# Effectiveness of Aquatic Invasive Plant Control in Emerald Bay, Lake Tahoe, California

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## Introduction

Emerald Bay is a unique, high profile attraction in the Lake Tahoe basin and is a primary destination for photographers, boaters, campers, hikers, and other recreationists (Figure 1). The establishment of invasive aquatic plant species in Emerald Bay is of great concern to a large variety of interests due to the adverse effects these plants can have on near shore ecology and visitor enjoyment. Potential impacts from invasive plant infestations include: localized degradation in water quality due to increased transfer of sediment-bound nutrients into the water column through plant root uptake and subsequent plant senescence; sediment accumulation and substrate alteration allowing further expansion of the infestation; changes in habitat conditions that favor non-native fish such as catfish and bass, and nuisance algae; adverse swimming conditions and negative impacts on recreational boating; increasing amounts of plant material washing up and fouling beaches; and the increased potential spread of invasive plants to other areas in Emerald Bay and Lake Tahoe (Eiswerth et al. 2000). Many of these potential impacts could be more substantial in Emerald Bay compared to Lake Tahoe proper because of the seasonally high recreational use, relatively smaller size, and essentially closed basin condition.

Figure 1. Emerald Bay on a summer day as viewed from the western end. The main tributary, Eagle Creek can be seen at the bottom of the photo. The inlet connecting Emerald Bay and Lake Tahoe is at the center of the photo.

The invasive aquatic plant, Eurasian watermilfoil (*Miriopyllum spicatum; hereafter EWM*), was first reported in the Tahoe Keys in the 1960's (Donaldson and Johnson 2009). Surveys in 1995 documented EWM in Emerald Bay. In 2000, a few plants were documented adjacent to a small northern outlet of Eagle Creek. By 2003, this infestation had expanded along the western edge of Emerald Bay past the Vikingsholm Pier to the north and past the outlet of Eagle Creek to the south, covering a total area of approximately 1 acre (1800 feet by 25 feet) (Anderson and Spencer 2006).

A cooperative effort among management and regulatory agencies, scientists, and professional divers was initiated to combat the invasive aquatic plant infestation in Emerald Bay after the dramatic expansion was discovered in 2003. A series of small-scale treatments were deployed in Emerald Bay between 2005 and 2009, but the infestation continued to persist. The recognition of persistence was documented by the California Department of Parks and Recreation through transect monitoring beginning in 2008 (Hymanson and Sasaki 2010; Figure 2).

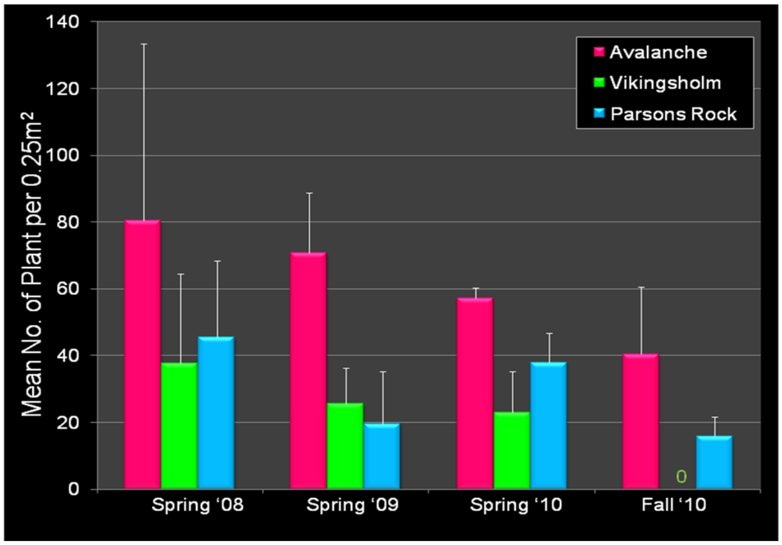


Figure 2. EWM densities at the three infestation sites in Emerald Bay, expressed as mean number of plants per 0.25 $m^2$. Mean values are based on samples sizes of three to six 0.25 $m^2$ quadrates. The white lines above each colored bar indicate one standard deviation. Post-project surveys in the fall of 2010 documented complete removal of EWM plants along the Vikingsholm monitoring transect.

By the end of 2009 three separate patches of EWM were established at the western end of Emerald Bay, covering a combined area of nearly 3 acres (Figure 3). In 2010 we pursued a combination of treatment methods over a larger proportion of one infestation site in a strategic attempt to attain control and eventually complete removal of a discrete infestation area. This paper describes the 2010 project and initial results.

## Methods

Emerald Bay is an embayment in the southwest corner of Lake Tahoe with a narrow inlet separating the bay from the lake (Figure 1). Formed through glacial activity in the last ice-age, the bay is approximately 1.7 miles long and 2/3 mile wide at the widest point (total


Figure 3. Delineation of approximate EWM infestation areas in fall, 2009.

surface area of approximately 704 acres). Three distinct areas infested with EWM were present in the western end of Emerald Bay in 2010 (Figure 3), covering approximately 3 acres.

Past control efforts employed two treatment methods: diver-assisted suction removal and benthic barriers. Diver-assisted suction removal involved divers working underwater to hand pull weeds and place them into a suction hose that transfers the plant into a container positioned on a boat. The weeds are captured in the screened-in container and then transferred into garbage cans for removal and disposal. Benthic or bottom barrier treatment consists of placing sections of gas permeable, black landscape cloth, plastic or other material, over the top of the weeds to exclude all light. The small-scale treatment efforts implemented between 2005 and 2009 did not attempt to combine treatment methods in any one discreet location, but largely deployed them independent of each other.

In 2010, our efforts were focused on a single, defined infestation: the Vikingsholm site (Figure 3). This site was chosen because: (1) it was deemed the highest risk of spread to other areas due to boat traffic; (2) it has a gradual slope and sparse logs and rocks on the lake bed making it conducive to benthic barrier placement; and (3) the location allowed use of personnel on shore to help with abatement operations thereby reduce diving time. We used a combination of both benthic barrier and diver-assisted suction removal methods and we attempted to treat the entire infestation. Diver-assisted suction removal was strategically conducted at two intervals: (1) following the installation of the barriers; and (2) following the removal of the barriers. During these intervals, three priorities for diver-assisted suction removal were identified: (1) remove as much EWM as possible from around Vikingsholm Pier, because this is the area of highest risk of spread; (2) remove EWM plants from around and between benthic barriers if present; and (3) work from the southern extent of the infestation towards the north to get as complete and continuous EWM removal as possible given available time and money.

We tested the cost-effectiveness of two benthic barrier materials; reusable 10’x40’ black plastic Lake Bottom Blankets (Lake Bottom Blanket, 32 Juniper Road, Wayne, NJ 07470) and 8’x300’ rolls of disposable landscape weed cloth. In May of 2010 divers and staff on shore covered approximately 4,360 ft.$^2$ of EWM with Lake Bottom Blankets and approximately 4,260 ft.$^2$ with weed cloth for a total area of approximately 8,620 ft.$^2$ (~0.2 acres). The disposable weed cloth was white on one side and black on the other and we placed the white side up on one section of weed cloth to test the visibility of different colored barrier material. These barriers were placed over the most contiguous infestation area. Transect surveys measuring plant density and percent cover continued to monitor the effectiveness of the earlier small-scale treatment efforts as well as the 2010 project.

**Results**

Transect monitoring data prior to our 2010 project indicated that EWM will begin to recolonize treatment sites within 15 months post-treatment (Figure 4) and that use of small barriers alone is unlikely to provide an effective strategy for controlling EWM in Emerald Bay. EWM growth patterns, density, and height are potentially influenced by seasonal patterns and local conditions such as annual differences in the length of the growing season (Kelting 2010). For this reason, effectiveness of treatment efforts that treat small portions of a single infestation may be difficult to document. The effectiveness of small-scale treatments also are expected to be limited without repeated treatment (Figure 4) as the treated sites would be susceptible to recolonization from the spread of adjacent EWM and from fragments brought in on boats and currents from other infested areas of the Bay.

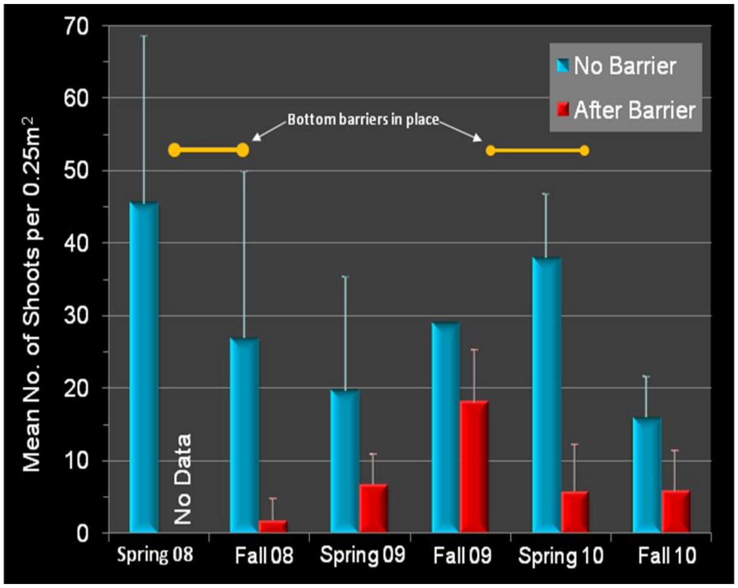


Figure 4. Mean density of EWM at one infestation site (Parsons Rock) in Emerald Bay. Numbers associated with each bar indicate the number of replicates that were sampled to estimate the mean density. The white lines above each bar indicate one standard deviation. The yellow horizontal bars indicate the approximate period of small-scale efforts to reduce EWM in a portion of the Parsons Rock infestation. After barrier data from Fall 2008 to Fall 2009 indicate the extent to which plants were able to recolonize the treatment area.

A comparison of disposable and reusable barrier materials indicated that disposable weed cloth was less costly for materials and labor during one installation, but that the reusable Lake Bottom Blankets would become more cost effective after a second installation and progressively more cost effective with each successive use (Table 1). The white-surfaced weed cloth was visible from points along the highway above Emerald Bay for most of the summer, while the black- surfaced material became difficult to see after two weeks.

Table 1. 2010 Emerald Bay aquatic weed abatement project cost comparison for one-time installation and removal of two bottom barrier types: disposable weed cloth and reusable Lake Bottom Blankets.

| Estimates of Effort and Costs 2010 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Size/ sq. ft.** | **number Installed** | **Overlap reduction (sq. ft.)** | **Total Est. Coverage (sq. ft.)** | **Total Est. Coverage (Acres)** | **Installation Shore and Diver (Person hours)** | **Removal Shore and Diver (Person Hours)** | **Total Person-hours** | **Labor Costs** | **Material Costs** | **Total Cost** | **cost/ sq. ft.** |
| Lake Bottom Blankets | 400 | 12 | 440 | 4360 | 0.10 | 32.8 | 30.1 | 62.9 | $2,515 | $2,969 | $5,484 | $1.26 |
| Weed Cloth | 1136 | 4 | 284 | 4260 | 0.10 | 45.3 | 30.2 | 75.5 | $3,019 | $1,184 | $4,203 | $0.99 |

| **Installation Notes** |
|---|
| Lake Bottom Blankets measure 10' x 40'. Weed cloth measures 8' x 300'. Each run of weed cloth was ~ 8' x 142' (i.e., full roll not used) |
| Installation and Removal time includes travel time to (30 minutes) and from (30 minutes) the site. |
| Diver prep and clean-up time= (1 hour travel time + 1 hours suit up and suit down + 1 hour surface interval)*number of divers. |
| Four divers installed all benthic barriers in one dive. It took 4 divers to install 2 runs of weed cloth and 3 divers to install the other 2. |
| Labor costs assume a $40/hour/person labor rate for all individuals involved. |
| Rebar costs totaled $1,030 and are split 40% for benthic barriers and 60% for weed cloth |
| **Removal notes** |
| Preparation and clean-up time includes travel time to (30 minutes) and from (30 minutes) the site. |
| Diver prep and clean-up time= (1 hour travel time + 1 hours suit up and suit down)*number of divers. |
| It took four divers one dive to remove all rebar, benthic barriers, and weed cloth. |
| Labor costs assume a $40/hour/person labor rate for all individuals involved. |
| **Materials cost notes** |
| Total materials cost - $4153.14 |
| Rebar (97 20'(3/8") pieces) - $589.95 |
| Rebar fabrication (cut & make candy canes) - $440.54 |
| Lake Bottom Blankets (12, 10'X40') - $2556.68 |
| Weed Pro-weed cloth (2, 8'X300') - $565.97 |

The 2010 benthic barrier deployment was followed by two successive diver-assisted suction removal efforts during late June and late September. The EWM was still alive under the barriers during the late June dive, indicating that barriers need to be left in place for greater than 6 weeks under growing conditions present during 2010. All EWM under the Lake Bottom Blankets and weed cloth were dead and largely decomposed after removal in mid-September confirming that 4 months was an adequate amount of time to kill EWM.

EWM was observed growing between and at the margins of the benthic barriers. The second interval of diver-assisted suction removal targeted these plants. Overall, the diver-assisted effort was estimated to have removed over 95% of the remaining EWM plants in the Vikingsholm infestation that were not covered by benthic barriers (Freeland, pers. comm. 2010), for a total estimate of greater than 95% removal of approximately 1 acre of EWM. Transect surveys conducted after all treatment work (in Fall 2010) found no plants in the Vikingsholm infestation (Figure 5), supporting the qualitative observations.

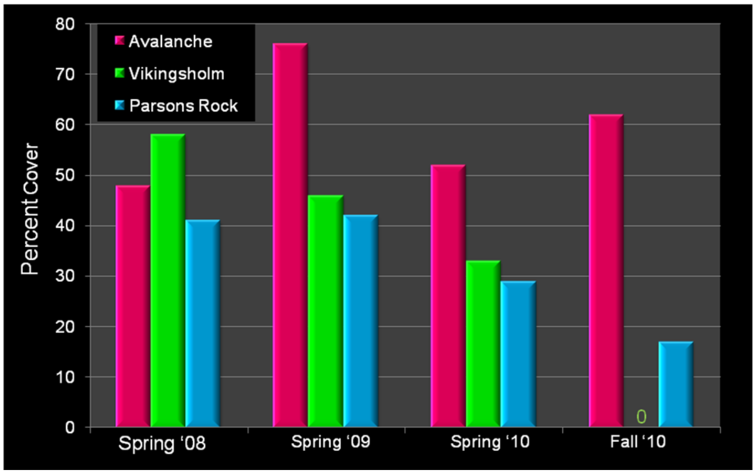


Figure 5. EWM at the three infestation sites in Emerald Bay expressed as percent cover. Sample sizes range from 20 -25 points along established transects at each location. Post-project surveys in the fall of 2010 documented complete removal of EWM plants along the Vikingsholm.

**Discussion**

Despite the previous small-scale efforts, EWM infestations in Emerald Bay had grown to approximately 3 acres by early 2010. This represents approximately 10% coverage of the suitable nearshore substrate within Emerald Bay. Monitoring of previous EWM control efforts in Emerald Bay established that a patchy and small-scale effort is not sufficient to reduce existing infestations or control the spread of aquatic invasive plants. This finding is consistent with past EWM research on recolonization of treated areas, which indicated that treated areas adjacent to untreated infestations are prone to rapid recolonization (Eichler et al. 1995).

The 2010 strategic effort to remove all plants in a discrete infestation with multiple treatment methods yielded promising initial success. By combining methods, a large continuous area was treated more efficiently, with benthic barriers treating the main area of the infestation, and diver-assisted suction removal specifically targeting hard to reach areas, margins and gaps in the barriers, and sparsely infested areas. This combination of treatment methods maximized the cost/benefit ratio, and one method reinforced the effectiveness of the other. Approximately one-third of the infested substrate in Emerald Bay was reduced to a level that can be maintained with small scale annual retreatments.

The Vikingsholm project area will require regular maintenance level retreatment efforts into the future to remove any EWM plants that may become established from EWM fragments coming from the other two infestations in Emerald Bay or from fragments brought into the bay on boats and currents. A strategic removal effort in the other two infestation areas in Emerald Bay in the near future should substantially reduce the rate of recolonization in the project area. Control of the remaining two infestation areas will also reduce potential continued and further EWM spread in the bay by limiting the habitat alterations caused by established plants, which reinforce continued infestation.

An Emerald Bay Aquatic Invasive Species Management Plan (Plan) was developed in parallel with the project detailed in this paper. The Plan identifies the long-term goal of EWM eradication, where feasible, and the near-term goal of reducing all infested areas in Emerald Bay to levels that can be controlled through regular maintenance. Annual maintenance would be conducted by State

Park employees or cooperators to remove remaining and newly established EWM plants until the risk of re-introduction into Emerald Bay is removed. Achieving this near-term goal would be accomplished by a continuation of annual control efforts commensurate with the successful effort of 2010.

**Management Implications**

Emerald Bay is a high priority site for control of invasive plants because the adverse impacts to this water body may be more pronounced than impacts in less contained locations in Lake Tahoe proper, and because of the unique character of this bay. An opportunity exists in Lake Tahoe to demonstrate successful removal efforts within this bounded and discrete water body. Continued monitoring and documentation of the results from this project and future treatment efforts should help to inform treatment actions in other parts of Lake Tahoe. If effective, this control strategy can assist in planning for survey and control of aquatic plants under a lake-wide systematic approach. Successful control of existing infestations is an important aspect of a comprehensive aquatic invasive species management program, which includes prevention, early detection and rapid response, and education and outreach. With less than 10% of the suitable shallow water habitat in Emerald Bay occupied by EWM, a large focused effort over one or two years can realistically demonstrate great success. Moreover, a successful control program in Emerald Bay could be extremely productive in garnering public support and sustaining the long term strategy of invasive aquatic plant control in Lake Tahoe.

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