). Reinwardtia, 6 (4): 327-427.