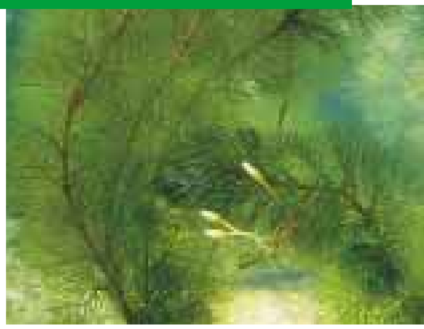
CABOMBA

Cabomba (*Cabomba* spp.) in Queensland

PEST STATUS REVIEW SERIES - LAND PROTECTION BRANCH

by A.P.Mackey



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Contents

1.0 Summary

Cabomba (*Cabomba caroliniana*) is a fully submerged aquatic plant; originally a native of the Americas it was introduced into Australia as an aquarium plant. It was first recognised as naturalised in 1986. Since then it has become established in areas of Queensland, New South Wales and Victoria either because of having been deliberately planted in native freshwaters for commercial purposes, or possibly through discarding by aquarists. Its complete distribution in Queensland is not known. It has now become a pest plant in at least two potable water storages in south-east Queensland.

The genus *Cabomba* is currently recognised as having five component species that are difficult to distinguish from each other. At least one other species, *C. furcata,* is used in the aquarium trade in Australia, although it does not appear to have naturalised yet. Bioclimatic modelling suggests that most of the eastern coastal strip of Queensland is excellent habitat for *C. caroliniana* and, particularly in the north of the state, *C. furcata* could become established.

Preliminary findings indicate that cabomba infestations increase the colour of potable water, hence increasing the cost of treatment; perhaps by up to $50/ML. Cabomba is also an aggressive invader of native freshwater systems, particularly if they are slightly eutrophic. It out-competes native freshwater plants and is of doubtful value to native fish or aquatic invertebrates. Potentially, it could be a very damaging environmental weed. Additionally, dense infestations impede aquatic recreational activities and the risk of drowning from entanglement is a real danger to people using the water body.

The ecology and life cycle of cabomba in Australia is not well known. In the north of Queensland, it grows and flowers throughout the year, but in south-east Queensland it may stop growing and flowering in the winter months (July and August). It can rapidly infest water bodies through vegetative growth of stem fragments as small as 1 cm. Cabomba in Queensland may be sterile as sexual reproduction has not been proven to occur here.

Effective control may be difficult to achieve. The n-butyl ester of 2,4-D mixed with diatomaceous earth has proven effective in still waters but may not be an acceptable control method in some situations. Drawdown of impoundments can be effective in controlling cabomba but again may not be a viable alternative. Biological control using grass carp could be possible but is not to be supported.

Stopping the illegal trade in cabomba, heightening public awareness of the weed potential of the species and early detection and control of new infestations are the keys to restricting further spread of the weed in Queensland. Declaration of the genus *Cabomba* statewide would give support to these activities.

2.0 Taxonomic Status

It is now generally agreed that *Cabomba* and the related genus *Brasenia* constitute a separate family, the Cabombaceae (Orgaard 1991). The Cabombaceae is characterised by submerged rhizomatous stems, floating, long-stalked, peltate leaves (Fig. 1) or submersed short-stalked, dissected leaves, long-stalked hypogynous flowers that are usually emergent, with three sepals and three petals and abundant perisperm in the seeds (Osborn *et al*. 1991).

Fig. 1. *Cabomba caroliniana* showing the mass of submerged leaves, small floating leaves and solitary flowers (image provided by the Information Office of the University of Florida, IFAS, Center for Aquatic Plants [Gainesville]).

There has been some confusion over the species constituting the species in the genus *Cabomba*. Eleven species have been described: *C. aquatica* Aublet, C*. furcata* Schultes & Schultes f., *C. caroliniana* A. Gray, *C. piauhyensis* Gardner, *C. warmingii* Caspary, *C. australis* Spegazzini, *C. pubescens* Ule, *C. pulcherrima* (Harper) Fassett, *C. palaeformis* Fassett, *C. schwartzii* Rataj and *C. haynesii* Wiersma. Five species are currently recognised: *C. aquatica* Aublet, *C. palaeformis* Fassett, *C. furcata* Schultes & Schultes f., *C. haynesii* Wiersma and *C. caroliniana* A. Gray (Orgaard 1991). Only one species, *Cabomba caroliniana* is known from Australia. The current definition of this species includes the previously separate species *C. pulcherrima* and several natural and horticultural varieties (Orgaard 1991, J.T. Swarbrick *in prep.*).

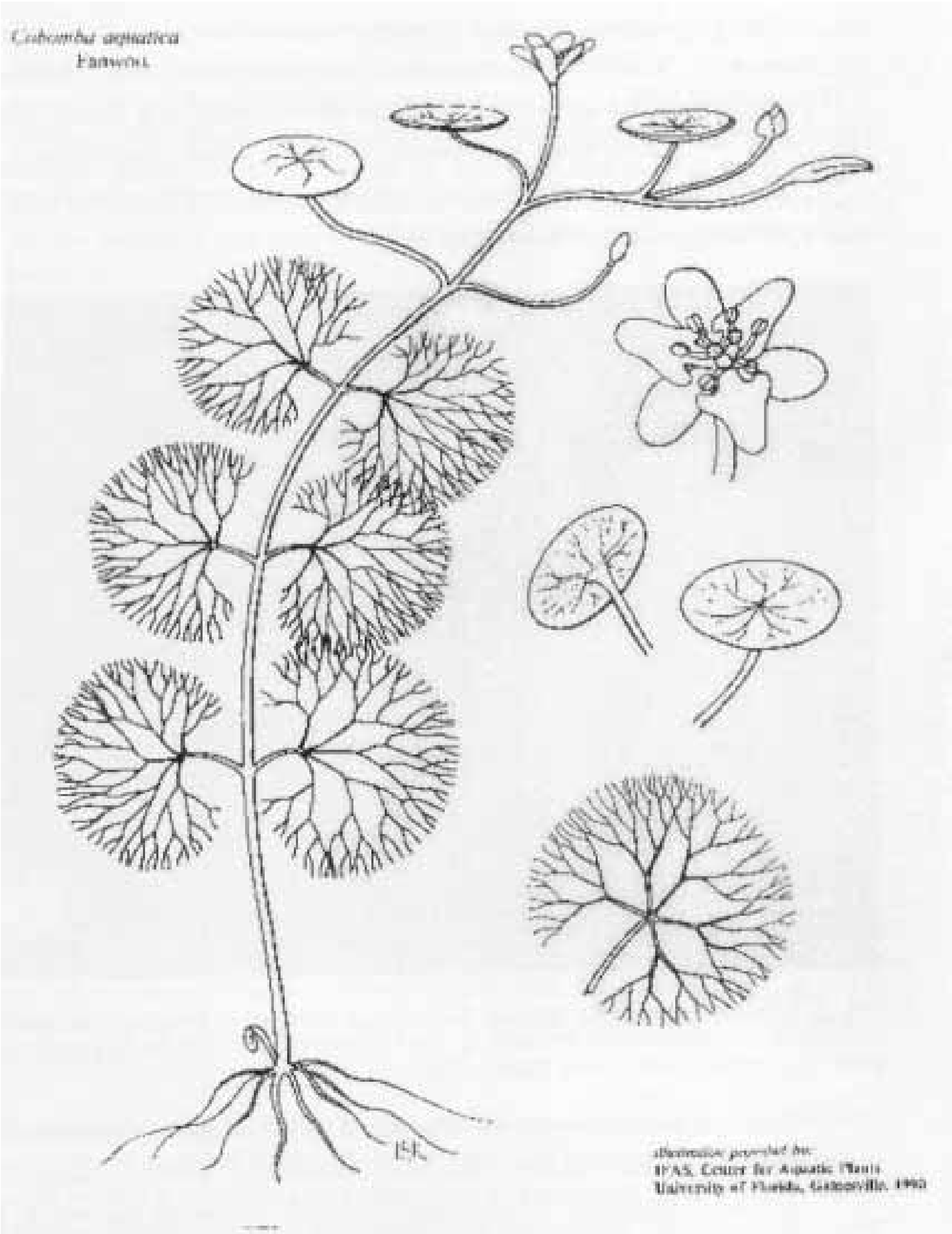

Fig. 2. *Cabomba caroliniana* (illustration provided by the Information Office of the University of Florida, IFAS, Center for Aquatic Plants [Gainesville]).

Three types of cabomba (*C. caroliniana* var. *caroliniana, C. c*. var. *multipartita* and *C. pulcherrima*) from eight sites in Florida were assessed for genetic diversity and it was concluded that they were genetically indistinguishable and that the differences were ecophenotypic rather than genotypic (Wain *et al*. 1983, 1985). Ecophenotypic plasticity is well known in aquatic plants (Sculthorpe 1967) and this is the likely explanation of morphological differences in the three forms tested. Godfrey and Wooten (1981) and Martin and Wain (1991) report that *Cabomba* with high levels of purple pigment grows in very warm waters but that plants from cooler waters have little purple pigment and are green. Although conversely, Leslie (1986) reports aquarists as saying that the purple colour develops in response to cold water conditions. Colour is the only morphological trait that separates *C. pulcherrima* (Wain *et al*. 1983). On the basis of flower colour, three varieties of C. *caroliniana* are now distinguished (Orgaard 1991): *C. caroliniana* var. *caroliniana*, *C. c.* var. *pulcherri* and *C. c.* var. *flavida* with, respectively, white, purple and yellow flowers.

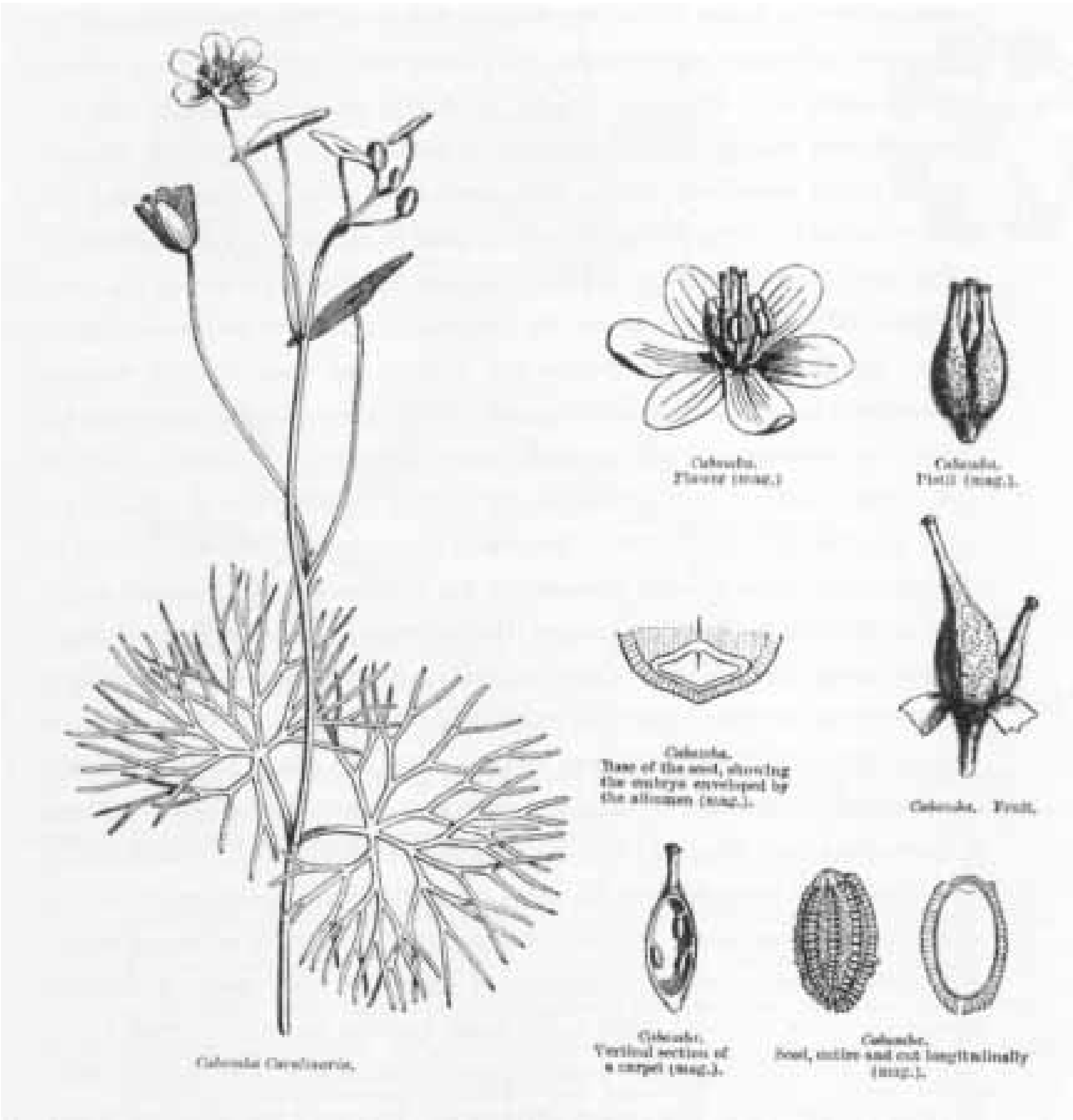

Fig. 3. *Cabomba caroliniana* (Watson and Dallwitz 1995 onwards).

Because of the ecophenotypic plasticity, differentiation of *Cabomba* species is best done on the basis of seed characteristics such as size, shape and surface structure (Orgaard 1991).
Unless otherwise specified, in this report the term ‘cabomba’ refers to *C. caroliniana* as defined by Orgaard (1991) and its horticultural varieties.

Because of the confusion surrounding the identity of cabomba in Australia, a detailed, technical description is given here.

Plants are strictly aquatic and completely submerged except for flowers and occasional floating leaves. Stems may be up to 10 m long. Shoots are grass green to olive green, sometimes reddish brown, often coated with mucilage and more or less pubescent (Orgaard 1991). When present, the floating leaves are alternate, with the blades peltately attached to the petioles (Fig. 3) and they have a firm texture (Fassett 1953). Floating leaves are green to olive green, have an entire peltate lamina are narrowly elliptic in outline, but can be ovate (trullate or sagittate) and are 5-20 mm in length and 1-3 mm wide (Orgaard 1991). They are borne on the flowering branches (Sanders 1979). Submerged leaves are petiolate, opposite, or less commonly in whorls of 3 (Fassett 1953) and divided. The divisions are linear but the terminal divisions may be slightly spathulate (Orgaard 1991). The semicircular leaves may be divided dichotomously and trichotomously several times (Fig. 2) (Sanders 1979) to give a great number of terminal divisions: from 3-20 in the basal parts to 150-200 for larger apical leaves (Orgaard 1991). The stems are slightly compressed, 2-4 mm in diameter and increase in width acropetally in the internodal region. Scattered short, white or reddish-brown hairs are present. The leaf margin is serrulate to denticulate, the teeth being barely visible. The teeth are really 3-celled trichomes that secrete gelatinous mucus that covers the entire plant. The venation of the submerged leaves corresponds to the leaf division. Erect and flowering shoots have proximately decussate phyllotaxy which changes near the surface of the water to 1/3 with a flower at nearly every node (Orgaard 1991). Flowers are solitary (Figs. 2 & 3) attached to a long axillary stalk (Sanders 1979, Ito 1986) and 6-15 mm in diameter and 6-12 mm long; milk-white, pale yellow or purplish (Orgaard 1991). The flower is hermaphroditic and generally trimerous but di- and tetramerous flowers are found. Sepals 3, elliptic to obovate, 5-12x2-7 mm, pale yellow to milk white, if whitish then often purplish tinged on margins and veins, base often greenish yellow on the abaxial face (Sanders 1979, Ito 1986, Orgaard 1991). The 3 petals alternate with the sepals and are slightly fused together at the base (Fassett 1953, Sanders 1979, Ito 1986) and are obovate to elliptic in shape, 4-12x2-5 mm in size, pale yellow to white, purple tinged or bright purple, with apex obtuse or emarginate (Sanders 1979, Ito 1986, Orgaard 1991). Petal base extended into two equal semicircular lobes curved more or less inwards towards the middle of the petal and partially covering the claw (Fig. 2); the lobes with two more less conspicuous yellow, elliptic, separate patches which function as nectaries; claw a deep yellow at the base, becoming paler apically (Schneider and Jeter 1982, Ito 1986, Orgaard 1991). Stamens (3-) 6 usually in one whorl. If six are present they are inserted on radii between petals and sepals. If three, they are antepetalous. Carpels (2-)3(-4), antepetalous when 4, divergent at maturity and with 1-5 anatropous, pendulous ovules (Fig. 3) (Ito 1986, Orgaard 1991) and stigma clavate (Ito 1986). The lower two ovules are attached at the dorsal side and the lower at the ventral side (Ito 1986).

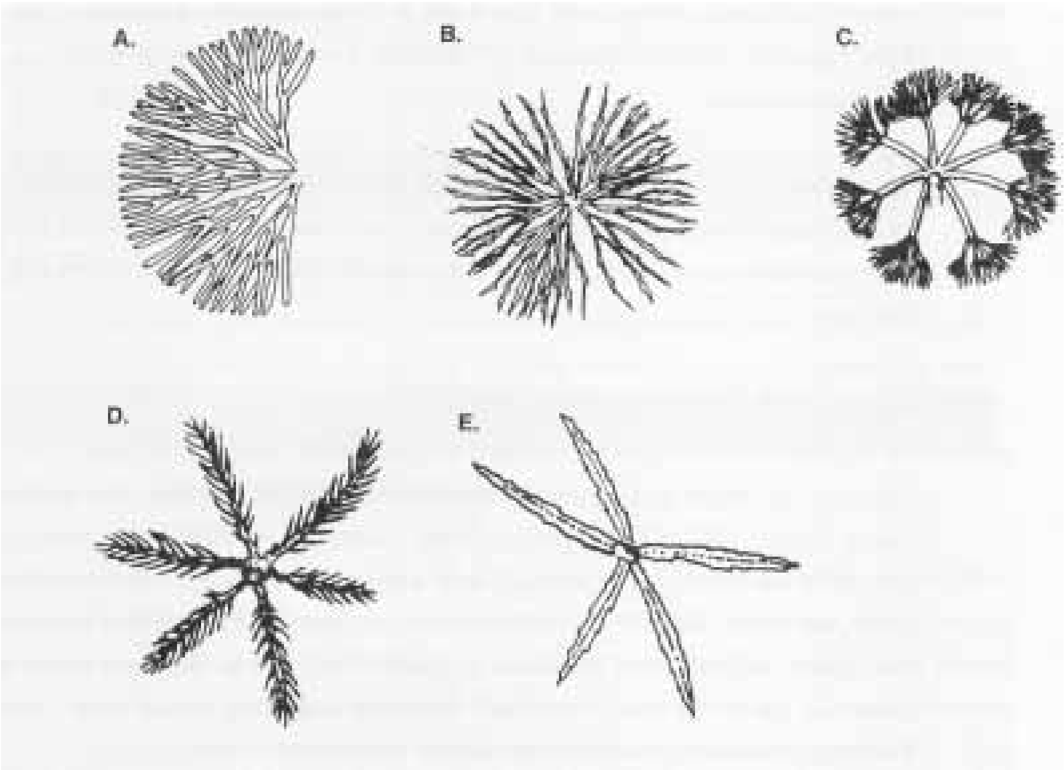

Fig. 4. **Arrangement of leaves in A: *Cabomba caroliniana* (cabomba), B: *Ceratophyllum demersum* (hornwort), C: *Nitella penicillata* (stonewort), D: *Myriophyllum aquaticum* (parrot's feather), E: *Hydrilla verticillata* (hydrilla). [S. Chown].**

Seeds (Fig. 3) ovate to ellipsoid-oblong, 1.5-3.0x1.0-1.5 mm in size (Sanders 1979, Schneider and Jeter 1982, Orgaard 1991) verrucate, cristate-costate (Orgaard 1991) outer testal layer composed of irregularly digitate cells uniformly and densely perforated with simple pits with 4 longitudinal rows of tubercles formed by the radial elongation of digitate cells (Schneider and Jeter 1982). Seeds covered with elongate processes and coated in a gelatinous slime (Sanders 1979). Pollen grains 60-90 Tm in polar axis, prolate (boat shaped to oblong), elliptic, monosulcate supratectal sculpturing striate (Orgaard 1991); monads at maturity. Fruit (Fig. 2) green when fresh, apocarpous with 1-4 dark brown carpels. The 'rhizomes' are erect, stout stems that have become prostrate and partially buried; they are not true rhizomes. They have opposite buds and sometimes small leaves. Some rhizomes are runners (horizontal) and possess upturned, erect heads. New rhizomes and floating shoots arise as axillary branches to these shoots. Rhizomes are fragile, break, and decay quickly. Adventitious roots occur on the rhizomes at 45 degrees dextral and sinistral to the leaves and branches (Moseley *et al.* 1984).

Chromosome number (Orgaard 1991): 2n=39, c.78, c.104; the basic number is x=13 (not x=12 as previously proposed). Specimens of *C. caroliniana* have been found that were apparently triploid, hexaploid or octoploid. Previous counts of 2n=24 are probably miscounts.

Seeds have not been reported from cabomba in Australia, so current identification must be largely based on vegetative characters. Cabomba may be distinguished from other Australian aquatic plants with filamentous leaves on the basis of leaf morphology (Fig. 4).

3.0 History of Introduction and Spread

Cabomba caroliniana is of relatively recent introduction into Australia; the earliest record is from 1967 (J.T. Swarbrick *in prep.,* Garraty *et al.* 1996) but it was not considered naturalised in Australia by Sainty and Jacobs (1981) and was first added to the New South Wales flora in 1986 (Jacobs and Lapinuro 1986). A long-standing assumption has been that naturalised populations are due to aquarists dumping unwanted plants into local waterways but more commonly, areas have been deliberately 'seeded' to allow wild cultivation for the aquarium trade.

Cabomba was introduced into Australia from the USA as an aquarium plant. In Queensland, cabomba was first noticed as a pest in 1989 when, as a result of an aquarium escape, it was infesting the swamp that fed Leslie Creek (Atherton Tablelands) although it had been present since 1986. It overgrew the fish breeding ponds at 'Quinkin Ponds' and by the end of the year it had infested the length of the creek and had spread into at least one arm of Lake Tinaroo, into which the creek flows. By 1991, further infestations were reported from Avondale Creek, north of Cairns and a drainage channel at Goondi, near Innisfail. In southern Queensland, concern about its weed potential developed when it was first observed in Six Mile Creek, the original impoundment for Lake MacDonald (Noosa shire), in April 1992 (Anderson and Garraty 1994) although non-weedy outbreaks were observed in the Caboolture River in 1991.

As a result of the infestation in Leslie Creek, its spread into Lake Tinaroo and the possible infestation of associated irrigation systems, *Cabomba caroliniana* was declared as P2 in Atherton and Eacham shires in May 1990 and the declaration extended in July 1992 to the Johnstone and Mulgrave shires

To date *C. caroliniana* is the only species of cabomba to have been naturalised in Australia, although two other forms: pink cabomba (*C. piauhyensis* now *C. furcata*) and green cabomba (*C. australis* now *C. c. var caroliniana*) are regularly traded by aquarists.

4.0 Current and Predicted Distribution

4.1 Distribution - overseas

Cabomba caroliniana has a curious and disjunct distribution in that it is considered native to both the south-eastern United States of America and southern Brazil, Paraguay, Uruguay, and north-eastern Argentina (Orgaard 1991). This distribution and that of other members of the genus suggest it could be naturalised in the USA and originally a native of South America.

C. c. var. *caroliniana* is found throughout the south-eastern USA (Fig. 5), southern Brazil, Paraguay, Uruguay and north-eastern Argentina. *C. c.* var. *pulcherrima* is found only in the southern parts of South and North Carolina, Georgia and Florida whilst *C. c.* var. *flavida* is confined to southern Brazil, Paraguay, Uruguay, and north east Argentina, mainly along the Rio Parana and its tributaries (Orgaard 1991). The distribution of *C. caroliniana* within the USA is extensive (Sanders 1979). It is able to live in a wide variety of climates and Leslie (1986) indicates it can tolerate average daily temperatures of 11.6-25.4^{o} C and average absolute temperatures of -19.5-41.1^{o}C.

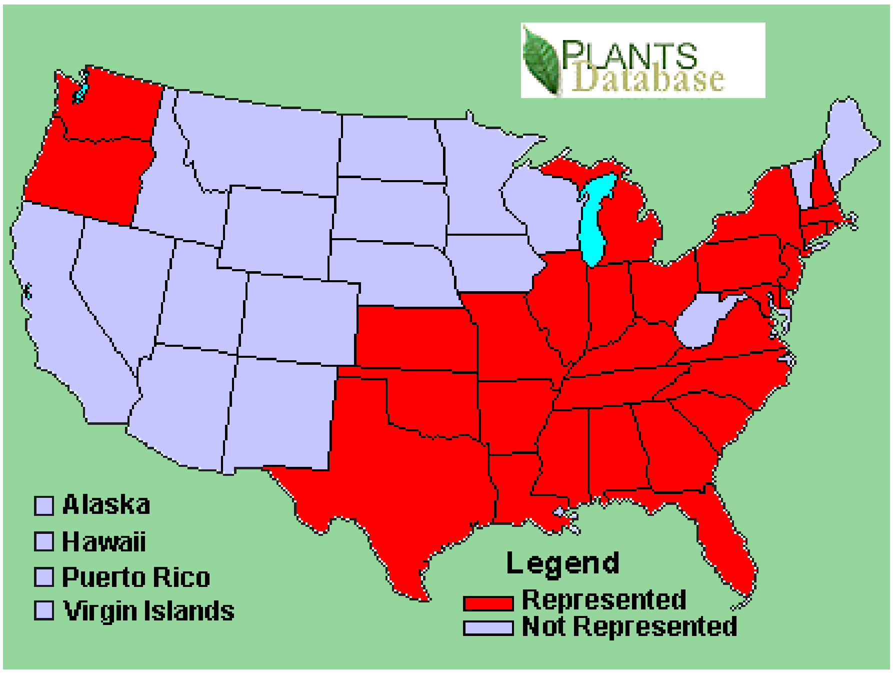

Fig. 5. The distribution of *Cabomba caroliniana* in the United States of America (data from the PLANTS database with acknowledgements to the contributions made by the National Resources Conservation Service and the Biota of North America Program [USDA, NRCS 1995]).

Because of its extensive use in the aquarium trade, it has been introduced to Malaysia, India, Japan and New Guinea (Orgaard 1991). In Japan *C. caroliniana* is considered a noxious weed (Oki 1992). Cabomba is sold as an aquarium plant, but is not yet naturalised in the ASEAN region (Malaysia, Singapore, Philippines, Indonesia, Thailand, Brunei). It is considered to have the potential to cause serious problems in aquatic ecosystems there because it grows well in the region and because of its rapid vegetative spread. It is considered imperative that strict quarantine regulations are enforced against cabomba in the ASEAN region (Revilla *et al*. 1991).

4.2 Distribution - Australia

In northern Queensland cabomba is known from Quincan Springs and Leslie Creek on the Atherton Tablelands, Canal Creek near Babinda, Avondale Creek, north of Cairns, and from Diggers Creek (El Arish), Maria Creek and a drainage channel at Goondi, near Innisfail. In the south-east it is found in the Caboolture River, Lake MacDonald (300 ha), the Ewen Maddock Dam and Cabbage Tree Creek. There is an unconfirmed report from Four Mile Creek (Strathpine). In New South Wales (J.T. Swarbrick *in prep.*) it is found at Dapto, Sydney, Glenbrook Lagoon, Burringbar Creek at Mooball, Barrington, north of Gloucester, Eastlakes golf course, the Griffith area and Bulahdelah north of Newcastle. In Victoria, cabomba is largely restricted to South Gippsland but it is considered a potential threat to permanent, freshwater wetland, aquatic vegetation throughout the state. Currently it is rare or localised although some populations are quite large (Carr *et al*. 1992).

The potential distribution of cabomba in Australia, and Queensland in particular, is difficult to establish as there is no good model available for predicting the distribution of a fully aquatic weed such as *C. caroliniana.* However, two approaches have been taken in this report. The modelling package CLIMEX (Skarrat *et al*. 1995) has been used to model the weed’s potential distribution based on temperature tolerance. Temperature is a major determinant of distribution in aquatic plants (Sculthorpe 1967). The second approach has been to model the potential distribution of cabomba on the basis of its current distribution in Australia, using GARP (Stockwell 1996a, b). GARP is a rule-based model that deduces from a species’ current distribution environmental rules that determine its distribution. Factors used in the present case were based average temperatures and their ranges, average rainfall and rainfall variation and geological factors such as soil type and soil nutrients. Clearly, with a weed such as cabomba that is in its initial invasive stages, not all environments in which it can occur may be represented in its current distribution and this limits the usefulness of the second approach. However, in Australia, cabomba is currently distributed across a wide climatic zone from northern Queensland to Victoria and this may mitigate against this problem.

The CLIMEX model was developed by adjusting the temperature parameters in the model until the predicted distribution of cabomba in the USA gave a sufficiently close match to its known distribution. The final model predicted the distribution of cabomba in the south-eastern USA but also predicted the presence of the weed along the west coast. This probably indicates that the distribution in the USA is not due solely to temperature. Interestingly, subsequent to the development of this model, the first records of cabomba in this region (Washington and Oregon) were found (Anon. 1995). When used to predict the distribution of cabomba in South America. The model predicted its recorded occurrence (Orgaard 1991) but again predicted a far wider distribution than the known distribution, suggesting again, that temperature is not the sole factor determining the distribution of this species in South America. The model was then used to predict the distribution of cabomba in Australia (Fig. 6). Much of coastal Australia, except for the north-west, is excellent habitat for cabomba, and the optimal area for growth of the weed is coastal Queensland.

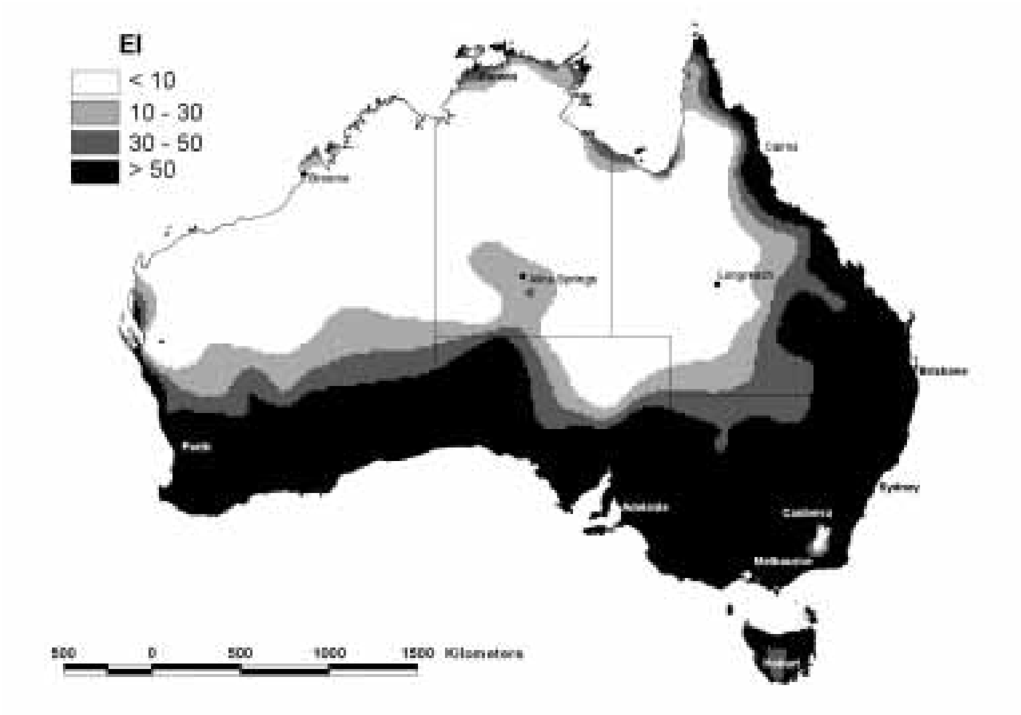

Fig. 6. The predicted distribution of *Cabomba caroliniana* in Australia (CLIMEX) (EI=Ecoclimatic Index; EI=0, potential for a permanent population extremely low; EI=100, this potential extremely high).

The GARP model (Fig. 7) predicted a much more restricted distribution of cabomba in Australia than the CLIMEX model, suggesting the distribution would be limited to southern coastal Queensland, NSW and Victoria.

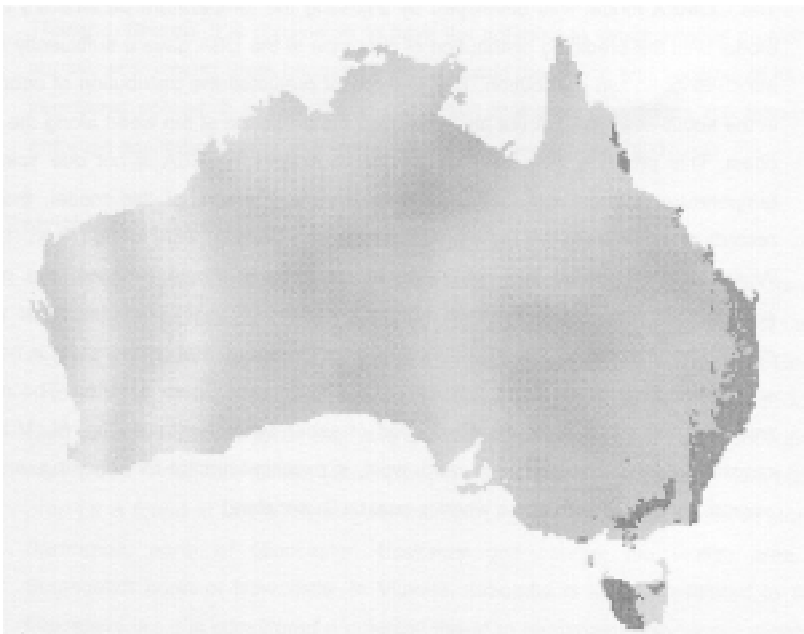

Fig. 7. The predicted distribution (light grey) of *Cabomba caroliniana* in Australia (GARP).

CLIMEX probably overestimates the potential distribution of cabomba whilst GARP probably underestimates its potential distribution. Both models make predictions of the distribution irrespective of whether there is a suitable water body for the weed to inhabit. Nonetheless, the results from both models suggest that the southern coastal strip of Queensland is suitable, if not optimal, habitat for cabomba.

Although *C. caroliniana* is the only species of cabomba to be naturalised in Australia, *C. furcata* is used by aquarists in Australia and therefore is a potential weed problem if it becomes naturalised. A CLIMEX model based on temperature preferences was developed for this species and used to predict its potential distribution in Australia (Fig. 8). *C. furcata* is a warm water species, and could probably establish in much of Queensland's coastal strip.

5.0 Estimates of Current and Potential Impact

Cabomba is still in its early invasive stages in Queensland and the true extent of the infestation is not known. Currently it appears to be having little impact in the state but until a survey has established its detailed distribution, its true importance cannot be known. Meanwhile, its potential impact can only be judged by reference to its impact overseas.

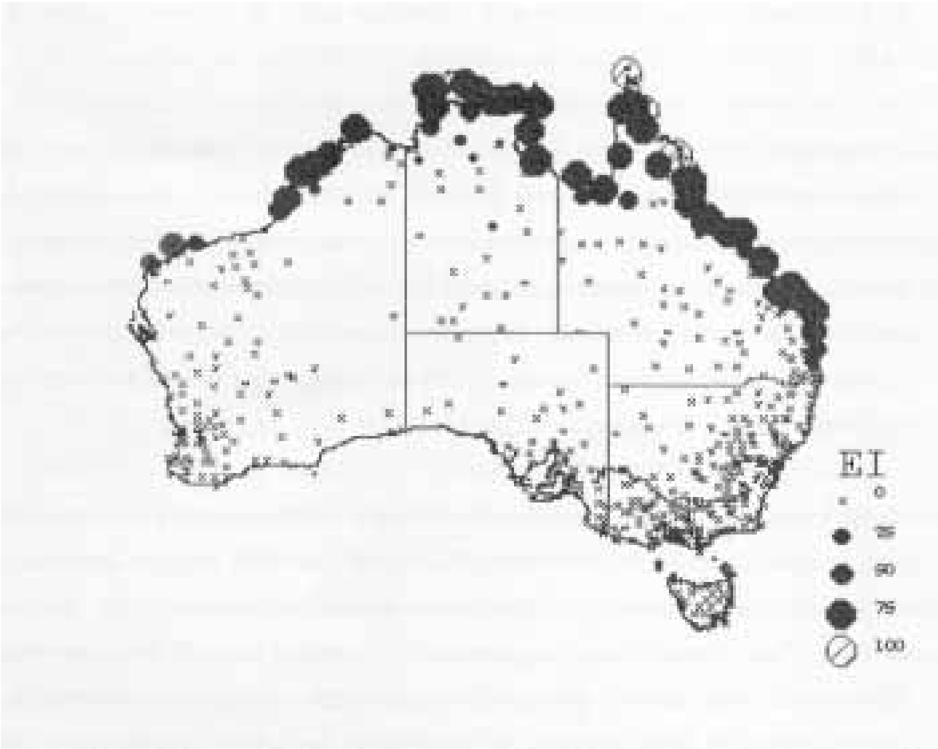

Fig. 8. The predicted distribution of *Cabomba furcata* in Australia (CLIMEX). (EI=Ecoclimatic Index; EI=0, potential for a permanent population extremely low; EI=100, this potential extremely high).

Hearne (1966) records cabomba as a weed in the Panama Canal with the potential of causing blockages. However, most information on cabomba comes from the USA where only *C. caroliniana* is recorded as a weed. Cabomba is considered a problem throughout the Gulf states particularly Louisiana (Tarver and Sanders 1977). In Florida, although the plant is extending its range (Sanders 1979) and increasing in abundance, it is not yet regarded as a nuisance plant (Hanlon 1990, Martin and Wain 1991). Hanlon (1990) reports that in 1982 in Florida, there were 850 ha of cabomba, in 1984 1250 ha and in 1988 1510 ha. Schardt and Nall (1982, cited in Leslie [1985]) however record 1425 ha of cabomba from 485625 ha surveyed in Florida and noted 1 severe and 7 moderate infestations. Despite the slight differences in figures, cabomba does not seem to be a critical aquatic weed, but whilst not being a major problem (Leslie 1986), it is one of the 19 plant species that cannot be transported, imported, cultivated, collected or sold in Florida (Clugston 1990).

A heavy weed infestation can raise water levels to a point where overflows and heavy seepage losses occur. In some situations they can cause oxygen drawdown as massive dieback and consequent decomposition occurs (Gracia

1966). Dense stands can interfere with recreational, agricultural and aesthetic functions of lakes and reservoirs (Riemer and Ilnicki 1968). In the USA commercial fishing camps have been forced to close, or have had their income severely reduced, private camp owners have sold out, with hunters, boatmen and fishermen going to uninfested areas (Sanders 1979).

In Australia, the type and degree of economic loss associated with cabomba infestations in the USA is not likely to occur, since natural lakes are relatively few and impoundments are not so commercially and intensively used for recreational and amenity purposes. Nevertheless, should cabomba infestations occur in water bodies used in these ways the potential exists for economic losses from damage to amenity values and even threats to human health and safety may ensue as water skiers or swimmers could easily become entangled by the weed and drown.

There is evidence that in Queensland cabomba infestations may deleteriously affect water quality (Anderson *et al.* 1996, Garraty *et al.* 1996) through increasing water colour with a subsequent estimated increase in the treatment costs for potable water of $50 per ML. There is also a suggestion (T. Anderson *pers. comm.*) that in southern Queensland the sudden release of manganese caused by the dieback and decomposition of large amounts of cabomba in the winter months could affect the manganese cycle and cause a reduction in water quality. Further research is required into these situations. If present in water storages, heavy infestations, because of the large volume of plant material, could cause water loss from overflow or seepage. Because of these problems and the ability of cabomba to grow rapidly, cabomba has the potential to become a major weed in water storages.

Irrigation canals could provide an ideal habitat in which cabomba could grow and where it could impede water flow, cause overflows and blockages. Although difficult to assess the economic loss this might cause, the nuisance value would be high.

5.1 Control Costs

Control costs are currently minimal in Queensland as very little control has been attempted and most of this has been associated with experimental trials. So far, $250-300,000 has been spent in trying to control cabomba in the Ewen Maddock Dam (R. Rainbird *pers. comm.*) and estimated costs for mechanical control in Lake MacDonald are $125,000 for the harvester and $20,000 per annum for harvesting costs (K. Garraty *pers. comm*). The cost of treating a volume of 20,000 m^3 of water (100x100x2 m) with the 2,4-D n-butyl ester/diatomaceous earth mixture would be approximately $3,000 so clearly, on cost grounds alone, it is unlikely large scale infestations would be chemically treated.

5.2 Environmental Costs

Under suitable environmental conditions cabomba is extremely persistent and competitive and can exclude well established native species (Riemer and Ilnicki 1968) although it can itself be out competed by such weeds as *Egeria* (=*Anacharis*) (Sanders and Mangrum 1973). Extracts of cabomba have allelopathic effects at medium and high concentrations and since allelopathy plays a role in determining the distribution of higher plants (Rice 1979) in the case of cabomba it would seem to be a mechanism for invading new habitats and ousting native species (Elakovich and Wooten 1989).

Anderson and Garraty (1994) have assessed the impact of cabomba on native aquatic plants and water quality in Lake MacDonald, Queensland. In summer, the mean standing crop of cabomba was 1.02 kg/sq m, a 7 fold increase from early spring levels. Other species were only found at very low standing crops in infested the areas and water clarity decreased, but it is not clear whether this was due to an increase in suspended solids, or due to the physical presence of the weed.

A primary concern with cabomba in Queensland should lie with its potential as an environmental weed. Cabomba is considered to be an important potential environmental weed of the Wet Tropics Heritage Area (Wet Tropics Management Authority 1995). Its ability to replace native aquatic plants with the likely result that native fish and invertebrate populations are displaced, together with the ability to effectively infest large areas of water suggest that if allowed to establish throughout the state native aquatic life would be considerably endangered.

5.3 Environmental Benefits

Where naturalised, cabomba provides the usual benefits that aquatic plants generally have in aquatic systems: it oxygenates the water, protects against bank and bed erosion and removes nutrients from the water. It can also often provide cover for young fish and a habitat for invertebrates as well as being a source of food for wild life (including water fowl) (Oki 1992). However, whilst it does provide fish habitat (at least in the USA) it has no wildlife value (Martin and Wain 1991, Harman 1994). In regions where it is invasive, it is not clear whether native fish and invertebrates utilise it readily as a habitat and in Queensland, research is needed to clarify the situation.

6.0 Biology and Ecology of Spread and Control

6.1 Habitat

Cabomba likes a warm-temperate, humid climate, with rain throughout the year and an annual temperature of 15-18^{o} C. Although it can withstand temperatures going to less than 0^{o} C its preferred temperature range is 13-27^{o}C (Leslie 1986). It is found in ponds, ditches, small shallow lakes and slow flowing streams in coastal vegetation of swamp forest and bog, and inland in areas of savannah (Orgaard 1991). It can grow in shallow (1-3 m) or deep (10 m) water but most commonly the plants grow rooted in shallow water where they are usually anchored by short, sympodial rhizomatous stems from which emerge several erect branches (Sanders 1979, Schneider and Jeter 1982, Tarver *et al*. 1978, Hanlon 1990). In Queensland it appears to prefer silty substrata and it does not root deeply. Where it occurs on hard or stony substrata the plant's vigour is reduced (Garraty *et al.* 1996).

Cabomba is reported from waters with both acid and alkaline pH's (Orgaard 1991) but the optimum pH for growth is 4-6 and growth inhibition occurs at pH 7-8. Above pH 8 the stem becomes defoliated and growth is inhibited (Riemer 1965, Gregory and Sanders 1974, Tarver and Sanders 1977). Consequently, cabomba grows best in acidic waters (such as those around the Florida panhandle) (Hanlon 1990). The robust population studied by Schneider and Jeter (1982) grew in a pH of 7.8, but there is no indication of whether this was a typical pH found in the cabomba stand (Leslie 1986). Nutrients are more available at acidic pH's and this could account for the greater growth (Gregory and Sanders 1974, Sanders 1979). In Japan, cabomba grows well in nutrient rich water. The ranges (mg/L) of habitat variables in which it occurs in Japan are: COD 3.2-8.23; inorganic-N 0.68-1.76; organic-N 0.06-0.25 (Oki 1992). Cabomba also grows optimally at very low calcium ion concentrations (4 ppm); higher levels of calcium inhibit growth (Riemer 1965).
The response of cabomba to water turbidity has been investigated in aquaria (Gregory and Sanders 1974, Sanders 1979). Growth was measured at low (30-45 Jackson turbidity units) medium (70-110 JTU's) and high (300-2350 JTU's) turbidities. Growth at medium turbidities was greatest, followed by growth at high turbidities. Moderate turbidity (70-110 JTU) enhances stem length growth compared to non-turbid (0-10 JTU) conditions and it is postulated that this is due to an auxin producing longer cells at moderate turbidity levels. Moderate to high turbidities (300-350 JTU) enhanced adventitious root development. Decreased underwater light intensity generally leads to growth limitation in submerged aquatic plants, so this result is somewhat counter-intuitive. In these experiments, turbidity was maintained by stirring the hydrosoil. This could have led to the increased release of nutrients to the water and hence increased availability to the plant as the shoots and stem are the main sites of nutrient uptake (Sanders 1979). Nevertheless, cabomba appears to be able to grow well in turbid conditions and since Australian freshwaters are generally turbid, and turbid water caused by inflows, usually helps to control aquatic weed problems, this characteristic of the weed is of concern.

In contrast to the above findings, in cultivation, cabomba is demanding of light and water quality and sensitive to competition and water motion (Orgaard 1991).

Like most fully aquatic plants, cabomba is sensitive to the drying out of its habitat. In experiments conducted in aquaria, 6.7% of cabomba seedlings survived a 30-day drawdown of the water level in which the hydrosoil remained unsaturated and growth of survivors started within 14 days of refilling aquaria. If the hydrosoil was saturated, 53% of seedlings survived and regrowth was evident after 7 days in these instances (Sanders 1979).

The ecology of other species of *Cabomba* is even less well known. Many of the tropical species are cold sensitive and *C. caroliniana* is apparently more cold tolerant than these. *C. aquatica* should not fall below 18^{o} C and the optimum is probably 25^{o}C; it is a sensitive plant and needs soft water (pH 6.5-7.0) and it does not tolerate water motion. Fanworts apart from *C. caroliniana* generally do not do well in poor light conditions and *C. furcata* (=*C. piahyensis*) and *C. c. pulcherrima* require 12 h light. Conversely, high light regimes induce algal problems (Leslie 1986) due to epiphytic algae shading out the plant.

Leslie (1986) on the basis of temperature data suggested that *C. aquatica, C. palaeformis* and *C. piauhyensis (=C. furcata)* could not overwinter even in the mild climate of southern Florida.

6.2 Morphology

The general morphology of the plant is shown in Figs. 1-3. The colour of the shoots is strongly influenced by light. In low light, the plant is green, in high light it can be reddish brown. The red colouration is lost if a plant is returned to low light levels. 1-10 adventitious roots can form spontaneously at the nodes of erect, vegetative and free floating shoots, without the need for contact with a substratum. In Queensland, 3-40 strong, flexible stems, 2-6 mm thick, arise from a single root mass (Garraty *et al.* 1996). Adventitious roots are thin, white and unbranched. Older, embedded roots are numerous, long, very slender, branched and dark brown to black. Horizontal rhizomes are really branches of short erect shoots that are buried in the substratum. They are fragile and break or decompose easily, isolating new erect shoots as separate plants. They can be very long and can develop adventitious roots (Orgaard 1991). The leaves are dimorphic and the floating leaves are produced by flowering shoots. The size of both types of leaf is quite variable. Larger leafed forms tend to come from areas of low light intensity, and smaller leafed forms from areas of high light intensity. Leaves from poorly lit conditions tend to have wide and spathulate terminal segments. The solitary flowers are raised above the water surface. Where environmental conditions are optimal, cabomba is capable of forming dense stands and surface mats although in New York State, close to the northernmost limit of its distribution, this does not happen and the plant grows with an open architecture (Harman 1994). The fruit is green and carried beneath the water but seeds have not been recorded from Australian plants.

6.3 Phenology

Little is known of the life cycle of cabomba in Queensland. In north Queensland it grows and flowers continuously throughout the year Swarbrick (*in prep*.) and in summer, in south-east Queensland, buoyant stems up to 6 m long are produced with a growth rate of up to 5 cm per day (P. Bell, *pers. comm*. 1995). In July and August in southern Queensland, the stems loose buoyancy, lie across the surface of the hydrosoil and fragment. When growth commences, these fragments re-root and initiate new plants (G. Diatloff *pers. comm.*). In mild winters, this die back may not occur (T. Anderson *pers. comm.*).

The following description refers to the life cycle of cabomba in the USA. Towards the end of the growing season, stems become denuded, brittle, and hard. Terminal stems especially tend to break free and these remain green and leafy until spring. Some terminal buds remain attached to the substratum, even under ice. Growth starts around April (Riemer and Ilnicki 1968). Even defoliated stem fragments buried in mud under ice may regrow (Orgaard 1991). Cabomba grows and disperses mainly from fragmentation (Sanders 1979, Hanlon 1990). Any detached shoot with at least one pair of expanded leaves is capable of growing into a mature plant. Larger sections than this can root at the nodes. A motorboat passing through a cabomba bed can produce hundreds of disseminules and in many situations, this is probably the major dispersive and infestive mechanism (Sanders 1979).

As Riemer and Ilnicki (1968) note, vegetative reproduction is very important in many aquatic plants. For example, *Ceratophyllum demersum* often does not reproduce sexually because conditions are too cold, but reproduces entirely by axillary buds on plant fragments from the previous year. Nevertheless, the species is abundant and often dominant in freshwaters where it does not sexually reproduce.

Most of the material supplied to the aquarium trade originally came from the San Marcos River in Texas. Here the plant is perennial and flowers throughout the year and although the number of flowers drops drastically during November to February isolated flowers can still be found. Floating leaves are produced during the flowering period (Schneider and Jeter 1982) and fruits appear shortly after the first flowers have emerged (Riemer and Ilnicki 1968). Fruit take about a month to mature (Schneider and Jeter 1982).

In the southern USA peak seed production is May-October, but occurs from April to December (Sanders 1979). In Louisiana it flowers from May to December, with peaks in May and September (Sanders and Mangrum 1973). In New Jersey, cabomba begins flowering in late June/early July and maximum flowering occurs in late July and continues through August. A few flowers continue to emerge until the first frosts (Riemer and Ilnicki 1968). Fruit set is often abundant throughout most of the year, but most seed is produced between May and October (Hanlon 1990). In the north-western part of its USA distribution fruit setting is often sparse (Orgaard 1991) and in New Jersey, sexual reproduction is negligible or non-existent as Riemer and Ilnicki (1968) found no seedlings seeds germinated and no seeds were found with embryos.

Schneider and Jeter (1982) indicate that submerged as well as emergent flowers and associated peltate leaves are produced in the San Marcos River, but pollen release does not occur in these flowers and seeds are not produced.

6.4 Floral Biology

This account of the floral biology of cabomba is based on Tarver and Sanders (1977), Sanders (1979), Schneider and Jeter (1981, 1982), Osborn *et al*. (1991) and Orgaard (1991).

Pollen fertility is low in *C. caroliniana* (45-95%) compared to the rest of the genus and is related to the high level of polyploidy. Flowers contain relatively few, large pollen grains and have small pollen-ovule ratios (560±123 [95% confidence limits] grains per flower; pollen-ovule ratio 62±14). These features are characteristic of entomophily (insect pollination). Flowers undergo a dianthesis in which flowers are structurally and functionally pistillate (♀) on the first day and staminate (♂) on the second. Anthesis lasts for two consecutive days. Flowers open in the morning around 10.00 a.m. and close in the afternoon at around 4.00 p.m. On closing flowers submerge. When open they are raised 1-4 cm above the water surface due to elongation of the peduncle. This occurs some 2 h before anthesis. Consequently, during the morning, second day flowers stand slightly higher than first day flowers.

Flowers are protogynous on the first day and stamens are short filamented and indehiscent and the longer pollen receptive stigmas arch out over the nectaries. The filaments elongate on the second day so that the anthers are level with the stigmas, but they point out towards the nectaries. The anthers undergo extrorse dehiscence on day 2 some 2-3 h after the flower is fully open but by then the stigmatic papillae are flaccid (suggesting loss of stigmatic receptivity) and the carpels reoriented inwards. Initially the pollen is a sticky mass, but it dries and become powdery. Flowers waterlogged by rain do not release pollen. If skies are overcast, anther dehiscence may be delayed by a few hours and stigmatal sensitivity extended.

The perianth persists until the seeds are released. Seeds are contained in long pistils and vary from 1-3 per pistil depending on environment (time of year - 1 in May; 2-3 September). Fruit are mature by 2-4 weeks. Pistils containing mature seed separate from the pedicel and fall to the bottom. The fruit wall decomposes and the seeds are released and lie on the hydrosoil surface. Eventually, seeds sink into the substratum and are protected from desiccation. It is speculated that seeds have the capability of remaining viable after long periods of desiccation or dormancy (Madsen 1996).

Schneider and Jeter (1982) claim that autogamy and apomixis does not occur and protogyny is absolute (stigmas only receptive on day 1 and never on day 2) but Orgaard (1991) observed fruit setting without hand pollination or observed insect pollination, so that some degree of autogamy seems possible. Similarly, Sanders' (1979) observations suggest that cabomba is only facultatively entomophilous. Wind or rain would be sufficient in nature to displace pollen onto the stigmas. Certainly though, self-pollination appears to be a rare event (Hanlon 1990). Tarver and Sanders (1977) found water, wind and hand pollination failed to produce seed but that insect pollination was successful. 40% of flowers that had been visited by insects produced mature seed after about 1 month. 20% of flowers visited on the first day produced seed and 60% of flowers visited on the second day produced seed, so pollination is due to insects and cross-pollination is the rule. Principal pollinators were *Enallagma* and *Anax* (Odonata), *Halictus* and *Apis* (Tarver and Sanders 1977) but Odonata probably are accidental pollinators as they are not nectar or pollen feeders. The major pollinators observed by Schneider and Jeter (1982) were small ephydrid flies.

Cabomba flowers are visited by numerous insects, particularly small flies. On day 1 whilst a fly is taking nectar, a stigma is in close proximity to its back or head. On day 2 it is the anther that is in this position. Flies were seen to carry pollen. The changes in morphology during flower development ensure that pollen is transferred from the 2-day-old flowers to the stigma of one-day-old flowers. After anthesis, the flower is pulled beneath the water surface, either by an acute bend in the peduncle, by coiling of the peduncle or loss of turgor pressure in the peduncle. Only fertilised flowers (swollen carpels - evident 1 week after pollination) were pulled underwater by the peduncle. Flowers not dehisced on the second day are pulled underwater but become water logged and do not release pollen (similarly if wet by rain). Abscission of the fertilised flower is prevented by auxins released by the ovary and transported down the peduncle. The coiling of the peduncle may also be due to auxins. The coiling is thought to protect carpels from being broken from the peduncle by fish and severe wave action.

6.5 Seed

After fertilisation, the perianth encloses the fruits and in a few days, the anthocarp becomes submerged due to recurvation of the pedicel (Orgaard 1991). Fruit (pistils) break away from the plant and fall to the bottom, decompose and leave the seed at the hydrosoil surface (Sanders 1979). The perianth persists until the seeds are released 14-30 days after anthesis. The seed is green when fresh with a scattered dark pigmentation and slowly turns brown with age. Seed is globose to ovoid-oblong with slightly flattened ends (Orgaard 1991). Seed anatomy is similar to that of other nymphaceous genera: there is abundant perisperm, little endosperm, a haustorial tube and a small dicotyledonous embryo (Schneider and Jeter 1981).

In Louisiana viable seed is produced but viability is low and only about 25% of seeds germinate naturally (Sanders 1979). About 5% of seeds germinate immediately and do not require a period of after-ripening. In experiments to try to assess the importance of different environmental conditions on germination only 1.8% germination occurred. Seeds generally germinate 5-10 weeks after fertilisation (Tarver and Sanders 1977) but seed can remain viable for more than 2 years. Factors believed to be important in affecting germination are red light, temperature and high carbon dioxide levels (Sanders 1979). Toward the northern edge of its US distribution, sexual reproduction does not occur (Riemer and Illnicki 1968). The embryo remains viable for up to 8 h if allowed to desiccate. Seed set in *C. caroliniana* is reduced compared to congeners but this could be explained by the reduced pollen fertility and/or reduced stigmatic receptivity; both associated with high ploidy. Climate and the environment may also affect seed set in this species (Schneider and Jeter 1982).

Seeds have not been recorded from Australian plants although two herbarium specimens from south-east Queensland possess fruit (J.T. Swarbrick *in prep.*). Since potential pollinators are plentiful, cabomba in Queensland may be sterile.

6.6 Dispersal

Orgaard (1991) suggested that like most water plants, seed dispersal is due to water birds, and this could be important in ensuring dispersal between lakes or river systems. Sanders (1979) states that the floating pistil helps disperse the seed (Sanders 1979). However, its range extension in the USA is generally considered to be due to the discarding of unwanted plants by aquarists (Hanlon 1990, Madsen 1996).

This survey of the ecology of cabomba has shown that relatively little is known, particularly in Australia. In Queensland, more information is required on its response to water chemistry and light regimes, its life cycle and whether the plant is truly sterile.

7.0 Efficacy of Current Control Methods

7.1 Chemical

Whilst it has been reported that cabomba is susceptible to a variety of commonly used herbicides (endothall, 2,4-D, 2,3,5-T, silvex, diquat, dichlor) their effects are erratic (Hiltibran 1974, 1977) and managers consider cabomba is difficult to control and re-treatment is often necessary (Leslie 1985, Madsen 1996).

Results of trials on 2,4-D are inconsistent (Hiltibran 1974) but a granulated formulation of 2,4-D as the butoxyethanol ester has been useful as a treatment for water weeds, including cabomba, in potable water supplies in Texas (Guerra 1974).

Symmetrical triazines are well known as effective aquatic herbicides (e.g. simazine). The triazine terbutryn has been suggested as a possible herbicide for cabomba. Treatments at doses between 0.05 and 0.20 ppm at treatment times of 31 days all reduced growth of cabomba below that of controls, in the field. However, the effect of the lowest concentration was greater than that of intermediate concentrations, particularly when exposure times were in the region of 6-10 days. In the laboratory, terbutryn had a stimulatory effect at concentrations of 0.05-0.10 ppm. At very low concentrations, it seems that terbutryn stimulates growth (Riemer and Trout 1980).

The potassium salt formulation of endothol-silvex controls cabomba particularly with the addition of surfactant (X-77) and has a low toxicity to fish and mammals (Lapham 1966). The granular formulation is recommended for the margins of deep water areas.

Endothall acid can be used to control cabomba particularly if formulated as the potassium salt as in Aquathol K or the more toxic alkylamine salt in Hydrothol 191. Since the 1960's, several million pounds of Hydrothol 191 have been applied in Florida to control aquatic weeds, including cabomba, without causing fish kills or adverse environmental effects. Endothall acid breaks down rapidly and completely. It will not leave residues, accumulate in the hydrosoil or food chain, or move significantly from the treatment site. Emergent plants need not be affected. Used at the recommended rates of 0.5-1.5 ppm Hydrothol 191 is not toxic to fish. It should be applied in sections or blocks, from the shore outwards so fish are not surrounded. Not more than 10% of the lake should be treated at any one time with rates exceeding 1.0 ppm. Canals should not be treated with rates in excess of 0.5 ppm (liquid) or 1.0 ppm (granular). A weighted hose should be used to apply the liquid herbicide as close to the bottom as possible, or preferably, the granular formulation should be used which is less toxic to fish. Hydrothal 191 is less toxic to fish in cool water (below 18^{o}C) (Moore 1991).

Endothall is not registered in Australia except as a defoliant for crops and as a post-emergence herbicide for winter grass in turf.

Sonar (fluridone) is an effective herbicide for cabomba (Tarver 1985). It gives long-term control, is easy to apply and is selective, as many plants are not susceptible (Tarver 1985, 1987). Chemically it is 1-methyl-3-phenyl-5--3 (trifluoromethyl) phenyl-4 (IH)-pyridinone. It is not volatile, is unaffected by pH

(4-14), has an average half-life of 20 days and is decomposed by ultra-violet light into non-herbicidal, non-toxic products. It is not deactivated by adsorption from suspended organics or clay particles; hence, it is effective in turbid waters. It acts by interrupting carotenoid synthesis and since carotenoids seem to protect chlorophyll from photodegradation by UV light. Affected plants show symptoms of bleaching (chlorosis). It is a systemic herbicide and plants will absorb sonar via the leaves and shoots and the roots. Control normally takes 30-90 days and this slow action helps prevent oxygen depletion of the water due to massive decomposition of dead vegetation. Control is best achieved during periods of active growth. To control cabomba in Florida, but to avoid damage to other susceptible plants such as lilies, a very early spring application (January-March) is used. Toxicity to fish is about 7.6-22 ppm and to invertebrates circa 1.4-4.4 ppm (the normal application rate concentration is around 0.1 ppm). The US Environmental Protection Authority has concluded that Sonar does not pose a risk as a chronic or acute toxicant in aquatic systems. Only the Slow Release Formulation (release occurring over 7-14 days) is approved for rivers by the US EPA and control is poor if applied during rapid flow conditions. In still waters, a spreader/sinking agent is recommended (Tarver 1987).

Fluridone was successfully used to eliminate cabomba from a lake in Florida over a 2-year period with only minor impacts on marginal vegetation (Leslie 1986) but when used in northern Queensland on Lesley Creek in an experimental field application, control was ineffective, perhaps due to the application being into moving water. Sonar is not commercially available in Australia and is not a registered in Queensland.

In south-east Queensland, before 1992 no attempt had been made to control or eradicate infestations of the weed because it had been non-invasive and there were no suitable herbicides registered for use against it. With the advent of the weed in two water storages it was realised effective control methods were required. As a result, an effective and relatively cheap chemical control for cabomba has been devised (Diatloff and Anderson 1995). 2,4-D n-butyl ester plus diatomaceous earth is mixed at 1 part to 20 parts of water injected 2 m below the water surface through a series of weighted nozzles to achieve a final concentration of 10 ppm clay/2,4-D active ingredient. This method of application allows the mixture to spread sideways to provide a blanket cover of the area being treated and completely cover the plant, which takes up the herbicide through the leaves and stems. It is important that the approximate depth of the area being treated is known so that the volume of water to be treated can be estimated to allow the correct application rate to achieve the required concentration of 10 ppm. In trials in the Ewen Maddock Dam this method provided effective control of cabomba within a matter of days and 2,4-D is now registered in Queensland for use against cabomba.

Fluridone was also assessed as an herbicide for cabomba in these trials but gave almost no control. The reasons for this clearly require more research but fluridone is totally water-soluble and in the trials it appeared to dissipate completely throughout the water body before any control could be effected. This may also explain why previous attempts at control using 2,4-D have given erratic results. A water solvent form may have been used. In contrast, 2,4-D ester is emulsifiable, not water-soluble and is adsorbed onto the diatomaceous earth, so it does not disperse very far. This enables quite precise control in applying the herbicide and localisation of the area being treated. The 2,4-D is quite selective in its action: other species present during the trials were not affected and whilst the closely related water lilies were removed, they quickly re-colonised from adjacent areas (Diatloff and Anderson 1995).

With careful application and attendance to ensuring the required concentration of active ingredient is met, it may also be feasible to use this method to control cabomba in slowly flowing streams and it should certainly be applicable to still water canals. In the case of infestations in irrigation canals, problems with using 2,4-D could arise as many crops are susceptible to the herbicide. However, if the canal can be bypassed, isolating the infestation, and its use withheld for a period, control work can be carried out. Before bringing the canal back on line bioassays can be performed using very sensitive test plants to ensure no subsequent damage to crops when the canal is brought back on-line. Since the half-life of 2,4-D in most aquatic systems is quite short canals may only need to be off-line for relatively short periods.

The use of 2,4-D in potable water supplies may cause some concerns. However, when properly used, it is non-persistent in the environment at harmful levels and does not accumulate in food chains Gangstad (1986). If used away from the take-off points, or if the reservoir can be taken off-line for a while, with close monitoring, its use for the control of cabomba may be acceptable.

7.2 Mechanical Control

Mechanical control methods can be very effective for aquatic weeds and in Japan, they are the most popular control method, but only temporary control is provided and this is expensive (Oki 1992). In the USA mechanical techniques have proven ineffective (Madson 1996). McComas (1993) provides a comprehensive survey of mechanical control methods, many of which could be used against cabomba. Cabomba does not root deeply and can easily be lifted out by the roots although in deeper water this operation has to be carried out by divers. A venturi dredge has been devised for use in the Ewen Maddock Dam (P.Bell, R. Rainbird *pers. comm.*) and a mechanical harvester has been used for control of cabomba in Lake MacDonald (K. Garraty *et al.* 1996). The mechanical harvester used in Lake MacDonald effectively halved the cabomba standing crop (from 48.7 to 25.9 t ha^{-1}) but in three weeks cabomba had grown back to pre-cut levels (51.9 t ha^{-1}).

A problem with using mechanical controls against cabomba is that the plant easily fragments and these fragments can float away and recolonise the treated area or invade adjacent non-weedy areas. As a consequence, mechanical harvesting is not suitable for small or new infestations, but may be the only acceptable method for large infestations in potable water supplies. Fragmentation is minimised by using a venturi dredge and additionally the whole plant is removed, including the root ball.

Cabomba grows well in nutrient rich waters and is an efficient utiliser of dissolved phosphate. In these situations, harvesting of cabomba may lead to an increase in water quality due to a reduction in dissolved phosphate and nitrate in the water (Anderson *et al.* 1996, Garraty *et al.* 1996). The removed material may be used for composting, but if the amounts removed are quite small, this may not be a financial proposition, nor may it be necessary as cabomba placed on the bank decomposes in 3-4 weeks (K. Garraty *pers. comm.*).

7.3 Biological Control

Chinese grass carp (white amur) is an effective biological control agent for *C. caroliniana*. It has been used in Arkansas, apparently with no adverse effects on fish and waterfowl populations. It is very effective as it can ingest several times its own body weight per day in submerged vegetation. In Arkansas, fish stocked at 22 fish/ha gave complete cabomba control in less than five years. In a Florida lake, control was achieved in 2 years by a residual population of 84 kg/ha (17 fish) and the only changes attributable to grass carp were an increase in nitrate-nitrite, presumably due to the decomposition of faecal plant material from the fish. Native fish populations did change, but with no discernible pattern in relation to carp populations (Beach *et al*. 1978).

In South Carolina, sterile (triploid) grass carp are being used to control *Hydrilla* and *Elodea* (de Kozlowski 1991). Sterility is ensured by checking through three different facilities. Carp with a minimum length of 25 cm are stocked at a rate of 60 per vegetated hectare.

Whilst grass carp appear to be an effective biocontrol agent for aquatic weeds such as cabomba and their effect on native ecosystems can be reduced by using sterile triploids, their release into Australian waters is not likely to be acceptable due to their pest potential and infestations of cabomba are not sufficient to warrant their consideration as a control agent.

Invertebrate herbivores of cabomba are poorly known; the larva of the moth *Paraponyx diminutalis* attacks cabomba (Buckingham and Bennett 1989) but also attacks a wide range of other aquatic plants and is probably unsuitable as a biocontrol agent. Adults of the larval leaf-mining fly *Hydriella balciunasi* have been recorded from *C. caroliniana* in Queensland (Balciunas and Burrows 1996).

7.4 Commercial Exploitation

Throughout the world cabomba is grown as an aquarium and outdoor aquatic plant because of its finely dissected leaves (Orgaard 1991). In Queensland, despite its declared status, it is still traded by a few northern growers, but this trade is certainly worth less than $10,000 annually (A. Birkill *pers. comm.*). Since it is suspected that at least some of the cabomba infestations in Queensland arose from growers ‘seeding’ the weed into natural waters commercial exploitation is clearly inimical to control of the weed and should be stopped.

7.5 Management Practices

The management techniques chosen must be appropriate to the type of weed problem and the uses and functions of the water body. The risk of adverse side effects for users of the water must always be given priority. In general, the more effective the weed clearance, the greater will be the risk of an adverse environmental impact (Oki 1992). In the case of cabomba, since sexual reproduction does not occur, control procedures can be timed to the stage when the plant is most susceptible to vegetative destruction (Riemer and Ilnicki 1968).

Experiments in aquaria have shown that drawdown should be an effective management tool: if water is removed but the hydrosoil remains moist there is

53% survival whereas if the hydrosoil dries out, less than 10% survival occurs. In the field, extreme temperatures accompanying the drying out are likely to render drawdown even more effective. If drawdown is used as a management technique, water removal should be complete (Sanders 1979).

For several years drawdown has been used as a management tool for aquatic weeds in Louisiana and is considered the only economic method (Manning and Sanders 1975). Drawdowns of 1.5-2.5 m have given 90% control of many weeds including cabomba, but unfortunately have enhanced the spread of water hyacinth and alligator weed. Tarver and Sanders (1977) showed that consecutive autumn-winter drawdowns yielded 99% reduction of cabomba in Black Lake, Louisiana but cabomba regrew after the lake refilled, due to the growth of seedlings. Although cabomba was most frequent and had its greatest biomass at depths (2.4-3.1 m) greater than the drawdown, cabomba was eliminated in areas that did not completely dry out, presumably because it was stressed too much, possibly by low winter temperatures. In Louisiana, a complete winter drawdown is the best way to manage cabomba although results are dependent on weather conditions during drawdown (Manning and Sanders 1975).

In the USA drawdown as a management tool has been controversial due to the economic losses ensuing from the temporary deprivation of fishing rights, boating facilities and hunting. Since the effective use of drawdown depends on the weather during the drawdown period, these losses may not be balanced by effective weed control. Proper timing of drawdown is therefore essential. In Louisiana an autumn/winter drawdown is most effective. During drawdown, cabomba fragments capable of growth may be carried or washed into the shallow remaining areas, become rooted, and act as refuges for the weed, resulting in rapid reinfestation. (Sanders 1979).

In Australia, losses from drawdown are not the same as in the USA as water bodies are not so intensively used for recreational purposes. However, water, particularly potable water, is a scarce resource in Australia and drawdown may not be acceptable for this reason. If it is an acceptable treatment option drawdown is the best available option for cabomba control, particularly in potable water supplies. Generally the thick silt in which cabomba becomes rooted takes a long time to dry, so in the wet tropics where much of the current Queensland infestation is found, drawdown would be best carried out in winter. If drawdown is used, it may require supplementary treatments to guarantee weed control. Diuron can be sprayed on the exposed root bases to enhance and speed control and is registered in Queensland for use in this type of situation or 2,4-D n-butyl ester can be used.

In Queensland, two drawdowns (of 4 and 7 m respectively) have been used to control cabomba in the Ewen Maddock Dam. The first gave incomplete control due to heavy rains partially refilling the dam. The second drawdown was more successful as the dam was dry for 4-5 months and most plants were killed. With partial refilling, two small reinfestations were noticed and are now being brought under control by hand pulling plants.

Chemical control using a mixture of 2,4-D n-butyl ester and diatomaceous earth is effective in still waters and possibly irrigation channels, and may be suitable for slowly moving waters if the correct concentration can be maintained. However, a chemical control method for more strongly flowing waters is not yet available.

For infestations in small creeks and irrigation canals control through shading may be viable although cabomba does appear to grow well at low light intensities. Adequate bankside vegetation can provide sufficient shade to stop submerged aquatic plants from growing (Dawson 1989). If the weed beds are localised, a temporary covering of the affected area by black shading fabric can effectively kill-off the plants (Dawson 1989). This option may be particularly suitable for infested irrigation canals although weed fragments must be contained to avoid infestation away from the treated area.
Because of the growth inhibition shown by cabomba at alkaline pH's and its calcium intolerance (Riemer 1965) liming of small water bodies may be a useful management practice (Sanders 1979). Although this appears never to have been tried, research into liming as a possible control technique should be carried out as it would be a relatively benign management technique.

8.0 Management and Control Practices

8.1 Legislative Status in Queensland

Cabomba, *Cabomba caroliniana*, is a declared plant under the provisions of the Rural Lands Protection Act. Currently it is declared as category P2 in the local government areas of Atherton, Eacham, Johnstone and Mulgrave and where found the plant must be destroyed and it is illegal to sell or keep the plant throughout the state.

The separation of the different species of cabomba is difficult for even experienced botanists and in the past, there has been confusion over the definition of the species that has led to concerns over which form of cabomba is the declared form. Because of this and the potential for other species of cabomba to establish in Queensland a revised declaration that covered the genus as a whole would make a preferable legislative instrument. Declaration for the whole state would raise awareness of cabomba as a potential significant threat to Queensland's freshwaters.

8.2 Containment and Eradication Strategies in Queensland

Cabomba currently appears to have a limited distribution in Queensland. The spread of cabomba into other areas must be guarded against. Now that an effective chemical control is available for the weed, local eradication and restriction of its distribution are feasible.

Goals for action on cabomba are:
- Locate all infestations of cabomba within the state.
- Eradicate current small and new infestations. This will only be achievable for small (<1 ha) localised infestations.
- Restrict the distribution of cabomba to the few major impoundments in which it is currently found.

The spread of cabomba can be restricted by:
- Early detection. Weed control officers and people in the water industry should be made aware of the weed and how to identify it.
- Increasing public awareness of the weed and its potential to disrupt aquatic recreational activities.
- Educating people on the need to clean boats and equipment after recreational or commercial use of an infested water body.
- Eradicating wild harvesting of cabomba and controlling illegal commerce in cabomba.
- The preparation and implementation of containment plans for cabomba in situations where infestations are located in catchment headwaters.

It is essential that where cabomba is known to occur in a publicly accessed water body information signs are positioned adjacent to access points such as boat ramps which clearly indicate the necessity of cleaning down boats and equipment to stop the spread of the weed to unaffected areas.

8.3 Management Strategies for Aquatic Systems.

There are two major problems constraining action in relation to cabomba:

- New infestations are difficult to detect since inspections for this type of weed are not regularly made and the weed is a fully submerged aquatic plant and is not easy to see until the affected area is quite large.
- The weed grows very quickly and it is highly invasive. Unless early control is initiated the weed quickly establishes throughout the system and eradication is a hopeless task.

The first constraint could be met through the development of an adequate and easily used detection system for submerged weeds. The SAVEWS system for the hydroacousitic detection and mapping of submerged water plants being developed by the Tennessee Valley Authority and the U.S. Army Corps f Engineers (Sabol and Melton 1995) is worthy of consideration for the easy detection of cabomba infestations in Queensland impoundments. Integrating the regular use of such a monitoring system into the routine management of reservoirs and impoundments would go a long way to meeting the second constraint through enabling early control efforts.

Control practices need to be integrated into the general management of the impoundment, canal or river. Since cabomba is likely to be able to establish in farm dams, landholders also need to be aware of its potential and integrate checks for the weed into their general property management plan.

The control practices used must be tailored to the particular type of water body being treated. In a potable water supply, very regular mechanical harvesting may be the only viable method. If an impoundment can be taken off-line then a suitably timed drawdown and a chemical treatment of the root mass may be an available option. If drawdown is not an available option, the infestation may be thinned by an initial chemical treatment and the remaining plants removed by hand. If impoundments flow, or could overflow, into catchment headwaters, containment plans must be put into place which will stop cabomba washing into the river system.

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