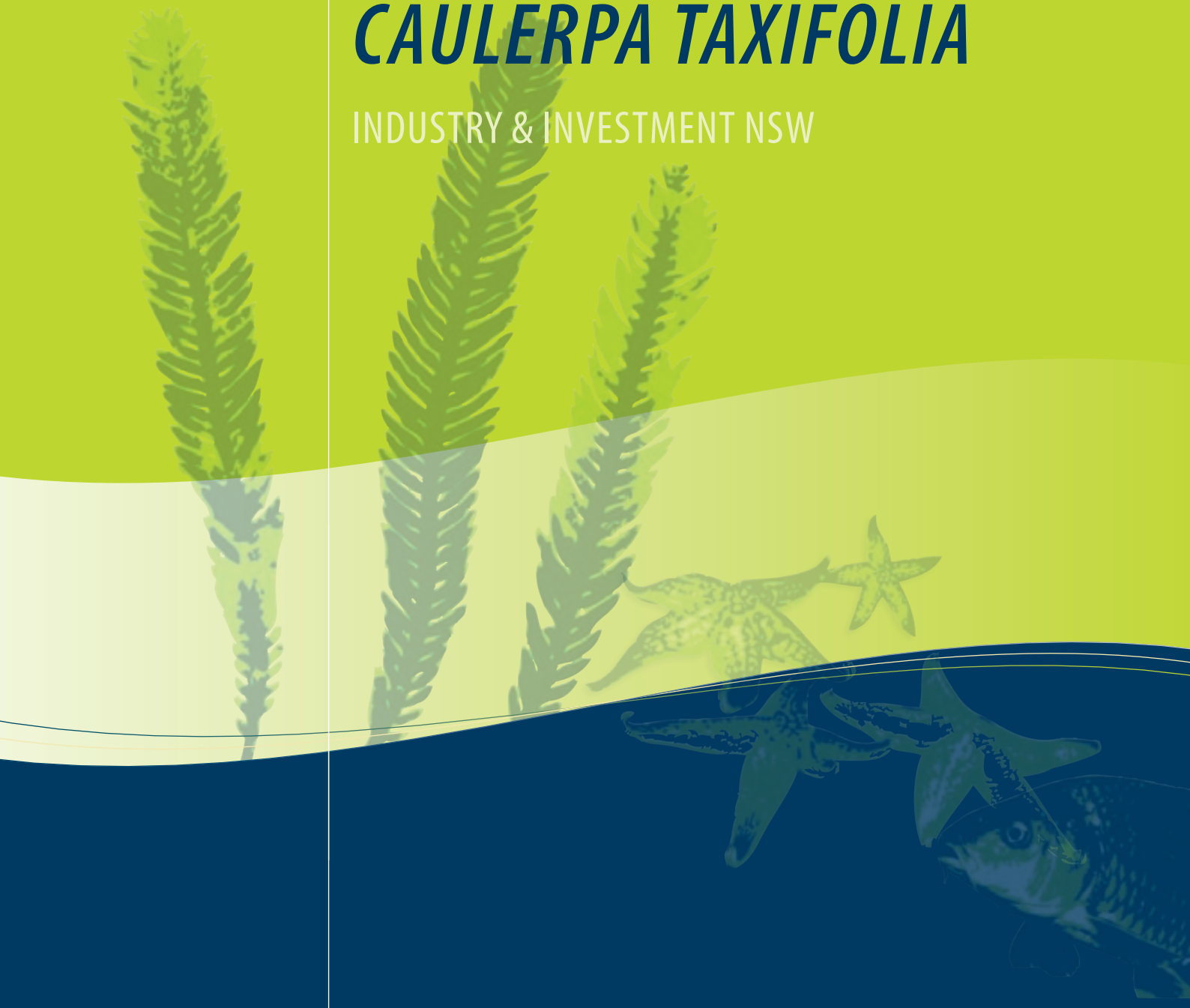
NSW GOVERNMENT | Industry & Investment

# NSW CONTROL PLAN for the

# NOXIOUS MARINE ALGA *CAULERPA TAXIFOLIA*

INDUSTRY & INVESTMENT NSW



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Written by Aquatic Biosecurity & Risk Management Unit, Industry & Investment NSW

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This book includes references to the work and programs of the former NSW Department of Primary Industries, one of the NSW government agencies which merged to form Industry & Investment NSW around the time this publication was written.

# NSW CONTROL PLAN FOR THE

# NOXIOUS MARINE ALGA

# *CAULERPA TAXIFOLIA*

AUGUST 2009

NSW GOVERNMENT
Industry & Investment

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## SUMMARY

The marine alga *Caulerpa taxifolia* (Caulerpa) is naturally distributed throughout the tropical regions, including northern Australia. It was first discovered in NSW waters in March 2000, in Port Hacking, 30 km south of Sydney. As of February 2009, it had been found in 14 NSW coastal lakes and estuaries and one small oceanic population off Sydney. The degree of invasion of Caulerpa varies from place to place, ranging from small, isolated patches to dense beds covering many hectares.

Research on the impacts of Caulerpa on native flora (seagrasses) and fauna (invertebrates and fishes) is in progress, but the full significance of the threat posed by the marine alga remains unclear.

In January 2002, a Natural Heritage Trust grant from the Commonwealth provided funds for initial investigations into the ecology and possible control of the marine alga in NSW. In July 2002, the NSW Government made available additional funding of nearly $1 million a year for 3 years to deal with Caulerpa and other aquatic pests in NSW. This allowed Industry & Investment NSW (I&I NSW, formerly NSW Department of Primary Industries) to conduct an extensive research and control program in affected estuaries. This management program continues today, albeit at a reduced scale. To date over 1500 tonnes of salt has been used to treat more than 6 hectares of Caulerpa.

These works and other management programs, including fishing closures and public education, appear to have slowed the spread of Caulerpa to new estuaries and helped to remove large amounts of Caulerpa from some waterways. However, permanent eradication of Caulerpa does not appear feasible in NSW. In addition, the extent of existing Caulerpa beds is far too large to allow comprehensive treatment of all areas.

In 2004, I&I NSW developed a NSW Control Plan to manage the risks and impacts of Caulerpa by:

- implementing measures to prevent the further spread of Caulerpa by focusing on high-risk vectors
- controlling existing populations of Caulerpa in high-priority areas
- conducting research on the environmental impacts of Caulerpa in NSW and potential alternative control measures
- conducting an ongoing community awareness and education program.

## SUMMARY (CONTINUED)

The 2004 NSW Control Plan for Caulerpa has been in place for 5 years. It has now been reviewed and updated to reflect the latest research findings and the outcomes of several additional years of control and education. The overall goals of the 2009 revised control plan presented here are to:

- prevent the further spread of Caulerpa within and between NSW estuaries
- reduce the impacts of existing populations of Caulerpa on biodiversity and fisheries productivity
- maximise the efficient and effective use of available resources by prioritising management programs and utilising best-practice techniques
- continue to support research into the environmental impacts of Caulerpa in NSW waters
- ensure that future management of Caulerpa is underpinned by rigorous, quantitative science and appropriate monitoring and evaluation
- continue to educate the community about the impacts of Caulerpa and the role of the community in management strategies to prevent spread and counteract impacts
- coordinate education programs and management of Caulerpa with the actions of relevant local and State government agencies.

Fronds of Caulerpa. Photograph I&I NSW

# SECTION 1
# BACKGROUND

## DESCRIPTION

Caulerpa is a light-green marine macroalga. It has a characteristic 'creeping' stem, called a stolon, which can measure over 1 m long and is attached to the bottom by root-like structures called rhizoids. The stolon bears flat, feather-like fronds that can grow up to 65 cm long, although in NSW they rarely measure more than 25 cm.

Caulerpa, often referred to as a weed, can be found as individual plants or as dense mats that cover many hectares. It can be distinguished from the *Caulerpa* species that are native to NSW (such as *C. flexilis* and *C. cactoides*) by the branching pattern and the size and shape of the pinnules (small lateral branches on the fronds).

The bright green pinnules attach directly opposite each other. Plants become pale green (starting from the tips of the pinnules) and then turn white as they die. This can occur in the cool winter months or in shallow water after heavy rainfall (T. Glasby, I&I NSW, pers comm. 2008).

The light to bright green fronds of Caulerpa have pinnules that attach directly opposite each other. Photograph Allan Millar Royal Botanic Gardens, Sydney

## WORLDWIDE DISTRIBUTION

Caulerpa is endemic to tropical and sub-tropical regions around the world, including in Australia, where its natural southern limit on the east coast is Moreton Bay, Queensland. It is primarily a subtidal species that can grow on hard or soft substrata.

The alga first came to the attention of the world in 1984 when plants were discovered growing in the Mediterranean Sea in front of the Monaco Oceanographic Museum (Meinesz & Hesse 1991). This infestation rapidly colonised thousands of hectares of subtidal hard and soft substrata (Meinesz 2002). From Monaco, Caulerpa spread to the French coast, Spain, Italy and Croatia, and it was found in Tunisia in 2000. By the end of 2000, the alga covered approximately 131 $km^2$ of seafloor in the Mediterranean (Meinesz *et al.* 2001).

The Caulerpa that invaded the Mediterranean was dubbed the 'aquarium strain', because it was presumed to have been a selectively bred clone of Caulerpa released from marine aquaria; it was (and still is) used for decoration in public aquaria and private fish tanks. One of the key features of this 'aquarium strain' was purportedly its tolerance to colder water, which allowed it to thrive in more temperate waters. However, more recent research has shown that even 'native' Caulerpa is naturally quite tolerant of colder waters (Glasby & Gibson 2007).

Infestations of Caulerpa were reported from two locations in California in 2000 (Jousson *et al.* 2000), but suspected outbreaks in Florida and Brazil were never substantiated. Outbreaks were recorded from temperate localities along the coast of NSW in 2000 (as described below) and from two locations in South Australia in 2002.

Caulerpa is just one of several *Caulerpa* species with invasive or 'weed-like' characteristics. For example, subsequent reports from the Mediterranean have suggested that another species, *C. racemosa*, is even more invasive than Caulerpa. Like Caulerpa, *C. racemosa* is native to tropical regions of Australia.

## *CAULERPA TAXIFOLIA* IN NSW

In NSW, Caulerpa was first identified in March 2000 in Port Hacking, 30 km south of Sydney, and was listed as a Class 1 noxious species in 2001, under the *Fisheries Management Act 1994*. It had not previously been observed in mainland NSW waters in the 200 years since European settlement, suggesting that its sudden appearance in NSW resulted from human introduction rather than a natural range extension from southern Queensland. The alga has since been identified in 14 lakes and estuaries and as one small oceanic population at Merri Reef, off Sydney. Caulerpa has been found in Lake Macquarie, Brisbane Water, Hawkesbury River (Patonga)/Broken Bay, Pittwater, Port Jackson, Botany Bay, Port Hacking, St Georges Basin, Lake Conjola, Narrawallee Inlet, Burrill Lake, Durras Lake, Batemans Bay and Wallagoot Lake. Some of these populations were identified during I&I NSW surveys to update the distribution of seagrasses in NSW, whereas others were reported by members of the public. No Caulerpa has been found in Lake Macquarie during the last 3 years of surveying, and consequently Lake Macquarie is now considered to be free of Caulerpa. See Section 5 for more information on the eradication of Caulerpa from Lake Macquarie.

There is still uncertainty about the source of outbreaks of Caulerpa in NSW, but genetic evidence suggests that the various populations of Caulerpa in NSW have come from multiple sources. It also appears that the so-called 'aquarium strain' from the Mediterranean is genetically similar to native Queensland populations of Caulerpa. Thus, it is likely that Caulerpa taken originally from Queensland was cultured in aquaria around the world over many years and eventually released into the Mediterranean and later into some waterways in NSW. Despite the uncertainty surrounding the origin of NSW populations of Caulerpa, it is clear that the alga has spread rapidly and covered areas of seafloor where it had never been recorded previously. This pattern of colonisation appears to be similar to the situation in the Mediterranean.

Dense Caulerpa growing in Wallagoot Lake in May 2009. Photograph James Sakker I&I NSW

## ECOLOGY

Research in the Mediterranean and in NSW (Wollongong University) has demonstrated that Caulerpa can tolerate temperatures as low as 10 °C (but tends not to grow unless water is a few degrees warmer) and is killed within a week by salinity levels less than 20 ppt. The alga can survive out of water in moist conditions (e.g. in anchor wells) for 2 or 3 days. It has been found on most kinds of substrata, including rock, sand, mud, seagrass beds and rhizomes of seagrass, and at depths from less than 1 m down to around 50 m. In NSW waters, by contrast, it has been recorded only down to about 12 m and occurs mainly in seagrass beds, sand or fine silt sediment, and occasionally on rocky reefs.

In its natural habitat Caulerpa can apparently reproduce sexually, but the main ways it spreads in areas outside its natural range are by vegetative growth and fragmentation. It has been demonstrated in laboratory experiments that very small fragments can settle and start generating rhizoids (root-like structures). Growth rates are greatest in the summer months and lowest during winter. The area covered by the weed may increase by a factor of 10 in a single summer growing season. Repeated surveys of Caulerpa in NSW have shown that many beds are highly dynamic and may expand, decrease in size or disappear over a short time for no obvious reason.

Research undertaken by I&I NSW has shown that Caulerpa can survive and remain viable for long periods of time buried under sediments (Glasby *et al*. 2005a).

Numerous research projects on Caulerpa in NSW have been completed, and more are currently underway (see Section 7), including research on its genetics, its value as habitat for fish and invertebrate communities (compared with the value of native seagrasses), its survival under different conditions, and its growth and dispersal via fragmentation.

## IMPACTS

There are two key characteristics of Caulerpa that have caused significant concern and may have helped Caulerpa to become established and spread in areas outside its natural range.

First, Caulerpa has rapid growth, leading to concerns that it could out-compete native flora such as seagrasses. There is anecdotal evidence for this, but little empirical evidence, which is why research in NSW has been focused on this issue. Given the ecological importance of seagrass beds (e.g. as recruitment, nursery and refuge sites for many species of native fish and invertebrates), any potential threat to them is of major concern.

Second, all species of Caulerpa (including those native to NSW) produce toxic substances (caulerpenynes). These act as deterrents to many epiphytes and herbivores (e.g. sea slugs, abalone and sea urchins), thus limiting grazing that might otherwise have reduced the biomass of the weed. For this reason there has been concern that few animals would eat Caulerpa and that toxins from the weed could have adverse effects on nearby native flora. Research conducted in NSW has confirmed that native grazers and fish do not consume much Caulerpa. The research has also found differences in the numbers and species of fish and invertebrates found in Caulerpa and native seagrass. See Section 7, 'Research', for more information on impacts.

## VECTORS

There are several human activities (vectors) that are likely to have contributed to the spread of Caulerpa, including release (accidental or intentional) from aquaria, and transport of fragments from existing populations via fishing and boating activities.

Caulerpa is a popular marine aquarium plant throughout the world and has been sold for many years within the aquarium industry (including Australia). It appears that, in several places, Caulerpa has been introduced into waterways, accidentally or otherwise, from aquaria. This was possibly the origin of the outbreaks in the Mediterranean and some places in NSW.

Human transport of fragments is one method by which Caulerpa spreads and establishes itself in new areas. Fishing (hauling) nets and boat anchors are likely to be the primary anthropogenic mechanisms that facilitate its spread within and between waterways. Fragments of Caulerpa can remain viable for up to 3 days in nets or anchor wells; this is more than sufficient time for fishing boats to travel to another estuary.

Natural events, such as currents, storms and disturbance of the seafloor by feeding animals such as rays, can also help fragment and translocate Caulerpa. These natural methods of translocation become increasingly important as the amount of Caulerpa at a site expands. Natural vectors are most likely to contribute to spread within a location (estuary). Spread to a new location by natural events could potentially occur if fragments were washed out to sea, carried by currents along the coast, and then swept into a new estuary. However, this risk is considered slight. Human vectors are considered more likely than natural vectors to introduce Caulerpa into new estuaries.

Fragments of Caulerpa can be spread by anchor chains. Photograph Melissa Walker I&I NSW

# SECTION 2
# SCOPE OF THIS PLAN

## RISK ASSESSMENT

The initial response to the discovery of Caulerpa in NSW waters was complicated by considerable uncertainty in relation to the alga's:

- origins (whether the strain found in NSW was derived from native Queensland populations and/or was the same as the 'aquarium' strain found in the Mediterranean and California)
- source of introduction (whether Caulerpa had reached NSW through a natural range extension or through human introduction, although the pattern of outbreaks suggested the latter)
- likely impacts (whether Caulerpa would have ecological impacts in NSW similar to those being reported in the Mediterranean).

Despite these uncertainties, the risk that the species could prove to be highly invasive and could have substantial impacts on native biodiversity meant that all possible action had to be taken to control the alga and prevent its spread, as dictated by the precautionary principle (where precautionary action is taken despite available information being incomplete).

Although much has been learned since the initial discovery of the marine alga in NSW, research is still ongoing and the full significance of the threat posed by Caulerpa remains unclear. Because of this uncertainty it is important to have a risk-based, adaptive management approach to Caulerpa that is based on the best available information but has the flexibility to be revised and improved as new information becomes available.

This control plan is based on a risk assessment to identify:

- the risk of Caulerpa spreading to new areas
- the risk of ecological and socio-economic impacts in affected areas
- the management actions taken to date, and their known or likely effectiveness in reducing the above risks
- any remaining (residual) or newly identified risks
- the likely significance of these residual/additional risks.

The results of the risk assessment are outlined in Appendix 1 and will be used to prioritise further management actions, including vector controls, treatment, monitoring, and advisory work. The methods used in the risk assessment are outlined in Appendix 2, and a synopsis of the risks at each site is given in Appendix 3. As this is an ongoing and iterative process, new information will be fed into the risk assessment as it becomes available (e.g. as research and monitoring projects are completed), and the results will be used to refine the management response.

## GOALS

The overall goals of this revised control plan are to:

- prevent the further spread of Caulerpa within and between NSW estuaries
- reduce the impacts of existing populations of Caulerpa on biodiversity and fisheries productivity
- maximise the efficient and effective use of available resources by prioritising management programs and utilising best-practice techniques
- continue to support research into the environmental impacts of Caulerpa in NSW waters
- ensure that the future management of Caulerpa is underpinned by rigorous, quantitative science and appropriate monitoring and evaluation
- continue to educate community members of the impact of Caulerpa and the community's role in management strategies to prevent the alga's spread and counteract its impacts
- coordinate education programs and management of Caulerpa collaboratively with relevant local and State government agencies.

## SCOPE

This control plan summarises the actions taken to date to contain and control Caulerpa in NSW, and sets out strategic actions for future work. These actions are divided into the following areas:

- vector management
- compliance, education and community involvement
- control and treatment in high-priority areas
- survey and monitoring
- research.


Caulerpa advisory signage. Photograph James Sakker I&I NSW

## SECTION 3
## VECTOR MANAGEMENT

Caulerpa is easily spread by fragmentation, with pieces that break off being capable of anchoring and growing into entire new plants. Research in NSW (Wollongong University) has shown that Caulerpa kept in a damp place such as an anchor well can remain viable for up to 3 days.

Table 1 lists some of the known or potential vectors for the spread of Caulerpa and the methods available to manage them. These measures can be crucial to limiting the spread of the alga within affected waterways and preventing its transport to other, currently unaffected, waterways.

Table 1. Caulerpa vector management

| VECTOR | VECTOR CONTROL METHODS |
|---|---|
| Commercial fishing nets | Fishing closures (netting), education |
| Recreational fishing gear | Fishing closures (netting), education |
| Diving equipment (e.g. wetsuits, fins) | Education |
| Boat propellers, hulls, trailers | Education, wash-down bays at boat ramps |
| Anchors and anchor chains | Education |
| Release from aquaria | Noxious listing (ban on sale and possession), education |
| Aquaculture (e.g. oyster trays) | Compliance: spot checks of infrastructure before movement, education |
| Ocean currents, tides and wave action | None (impossible to manage) |

Commercial and recreational fishing vessels and yachts that travel between estuaries pose a risk of transferring the alga to uninfected estuaries via fragments caught in nets, anchor chains or other equipment. These vectors are probably the primary means of dispersal of Caulerpa from infected estuaries into new areas. The movement of aquaculture equipment such as oyster trays also poses a potential risk.

## COMMERCIAL AND RECREATIONAL FISHING

The commercial fishing method most likely to affect Caulerpa beds is estuary hauling (netting). Some recreational fishing methods, such as prawning with hand-haul nets and scissor nets, also have the potential to spread Caulerpa.

To manage the potential spread of Caulerpa via both commercial and recreational fishing gear, various closures under the *Fisheries Management Act 1994* have been implemented in affected estuaries, as summarised in Table 2. These closures include Section 8 fishing closures, which ban the use of all nets other than a landing net (as prescribed in Clause 53 of the *Fisheries Management (General) Regulation 2002*) in specific areas of each estuary. Batemans Marine Park zoning prohibits netting by commercial methods in habitat protection zones and prohibits all fishing in sanctuary zones. Closures under Clause 21 of the *Fisheries Management (General) Regulation 2002* ban the use of all nets in the entire estuary other than a landing net (as prescribed in the Regulation).

In addition to being subject to management of vectors (netting) through Marine Park zoning and/or closures under Section 8 and Clause 21 of the Regulation, six of the 14 sites currently known to have been affected by Caulerpa are declared Recreational Fishing Havens. Under this arrangement, all forms of commercial fishing (excluding abalone gathering and lobster trapping in Botany Bay) in these areas were phased out from 1 May 2002. The six Caulerpa affected areas that are within Recreational Fishing Havens are:

- Lake Macquarie (now considered to be free of Caulerpa)
- Botany Bay
- Lake Conjola
- Burrill Lake
- Narrawallee Inlet
- St Georges Basin.

Both recreational and commercial netting is prohibited by Clause 21 of the *Fisheries Management (General) Regulation 2002* in Brisbane Water and Port Hacking, reducing the risk of transferring Caulerpa by these methods. Both Batemans Bay and Durras Lake are located within the Batemans Marine Park, and Caulerpa affected areas are closed to commercial netting as part of the marine park zoning. Port Jackson is closed to commercial fishing.


Caulerpa closure buoy. Photograph Steven Kay I&I NSW

Of the Caulerpa affected estuaries, Pittwater and the Hawkesbury River are the only locations where commercial net fishing is permitted. The Hawkesbury River currently has only two small Caulerpa affected areas, which are outside commercially netted areas. Pittwater has a current Section 8 Caulerpa netting closure over most affected areas that were previously commercially hauled. Other locations outside this closure area in Pittwater are open to commercial net fishing.

Further closures to hauling in Pittwater are being considered to protect beds of the native seagrass *Posidonia australis* (Posidonia). If these closures are implemented, the Caulerpa closure in Pittwater will be revoked.

Table 2. Management of netting over Caulerpa infestation areas

| ESTUARY | MANAGEMENT (CLOSURE) METHOD |
|---|---|
| Brisbane Water | All netting prohibited under Clause 21 of the *Fisheries Management (General) Regulation 2002* |
| Hawkesbury River (Patonga)/Broken Bay | Infested areas very small and not hauled, no closure in place |
| Port Jackson | Closed to commercial fishing |
| Botany Bay | Recreational Fishing Haven closed to commercial netting |
| Batemans Bay | Netting prohibited under Batemans Marine Park zoning in affected areas |
| Port Hacking | All netting prohibited under Clause 21 of the *Fisheries Management (General) Regulation 2002* |
| Narrawallee Inlet and its tributaries | Section 8 closure |
| Burrill Lake and its tributaries | Section 8 closure |
| Lake Conjola and Berringer Lake and their tributaries | Section 8 closure |
| St Georges Basin | Section 8 closure |
| Pittwater | Section 8 closure |
| Durras Lake | Section 8 closure (recreational netting); Batemans Marine Park zoning (commercial netting) |
| Wallagoot Lake | Section 8 closure |

Note: See the Primary Industries section of the I&I NSW website **www.industry.nsw.gov.au** – search for '*Caulerpa taxfolia*' for maps of known Caulerpa infestation areas, and 'Caulerpa closures' for maps of current Section 8 Caulerpa closures.

Line fishing and spearfishing also have the potential to spread Caulerpa if fragments are caught up in fishing equipment or wetsuits. However, the risk from this is considered relatively minor and is best managed through public education and awareness campaigns (see Section 4). For example, divers and fishers can minimise their chances of spreading Caulerpa by inspecting gear for fragments, and properly disposing of any found. Soaking in fresh water has also been shown to be an effective way of treating gear that may be carrying small Caulerpa fragments.

### WHAT I&I NSW IS DOING

**I&I NSW is undertaking an ongoing review process of existing fishing closures before their renewal to ensure they are appropriate and effective in limiting the potential for spread by fishing gear.**

### GOAL: FISHING CLOSURES

**Respond to any new areas of infestation within NSW estuaries with new fishing closures, if appropriate.**

## BOATING

There is potential for Caulerpa plants to be fragmented and dispersed by boat propellers or via pieces caught in anchor chains and other equipment, particularly in shallow areas where there are dense Caulerpa beds.

Wash-down bays have been provided at some boat ramps to allow boat owners to clean boats (including removing any Caulerpa fragments) with fresh water before leaving the area. Signs in these areas inform boat owners about the Caulerpa problem and the importance of inspecting and cleaning equipment, including anchor wells and chains. Education of waterway users through signage, media releases, brochures and boat ramp education by Fisheries Officers and Fishcare Volunteers remains the best tool for limiting translocation through boating activities.

## AQUACULTURE

Movement of oysters between estuaries presents opportunities for the translocation of fragments of Caulerpa. There are currently aquaculture leases in six of the 14 estuaries known to have been infested with Caulerpa: Batemans Bay, Brisbane Water, Hawkesbury River, Botany Bay, Lake Conjola and Burrill Lake.

This vector is addressed through education of aquaculturists and random inspections of trays by local Fisheries Officers before the oysters are moved (see Section 4).

## AQUARIUM TRADE

The aquarium trade has been identified as the most likely conduit by which Caulerpa was first introduced into NSW waterways. The Minister for Fisheries made an emergency declaration of Caulerpa as noxious marine vegetation in October 2000. Since this time (and following consultation with members of the aquarium industry), amendments to the NSW *Fisheries Management (General) Regulation 2002* have been made to include Caulerpa as a Class 1 (prohibited) noxious species under clause 340. This means that it may not be kept by anyone, even in aquaria, without a specific permit.

This action, together with educational activities, has markedly reduced the use of Caulerpa in aquaria. The importation of 'live rock' from parts of Queensland where Caulerpa occurs naturally has been identified as a potential route for inadvertently introducing the marine alga into aquaria, but this needs to be further investigated. Efforts to ensure compliance will continue through educational activities and targeted inspections of aquarium businesses (see Section 4). Ongoing liaison with Queensland fisheries managers will ensure better compliance and control of interstate movement of Caulerpa.


Fisheries Officers installing Caulerpa netting closure buoy. Photograph Melissa Walker I&I NSW

# SECTION 4
# COMPLIANCE, EDUCATION AND COMMUNITY INVOLVEMENT

Since the implementation of initiatives such as netting closures there have been some problems associated with non-compliance.

Compliance with the rules and regulations associated with Caulerpa requires both effective education and law enforcement. Community education and advisory programs can help promote compliance through increased awareness and understanding of the netting closures, bans on sale, and other rules. It is also vital that community members understand the importance of, and their role in, preventing the spread of the alga and limiting its impacts, for example by inspecting and cleaning fishing, diving and boating equipment, keeping a lookout for the species, and reporting any new outbreaks.

## COMPLIANCE

I&I NSW compliance staff are actively involved in advisory work on Caulerpa. Their ongoing role in enforcement includes:

- policing of netting closures applying to commercial and/or recreational users in affected estuaries
- random inspections of aquaculture trays before movement to other estuaries
- targeted inspections of aquarium businesses to ensure that the trade of Caulerpa is not continuing.

### WHAT I&I NSW IS DOING

**I&I NSW compliance staff are continuing to police Caulerpa netting closures, conducting random aquaculture inspections and targeted inspections of aquarium shops.**

## EDUCATION AND COMMUNITY INVOLVEMENT

A comprehensive education program, designed to increase community awareness of the alga, its impacts and the actions that can be taken to minimise its spread, has been undertaken by I&I NSW in collaboration with other organisations. This advisory campaign has targeted Caulerpa affected estuaries and has employed a range of media. Strategies used to date are summarised in Table 3.

Table 3. Components of the community education and awareness program

| ADVISORY MATERIALS |
|---|
| • Advisory brochures have been produced and circulated to all key stakeholders and other groups and individuals upon request. All advisory materials include a description of Caulerpa and the threat it poses and provide contact points for reporting any new outbreaks.<br>• Advisory brochures have been prepared in collaboration with Southern Rivers Catchment Management Authority and Hawkesbury Nepean Catchment Management Authority, describing the specific locations of Caulerpa in these catchment areas.<br>• Aquatic pest identification cards, including a Caulerpa ID card, have been prepared and distributed.<br>• Information on Caulerpa and related closures is available on the I&I NSW website (**www.industry.nsw.gov.au**).<br>• Caulerpa information has been included on large posters and circulated to key stakeholders, Fisheries Offices, and bait and tackle shops.<br>• An advisory program in the Sydney region and on the South Coast has been conducted by I&I NSW staff (in conjunction with Catchment Management Authorities and local councils) to raise public awareness of Caulerpa. |
| SIGNS |
| • Signs have been erected at all locations where Caulerpa has been identified. These signs alert water-users to the presence of the weed and advise them of the precautions needed to stop the further spread of the species.<br>• Signs for uninfested estuaries have also been developed and installed in high-risk estuaries such as Jervis Bay, Wallis Lake, Port Stephens and Tuggerah Lake.<br>• I&I NSW has also provided Caulerpa information on signs produced by other agencies, such as the Marine Parks Authority (for areas of Batemans Marine Park), and local councils interested in promoting information about this aquatic pest. |
| DIRECT COMMUNICATION |
| • I&I NSW has held many meetings with the community and key stakeholders, including recreational and commercial fishers in affected areas, to discuss Caulerpa management options and education programs.<br>• Trained Fishcare Volunteers have distributed information on Caulerpa as part of their work in educating local communities. They have conducted dedicated 'Boat Ramp Days' to disseminate information about Caulerpa in some affected estuaries.<br>• A council officer dedicated to public education on Caulerpa was employed by Shoalhaven Council. The council developed site-specific brochures and signage for all the infested estuaries located within its jurisdiction. |
| COMMUNITY MONITORING AND REPORTING |
| • A 24-hour recorded telephone 'hotline' (02 4916 3877) and e-mail address (**aquatic.pests@industry.nsw.gov.au**) have been operating for over 7 years, allowing members of the public to report sightings of suspected new infestations.<br>• An Aquatic Pest Sightings form (available on I&I NSW website) has been developed that enables the community to make a report about species of concern.<br>• All community reports of Caulerpa are followed up and investigated. |

These initiatives need to be continued to ensure a high level of public awareness of Caulerpa on an ongoing basis.

## WHAT I&I NSW IS DOING

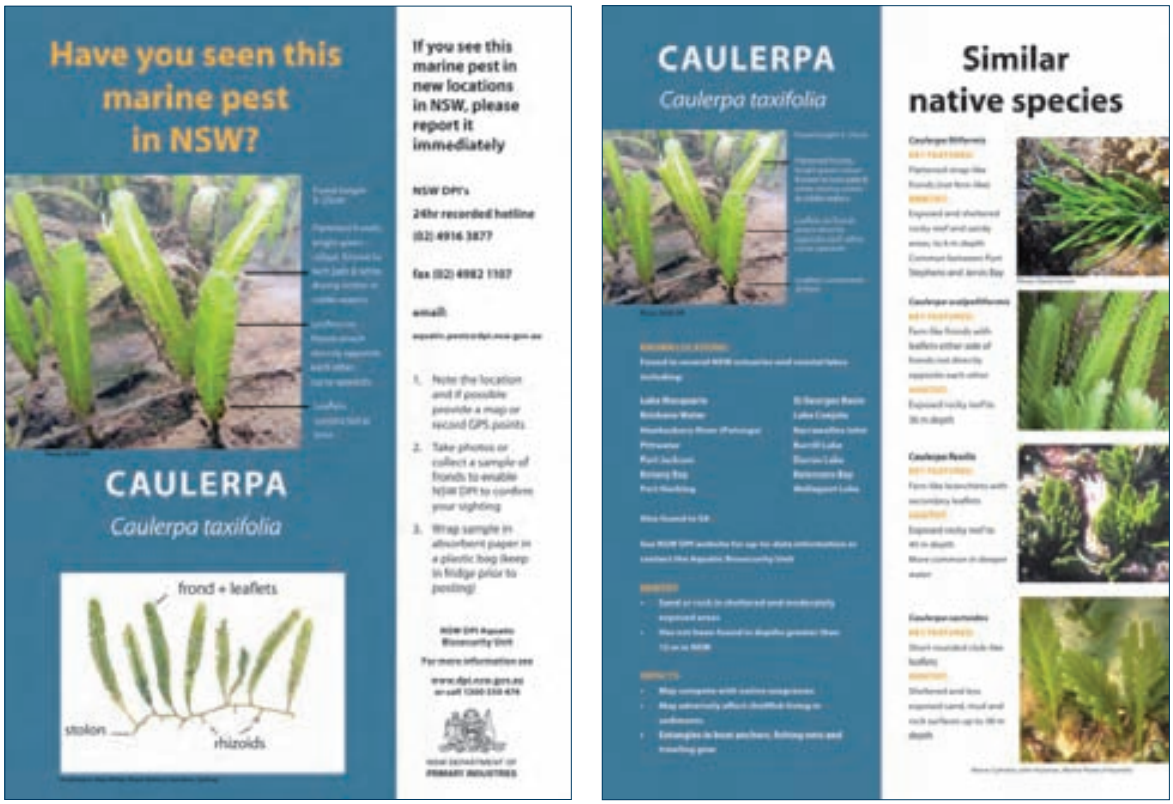
**Maintaining and updating advisory material, including website and brochures as appropriate.**

**Maintaining signage at key sites (e.g. boat ramps) in both infested and high-risk unaffected estuaries.**

**Continuing targeted training for Fishcare Volunteers, and other groups as needed, on the identification and management of Caulerpa.**

## GOAL: COMMUNITY EDUCATION AND INVOLVEMENT

**Widely publicise the Aquatic Pest Sighting program (and encourage reporting) through community information sessions, Fishcare Volunteers and distribution of materials to target groups.**



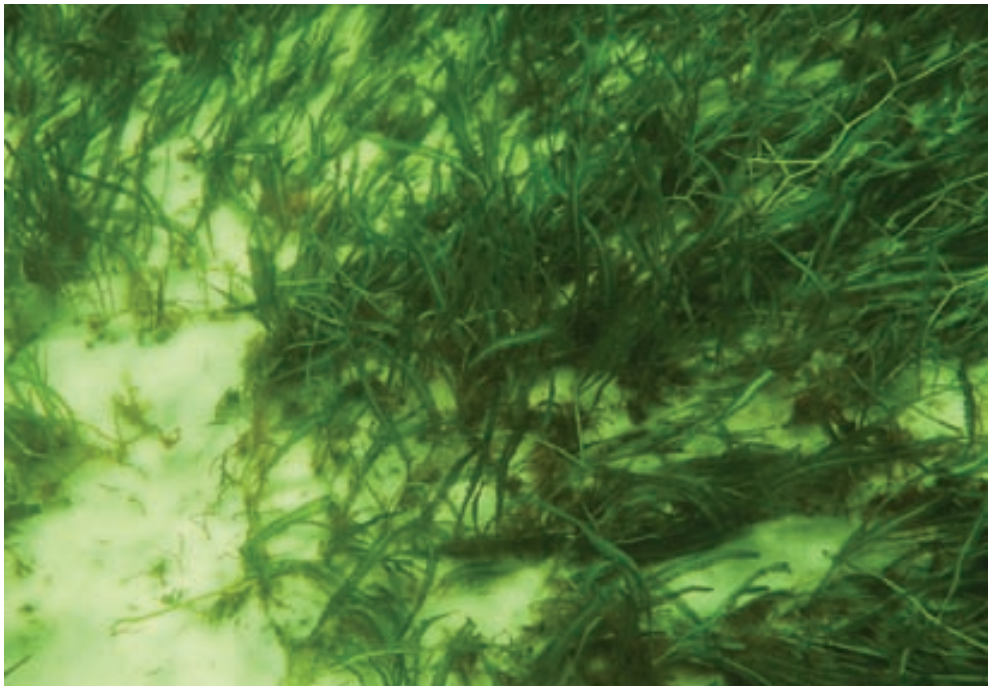

Caulerpa ID card

# SECTION 5
# CONTROL AND TREATMENT

## CONTROL METHODS

Several methods for controlling Caulerpa have been trialled overseas and within Australia, ranging from physical removal (by hand or mechanically) to smothering and treatment with various chemicals (Table 4). From 2001, I&I NSW conducted experimental trials of some of the most promising of these methods (particularly smothering with various materials, suction dredging and salt treatment). Primary Industries and Resources South Australia have also trialled various methods, including large-scale treatment with fresh water. In California, outbreaks of Caulerpa have been successfully treated with a chlorine solution.

All of these methods have advantages and disadvantages relating to their specificity, risk of increased fragmentation, ecological impacts, ease of implementation, and the need for repeat treatments and cost. Most of these factors depend to some extent on the size and nature of the affected area. No single method has yet been demonstrated as achieving permanent eradication of large, established areas of Caulerpa.



Attempted control of Caulerpa using salt. Photograph James Sakker I&I NSW

Table 4. Potential control methods for Caulerpa trialled by I&I NSW or elsewhere

| CONTROL METHOD | PROS | CONS |
|---|---|---|
| PHYSICAL REMOVAL | | |
| Hand-picking | • Highly targeted.<br>• Can remove very small patches (e.g. remnants at Mannering Park, Lake Macquarie).<br>• Minimal resources required. | • Removal patchy.<br>• Requires repeat treatments.<br>• Likely to fragment and further distribute Caulerpa.<br>• Time consuming.<br>• Requires good visibility.<br>• Requires expertise on identification and thorough removal.<br>• Despite regular use in Spain, Italy and France, Caulerpa remains at all sites. |
| Dredging using small diver-operated air lift or suction dredges | • Highly targeted. | • Removal patchy.<br>• Requires repeat treatments to ensure all Caulerpa is removed.<br>• May fragment or distribute Caulerpa.<br>• Non-selective (vacuum will take in other organisms and sediment).<br>• Time consuming.<br>• Fine sediments can clog suction and filter apparatus (though possible to minimise clogging through filter setup). |
| SMOTHERING | | |
| Conventional dredging or trawling | • Potential use over larger areas. | • Logistical difficulties (e.g. access, suitability of substrate).<br>• Highly likely to fragment or distribute Caulerpa.<br>• Non-selective (removes other organisms and sediment).<br>• Need for disposal of dredge spoil.<br>• Caulerpa can withstand burial by sediment for considerable periods. |
| Smothering with used conveyor belting | • Kills covered Caulerpa within 1 month. | • Expensive.<br>• Potential to fragment or distribute Caulerpa.<br>• Deployment and retrieval are labour intensive.<br>• Requires relatively smooth seafloor.<br>• Collateral damage high (all other organisms covered are killed).<br>• Non-biodegradable. |
| Smothering with black plastic | • Kills covered Caulerpa within 1 month. | • Deployment and retrieval are labour intensive.<br>• Requires relatively smooth seafloor.<br>• Potential to fragment or distribute Caulerpa.<br>• Collateral damage high (all other organisms covered are killed).<br>• Non-biodegradable.<br>• Material needs to be weighted down with heavy objects; unsuitable where there is a lot of water movement. |

| CONTROL METHOD | PROS | CONS |
|---|---|---|
| SMOTHERING (CONTINUED) | | |
| Smothering with sand filled geo-textile bags | • Kills covered Caulerpa within 1 month.<br>• Biodegradable. | • Deployment is labour intensive.<br>• Potential to fragment or distribute Caulerpa.<br>• Collateral damage high (all other organisms covered are killed).<br>• Requires relatively flat seafloor.<br>• Caulerpa may encroach from the sides if not adequately covered, colonising the bag. |
| Smothering with jute matting | • Kills covered Caulerpa within 1 month.<br>• Biodegradable.<br>• Relatively easy to deploy. | • Collateral damage high (all other organisms covered are killed).<br>• Potential to fragment or distribute Caulerpa.<br>• Requires relatively smooth seafloor.<br>• Caulerpa may encroach from the sides if not adequately covered, colonising the matting.<br>• May take a long time to biodegrade.<br>• Material needs to be weighted down with heavy objects. |
| OSMOTIC SHOCK | | |
| Application of domestic pool salt | • Kills Caulerpa within 24 to 48 hours.<br>• Capacity for large-scale deployment with mechanical devices.<br>• Suitable for small patches.<br>• Appears to be selective in impacts (minimal impact on associated biota, apart from Posidonia seagrass). | • Deployment is labour intensive.<br>• May require repeat treatments (though there is a reduced need for these compared with some other methods).<br>• Biodiversity impacts not fully understood.<br>• Cannot be used in areas of Posidonia seagrass.<br>• Large established beds difficult to cover thoroughly and require a large quantity of salt.<br>• Not feasible in deeper water because of poor visibility and inability to cover all runners. |
| Fresh water | • Salinity of 10 ppt kills Caulerpa within days.<br>• Suitable for enclosed water bodies (e.g. West Lakes, South Australia).<br>• Potential to treat very large infestations.<br>• Likely to have little residual or long-term impact (potential for rapid recolonisation). | • Logistically difficult: may require substantial engineering work.<br>• Requires a major (reliable) source of freshwater – currently no suitable sites in NSW.<br>• Short-term water quality problems, including anoxia (lack of oxygen) and fish kills.<br>• May take weeks or months to reach 'fresh' water status and subsequently return to desired salinity levels.<br>• Potential for survival in highly saline 'pockets'. |

| CONTROL METHOD | PROS | CONS |
|---|---|---|
| CHEMICAL TREATMENT | | |
| Chlorine | • Rapidly kills Caulerpa.<br>• Successfully used in California to treat discrete patches (by covering with plastic 'tents'). | • Collateral damage high (all other organisms in vicinity are killed).<br>• Chlorine levels rapidly drop to negligible levels unless enclosed.<br>• Effectiveness may not be any greater than with smothering alone. |
| Other chemicals (e.g. copper and other metal compounds, herbicides, acetic acid, hydrogen peroxide, lime) | • Toxicity demonstrated (in some cases) in laboratory trials.<br>• Copper particularly effective and regularly used in France in the form of 'copper covers'. | • Collateral damage may be high (other organisms in vicinity killed).<br>• Residual impacts may be high (e.g. copper may remain in sediments).<br>• Severe water quality impacts with use of copper and other metal compounds.<br>• Lack of community acceptability. |
| BIOLOGICAL CONTROL | | |
| Grazing by herbivorous fish | • Potentially selective in their impacts. | • No suitable native herbivore yet identified.<br>• Unlikely to occur naturally in sufficient numbers to maintain effective control.<br>• Use of non-native species is generally avoided because of potential for substantial unforeseen impacts on other species. |

Bleached Caulerpa showing dieback. Photograph James Sakker I&I NSW

## EFFECTIVENESS OF CONTROL WORK

I&I NSW has found salt treatment to be the most useful control option to date in the short-term control of Caulerpa. Covering beds with around 3 to 6 centimetres of coarse salt (equivalent to 50 kg per $m^2$) rapidly kills almost all of the treated Caulerpa. Although other species such as seagrasses and benthic invertebrates are also affected in the short term, they appear to recover relatively rapidly, apart from Posidonia seagrass, which is susceptible to salting.

Since 2001, I&I NSW has conducted an extensive Caulerpa control program utilising salt in the majority of affected estuaries. This has involved the application of over 1500 tonnes of salt to more than 6 hectares of Caulerpa beds. During this time, significant reductions in Caulerpa were achieved at Lake Macquarie and Narrawallee Inlet. However, although salt treatment is able to dramatically reduce the amount of Caulerpa at a site, to date the permanent eradication of Caulerpa by using this method has not been demonstrated in NSW except at Lake Macquarie. In addition, the area covered by existing Caulerpa beds is far too large to allow comprehensive treatment of all areas. Current knowledge of the effectiveness of control work utilising salt has resulted in control work being restricted to small outbreaks in newly affected estuaries such as Wallagoot Lake.

Consequently, new estuaries infested with Caulerpa need to be individually assessed and a priority list for treatment developed to allow the most effective use of available resources.

Applying salt at Wallagoot Lake for Caulerpa control using I&I NSW purpose-built punt.
Photograph James Sakker I&I NSW

## IMPLEMENTATION OF CONTROL WORKS

In general, salt control work will be undertaken only where there are new outbreaks in previously unaffected estuaries. New outbreaks, if detected early, and if in discrete areas, have a small window of opportunity and potential for complete eradication. Each new estuary infested with Caulerpa becomes a new source for further infestations and is likely to increase the environmental, social and economic impacts. The potential to eradicate a new outbreak will be assessed in each case on the basis of size, location, logistics and conservation value.

### WHAT I&I NSW IS DOING

**I&I NSW will continue to assess new outbreaks in previously unaffected areas for treatment suitability.**


Salt being loaded from pallets into customised hopper for control work. Photograph Steven Kay I&I NSW

# SECTION 6
# SURVEY AND MONITORING

Since 2000, Caulerpa has been detected in surveys by I&I NSW in 14 estuaries from Lake Macquarie in the north to Wallagoot Lake in the south; there is also one oceanic population at Merri Reef, near Cronulla. The alga is currently known to occur in 13 estuaries, with Lake Macquarie now believed to be Caulerpa free (as at February 2009).

The former program of Caulerpa mapping (which consisted of both summer and winter surveys in known and adjacent estuaries) has been replaced in 2009 with the Invasive Species Monitoring Evaluation and Reporting (MER) strategy. All estuaries will have a series of permanent transects established that will be checked for the presence or absence of Caulerpa as well as other introduced species during the next 2 years. Regular examination has also been carried out in areas where permanent monitoring sites have been established to assess the interaction of Caulerpa and seagrass.

The new Invasive Species MER program will focus on the extent of Caulerpa in summer, when the weed grows prolifically and is easy to find.

Surveys are limited by issues of scale and accessibility. In some areas, the size of a lake or estuary makes an accurate appraisal of current infestations difficult. The new Estuarine and Coastal Lakes MER surveys of unaffected estuaries will help with early identification of any new Caulerpa infestations.

Many of the patches detected to date in NSW have been reported by fishers and other members of the general public who have accidentally come across the weed. Community awareness and reporting of Caulerpa sightings are therefore crucial to ensuring that new patches are documented and controlled if possible. I&I NSW will continue to investigate community reports of new Caulerpa sightings,

### WHAT I&I NSW IS DOING

**Monitoring estuaries for the presence of Caulerpa through the Monitoring Evaluation and Reporting Strategies.**

### GOAL: SURVEYS AND MAPPING

**Follow up reports of new sightings with field validation as soon as possible.**

## SECTION 7
## RESEARCH IN NSW

More is being discovered about Caulerpa and its effects on native biota in NSW estuaries. There are numerous ongoing research projects in NSW, and many studies have been published recently.

### IMPACTS

I&I NSW is continuing to study the potential effects of Caulerpa on the native seagrasses Posidonia and *Zostera capricorni* (Zostera). To date, it appears that dense beds of either of these native seagrass species are relatively resistant to invasion by Caulerpa. Sparse seagrass, and sparse Zostera in particular, may, however, be at risk from Caulerpa. Research has documented a considerable decline in small beds of Zostera in some long-term monitoring sites (Glasby & Creese 2007). Encouragingly, however, in areas where Caulerpa has failed to persist, Zostera has grown back to a limited extent. Beds of Posidonia have also extended and grown into areas that were previously dominated by Caulerpa.

The numbers of species of fishes have been found to vary between Caulerpa and native seagrass. Specifically, Caulerpa supports far fewer sygnathids (seahorses) than do seagrasses, whereas there are more gobies in Caulerpa (York *et al.* 2006).

Recently, a great deal of research has focused on the impacts of Caulerpa on invertebrates living in and on sediments. The cockle *Anadara trapezia* has been studied the most, and it has been found that it recruits in greater numbers to Caulerpa than to seagrass or unvegetated areas. However, the survival and reproductive output of female cockles are lower in Caulerpa (Gribben & Wright 2006a,b; Wright *et al.* 2007). Low levels of oxygen in water under the Caulerpa and in the sediments appear to be the cause of many of the observed impacts on these invertebrates (Gribben *et al.* 2009).

Native grazers (fish and invertebrates) have been found to consume relatively little Caulerpa (Gollan & Wright 2006).

### GENETICS AND GENERAL BIOLOGY

The genetic origins of the Caulerpa that has invaded NSW are still being elucidated. There is considerable genetic variability among strains of Caulerpa (Fama *et al.* 2002), and recent research by CSIRO has indicated that the majority of NSW populations of Caulerpa are genetically different from native Caulerpa from Queensland and different from the original Mediterranean strain of Caulerpa (Grewe *et al.* 2008). There appears to have been at least two separate incursions of Caulerpa into NSW, with the Sydney and Brisbane Water populations being different from those in the rest of NSW.

The growth and fragmentation of Caulerpa have been studied by Wright (2005) and Wright and Davis (2006). They found that the strain of Caulerpa in NSW tends to fragment more than does the native strain from Moreton Bay (Queensland). They also concluded that the major expansion of Caulerpa in NSW was due to vegetative growth from stolons, rather than dispersal and growth of fragments.

The supposed cold-tolerance of the Mediterranean 'aquarium strain' of Caulerpa was investigated by Glasby and Gibson (2007), who found little evidence to support this notion. Instead, they showed that native Caulerpa is naturally quite tolerant of cooler water. They also found that the morphology of Caulerpa can change considerably with temperature; this may explain why the Caulerpa that has invaded the cooler areas is generally a different shape from the native Caulerpa in tropical waters.

Caulerpa has been found to be relatively resistant to burial by sediment (Glasby *et al.* 2005a), meaning that mapping is likely to underestimate the weed's abundance and distribution: sediments in estuaries are quite mobile and can often cover low-lying beds of Caulerpa.

One laboratory-based research project suggested that Caulerpa does not tolerate salinities less than 20 ppt and does not grow at temperatures less than 20 °C (West & West 2007). However, in the field the weed clearly can survive temperatures much lower than 20 °C (possibly as low as 9 °C), as seen in Lake Conjola, Burrill Lake and Wallagoot Lake.

The transport of Caulerpa by boat anchors was investigated by West *et al.* (2007), who found that rock and sand anchors removed similar amounts of Caulerpa, but the presence of a chain on the anchor resulted in even more being removed. Moderately sized clumps of Caulerpa amongst damp rope survived for 1 day, but not 3 days.

### CONTROL

Application of salt has been demonstrated to be effective for killing Caulerpa. Single applications of salt have been found to have short-term (less than 6 months) effects on aquatic animals that live in the sediments (Glasby *et al.* 2005b) and invertebrates living on Zostera leaves (O'Neill *et al.* 2007).

### WHAT I&I NSW IS DOING

**Continuing ongoing research into the biology and ecology of Caulerpa and the impacts of the alga on native biota, including seagrasses.**

### GOAL: RESEARCH

**Identify funding sources and partners for collaborative research.**


I&I NSW researchers in Burrill Lake monitoring Caulerpa. Photograph James Sakker I&I NSW

# SECTION 8
# IMPLEMENTATION AND REVIEW

## IMPLEMENTATION

Implementation of this plan is the responsibility of I&I NSW and other agencies with an interest in natural resource management at a regional or local level, particularly Catchment Management Authorities (CMAs) and local councils.

Time frames for implementation have not been provided; goals are to be completed as resources permit.

## REVIEW

The control plan will undergo a review within 5 years of the date on this plan.

## SECTION 9
## REFERENCES AND FURTHER READING


Benzie JAH, Ballmant E, Chisholm JRM, Jaubert JM (2000). Genetic variation in the green alga *Caulerpa taxifolia*. *Aquatic Botany* **66**, 131–139.

Ceccherelli G, Cinelli F (1998). Habitat effect on spatio-temporal variability in size and density of the introduced alga *Caulerpa taxifolia*. *Marine Ecology Progress Series* **163**, 289–294.

Ceccherelli G, Cinelli F (1999). The role of vegetative fragmentation in dispersal of the invasive alga *Caulerpa taxifolia* in the Mediterranean. *Marine Ecology Progress Series* **182**, 299–303.

Ceccherelli G, Piazzi L, Balata D (2002). Spread of introduced *Caulerpa* species in macroalgal habitats. *Journal of Experimental Marine Biology and Ecology* **280**, 1–11.

Fama P, Jousson O, Zaninetti L, Meinesz A, Dini F, Di Giuseppe G, Millar AJK, Pawlowski J (2002). Genetic polymorphism in *Caulerpa taxifolia* (Ulvophyceae) chloroplast DNA revealed by PCR-based assay of the invasive Mediterranean strain. Journal of Evolutionary Biology 15: 618–624

Glasby TM, Creese RG (2007). Invasive marine species management and research. In: *Marine Ecology* (eds S. D. Connell and B. M. Gillanders) pp. 569–94. Oxford University Press, Melbourne.

Glasby TM, Gibson PT (2007). Limited evidence for increased cold-tolerance of invasive versus native *Caulerpa taxifolia*. *Marine Biology* **152**, 255–63.

Glasby TM, Creese RG, Gibson PT (2005b). Experimental use of salt to control the invasive marine alga *Caulerpa taxifolia* in New South Wales, Australia. *Biological Conservation* **122**, 573–80.

Glasby TM, Gibson PT, Kay S (2005a). Tolerance of the invasive alga *Caulerpa taxifolia* to burial by sediment. *Aquatic Botany* **82**, 71–81.

Gollan JR, Wright JT (2006). Limited grazing pressure by native herbivores on the invasive seaweed *Caulerpa taxifolia* in a temperate Australian estuary. *Marine and Freshwater Research* **57**, 685–694.

Grewe PM, Murphy N, Ward B (2008). *Multilocus Genotyping to Assess Genetic Strain Identification of Caulerpa Taxifolia Populations in Australian Waters*. Report for Department of Agriculture Forestry and Fisheries by CSIRO Marine and Atmospheric Research, Hobart.

Gribben PE, Wright JF (2006a). Sublethal effects on reproduction in native fauna: are females more vulnerable to biological invasion? *Oecologia (Berl)* **149**, 352–61.

Gribben PE, Wright JT (2006b). Invasive seaweed enhances recruitment of a native bivalve: roles of refuge from predation and habitat choice. *Marine Ecology Progress Series* **318**, 177–185.

Gribben PE, Wright JT, O'Connor WA, Doblin MA, Eyre B, Steinberg PD (2009). Reduced performance of native infauna following recruitment to a habitat-forming invasive marine alga. *Oecologica* **158(4)**, 733–745.

Jaubert JM, Chisholm JRM, Ducrot D Ripley HT, Roy L, Passeron-Seitre G (1999). No deleterious alterations in *Posidonia* beds in the Bay of Menton (France) eight years after *Caulerpa taxifolia* colonization. *Journal of Phycology* **35**, 1113–1119.

Jousson O, Pawlowski J, Zaninetti L, Zechman FW, Dini F, Di Guiseppe G, Woodfield R, Millar A and Meinesz A (2000). Invasive alga reaches California. *Nature (London)* **408**, 157-158

Jousson O, Pawlowski J, Zaninetti L, Meinesz A, Boudouresque CF (1998). Molecular evidence for the aquarium origin of the green alga *Caulerpa taxifolia* introduced to the Mediterranean Sea. *Marine Ecology Progress Series* **172**, 275–280.

Meinesz A, Belsher T, Thibaut T, Antolic B, Ben Mustapha K, Boudouresque CF, Chiaverini D, Cinelli F, Cottalorda JM, Djellouli A, El Adeb A, Orestano C, Grau AM, Ivesa L, Jaklin A, Langar H, Massuti-Pascual E, Peirano A, Tunesi L, de Vaugelas J, Zavodnik N and Zuljevic A (2001). The introduced green alga *Caulerpa taxifolia* continues to spread in the Mediterranean. *Biological Invasions* **3**, 201-210.

Meinesz A and Hesse B (1991). Introduction et invasion de l'algue tropicale *Caulerpa taxifolia* en Méditerranée nord-occidentale. *Oceanologica Acta* **14**, 415-426

Meinesz A (2002). *Killer Algae: the True Tale of a Biological Invasion*. University of Chicago Press, Chicago.

Murphy NE, Schaffelke B (2003). Use of amplified fragment length polymorphism (AFLP) as a new tool to explore the invasive green alga *Caulerpa taxifolia* in Australia. *Marine Ecology Progress Series* **246**, 307–310.

O'Neill KM, Schreider MJ, Glasby TM, Redden AR (2007). Lack of epifaunal response to the application of salt for managing the noxious green alga *Caulerpa taxifolia* in a coastal lake. *Hydrobiologia* **580**, 135–142.

Phillips JA, Price IR (2002). How different is Mediterranean *Caulerpa taxifolia* (Caulerpales: Chlorophyta) to other populations of the species? *Marine Ecology Progress Series* **238**, 61–71.

Schaffelke B, Murphy N, Uthicke S (2002). Using genetic techniques to investigate the sources of the invasive alga *Caulerpa taxifolia* in three new locations in Australia. *Marine Pollution Bulletin* **44**, 204–210.

West EJ, West RJ (2007). Growth and survival of the invasive alga, *Caulerpa taxifolia*, in different salinities and temperatures: implications for coastal lake management. *Hydrobiologia* **577**, 87–94.

West EJ, Barnes PB, Wright JT, Davis AR (2007). Anchors aweigh: fragment generation of invasive *Caulerpa taxifolia* by boat anchors and its resistance to desiccation. *Aquatic Botany* **87**, 196–202.

Wiedenmann J, Baumstark A, Pillen TL, Meinesz A, Vogel W (2001). DNA fingerprints of *Caulerpa taxifolia* provide evidence for the introduction of an aquarium strain into the Mediterranean Sea and its close relationship to an Australian population. *Marine Biology* **138**, 229–234.

Wright JT (2005). Differences between native and invasive *Caulerpa taxifolia*: a link between asexual fragmentation and abundances in invasive populations. *Ecology* **147**, 559–569.

Wright JT, Davis AR (2006). Demographic feedback between clonal growth and fragmentation in an invasive seaweed. *Ecology* **87**, 1744–1754.

Wright JT, Gribben PE (2008). Predicting the impact of an invasive seaweed on the fitness of native fauna. *Journal of Applied Ecology* **45**, 1540–1549.

Wright JT, McKenzie LA, Gribben PE (2007). A decline in the abundance and condition of a native bivalve associated with *Caulerpa taxifolia* invasion. *Marine and Freshwater Research* **58**, 263–272.

York PH, Booth DJ, Glasby TM and Pease BC (2006). Fish assemblages in habitats dominated by *Caulerpa taxifolia* and native seagrasses in south-eastern Australia. *Marine Ecology Progress Series* **312**, 223-234.

# APPENDIX 1
# RISK ANALYSIS – 2008

## AIMS AND SCOPE

The aim of this risk analysis is to identify the risks and benefits associated with the proposed *Caulerpa taxifolia* (Caulerpa) management program compared with the historical management program of Caulerpa, and to identify any areas in the proposed program where effort could be redirected to reduce risk or increase benefit.

The risk assessment methodology is described in Appendix 2. Environmental risks and social/economic risks were evaluated separately, as they are often not well correlated. The scenario considered to demonstrate impact was 'significant further spread', which was defined as follows:

### Environmental

***Significant further spread of Caulerpa***: increase in area covered by 50% or more, or spread into an environmentally sensitive area, including other estuaries in the region. 'Environmentally sensitive' habitat is classed as native seagrass beds.

### Social/economic

***Significant further spread of Caulerpa***: increase in area covered by 50% or more, or spread into a socially sensitive area (e.g. a popular fishing or recreation area or an area of high perceived conservation or other value, including adjacent estuaries).

Risks were evaluated for each of the 14 estuaries where Caulerpa is known to have occurred. Both intra-estuary risk (the risk of spread within the estuary), and inter-estuary risk (the risk of spread to adjacent estuaries) were evaluated. When considering the likelihood and consequences of particular scenarios, a time frame of 2 to 3 years was considered (i.e. panel members were asked to evaluate the likelihood of a particular scenario occurring within the next 2 to 3 years).

## RESULTS

### Environmental risk assessment

Table A1 summarises the environmental risk under the proposed and former management programs. The likelihood of significant further spread of Caulerpa was considered high within four estuaries; however, on the basis of what is known about the impacts of Caulerpa, the environmental consequences of spread were generally rated as low-medium. The environmental consequences of spread to unaffected estuaries were rated medium-high because of the uncertainty of the environmental effects and the limited, if any, chance of control once Caulerpa is introduced to an estuary.

Environmental risks ranged from low-medium-high among the different estuaries, but, importantly, for all sites the estimated risk (both within the estuary and for adjacent estuaries) did not change under a program without salting-control work.

## Social/economic risk assessment

Risks were evaluated for each of the 14 estuaries where Caulerpa is known to have occurred; the results are summarised in Table A2. Both intra-estuary risk (the risk of spread within the estuary), and inter-estuary risk (the risk of spread to adjacent estuaries) were evaluated.

Social/economic risks ranged from low-medium-high among the different estuaries, but, importantly, for all sites the estimated risk (both within the estuary and for adjacent estuaries) did not change under a program without salting-control work.

Table A1. Environmental risks under former and proposed management programs

| ENVIRONMENTAL RISK | FORMER MANAGEMENT RISK | FORMER MANAGEMENT RISK | PROPOSED MANAGEMENT RISK | PROPOSED MANAGEMENT RISK |
|---|---|---|---|---|
| SITE | INTER-ESTUARY | INTRA-ESTUARY | INTER-ESTUARY | INTRA-ESTUARY |
| Batemans Bay | M | M | M | M |
| Botany Bay | L | L-M | L | L-M |
| Brisbane Water | L-M | M-H | L-M | M-H |
| Burrill Lake | L-M | L | L-M | L |
| Durras Lake | M-H | M | M-H | M |
| Hawkesbury/Broken Bay | L | M-H | L | M-H |
| Lake Conjola | L-M | L | L-M | L |
| Lake Macquarie | L | L | L | L |
| Narrawallee Inlet | L-M | L | L-M | L |
| Pittwater | M-H | H | M-H | H |
| Port Hacking | L | L | L | L |
| Port Jackson | L | L-M | L | L-M |
| St Georges Basin | M-H | M-H | M-H | M-H |
| Wallagoot Lake | M-H | M-H | M-H | M-H |

L, low; M, medium; H, high

## CONCLUSION

On the basis of current knowledge of the impacts of Caulerpa in NSW, the overall environmental risk posed by Caulerpa in the 2 to 3 year time frame considered in this document is low-medium. The risk remains low-medium under the proposed arrangements with no salting control, except for new incursions of Caulerpa in discrete areas of high priority. The reason for this is not that Caulerpa is unlikely to spread, but that 1) it is unclear what, if any, long-term impact Caulerpa has on seagrass habitats, and 2) salting control appears to an ineffective long-term solution for eradicating the weed. It is important to acknowledge, however, that this prediction of low-medium risk is based on 5 years of data collected from monitoring sites in Botany Bay and 3 years of data from monitoring sites in Pittwater, Port Hacking, Lake Conjola and Burrill Lake. The longer term impacts of Caulerpa as it spreads further are unknown. Further monitoring is continuing.

Social/economic risks of both intra- and inter-estuary spread of Caulerpa increased in the more recently affected estuaries. However, in these areas where the risk increased, education is considered to be sufficient to counter the concerns of stakeholders. Furthermore, social/economic risk decreased in estuaries where the community and media were engaged in education and advisory programs.

Table A2. Social/economic risks under the former and proposed management programs

| SOCIAL/ECONOMIC RISK | FORMER MANAGEMENT RISK | FORMER MANAGEMENT RISK | PROPOSED MANAGEMENT RISK | PROPOSED MANAGEMENT RISK |
|---|---|---|---|---|
| SITE | INTER-ESTUARY | INTRA-ESTUARY | INTER-ESTUARY | INTRA-ESTUARY |
| Batemans Bay | M | L-M | M | L-M |
| Botany Bay | L | L | L | L |
| Brisbane Water | M | L-M | M | L-M |
| Burrill Lake | L-M | L | L-M | L |
| Durras Lake | M-H | M | M-H | M |
| Hawkesbury/ Broken Bay | L | L-M | L | L-M |
| Lake Conjola | L-M | L | L-M | L |
| Lake Macquarie | L-M | M | L-M | M |
| Narrawallee Inlet | L | L | L | L |
| Pittwater | L-M | L-M | L-M | L-M |
| Port Hacking | L | L | L | L |
| Port Jackson | L | L | L | L |
| St Georges Basin | M-H | L-M | M-H | L-M |
| Wallagoot Lake | M-H | M-H | M-H | M-H |

L, low; M, medium; H, high

## RECOMMENDATIONS

1. Broad-scale salting control work is to be discontinued in all estuaries. Consideration will be given to limited control work (utilising salt) of new discrete outbreaks in high-priority areas of estuaries that have not previously been affected by Caulerpa. Salting-control work has been replaced by targeted community education. The education program has helped boat-users and fishers to minimise the spread of Caulerpa within and between estuaries and has alleviated community concern about the cessation of salting-control work.

2. Education work using Fishcare Volunteers is to continue in recently affected areas such as Wallagoot Lake, Batemans Bay and Durras Lake. Other locations are to have signage maintained and brochures available in key locations such as fishing tackle shops and information centres.

3. Targeted community awareness and education programs are to be continued to help raise public awareness, minimise the spread of Caulerpa within and between estuaries, and communicate the results of I&I NSW research to key stakeholders.

# APPENDIX 2
# RISK ASSESSMENT METHODS

***Aims***: to identify the risks and benefits of the proposed *Caulerpa taxifolia* (Caulerpa) management program compared with the previous management program.

Risk assessment will be qualitative and follow a **likelihood** × **consequence** model, where the risk is determined by the following matrix:

| | | LIKELIHOOD | | |
|---|---|---|---|---|
| | | LOW | MEDIUM | HIGH |
| CONSEQUENCE | LOW | L | L-M | M |
| | MEDIUM | L-M | M | M-H |
| | HIGH | M | M-H | H |

**Temporal scale:** next 2 to 3 years

## RISKS

Risks are separated into environmental risk and social/economic risk, since the two are often not well correlated. Risk analysis was based on expert opinion, evaluating the likelihood and consequences of a particular scenario for each type of risk (environmental and social/economic).

The risk of these scenarios was evaluated by a panel of experts from within I&I NSW Aquatic Biosecurity and Science and Research teams, using a consensus approach. Risk was evaluated under the proposed management arrangements and under the former management program. The main difference between the former management program and the proposed program is in the scale of salting-control work. The proposed program would conduct salting control of Caulerpa only in very limited circumstances in newly affected estuaries. Thus the main risk evaluated is the removal of salt control from currently affected estuaries in the proposed program.

### Environmental risk

Risk to the environment under past and proposed management options was evaluated.

***Environmental risk*** = likelihood of significant further spread of Caulerpa under a particular regime x environmental consequences of spread.

***Significant further spread*** was defined as an increase in area covered by 50% or more, or spread into an environmentally sensitive area, including other estuaries in the region. 'Environmentally sensitive' habitat is classed as seagrass beds. Caulerpa can also affect fish assemblages and reduce populations of fauna, such as molluscs and invertebrates, in sediment.

***Likelihood scores*** were assigned on the following basis:

- Low: low probability (<50% chance of occurring)
- Medium: 50/50 chance of occurring
- High: will probably occur (>50% chance of occurring)

***Consequence scores*** were assigned on the following basis:

- Low: no environmentally sensitive habitat would be affected.
- Medium: small proportion of environmentally sensitive habitat affected, or 'lower value' environmentally sensitive habitat affected.
- High: Moderate to large proportion of environmentally sensitive habitat affected.

### Social/economic risk

Risk to use, amenity or conservation value under past and proposed management options was evaluated.

***Social/economic risk*** = likelihood of significant further spread of Caulerpa under past and present management × social consequences of spread.

***Significant further spread*** was defined as an increase in area covered by 50% or more, or spread into a socially sensitive area (e.g. a popular fishing or recreation area, or an area of high perceived conservation or other value, including adjacent estuaries).

***Likelihood scores*** were assigned on the following basis:

- Low: low probability
- Medium: 50/50 chance of occurring
- High: will probably occur (>50% chance of occurring)

***Consequence scores*** were assigned on the following basis:

- Low: no socially/economically sensitive habitat would be affected.
- Medium: small proportion of socially/economically sensitive habitat affected, or 'lower value' socially/economically sensitive habitat affected.
- High: Moderate to large proportion of socially/economically sensitive habitat affected.

## OPTIONS TO BE EVALUATED

- Proposed management: what is the risk under the proposed management program?
- Past management: what was the risk under the former management program?

## PROCEDURE FOR DETERMINING RISK

The risk assessment as outlined above will be a consensus-based assessment. The knowledge group will come up with the best estimate of the likelihood of Caulerpa spreading and will use its collective expertise to determine the environmental and social/economic consequences of spread.

# APPENDIX 3
# SITE SYNOPSIS: 2 TO 3 YEAR FORECAST

## BATEMANS BAY
### CAULERPA FIRST DETECTED IN FEBRUARY 2007

#### Environmental factors

The likelihood of *Caulerpa taxifolia* (Caulerpa) significantly spreading within Batemans Bay is judged to be low because of the relatively low abundance of Caulerpa and the oceanic nature of large areas of Batemans Bay, which inhibits the establishment of Caulerpa. Vectors are reduced by the zoning of the Batemans Marine Park: the habitat protection zone prohibits commercial netting in all current Caulerpa-affected areas, and the sanctuary zone in the northern part of the bay prohibits fishing and anchoring in seagrass beds. The consequence of Caulerpa spreading is judged to be high because of the potential for Caulerpa to replace the only Posidonia bed in Batemans Bay, located at Corrigans Beach. Caulerpa currently affects over 70% of this bed. Since environmental risk = likelihood of significant further spread × environmental consequences of spread, the overall risk of Caulerpa spreading within Batemans Bay is medium.

The likelihood of Caulerpa spreading to other estuaries from Batemans Bay is judged to be low because of the relatively low abundance of Caulerpa and the minimisation of vector factors through the marine park zoning, as discussed above. The consequence of Caulerpa spreading is judged to be high owing to the risk of Caulerpa affecting large beds of seagrass in adjacent unaffected estuaries, such as Lake Tabourie and the Moruya River, and the lack of effective control measures that can be applied to Caulerpa. The overall risk of Caulerpa spreading from Batemans Bay to other estuaries is medium.

#### Social/economic factors

Batemans Bay is considered to be of high conservation value and is part of Batemans Marine Park. The bay has limited commercial fishing permitted and is a popular place for recreational fishing. Caulerpa has had no discernible economic impact in Batemans Bay to date. The overall risk of Caulerpa spreading within Batemans Bay is low-medium. Since social/economic risk = likelihood of significant further spread × social/economic consequences of spread, the overall risk of Caulerpa spreading from Batemans Bay to other estuaries is medium.

## BOTANY BAY
### CAULERPA FIRST DETECTED IN APRIL 2001

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Botany Bay is judged to be low because of the relatively high abundance of Caulerpa, with few suitable areas left to colonise. Five years of monitoring the interactions between seagrass and Caulerpa in Quibray Bay (an aquatic reserve within Botany Bay) have shown Caulerpa to be quite dynamic, with large fluctuations in density and abundance at the monitoring sites. The consequence of Caulerpa spreading is judged to be medium owing to its widespread distribution and fluctuation in density, as increases in density may affect seagrass beds. The overall risk is low-medium for the spread of Caulerpa within Botany Bay.

The likelihood of Caulerpa significantly spreading from Botany Bay to nearby estuaries is judged to be low because of the presence of Caulerpa in these estuaries and the lack of commercial fishing vectors. The consequence of Caulerpa significantly spreading from Botany Bay to nearby estuaries is also judged to be low because of the presence of Caulerpa in these estuaries. The overall risk is low for the spread of Caulerpa from Botany Bay to other estuaries.

### Social/economic factors

Botany Bay is a Recreational Fishing Haven, and is therefore closed to commercial fishing. A total recreational and commercial fishing closure applies in the aquatic reserve in Quibray Bay. No Caulerpa fishing closures were imposed in Botany Bay, because the importance of vectors was assessed as low (no commercial fishing, all other Sydney estuaries are affected by Caulerpa, and there is limited movement of recreational anglers to unaffected estuaries outside Sydney). Caulerpa does not appear to be an issue of community concern in Botany Bay, and Caulerpa has had no discernible economic impact there. The overall risk is low for the spread of Caulerpa within Botany Bay. The overall risk is also low for the spread of Caulerpa from Botany Bay to other estuaries.

## BRISBANE WATER
## CAULERPA FIRST DETECTED IN APRIL 2006

### Environmental factors

The likelihood of Caulerpa significantly spreading within Brisbane Water is judged to be high because of the abundance of seagrass beds that provide suitable habitat for Caulerpa, the low abundance but relatively widespread distribution of Caulerpa within Brisbane Water, and the presence of vectors. There are abundant recreational boat movements within Brisbane Water and boat movements from nearby heavily infested Pittwater sites. Some Caulerpa affected sites, such as Booker Bay and Ettalong, are adjacent to high-tidal-movement areas, providing the means to naturally move Caulerpa within Brisbane Water. The consequence of significant spread within Brisbane Water is judged to be medium owing to the current low abundance of Caulerpa within Brisbane Water, the presence of large seagrass beds in this estuary, and the length of time it would take for Caulerpa to have any potential impact. The overall risk is medium-high for the spread of Caulerpa within Brisbane Water.

The likelihood of Caulerpa significantly spreading from Brisbane Water to adjacent estuaries is judged to be low because of the low abundance of Caulerpa, the lack of commercial fishing vectors, and the presence of Caulerpa in both the Hawkesbury and all Sydney estuaries to the south. Tuggerah Lake to the north is the estuary most at risk from Caulerpa in Brisbane Water. The consequence of Caulerpa significantly spreading from Brisbane Water is judged to be medium because of the presence of the large beds of Zostera seagrass in Tuggerah Lake. The overall risk is low-medium for the spread of Caulerpa from Brisbane Water to adjacent estuaries.

### Social/economic factors

Brisbane Water is closed to commercial fishing and is a very popular recreational fishery. As net and trap fishing are prohibited, no further Caulerpa-related closures were deemed necessary. A moderate level of community concern was initially expressed, but as Caulerpa has remained at a low density community concern appears low. Caulerpa has had no discernible economic impact in Brisbane Water. The overall risk is low-medium for the spread of Caulerpa within Brisbane Water. The overall risk is medium for the spread of Caulerpa from Brisbane Water to adjacent estuaries.

## BURRILL LAKE
### CAULERPA FIRST DETECTED IN MARCH 2001

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Burrill Lake is judged to be low because of the relatively high abundance of Caulerpa, with few suitable areas left to colonise. The consequence of Caulerpa spreading is judged to be low because of the weed's widespread and relatively stable distribution. The overall risk is also low for the spread of Caulerpa within Burrill Lake.

The likelihood of Caulerpa significantly spreading from Burrill Lake to adjacent estuaries is judged to be low because there are few vectors: the lake is a Recreational Fishing Haven and is therefore closed to commercial net fishing, and there is limited recreational boat movement. The consequence of Caulerpa significantly spreading from Burrill Lake is judged to be medium owing to the presence of sparse beds of Zostera seagrass in the unaffected Lake Tabourie to the south. Two adjacent estuaries to the north of Burrill Lake, Narrawallee Inlet and Lake Conjola, are both affected by Caulerpa. The overall risk is low-medium for the spread of Caulerpa from Burrill Lake to adjacent estuaries.

#### Social/economic factors

Burrill Lake is a Recreational Fishing Haven. The majority of the lake is closed to hoop netting and prawning. The entrance channel, a popular prawning and crabbing location, has been excluded from the closure and has been regularly salted in an attempt to lower the abundance of Caulerpa. I&I NSW has conducted a long-running extensive education campaign at Burrill Lake, and consequently community knowledge of Caulerpa issues is high and community concern has decreased over time. Caulerpa has had no discernible economic impact in Burrill Lake. The overall risk is low for the spread of Caulerpa within Burrill Lake. The overall risk is low-medium for the spread of Caulerpa from Burrill Lake to adjacent estuaries.

## DURRAS LAKE
### CAULERPA FIRST DETECTED IN APRIL 2007

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Durras Lake is judged to be high because of the presence of vectors such as commercial fishing (although the only form of commercial fishing permitted by marine park zoning is trapping), recreational fishing and the inadvertent disturbance of the weed by the propellers of outboard motors, sometimes referred to as 'prop-dredging'. The consequence of Caulerpa spreading is judged to be low-medium because of the weed's current limited distribution and proximity to seagrass beds. The overall risk is medium for the spread of Caulerpa within Durras Lake.

The likelihood of Caulerpa significantly spreading from Durras Lake to adjacent estuaries is judged to be medium-high because of the presence of vectors, including recreational boat movement and (limited) commercial fishing. The consequence of Caulerpa significantly spreading from Durras Lake is judged to be medium owing to the presence of sparse beds of Zostera seagrass in the unaffected Lake Tabourie to the north. The overall risk is medium-high for the spread of Caulerpa to other estuaries from Durras Lake.

### Social/economic factors

Durras Lake is considered to be of high conservation value. It is part of Batemans Marine Park and is zoned either habitat protection or sanctuary zone. Limited commercial fishing is permitted in the lake, which is a popular place for recreational fishing. Caulerpa has had no discernible economic impact in Durras Lake to date. Initial concern expressed by a local environmental group has been alleviated through education, the distribution of information brochures, and the holding of information sessions. However, further spread within the lake would be expected to attract more concern. Community concern could be expected if other estuaries in the marine park become infested. The overall risk is medium for the spread of Caulerpa within Durras Lake. The overall risk is medium-high for the spread of Caulerpa to other estuaries from Durras Lake.

## HAWKESBURY RIVER/BROKEN BAY
## CAULERPA FIRST DETECTED IN FEBRUARY 2007

### Environmental factors

The likelihood of Caulerpa significantly spreading within the Hawkesbury River/Broken Bay is judged to be high because of the influence of vectors, including recreational and commercial boat movement from Pittwater and Brisbane Water, the use of commercial fishing gear by fishers working in Pittwater and the Hawkesbury River, and also the natural wind, wave and tidal movement of fragments. The consequence of significant spread within the Hawkesbury River/Broken Bay is judged to be medium owing to the current low abundance of Caulerpa within the Hawkesbury River/Broken Bay, the sparse nature of the Zostera seagrass beds in the tributaries of this estuary (such as Berowra and Cowan creeks), and the length of time it would take for Caulerpa to have any impact on these beds. The overall risk is medium-high for the spread of Caulerpa within the Hawkesbury River/Broken Bay.

The likelihood of Caulerpa significantly spreading from the Hawkesbury River/Broken Bay to adjacent or nearby estuaries is judged to be low, because Caulerpa is already present in these estuaries. The overall risk is also low for the spread of Caulerpa from the Hawkesbury River/Broken Bay to other estuaries.

### Social/economic factors

Hawkesbury River/Broken Bay is a major commercial and recreational fishery in Region 5 (which ranges from The Entrance to Wollongong). Commercial methods include prawn and squid trawling, hauling, mesh netting and trapping. Most of Region 5 is now closed to commercial fishing, with only Pittwater, the Hawkesbury River and Broken Bay open to commercial fishing. Botany Bay has become a Recreational Fishing Haven and Port Jackson has been closed because of dioxin contamination. Closing any further areas to commercial fishing would have a significant social and economic effect. Caulerpa has been detected only at Patonga to date, in two small patches.

The limited Caulerpa closures instituted in Pittwater have received significant opposition from commercial fishers, however Caulerpa education displays and information sessions at boat ramps at Hawkesbury River/Broken Bay have received little interest or concern from the community, particularly when compared with community interest demonstrated in nearby Pittwater. Caulerpa has to date had no discernible economic impact in this area. The overall risk is low-medium for the spread of Caulerpa within the Hawkesbury River/Broken Bay. The overall risk is low for the spread of Caulerpa from the Hawkesbury River/Broken Bay to other estuaries.

## LAKE CONJOLA
### CAULERPA FIRST DETECTED IN APRIL 2000

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Lake Conjola is judged to be low because of the high abundance of Caulerpa: there are few, if any, suitable areas left to colonise. The consequence of Caulerpa significantly spreading within Lake Conjola is judged to be low for the same reasons. The overall risk is low for the spread of Caulerpa within Lake Conjola.

The likelihood of Caulerpa significantly spreading from Lake Conjola to adjacent estuaries is judged to be low because the adjacent estuaries are already affected by Caulerpa. Moreover, there is high community awareness of Caulerpa issues, and precautions have been taken to minimise spread, including the provision of washdown bays to treat boats and fishing gear and the placement of prominent signage.

The consequence of Caulerpa significantly spreading to adjacent estuaries from Lake Conjola is judged to be medium because of the presence of sparse beds of Zostera seagrass in the unaffected Lake Tabourie to the south and Jervis Bay Marine Park to the north. The overall risk is low-medium for the spread of Caulerpa from Lake Conjola to adjacent estuaries.

#### Social/economic factors

Lake Conjola is a Recreational Fishing Haven, and tourist operators rely heavily on recreational anglers for income. The lake, with the exception of Pattimores Lagoon, is closed to hoop netting and prawning. I&I NSW has conducted a long-running, extensive education campaign at Lake Conjola, and the long-term presence of Caulerpa has been accepted and is no longer of significant concern to the local community. Caulerpa has had no discernible economic impact since the establishment of the Recreational Fishing Haven and the closure of the lake to commercial fishing. The overall risk is low for the spread of Caulerpa within Lake Conjola. The overall risk is low-medium for the spread of Caulerpa from Lake Conjola to adjacent estuaries.

## LAKE MACQUARIE
### CAULERPA FIRST DETECTED IN FEBRUARY 2001

#### Environmental factors

Monitoring of Lake Macquarie has not detected Caulerpa in 3 consecutive years (2005–2008), and Lake Macquarie is consequently considered to now be free of Caulerpa (see Section 5 of Control Plan for further details). The risks of spread within or from Lake Macquarie are therefore low.

#### Social/economic factors

The discovery of Caulerpa in Lake Macquarie caused widespread community concern. Commercial fishing closures were implemented in affected areas before the lake became a Recreational Fishing Haven. Significant concern from the community and from stakeholders such as the Anglers Action group can be expected if Caulerpa is again found in the lake. Caulerpa has had no discernible economic impact since the lake was closed to commercial fishing through the Recreational Fishing Haven implementation. The overall risk is medium for the spread of Caulerpa within Lake Macquarie. The overall risk is low-medium for the spread of Caulerpa from Lake Macquarie to adjacent estuaries.

## NARRAWALLEE INLET
### CAULERPA FIRST DETECTED IN APRIL 2001

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Narrawallee Inlet is judged to be low because of the dynamic nature of the estuary: the movement of large amounts of sand limits the growth of Caulerpa. For the same reason, the consequences of Caulerpa significantly spreading within Narrawallee Inlet are judged to be low. The overall risk is low for the spread of Caulerpa within Narrawallee Inlet.

The likelihood of Caulerpa significantly spreading from Narrawallee Inlet to adjacent estuaries is judged to be low because of the low abundance of Caulerpa, the lack of commercial fishing vectors, the very limited nature of the boating access, and the presence of Caulerpa in adjacent estuaries. Lake Tabourie to the south is the estuary most at risk from Caulerpa in Narrawallee Inlet. The consequence of Caulerpa significantly spreading from Narrawallee Inlet is judged to be medium because of the presence of sparse beds of Zostera seagrass in the unaffected Lake Tabourie to the south. The adjacent estuaries to the north and south of Narrawallee Inlet are both affected by Caulerpa.

The overall risk is low-medium for the spread of Caulerpa from Narrawallee Inlet to adjacent estuaries.

#### Social/economic factors

Narrawallee Inlet is a Recreational Fishing Haven with a low number of users because of the difficult access and the small size of the estuary. I&I NSW has conducted a long-running, extensive education campaign at Narrawallee Inlet, and the long-term presence of Caulerpa has been accepted and is no longer of significant concern to the local community. Caulerpa has had no discernible economic impact since the declaration of the lake as a Recreational Fishing Haven and its subsequent closure to commercial fishing. The overall risk is low for the spread of Caulerpa within Narrawallee Inlet. The overall risk is low-medium for the spread of Caulerpa from Narrawallee Inlet to adjacent estuaries.

## PITTWATER
### CAULERPA FIRST DETECTED IN DECEMBER 2000

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Pittwater is judged to be medium because of the widespread distribution of Caulerpa already in Pittwater and the effects of vectors, such as recreational and commercial boat movement within Pittwater and from affected Sydney estuaries and Brisbane Water. Other major vectors include the use of commercial fishing gear by fishers working in Pittwater and the Hawkesbury River and the natural tidal, wind and wave movement of fragments. The consequence of significant spread within Pittwater is judged to be high because of the observed negative effect of Caulerpa on Posidonia seagrass beds at long-term monitoring sites within Pittwater, such as Scotland Island. The overall risk is medium-high for the spread of Caulerpa within Pittwater.

The likelihood of Caulerpa significantly spreading from Pittwater to adjacent estuaries is judged to be high because of the widespread distribution of Caulerpa and the presence of vectors, including recreational and commercial boat movement from Pittwater to the Hawkesbury River, Broken Bay, Berowra Creek and Cowan Creek. Other major vectors include the use of commercial fishing gear by fishers working in both Pittwater and the Hawkesbury River and the natural tidal movement of fragments. The consequence of significant spread from Pittwater is judged to be medium owing to the current (low) abundance of Caulerpa within the Hawkesbury River/Broken Bay, the sparse nature of the Zostera seagrass beds in the tributaries of this estuary such as Berowra Creek and Cowan Creek, and the length of time it would take for Caulerpa to have any impact on these beds. The overall risk is medium-high for the spread of Caulerpa from Pittwater to adjacent estuaries.

### Social/economic factors

Pittwater is a major commercial and recreational fishery in Region 5. Commercial methods include hauling, mesh netting and trapping. Most of Region 5 is now closed to commercial fishing, with only Pittwater, the Hawkesbury River/Broken Bay open to commercial fishing since Botany Bay became a Recreational Fishing Haven and Port Jackson was closed because of dioxin contamination. The limited Caulerpa closures instituted in Pittwater have met with significant opposition from commercial fishers. The closure of any further areas to commercial fishing would be likely to have significant social and economic effects. As described previously, Caulerpa fishing closures have reduced access to fishing grounds in Pittwater, and hence Caulerpa has had an economic impact on commercial fishers in Pittwater. Other stakeholders such as the Sydney Coastal Councils Group, Pittwater Council and charter boat operators have maintained a keen interest in Caulerpa in Pittwater. I&I NSW has conducted a long-running and extensive education campaign in Pittwater.

The overall risk is low-medium for the spread of Caulerpa within Pittwater. The overall risk is also low-medium for the spread of Caulerpa from Pittwater to other estuaries.

**Note:** New closures to protect Posidonia seagrass by prohibiting commercial hauling are being considered. If these new closures are implemented, the current Caulerpa closure in Pittwater will be revoked.

## PORT HACKING
## CAULERPA FIRST DETECTED IN MARCH 2000

### Environmental factors

Port Hacking is closed to commercial fishing, with the exception of Salmon Haul Bay and Jibbon Beach, where hauling is permitted on weekdays. The long-term presence of Caulerpa has been accepted and appears to no longer be a concern to the local community. The likelihood of Caulerpa significantly spreading within Port Hacking is judged to be low because of the relatively low abundance of Caulerpa. In the 8 years since Caulerpa was discovered in Port Hacking, Caulerpa has fluctuated in density and abundance and is currently abundant only in Gunnamatta Bay. The consequence of Caulerpa spreading is judged to be low because of the nature of the alga's past distribution patterns. The overall risk is low for the spread of Caulerpa within Port Hacking.

The likelihood of Caulerpa significantly spreading from Port Hacking to nearby estuaries is judged to be low because Caulerpa is already present in these estuaries and there is a lack of commercial fishing vectors. The consequence of Caulerpa significantly spreading from Port Hacking to nearby estuaries is also judged to be low owing to the presence of Caulerpa in these estuaries. The overall risk is low for the spread of Caulerpa from Port Hacking to other estuaries.

### Social/economic factors

Port Hacking is closed to commercial fishing, with the exception of Salmon Haul Bay and Jibbon Beach, where hauling is permitted on weekdays. The long-term presence of Caulerpa has been accepted and appears to no longer be a concern to the local community. Caulerpa has to date had no discernible economic impact in Port Hacking. The overall risk is low for the spread of Caulerpa within Port Hacking. The overall risk is low for the spread of Caulerpa from Port Hacking to adjacent estuaries.

## PORT JACKSON
## CAULERPA FIRST DETECTED IN APRIL 2002

### Environmental factors

The likelihood of Caulerpa significantly spreading within Port Jackson is judged to be low because of the relatively low abundance of Caulerpa and the closure of the area to commercial fishing. In the 6 years since Caulerpa was discovered in Port Jackson Caulerpa has fluctuated in density and abundance, but overall a slow increase in distribution has been observed. The consequence of Caulerpa spreading is judged to be medium owing to its history of distribution and the slow rate of spread. The overall risk is low-medium for the spread of Caulerpa within Port Jackson.

The likelihood of Caulerpa significantly spreading from Port Jackson to nearby estuaries is judged to be low because of the presence of Caulerpa in these estuaries and the lack of commercial fishing vectors. The consequence of Caulerpa significantly spreading from Port Jackson to nearby estuaries is also judged to be low owing to the presence of Caulerpa in these estuaries. The overall risk is low for the spread of Caulerpa from Port Jackson to other estuaries.

### Social/economic factors

Port Jackson is closed to commercial fishing because of dioxin contamination. The long-term presence of Caulerpa has been accepted and is no longer a significant concern to the majority of the community. Environmental groups maintain an interest in the distribution of Caulerpa in Port Jackson. Caulerpa has to date had no discernible economic impact in this area. The overall risk is low for the spread of Caulerpa within Port Jackson. The overall risk is low for the spread of Caulerpa from Port Jackson to adjacent estuaries.

## ST GEORGES BASIN
### CAULERPA FIRST DETECTED IN MARCH 2004

#### Environmental factors

The likelihood of Caulerpa significantly spreading within St Georges Basin is judged to be medium because of the dynamic nature of Caulerpa in this estuary, with major fluctuations in abundance. The consequence of Caulerpa significantly spreading within St Georges Basin is medium-high owing to the presence of susceptible sparse Zostera seagrass beds. The overall risk is medium-high for the spread of Caulerpa within St Georges Basin. The Caulerpa infestation at Basin View boat ramp is regarded as the highest risk to Jervis Bay Marine Park.

The likelihood of Caulerpa significantly spreading from St Georges Basin to adjacent estuaries is judged to be medium because of the relatively low abundance of Caulerpa and the lack of commercial fishing vectors, balanced with the close proximity of Jervis Bay Marine Park and the movement of recreational fishing vessels between each estuary. The consequence of Caulerpa significantly spreading from St Georges Basin is judged to be medium-high because of the presence of sparse beds of Zostera seagrass in the unaffected Jervis Bay Marine Park to the north. The adjacent estuaries south of St Georges Basin are affected by Caulerpa. The overall risk is medium-high for the spread of Caulerpa from St Georges Basin to adjacent estuaries.

#### Social/economic factors

St Georges Basin is a Recreational Fishing Haven. I&I NSW has conducted a long-running and extensive education campaign; consequently, community knowledge of Caulerpa issues is high and community concern has decreased over time. The main concern expressed by community groups is the close proximity of Jervis Bay Marine Park and the movement of recreational fishing vessels between each estuary, potentially spreading Caulerpa. Caulerpa has to date had no discernible economic impact in this area. The overall risk is low-medium for the spread of Caulerpa within St Georges Basin. The consequence of Caulerpa significantly spreading from St Georges Basin is judged to be medium-high owing to the high conservation value of the unaffected Jervis Bay Marine Park to the north. The adjacent estuaries south of St Georges Basin are affected by Caulerpa. The overall risk is medium-high for the spread of Caulerpa from St Georges Basin to adjacent estuaries.

## WALLAGOOT LAKE
### CAULERPA FIRST DETECTED IN JULY 2007

#### Environmental factors

The likelihood of Caulerpa significantly spreading within Wallagoot Lake is judged to be high because of the existence of vectors such as commercial fishing, recreational fishing and prawning. The lake has been stocked with eastern king prawns by I&I NSW, attracting recreational net fishers to the lake. The consequence of Caulerpa spreading is judged to be low-medium because of the alga's current limited distribution and proximity to seagrass beds. The overall risk is medium-high for the spread of Caulerpa within Wallagoot Lake.

The likelihood of Caulerpa significantly spreading from Wallagoot Lake to adjacent estuaries is judged to be medium because of the presence of vectors, including recreational boat movement and commercial fishing, balanced against the low level of Caulerpa in the lake. The consequence of Caulerpa significantly spreading from Wallagoot Lake is judged to be high because all of the adjacent estuaries are unaffected. The overall risk is medium-high for the spread of Caulerpa from Wallagoot Lake to adjacent estuaries.

Control work using over 100 tonnes of salt was conducted during 2007, 2008 and the first 6 months of 2009 in Wallagoot Lake; the success of the control work is still to be evaluated.

### Social/economic factors

Wallagoot Lake is open to commercial fishing, recreational fishing and prawning. The lake has been stocked with eastern king prawns, attracting recreational net fishers to the lake. The current Caulerpa closure has minimal social and economic impact because of the small size of the closure. The Bournda Environmental Education Centre (NSW Department of Education and Training) is located at Wallagoot Lake; members are concerned about, and engaged in, the issue of Caulerpa and are actively participating in monitoring and public education. The overall risk is medium-high for the spread of Caulerpa within Wallagoot Lake.

The social and economic consequence of Caulerpa significantly spreading from Wallagoot Lake to adjacent estuaries is judged to be high because of the impact on recreational and commercial fishing and the general lack of awareness of Caulerpa issues on the far south coast. Local communities are likely to be initially concerned about a new pest species appearing in local waterways. The overall risk is medium-high for the spread of Caulerpa from Wallagoot Lake to adjacent estuaries.

NSW CONTROL PLAN for the

# NOXIOUS MARINE ALGA *CAULERPA TAXIFOLIA*

AUGUST 2009

NSW GOVERNMENT
Industry & Investment