Cabomba caroliniana Gray – cabomba

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ABSTRACT

Cabomba is a submerged aquatic plant that originates from two areas in the Americas – north-eastern Argentina and the south-eastern USA. Despite its restricted native distribution, it has been invading new habitats worldwide and has a large latitudinal range, from cold temperate lakes in Canada and Holland to tropical waters in Australia. It prefers the slow-moving waters of lakes and impoundments where it produces thick stands that reduce the abundance of native species, negatively affect irrigation and potable water treatment, and impede human activities such as boating, fishing and swimming. There are no sustainable methods to manage cabomba and a biological control research program was instigated by the CSIRO in 2003. Several potential biological control agents have been identified in the native range and on closely related plants in the Cabomba genus. The host-specificity of an aquatic weevil, *Hydrotimetes natans*, is being tested in quarantine.

Key words: invasive aquatic macrophyte, insect, herbivore, water fanwort, *Paracles* sp., *Paraponyx diminutalis*.

INTRODUCTION

Cabomba (*Cabomba caroliniana* Gray, Cabombaceae), or water fanwort, has a disjunct native range – in South America centred around northern Argentina and in the southern USA along the Atlantic and Gulf coasts (Orgaard 1991). The plant's tolerance of fragmentation and delicate appearance make it a desirable aquarium plant (Hiscock 2003) and consequently it has been introduced into many countries by the aquarium trade. Cabomba has subsequently been introduced into lakes and streams, both accidentally through the dumping of aquarium water and on purpose to enable cultivation for later collection and sale. It is primarily spread across catchments by watercraft, boat trailers and eel-trapping cages.

Cabomba is a fast-growing submerged aquatic plant that has the potential to infest permanent water bodies in a range of regions, from tropical to cool temperate, throughout the world. It is considered a serious pest in the USA north of the Carolinas and along the west coast, in Canada, the Netherlands, Japan, India, China and Australia, and is present in Hungary, South Africa, France and the UK. Cabomba grows well in slow-moving water bodies and is found mostly in areas of permanent standing water less than 4 m deep; it occurs at depths up to 6 m in Australia (Schooler and Julien 2006). The weed is recognised by its opposing pairs of finely dissected underwater leaves that are feathery or fan-like in appearance (Fig. 1). Small white flowers bearing three petals and three sepals (Fig. 2) extend above the water surface, making infestations more visible in summer months (Fig. 3). Reproduction is almost entirely vegetative throughout most of its introduced range and any fragment that includes a node can grow into a new plant (Sanders 1979).

Cabomba negatively affects the environment, recreational activities, public safety and water quality (Mackey

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Figure 1: *Cabomba caroliniana.* a) Plant. b) Fruit. c) Flower. d) Non-dissected upper leaves. e) Dissected lower leaves. Illustration: S Wragg, CSIRO.

and Swarbrick 1997). The weed can smother native submerged plants and may also reduce germination of desirable native emergent plants. Alteration of the flora by cabomba is thought to have reduced populations of platypus (*Ornithorhynchus anatinus* Shaw, Ornithorhynchidae), water rats (*Hydromys chrysogaster* Geoffroy, Muridae) (Mackey and Swarbrick 1997) and populations of the endangered Mary River cod (*Maccullochella peelii mariensis Rowland,* Percichthyidae) (T Anderson, *pers. comm.* 2004). The long stems of cabomba impede boat movement and they can get tangled in propellers, paddles and fishing lines. They are also a potential danger to swimmers. In its native range, however, cabomba seldom covers large expanses or becomes a problematic plant.

It is difficult to assess the cost of the damage caused by cabomba, but some data on the cost of managing cabomba are available. Herbicides are largely ineffective and herbicide use is severely regulated in or around public water supplies (Anderson and Diatloff 1999). Eradication of cabomba from the Darwin River (12.521°S, 131.055°E) is currently being attempted using herbicides. However, supplying water to residents, water quality testing, public education and repeated applications of herbicide have cost over $360 000 in the 2006–07 financial year alone (S Wingrave, *pers. comm.* 2007). Physical control methods are also being used to manage cabomba. From 2000 to 2005, Caloundra Shire Council in Qld spent over $240 000 per year to physically remove cabomba around public areas of Ewen Maddock Reservoir (26.797°S, 152.990°E) using scuba divers and suction pumps (R Rainbird, *pers. comm.* 2007) and Noosa Shire Council spent in excess of $140 000 per year to mechanically remove cabomba from

Figure 2: Cabomba flower with three petals and three sepals. Note small non-dissected upper leaves floating on the water under the flower. Photo: S Schooler, CSIRO.

a small fraction of Lake Macdonald (26.385°S, 152.929°E) using a floating weed harvester (B McMullen, *pers. comm.* 2007). The only sustainable method of managing cabomba appears to be biological control (Schooler *et al.* 2006).

Cabomba has a wide potential distribution. In Australia it is found from Melbourne to Darwin (Fig. 4). Current latitudinal distribution is from monsoonal tropical (Darwin River, Darwin, 12°S) to cold temperate (Loosdrecht Lakes, Holland, 52°N) environments and it can persist under ice in continental temperate climates (Wilson *et al.* 2007). It is primarily a problem in lakes and reservoirs but it can also establish populations in streams, rivers and irrigation canals. It is often found near bridges, either because there are pools of slow-moving water and/or because it was planted for later collection and sale.

BIOLOGICAL CONTROL HISTORY

In 2003, CSIRO commenced a project to discover and test biological control agents from the native range in South America for possible release in the introduced range of

Figure 3: Cabomba infestation in a small farm dam in south-east Qld, 2006. The white flowers emerge above the surface, making the weed more visible during the summer months. Maximum depth is 4 m. Photo: S Schooler, CSIRO.

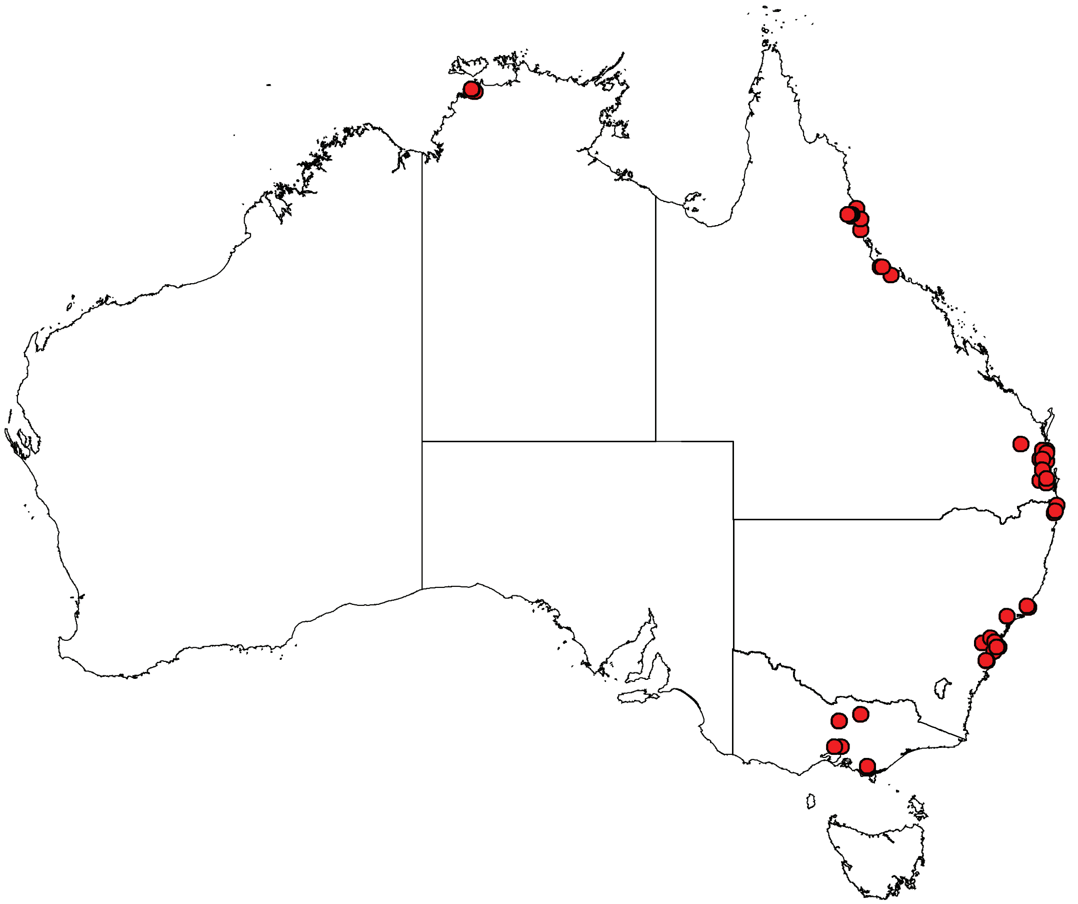

Figure 4: Distribution of *Cabomba caroliniana* in Australia based on herbarium records as of February 2010. Location data records extracted from the Australian Virtual Herbarium. Specimen data reproduced from Australia's Virtual Herbarium with permission of the Council of Heads of Australasian Herbaria Inc.

this weed. Surveys for herbivores in the native range are being completed and host-specificity tests conducted on selected agents in quarantine.

Hydrilla verticillata (L.f.) Royle (Hydrocharitaceae) is the only other submerged weed for which biological control has been attempted, with four agents released in the USA (Julien and Griffiths 1998). So far that project has not resulted in effective control. This may be because the specific life-cycle requirements of the agent are not met in the introduced range (Center *et al.* 2002).

PLANT TAXONOMY

Few plants in Australia are closely related to *Cabomba caroliniana*. Cabomba occurs within Nymphaeales, which consists of two families, Nymphaeaceae and Cabombaceae. One of only two genera in the Cabombaceae, *Cabomba* consists of *C. caroliniana* and four other species (*C. aquatica* Aublet, *C. palaeformis* Fassett, *C. furcata* Schultes and Schultes and *C. haynesii* Wiersema), all of which are endemic to Central and South America (Orgaard 1991).

In its native range in South America there are two varieties of cabomba: *C. caroliniana* Gray var. *caroliniana* Gray, a stout plant with white flowers, and the smaller and more delicate *C. caroliniana* var. *flavida* Orgaard that has yellow flowers. These two varieties do not grow in the same habitats. *C. c. flavida* occurs only in small streams, shallow ponds and irrigation ditches, whereas *C. c. caroliniana* occurs in larger and deeper water bodies. In North America there is another variety, *C. c.* var. *pulcherrima* Harper, known only from the south-eastern USA (North Carolina to Florida). Preliminary genetic analysis indicates that most of the populations of cabomba in Australia are a hybrid between *C. c. caroliniana* and *C. c.* var. *pulcherrima*. However, two localised populations are different; one is more similar to *C. c. caroliniana* and the second appears to be a hybrid between *C. c. caroliniana* and *C. aquatica* (A Weiss, *pers. comm.* 2008). This suggests that there have been at least three separate introductions of cabomba into Australia.

EXPLORATION

Northern and central Argentina and southern Paraguay and Uruguay were surveyed from 2003 to 2009 (W Cabrera-Walsh, unpub. data). In Brazil, surveys were conducted in the Pantanal, Mato Grosso do Sul, during 2004 and in the four south-eastern states during 2006 (C Wikler, *pers. comm.* 2006). Waterways and water bodies along more than 21 000 km of road were surveyed. Cabomba was mostly found in clear-water lakes and streams with low current velocity at 1–4 m depth. These environments were found in Argentina (in the province of Corrientes and in isolated locations along the Paraná-Uruguay basin in the provinces of Formosa, Chaco, Entre Ríos and Buenos Aires), in southern Paraguay and in a few isolated populations on the south-east coast of Brazil. Surveys were also conducted in tropical America (Venezuela, Costa Rica, Puerto Rico and Mexico) on three congeneric species (*C. palaeformis, C. furcata,* and *C. aquatica*) in 2006–08 by Ricardo Segura and Shon Schooler, CSIRO. Specimens of the herbivorous insects found during these surveys are currently housed at the CSIRO Mexican Field Station, where they are being identified.

Ad hoc surveys have been conducted in southern USA by various researchers during the last decade. In 2007–09 several surveys were conducted by Min Rayamajhi, USDA-ARS, looking specifically for plant pathogens. No potential cabomba biological control agents have yet been identified in the USA.

CANDIDATES

After six years of sampling, we believe we have identified most potential biological control agents in the native range of *C. caroliniana* in South America. The area with the greatest density of cabomba sites has been located and numerous lakes in this area sampled throughout the year, to ensure that we have identified potential agents with differing life-cycles. Surveys have focused on arthropods because pathogens are difficult to recognise when sampling submerged aquatic plants with highly dissected leaves. Three potential agents have been found and studies have examined their life-cycles and methods for laboratory rearing. Preliminary host-specificity testing has been carried out at the USDA-ARS South American Biological Control Laboratory in Buenos Aires, Argentina.

Among many obviously generalist herbivores, the three potentially specialist phytophagous insects (Table 1) include an aquatic weevil (*Hydrotimetes natans* Kolbe) and two moth species, *Paracles* sp. and *Paraponyx diminutalis* (Snellen).

***Hydrotimetes natans* Kolbe (Coleoptera: Curculionidae)** This weevil feeds on plant tips as an adult, and the larvae mine the plant stems (Schooler *et al.* 2009; Cabera-Walsh *et al.* 2011). Development from egg to adult requires about 40 days in the laboratory. At high densities, adults can cause extensive tip damage and the larvae can induce

Table 1: Species of herbivores associated with *Cabomba caroliniana* in Argentina

Species	Order: Family	Natural hosts
Hydrotimetes natans Kolbe	Coleoptera: Curculionidae	Cabomba
Ilyodytes lembulus Kuschel	Coleoptera: Curculionidae	*Egeria naias*
Oryzophagus oryzae Lima	Coleoptera: Curculionidae	Rice, others
Dryops sp	Coleoptera: Dryopidae	Cabomba, *Egeria* spp.
Paracles nr. *burmeisteri*	Lepidoptera: Arctiidae	Cabomba, *Eichhornia azurea*
Paraponyx diminutalis (Snellen)	Lepidoptera: Pyralidae	Cabomba, *E. naias*
Synclita nr. *obliteralis* Walker	Lepidoptera: Pyralidae	Cabomba, *Nymphoides indica*
Rhopalosiphum nymphaeae L.	Hemiptera: Aphididae	Generalist
Hedriodiscus sp.	Diptera: Stratyomyidae	Generalist
Ephydra riparia Fallen	Diptera: Ephydridae	Generalist
Midges	Diptera: Chironomidae	Detritivorous
Limpets, snails	Gastropoda	Generalists

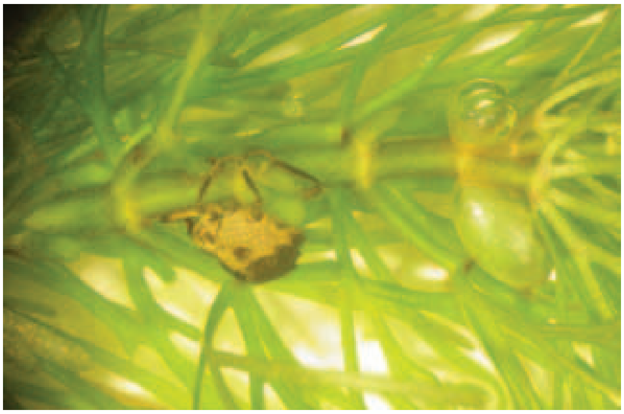

Figure 5: *Hydrotimetes natans* adult weevil on a cabomba stem. Note pupal case to the right of the weevil. Photo: R Chan, CSIRO.

stem decay. In the field, adults are present year-round. They survive for approximately one year in the laboratory. From December to February, adults are often observed alone or mating on the flowers, but they remain underwater most of the time (Fig. 5). Larvae have been found within plant stems from October to July with populations peaking at the beginning of summer (Cabera-Walsh *et al*. 2011). Tunnels have been found through the stem from base to tip down to depths of 3 m. The weevil can mine stems greater than 1.8 mm in diameter, depending on larval stage.

To determine host-range of the weevil in the field, samples of submerged plants occurring near cabomba were collected and suspended in cloth Berlese funnels. Thus far, *H. natans* larvae have only been extracted from cabomba samples (Table 2). Some adult weevils (<0.6%) were found on *Egeria naias* and *Utricularia platensis* when these plants were collected growing intertwined with cabomba in the field. However, we have found no evidence that this weevil uses them as a host.

Host-range tests have been conducted in shadehouses to confirm the field observations, but rearing *H. natans* in the laboratory in containers small enough to closely observe its development and behaviour has not yet been possible. In 2006, colonies were raised outdoors in Buenos Aires, in 1000 L glass tanks where stems with larvae, pupae and adults were observed. In these tanks, cabomba was grown alongside *Egeria densa* Planchon (Hydrocharitaceae), *Potamogeton illinoensis* Morong (Potomogetonaceae) and *P. pusillus* L., thus exposing these plants to *H. natans*. These are key test plant species as they are the plants in Argentina that are closely related to potential hosts in Australia – native *Potamogeton* species and native Australian Hydrocharitaceae (e.g. *H. verticillata*, *Maidenia rubra* Rendle, *Blyxa* spp.). During the 11 month trial period, no *H. natans* of any stage and no damage attributable to *H. natans* was observed on plants other than cabomba (Walsh *et al.* in press).

Table 2: Plant species sampled in the field for presence of *Hydrotimetes natans*

Species	No. of samples	*H. natans* adults	*H. natans* larvae
CABOMBACEAE			
C. caroliniana var. *caroliniana*	111	975	879
C. caroliniana var. *flavida*	9	0	0
Cabomba haynesii	5	0	0
HYDROCHARITACEAE			
Egeria naias	19	3	0
Egeria densa	2	0	0
MENYANTHACEAE			
Nymphoides indica	2	0	0
POTAMOGETONACEAE			
Potamogeton illinoensis	2	0	0
Potamogeton gayi	4	0	0
LENTIBULARIACEAE			
Utricularia platensis	5	2	0
Utricularia foliosa	3	0	0

One sample = 24 L tray (approx. 8 kg fresh weight).

Table 3: Field and no-choice laboratory host-range of *Paracles* sp. larvae

Host plant	Field feeding	Laboratory tests, first instars		Laboratory tests, third instars	
		Feeding	Development	Feeding	Development
Cabomba caroliniana	Yes	Yes	Normal	Yes	Full
Egeria densa	No	Yes	Normal	Yes	Full
Egeria naias	No	No	0	Yes	Partial
Eichhornia azurea	Yes	Yes	1-2 moults, poor development	Yes	Partial
Myriophyllum aquaticum	No	No	0	Yes	No
Ceratophyllum demersum	No	Yes	1 moult and death	Yes	Partial
Panicum sp.	Yes	No	1-2 moults, poor development	Yes	Full
Nymphoides indica	No	No	No	No	No
Potamogeton gayi	No	No	No	Yes	No
Potamogeton illinoensis	No	No	No	Yes	No
Hydrocleis nymphoides	Yes	No	No	Yes	No
Ludwigia peploides	No	No	No	No	No

***Paracles* sp. (Lepidoptera: Arctiidae)** The large aquatic larvae of this moth were collected in several locations in Corrientes province. They cause heavy defoliation of cabomba and are most often found on the leaves near the apical tips. They feed underwater, keeping air bubbles amid short hydrophobic hairs on the dorsum. The cocoon is also aquatic, resembling a canoe, and pupating larvae sometimes form a 'raft' of cocoons woven together in which only silk tufts at the ends remain dry and above the water surface. The adult is brown and has a 25 mm wingspan. It stretches its wings on the floating cocoon upon emergence. The life-cycle of *Paracles* sp. lasts about 40 days. Mating occurs within two days after emergence and the female lays 20–70 whitish eggs (in a mass covered with pale orange scales) on any vertical surface over the water. The eggs hatch in approximately eight days; the larval and pupal stages last 22 and 10 days respectively, at ambient temperature.

Laboratory no-choice and preference host-range tests were performed with this moth on 12 aquatic plants. Since cabomba has no related species at the family level in Argentina, test plants were selected based on damage observed in the field and their co-occurrence with cabomba. When first instars were transferred to test plants in no-choice trials, a narrow host-range was observed. However, feeding of mature larvae was observed in the field on some plants that had been rejected in the laboratory. The survival of more mature larvae on plants rejected by the first instars was therefore tested. More plants were accepted as hosts, and supported development, for second and third instars than for first instars. Mature larvae could develop into fertile adults on the aquatic grass *Panicum* sp. (Poaceae) as well as cabomba, and live for a considerable length of time on four other species (Table 3).

Further choice tests were conducted in three interconnected 1000 L tanks under cages. In this mixed-choice/no-choice test, 10 gravid females were allowed to choose to oviposit over tanks with *Eichhornia azurea*, *Egeria densa* and cabomba, but the larvae were confined to feeding only on the plant species over which the female had laid the eggs. Adults oviposited indiscriminately on any vertical surface and eggs were laid in every tank. Complete development was obtained on all three plant species, though *E. densa* had been rejected when neonates had been transferred to it in previous experiments. This suggests that, in the first test, initial feeding on cabomba, however brief, precluded acceptance of the other test plant. However, when the larvae emerged directly onto these alternative hosts, development was possible (Tables 3 and 4). This imprinting process has been observed before for other Lepidoptera larvae (Renwick 2001).

It is still not known if *Paracles* sp. can accept these plants as permanent hosts in the field and *Paracles* has not been observed on *E. densa* in the field. However, it suggests plasticity in host acceptance. Australia has several native aquatic genera within the Hydrocharitaceae

Table 4: Mixed-choice test for larval development of *Paracles* sp.

Host	Larval survival (%)	Pupation time (d)	Adult emergence (%)
C. caroliniana	33.3	32±1	100
Egeria densa	26.7	35±1.5	100
Eichhornia azurea	20	40±4	100

Gravid females were allowed to oviposit over any of the three plant species, but larvae were allowed to feed only on the species upon which the female had laid her eggs.

(e.g. *Hydrilla*, *Blyxa*, *Vallisneria* and *Maidenia*), so the priority of this potential agent has been reduced.

Paraponyx diminutalis **(Snellen) (Lepidoptera: Pyralidae).** The gilled larvae of this moth feed on the terminal shoots of cabomba stems, stunting stem growth. Because of their cryptic habits the larvae are hard to detect despite being >15 mm long in later instars. At the end of its larval stage (45 days), *P. diminutalis* spins an irregular cocoon attached to the plant tips and wrapped with live leaves. In the field it is quite common during spring and early summer but its presence is erratic on cabomba; it is more common on *Egeria naias*. *P. diminutalis* is a well-known natural enemy of several aquatic plants in its native range of south-east Asia (Indonesia to Pakistan) and East Africa (Balloch and Sana-Ullah 1974; Buckingham and Bennett 1989). Unfortunately, the literature (referenced above) and observations in Argentina (Schooler *et al.* 2009) indicate that this species is not host-specific enough to consider it a candidate for biological control of cabomba in Australia.

Surveys on other Cabomba species

The suite of specialist natural enemies found on cabomba in Argentina is relatively small, so surveys of populations of four closely related *Cabomba* species, for additional potential biological control agents, were begun in 2005. Since no closely related native or economically important plants occur in Australia, effective agents that are host-specific to the *Cabomba* genus may be found.

DISCUSSION

In addition to the biological control agent surveys, the effects of water quality and physical variables on cabomba populations and distribution in the native and introduced ranges were examined. There are four main differences between cabomba populations in their native and introduced ranges.

- The climatic variation in the native range is quite narrow (restricted to the Parana-Uruguay basin in eastern Argentina), while climatic variation in the introduced range is extreme (tropical to cold continental climates).
- Cabomba is rarely found in depths less than 1.5 m in the native range (usually 1.5–4 m) because floating vegetation usually occurs around the edges of lakes and ponds. This vegetation greatly reduces light penetration and consequently prevents the growth of cabomba. However, native floating vegetation is rare in most water bodies in subtropical Australia and cabomba grows up to the water's edge.
- Cabomba tends to grow in oligotrophic conditions in the native range, whereas it grows in both oligotrophic and eutrophic conditions in its introduced range.
- Populations are patchy in the native range and often grow mixed with other species (Table 5), but approach monospecific stands in the introduced range. This dearth of large dense stands in the native range is presumably due to the combination of herbivory by natural enemies and competition (and disturbance) caused by floating vegetation.

In Australia, a sampling program was developed to detect the environmental factors that produce variations in plant biomass. Apart from water depth and clarity, no seasonal related factors could be identified in subtropical habitats (Schooler *et al.* 2006). This is not likely to be the case in temperate climates, but it has yet to be assessed for Australia. A similar assessment in China determined that the plant presented maximum biomass in summer (Yu *et al.* 2004), suggesting that plant behaviour will vary according to climate throughout its introduced distribution. However, once established it seems to hold its ground.

In Australia, cabomba grows in dense and temporally stable monospecific stands, thus it is expected that an agent that is present year-round and is host-specific should fluctuate with its host population. The result should be a reduction of cabomba abundance, particularly in areas of deep water where disturbance will exacerbate the effects of herbivore damage and in shallow areas where damage to cabomba will increase the relative competitive ability of native plant species (Schooler *et al.* 2006).

Table 5: Submerged plant species observed to grow mixed with cabomba in its native range

Plant species	Locality	Province/state, country
Ceratophyllum demersum	Mburucuya Cross Creek	Corrientes, Argentina Florida, USA
Chara sp.	Many	Corrientes, Argentina
Egeria densa	Otamendi Iberá	Buenos Aires, Argentina Corrientes, Argentina
Egeria naias	Many	Corrientes, Argentina
Myriophyllum aquaticum	Otamendi	Buenos Aires, Argentina
Myriophyllum spicatum	San Marcos	Texas, USA
Hydrilla verticillata	San Marcos Orange Lake	Texas, USA Florida, USA
Utricularia spp.	Iberá Loch Loosa	Corrientes, Argentina Florida, USA
Vallisneria americana	San Marcos	Texas, USA

Host-specificity testing on the most promising agent, *H. natans*, is being conducted in quarantine in Brisbane and is expected to be completed in 2011. However, this may be delayed due to difficulties in obtaining export permits from Argentina and difficulties in rearing the weevil in quarantine. Given that *P. diminutalis* and *Paracles* spp. are not host-specific, future research will be concentrated on the organisms found in surveys of the other *Cabomba* species.

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