

**Eradication and Surveillance of *Caulerpa taxifolia* within
Agua Hedionda Lagoon, Carlsbad, California
Second Year Status Report**

Fall 2001 through Summer 2002

Prepared for:

Steering Committee of the Southern California *Caulerpa* Action Team

- ? California Regional Water Quality Control Board – San Diego Region (SDRWQCB)
- ? California Regional Water Quality Control Board – Santa Ana Region (SARWQCB)
- ? California Department of Fish and Game (CDFG)
- ? National Marine Fisheries Service (NOAA-NMFS)
- ? U.S. Department of Agriculture (USDA)

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Fall 2001 through Summer 2002

EXECUTIVE SUMMARY

On June 12, 2000 the first known infestation in the Western Hemisphere of the invasive strain of the tropical marine alga, *Caulerpa taxifolia*, was discovered in Agua Hedionda Lagoon, in Carlsbad, California. This document reports the results of the second year of the eradication program undertaken by the Southern California *Caulerpa* Action Team (SCCAT). Merkel & Associates has been contracted to conduct this phase of the eradication, under the oversight of the SCCAT, a broad-based task force assembled from federal and state resource and regulatory agencies, exotic species experts and marine resource scientists.

During the second year, covering fall 2001 to the end of summer 2002, considerable progress has been made in the eradication effort. While the first year focused on aggressive treatment, the second year's efforts primarily involved surveillance for residual patches of *Caulerpa* not detected during the first year. The program consisted of intensive survey work, followed by treatment of any detected *Caulerpa* with the application of chlorine under vinyl containment tarps. During the second year, the amount of *Caulerpa* found was reduced with each consecutive survey, with the square meters of coverage of *Caulerpa* in fall 2001, winter 2001, spring 2002, and summer 2002 measuring 33.6, 2.7, 0.5, and 0.4 m², respectively. The summer 2002 figure of 0.4 m² represents a 99.96% decrease from the estimated original cover of 1076.2 m² in June 2000. In the first year of the program, approximately \$1.1 million was spent on eradication at the lagoon. In the second year, approximately \$0.8 million was spent at Agua Hedionda Lagoon, with a total of approximately \$1.9 million spent at the site since June 2000.

As the amount of *Caulerpa* continues to be reduced with the progression of the eradication effort, it becomes more difficult to detect smaller and less numerous remaining patches. As a result, surveillance has replaced treatment as the most costly element of the eradication program. During the next years of the program, it is anticipated that a budget of approximately \$800,000/year for the next few years will be required to continue to locate and treat remaining patches of *Caulerpa*. Early results from the eradication efforts are very promising, and it is imperative that the program be completed in order to ensure effectiveness.

BACKGROUND

The highly invasive Mediterranean strain of the tropical marine alga, *Caulerpa taxifolia*, was discovered in Agua Hedionda Lagoon, Carlsbad, California in June 2000 (Figure 1). Its discovery represented the first known occurrence of this strain within the Western Hemisphere and is believed to pose a major threat to coastal ecosystems and recreational and commercial uses dependent upon coastal resources. While the species has also been identified at a second site in California (Huntington Harbour, Orange County), the Agua Hedionda Lagoon infestation is the larger of the two known infestations. It is likely that *Caulerpa taxifolia* had been in the lagoon for at least four years prior to its discovery. It is not known whether other infestations also exist elsewhere in the United States. The continued wide availability and use of this species by saltwater aquarists is cause for concern.

In the United States, the Mediterranean strain of *Caulerpa taxifolia* has been banned from importation and interstate commerce since 1999 through the Federal Noxious Weed Act. Legislation banning the transport, sale, and possession of nine potentially invasive species of *Caulerpa*, including *Caulerpa taxifolia*, was enacted in the State of California in September 2001. Earlier in 2001, the City of San Diego adopted an ordinance with similar restrictions applicable to the entire genus of *Caulerpa*.

Since the discovery of *Caulerpa* in Agua Hedionda Lagoon in June 2000, eradication, surveillance, public outreach efforts, eradication research, and legislative efforts have been initiated and are on-going (Woodfield & Mooney, 2002). The primary focus of the Southern California *Caulerpa* Action Team (SCCAT), which is made up of resource managers, marine resource and pest control scientists, permitting agencies, marine biological consultants, land-owners and environmental stakeholder representatives, has been on eradication of the known infestations.

From the date of discovery (June 2000) until the end of the Summer 2001 survey, the eradication effort at Agua Hedionda Lagoon involved the treatment of all detected *Caulerpa*, as reported in the One Year Status Report - Eradication and Surveillance of *Caulerpa taxifolia* within Agua Hedionda Lagoon, Carlsbad, California, (Merkel & Associates, 2001a).

The second year of the eradication efforts included both survey and treatment components conducted from Fall 2001 to Summer 2002 (September 2001 to September 2002). Funding for the eradication effort was provided during this year by the State Water Resources Control Board, the California Department of Fish and Game, National Marine Fisheries Service (NOAA), and Cabrillo Power LLC. This document provides a synopsis of the second year's efforts and reports on the progress toward the final goal of full eradication of *Caulerpa taxifolia* from Agua Hedionda Lagoon.



Snug
Harbor

AGUA
HEDIONDA
LAGOON



Agua Hedionda Lagoon
Carlsbad, CA

Figure
1

FALL 2001 THROUGH SUMMER 2002 ERADICATION PROGRAM

Following the intensive summer 2001 survey and treatment season, systematic quarterly surveys were undertaken to search for additional patches of *Caulerpa*. The surveys are lagoon-wide, covering the west, central, and east basin of Agua Hedionda Lagoon. The method employs the use of SCUBA divers swimming along transects lines deployed by a small boat using survey-grade differential GPS. The divers use a guide-line to maintain their spacing at 1 meter apart, and vary their swimming speed based on visibility and density of eelgrass. Having tested a variety of other survey methods, including towed divers, towed cameras, and laser line scan, it is appears that the most effective approach to conducting intensive surveys that can locate very small fronds of *Caulerpa*, even within dense eelgrass beds, is the current method employed. This survey intensity is defined as an eradication level survey in which divers are used to make visual searches to ensure 100% viewing of the study area (NMFS, 2002).

An exception to this method occurs in the Snug Harbor portion of the east basin of the lagoon. Shortly after the original discovery of *Caulerpa* growing Snug Harbor in June 2000, a survey grid of line was immediately deployed over what was believed to be the extent of the infestation. This grid has numbered and lettered axes that allow for systematic, repeatable surveys and facilitate mapping of and return to discovered *Caulerpa* for treatment. This grid remains in place and is surveyed also by SCUBA divers as part of regular quarterly surveys. The results of grid surveys continue to be reported separately from lagoon-wide surveys because they allow for simple tracking of temporal and spatial changes in *Caulerpa* distribution. The area, methodology, and intensity of the survey in the grid have changed very little since June 2000, whereas methodology in lagoon-wide surveys has evolved throughout the first year of the eradication, making temporal comparisons more difficult. The results presented below will report findings in the grid, out of the grid, and lagoon-wide (the sum of in and out of the grid).

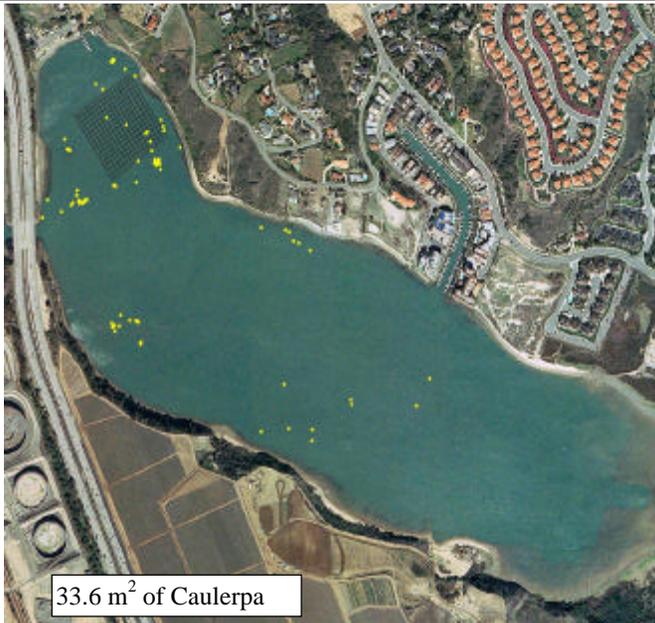
A full survey of Agua Hedionda Lagoon requires between 38 and 45 working days. When *Caulerpa* is detected, its location is recorded by GPS and the patch is assessed by a biologist. The dimensions and, if possible, the number of fronds, number and length of thalli, and typical frond lengths are recorded for each patch located. The patch is marked by colored pin-flags that are left in place during treatment in order to relocate the treated *Caulerpa* at a later date if necessary for efficacy investigations. Generally within 24 hours the *Caulerpa* is contained with a PVC tarp and treated with solid chlorine pucks, as outlined in the Revised Eradication Plan for *Caulerpa taxifolia* in California (Merkel & Associates, 2001b).

The results of each of four quarterly surveys at Agua Hedionda Lagoon, conducted during each calendar season, are discussed below. Figure 2 presents four maps displaying the results of each survey during the second year. Following these discussions is a section reviewing the progress of the eradication efforts over time, both within the second survey year and from the initiation of the project in summer 2000 through summer 2002.

Fall 2001

The Fall 2001 survey and treatment effort was conducted from mid-October 2001 to early January 2002. This survey was not initiated until well into the fall season due to residual treatment and survey needs from the summer 2001 survey. In addition, lost days due to rain and

1. Fall
2001



2. Winter
2001



3. Spring
2002



4. Summer
2002



**Finds of *Caulerpa* By Survey During Year 2 of Eradication Effort
Fall 2001 - Summer 2002
Agua Hedionda Lagoon, Carlsbad, CA**

Figure
2

associated water quality issues caused further delay in the surveillance and eradication schedule during fall. In the interest of maintaining a quarterly survey schedule rather than perpetuate the delay, the fall survey covered only high risk areas, defined as all areas ever known to support *Caulerpa* plus a 50-m (164-ft) buffer). The entire lagoon was not surveyed, rather only the east basin in the areas where *Caulerpa* had been known to occur.

The survey of the grid was performed on November 20, 2001 and December 17, 2001. Excellent visibility and low eelgrass density allowed a complete survey of the grid in two days. Six small patches of *Caulerpa* were found within five cells of the grid, totaling 1.2 m² (13 ft²) of *Caulerpa*.

During the remaining survey outside of the grid, 86 more patches of *Caulerpa*, totaling 32.6 m² (349 ft²), were found and treated. All were clearly associated with areas previously identified to support *Caulerpa*.

Due to the time constraints discussed above, no surveillance was conducted in the central or west basins this quarter. No *Caulerpa* has been found in prior surveys in these basins.

In summary, lagoon-wide (both in and out of the grid), a total of 33.8 m² (362 ft²) of *Caulerpa* was encountered during the Fall 2001 survey, consisting of approximately 92 small patches. Although major patches, defined as 9.3 m² (100 ft²) or greater, were commonly encountered during all prior surveys, only 1 major patch was found during the Fall survey (9.5 m² [103 ft²]). Most patches were 0.3 m² (3 ft²) or less.

Winter 2001

The Winter 2001 survey and treatment effort was conducted from January 8, 2002 to March 26, 2002. The entire lagoon was surveyed at the eradication survey level, including the west and central basin.

The survey of the grid in February 2002 found three patches of *Caulerpa*, totaling 0.4 m² (4.8 ft²), in three grid cells. All patches were treated.

The survey of the entire east basin (outside of the grid) was initiated on January 25, 2002 and completed on March 26, 2002. During this survey 16 patches of *Caulerpa*, totaling 2.3 m² (25.3 ft²), were found and treated. None were major patches, however a new infestation area was identified on the north shore of the east basin, just west of Bristol Cove. *Caulerpa* had not been found in that area during any prior surveys, with the closest patch being about 160 m (525 ft) away. The other patches found were closely associated with infested areas and previously laid tarps.

A survey of the middle basin was initiated on January 8, 2002 and completed on January 11, 2002. A survey of the west basin was performed between January 21, 2002 and January 29, 2002. The seafloor under the aquaculture facility was searched by divers without the aid of GPS derived transect lines. Divers placed transects using the mooring blocks at either end of each of the shellfish racks. Each rack area was then surveyed by the dive team using the same techniques described above. No *Caulerpa* was found in either basin.

In summary, lagoon wide (both in and out of the grid), a total of 2.7 m² (30.1 ft²) of *Caulerpa* was encountered during the Winter 2001 survey, consisting of 19 small patches (Figure 2). All identified patches were small, with the largest being 0.5 m² (5.3 ft²).

Spring 2002

The Spring 2002 survey and treatment effort was conducted from March 27 to June 20, 2002. The entire lagoon was surveyed at the eradication survey level, including the west and central basins.

The grid was surveyed in March. Only 1 patch of *Caulerpa* was found and treated. It was 0.1 m² (1.5 ft²), located in one grid cell.

The survey of the entire east basin (outside of the grid) was initiated on March 28 and completed by May 16, 2002. During this survey 3 patches of *Caulerpa*, totaling 0.4 m² (4.3 ft²), were found and treated. All were closely associated with known infested areas and previously laid tarps.

A survey of the middle basin was conducted on March 27 and 28, 2002. A survey of the west basin was performed over a period of seven days in March and April 2002. No *Caulerpa* was found in either basin.

Due to good weather and little detected *Caulerpa*, the survey of the entire lagoon was completed by May 16. Therefore additional surveys of some of the high risk areas were conducted, with the goal of detecting any *Caulerpa* that may have been missed during the first sweep, but had become larger as the water began to warm up. This survey took 11 days, until June 20, 2002. No *Caulerpa* was found during this second sweep.

In summary, lagoon wide (both in and out of the grid), a total of 0.5 m² (5.8 ft²) of *Caulerpa* was encountered during the Spring 2002 survey, consisting of 4 small patches. All identified patches were small, with the largest being 0.4 m² (4.0 ft²).

Summer 2002

The Summer 2002 survey and treatment effort was conducted from June 21 to September 20, 2002. The entire lagoon was surveyed at the eradication survey level, including the west and central basins.

The grid was surveyed on July 10 and 11. No *Caulerpa* was found. A repeat survey was done on September 9, also with no *Caulerpa* found.

The survey of the entire east basin (outside of the grid) was initiated on June 27 and completed by September 6, 2002. During this survey, 3 patches of *Caulerpa*, totaling 0.1 m² (1.3 ft²), were found and treated. While all were closely associated with infested areas and previously laid tarps, none were found in Snug Harbor, the area suspected of being the central core and original starting point of the infestation. Because there were additional days left in the summer season, repeat surveys were done of the three high risk areas where *Caulerpa* had just been found. During this follow-up survey, 2 additional patches were found and treated, totaling 0.3 m² (2.8 ft²).

A survey of the middle basin was conducted between June 21 to 27, 2002. A survey of the west basin was performed from July 15 to 18, 2002. No *Caulerpa* was found in either basin.

In summary, lagoon-wide (both in and out of the grid), a total of 0.4 m² (4.0 ft²) of *Caulerpa* was encountered during the Summer 2002 survey, consisting of 5 small patches. All identified patches were small, with the largest being 0.1 m² (1.1 ft²).

During the Summer survey, a survey of waters offshore of the mouth of Agua Hedionda Lagoon lagoon was also conducted in June. While the offshore reefs to the south of the lagoon mouth had been surveyed several times early on in the eradication effort, only minimal coverage of the area to the north had been undertaken. Therefore, this survey focused on this northern area, extending from Pine Street south to the lagoon mouth. The intent of the survey was to detect any large infestations on the offshore reefs that had never been identified. The survey was conducted by SCUBA divers towed on a sled behind the survey vessel. Four 1.4 km (0.6 mi) transects were established, 100 m (330 ft) apart and parallel to shore (Figure 3). Favorable conditions allowed the divers to survey approximately a 5-m wide area along each transect. No *Caulerpa* was found during this survey.

ERADICATION STATUS

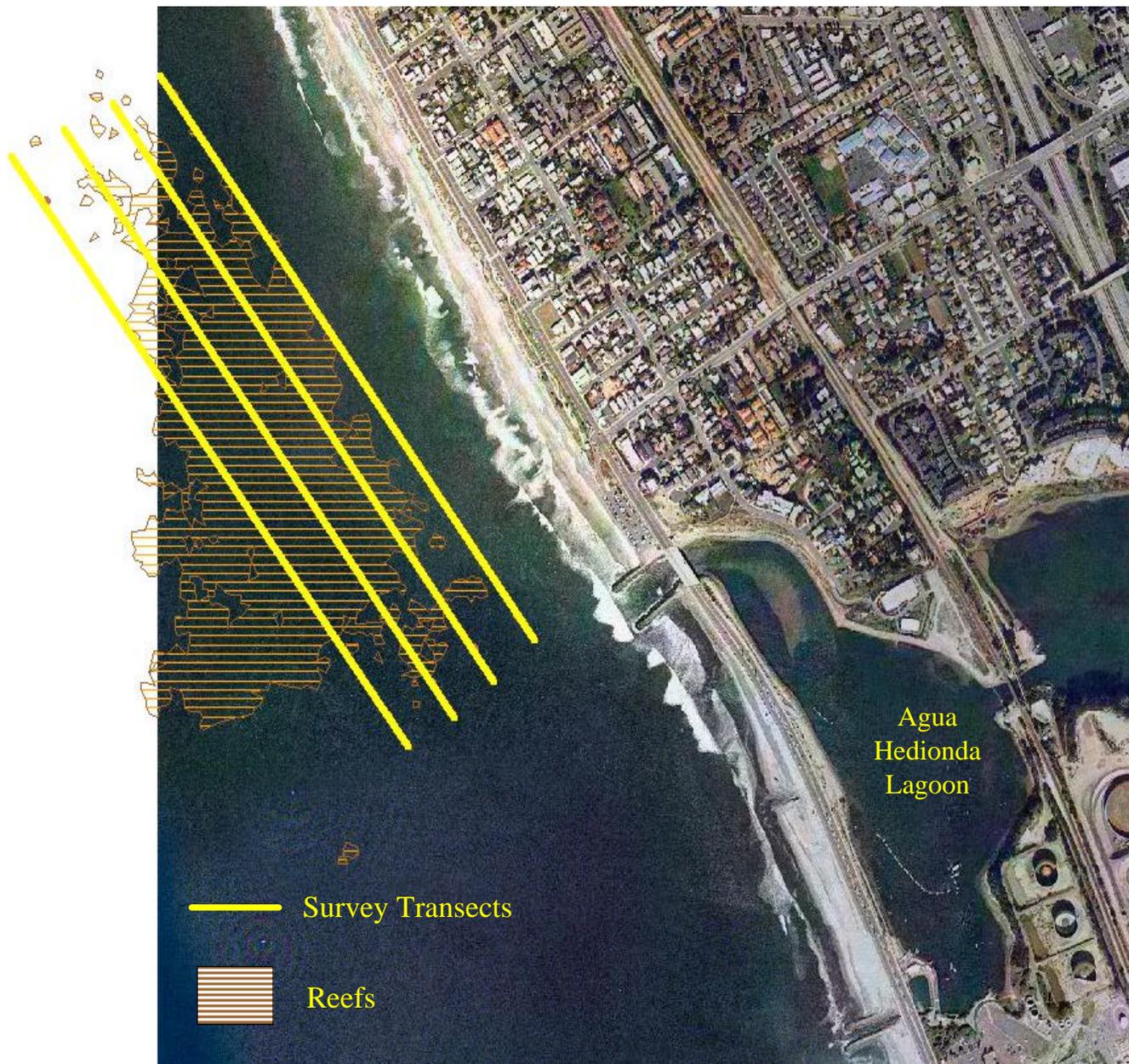
Second Year

Following the intensive treatment efforts of summer 2001, the second survey year made a clear shift in the focus of the effort, with time being devoted primarily to surveillance rather than treatment. With the reduction in the patch size and abundance, detection of *Caulerpa* became less frequent, while the effort necessary to search for it remained the same or even greater, with smaller patches being sought. The survey results for the year show continued reduction in the amount of *Caulerpa* found, both in area and number of patches.

By the end of the second year, no *Caulerpa* was detected in the grid (Table 1). This site was the most heavily infested area in Agua Hedionda Lagoon, and has received the most extensive effort during the eradication program.

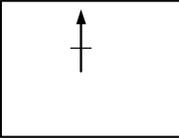
Parameter	Fall 2001	Winter 2001	Spring 2002	Summer 2002
Areal Extent (m ²)	1.2	0.4	0.1	0
Number of Dirty Grid Cells (out of 1024 total)	5	3	1	0

When examining progress lagoon-wide over the second year, the results are equally encouraging, with coverage and number of patches declining over the winter and spring and continuing into summer (Table 2). This appears to be in spite of the favorable environmental conditions found in the lagoon during the summer survey. This strain has been shown to stop growing when water temperatures drop below 12.5°C (55°F), typical of our cooler winter months, with frond growth



Agua
Hedionda
Lagoon

— Survey Transects
Reefs



Caulerpa taxifolia Survey Area
Tamarack Beach - Offshore Agua Hedionda Lagoon
Carlsbad, CA

Figure
3

resuming when the water warms back up to 17-18°C (63-64°F) (Komatsu et al. 1997). The water at Agua Hedionda Lagoon averaged about 14°C (57°F) during the winter, but dropped as low as 12°C (54°F) at one point in February 2002. Temperatures reached up to 17°C (63°F) again in late April and continued to rise to 24°C (75°F) in July 2002. Despite these conditions favoring the active growth of existing patches of *Caulerpa*, very little was found during the summer months. It is possible that any small patches that were missed during the fall and winter surveys were not able to survive the cold winter, further reducing the amount of *Caulerpa* in the lagoon.

Table 2. Status Lagoon-Wide During Year 2 (Including Grid)

Parameter	Fall 2001	Winter 2001	Spring 2002	Summer 2002
Areal Extent (m ²)	33.6	2.7	0.5	0.4
Number of Patches	92	19	4	5

Figure 5 shows the location of all *Caulerpa* found throughout the year by quarter. All finds were generally in the vicinity of previous occurrences, with fewer finds in each area during each subsequent survey.

Status Since Initiation of Eradication Effort

Because the grid has been repeatedly surveyed since the beginning of the eradication effort, it provides a good long-term indication of the success of the effort. The survey size, intensity, and methodology have remained the same since summer 2000 making annual and seasonal comparisons useful. Figure 4 plots the amount of *Caulerpa* found in the grid from summer 2000 to summer 2002.

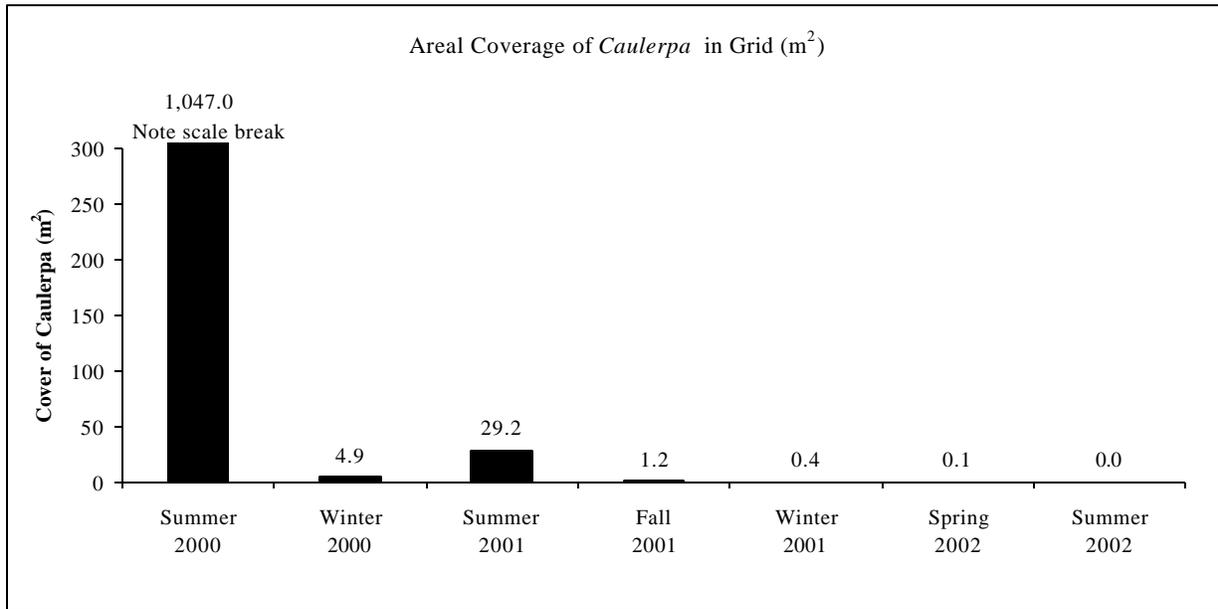
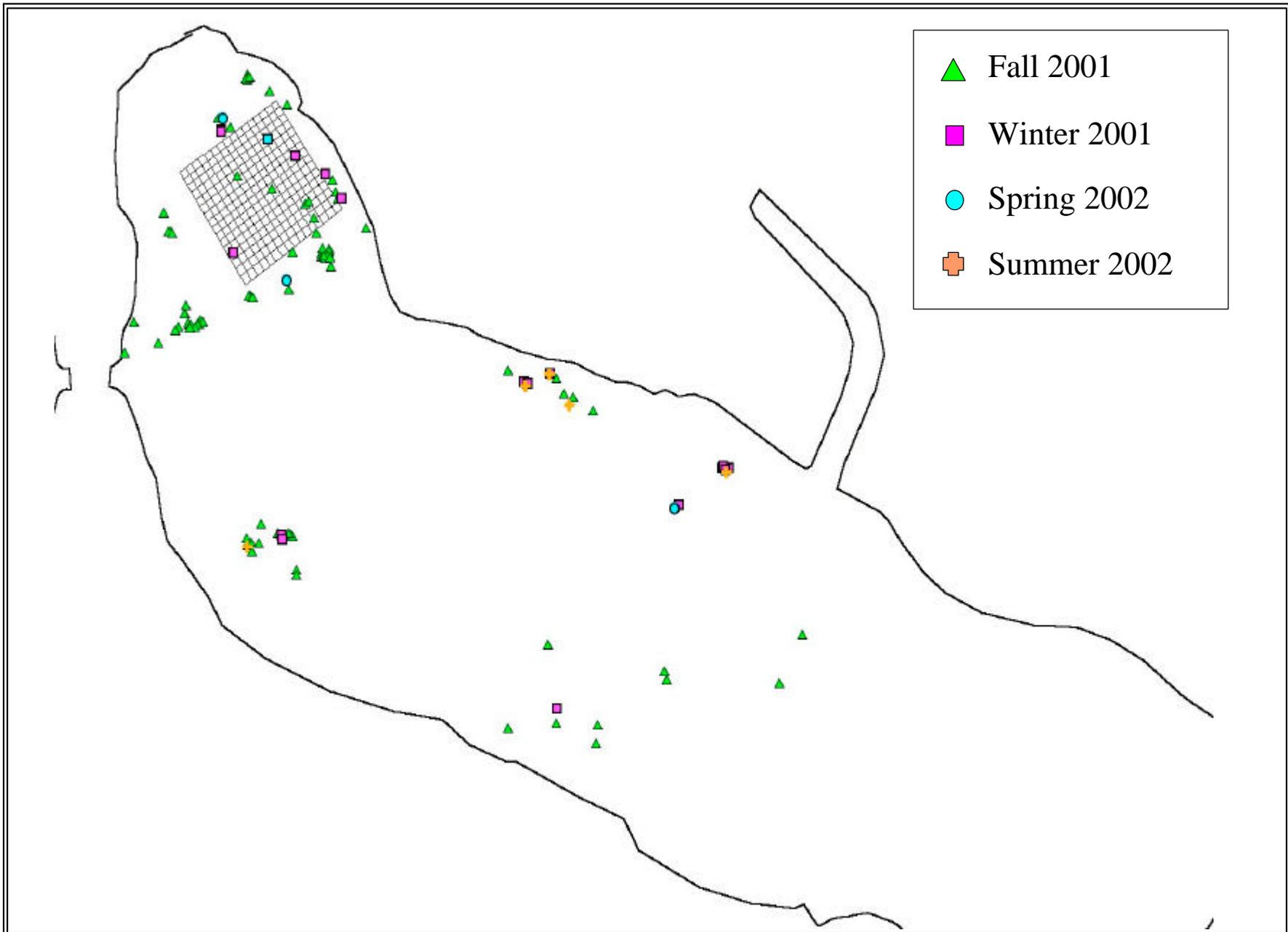
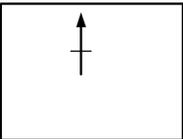
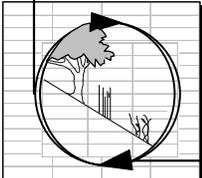


Figure 4. Areal Coverage of *Caulerpa* in the Grid in Square Meters.



- ▲ Fall 2001
- Winter 2001
- Spring 2002
- ⊕ Summer 2002



Cumulative Finds of *Caulerpa* During Year 2 of Eradication Effort
Fall 2001 - Summer 2002
Agua Hedionda Lagoon, Carlsbad, CA

Figure
 5

As reported in the Year 1 report, additional *Caulerpa* was discovered outside of the grid in 2001 and thus no data on the size or extent of the full infestation that was present in these areas in 2000 are available. If it were assumed that the *Caulerpa* found outside of the grid during summer 2001 was also there during summer 2000, an estimate of the total *Caulerpa* that was present lagoon-wide, at the start of the eradication effort (summer 2000), could be made by combining the two summer figures, for a total of 1,076.2 m². When comparing this with the 0.4 m² found lagoon-wide in summer 2002, it is apparent that considerable progress has been made in controlling the algae.

Following the completion of the Summer 2001 survey (reported on in the Year 1 report), it was believed likely that all major areas of *Caulerpa* infestation in Agua Hedionda Lagoon had been identified and treated at that time. The expectation was that any additional *Caulerpa* detected during the second year would be associated with those previously identified areas. This was the case with one exception, which occurred during the Winter 2001 survey, when a new area of the infestation was identified (Figure 6). This figure also illustrates the close relationship of *Caulerpa* found during the Year 2 survey to that found during the Year 1 work.

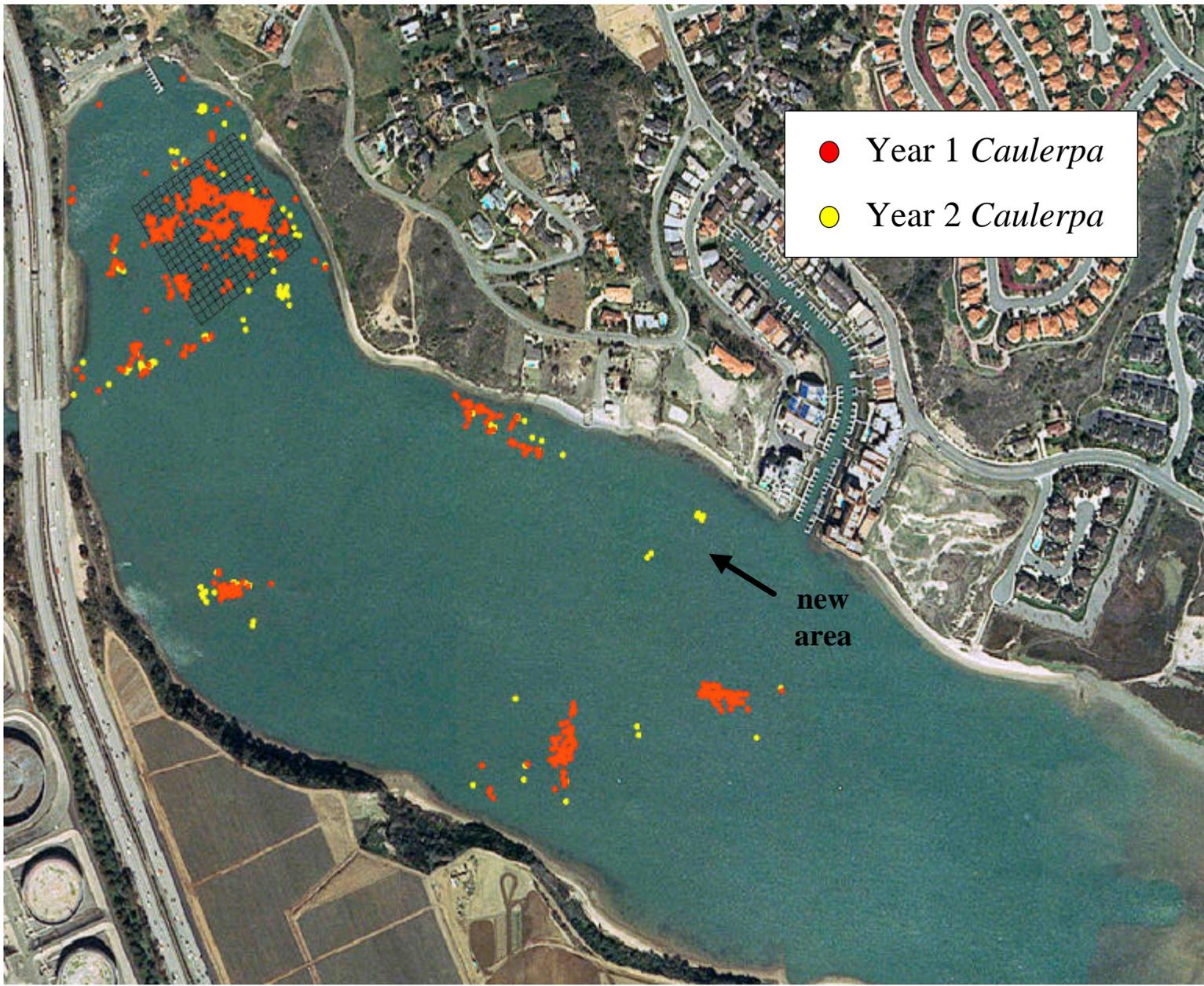
STATUS OF THE LAGOON AND COORDINATION WITH LAGOON USERS

During the second year, activities on the lagoon were coordinated through the Interim Management Plan, a document drafted and adopted by the SCCAT, the Agua Hedionda Lagoon User Representatives, and the City of Carlsbad. This plan partitioned the lagoon into management units and established safety guidelines for both the eradication crew and recreational users of the lagoon. To coordinate the activities of all users, informational signage was installed at access points around the lagoon, regular activity updates were posted on the signs, and a recorded phone message with schedule updates was maintained. This allowed the survey work to be conducted more safely and efficiently than before the adoption of the plan. The City of Carlsbad plans to review the Interim Management Plan on an annual basis to assess its efficacy.

At the end of the summer 2002 season, restrictions on the lagoon relating to the control of *Caulerpa* included a ban on anchoring and fishing throughout the east basin, a prohibition of wake height by boats in excess of 0.3 m (12 inches) when measured from the undisturbed water surface to the top of crest, and continued exclusion of all unauthorized vessels from most of Snug Harbor, the most infested area of the lagoon.

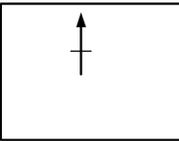
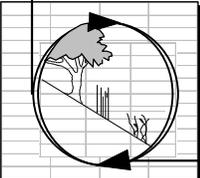
TREATMENT EFFICACY

During the second year of the eradication effort, several efforts were undertaken to investigate the efficacy of the treatment methodology of tarping and chlorinating that has been used at Agua Hedionda Lagoon. In December 2001, M&A divers collected sample cores from underneath tarps that had been placed over *Caulerpa* in both summer 2000 and in summer 2001. The cores were taken from the location under the tarp where *Caulerpa* had been growing. The cores were transported to UC Davis where they were set up in aquarium to be monitored to see if any



- Year 1 *Caulerpa*
- Year 2 *Caulerpa*

new
area



Location of Year 2 *Caulerpa* in Relation to Year 1 *Caulerpa*
2000-2002
Agua Hedionda Lagoon, Carlsbad, CA

Figure
6

Caulerpa was able to grow up out of the cores. After over 10 weeks, researchers reported no *Caulerpa* had grown from the cores, suggesting that the method of excluding light and water circulation as well as chlorine treatment was an effective treatment approach.

Based on these findings, and reports from European experiments suggesting that treatment with tarps alone was effective after three months of treatment (Zuljevic and Antolic, 2001), further efficacy studies were undertaken in the field. In April 2002, small circles were cut out of selected tarps of various ages and monitored for regrowth of *Caulerpa*. By the end of the monitoring period covered by this report, 22 weeks had passed with no regrowth of *Caulerpa* from any of the study plots. Each plot continues to be monitored both for *Caulerpa* regrowth and for recovery of native species to the exposed bottom. A separate report on this project is being prepared for publication.

FUTURE ACTIONS IN THE ERADICATION PROGRAM

As the eradication program proceeds, surveillance efforts will continue to exceed treatment efforts in terms of both cost and time. With the biomass and areal coverage of *Caulerpa* significantly reduced, efforts will focus on seeking smaller patches over larger areas. Intensive surveys seeking the detection of any new patches arising from small, previously undetected fragments will be the focus during the subsequent monitoring year (fall 2002- summer 2003).

A full Fall 2002 survey will be conducted using the eradication level of survey. However, based on the seasonal factors discussed above that limit the growth of *Caulerpa* during cold months, it is anticipated that the Winter 2002 survey will focus primarily on the high-risk areas previously known to support *Caulerpa*. This will conserve fiscal resources for use when *Caulerpa* is more likely to be actively growing and therefore more detectable, such as in summer and fall, or even in spring if early warming is found. This will also serve to extend the amount of time before financial resources for the monitoring program are exhausted, in the event that permanent monitoring funds are not secured.

Given the progress that has been made, it is hoped that during the third year few or no new occurrences will be identified. At the present time, it is anticipated that at a minimum, *Caulerpa* must not be detected for two to three years before the lagoon would be declared free of *Caulerpa*. With an approximate 99.96% reduction in the cover of *Caulerpa* at Agua Hedionda Lagoon since the initiation of the eradication effort, it appears that success may be an attainable goal.

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