USDA Agricultural Research Service and by funds from the State of California provided to the San Francisco Estuary Institute. Mention of a manufacturer does not constitute a warranty or guarantee of the product by the U.S. Department of Agriculture nor an endorsement over other products not mentioned.

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Evaluating Impacts of Lake Maid™ Plant Control

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ABSTRACT

The Lake Maid™ is a mechanical control device for removing nuisance aquatic vegetation in small areas around docks (up to 200 m^2 at a time). Direct impacts of the Lake Maid™ on water quality and the potential for spread of viable plant fragments were evaluated in this study, conducted on the San Joaquin River Delta. Analyses of water nutrient concentrations (total and dissolved phosphorus, nitrate and nitrite, and organic carbon) and measurements of conventional water quality parameters as well as fragment density were conducted over a 10-day treatment period. A mesocosm experiment, plant biomass estimation, and a cost-effectiveness evaluation were also performed. The Lake Maid™ successfully removed all above ground plant biomass at two study sites and partially removed plant biomass at a third site without affecting nutrient concentrations or water quality in the treatment areas. The likelihood of spreading plant fragments is high, but in areas of extensive aquatic plant infestation, like the San Joaquin River Delta, this may not be a management concern. During the 10-day treatment period, the Lake Maid™ proved to be an effective, low-maintenance plant control method for removal of submersed vegetation in small areas where additional plant fragmentation is tolerable.

Key words: mechanical control, fragments, re-growth, San Joaquin River, *Egeria densa, Ceratophyllum demersum.*

INTRODUCTION

Introduced aquatic plants impair the use of water resources in many ways. Problems associated with exotic plants include degradation of water quality, interference with flood control measures, obstruction of boat traffic, and decreased

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recreational opportunities (Madsen 1997, 2004; Pimentel et al. 2000). The Lake Maid™ was invented as a non-chemical control method for small areas (up to 230 m^2 or ~ 0.06 acres) particularly around docks, in water bodies that are infested with invasive plant species. Plants are up-rooted from the sediment and collected by underwater rakes that are pulled by a water pump-driven floating arm. The floating arm cycles back and forth in an arc from a fixed attachment point. Arm length and cycling frequency can be modified as can rake depth. This study evaluated whether the Lake Maid™ could effectively eliminate plants from a treatment area and the potential impacts of this method on the nearby ecosystem. The Lake Maid™ has been well publicized (Kretsch 2003) but not yet independently studied. Potential impacts of this mechanical control method include water quality changes and production of viable fragments.

The Sacramento-San Joaquin River Delta (California, USA) is impacted by introduced plant species, including *Egeria densa* (egeria) and *Eichhornia crassipes* (water hyacinth) (Bock 1969; Anderson 1990; California Department of Boating and Waterways 2001). Due to the Talent decision (243 f. 3d 526 (9th Cir. 2001) Headwaters, Inc. vs. Talent Irrigation District, the U.S. Court of Appeals for the Ninth Circuit), National Pollution Discharge Elimination System (NPDES) permits and associated monitoring are now required in California for application of aquatic herbicides. The permitting and monitoring costs have added considerable expense to chemical pesticide control options (Siemering 2004). Not only is the examination of alternative control methods required in NPDES permits, but the study of such methods may identify techniques that small businesses, including marinas, resorts, and other shoreline property owners may find preferable, when the high regulatory costs of chemical pesticide applications are considered.

The Aquatic Pesticide Monitoring Program, funded by the California State Water Resources Control Board, evaluated many non-chemical alternative control methods (Greenfield et al. 2004, 2006). One major concern with mechanical plant control methods is the spread of plant infestations due to increased production of plant fragments. For species like egeria, *Ceratophyllum demersum* (coontail), and *Hydrilla verticillata* (Lf) Royle (hydrilla), which reproduce by stem fragments (Cook and Urmi-Konig 1985, Anderson and Dechoretz 1982), the production of viable fragments can cause re-infestation of a treated area or spread infestations to new regions. Long-term water quality impacts from re-suspension of particle-bound nutrients are another concern, particularly for treatments which disturb sediments (Getsinger et al. 2002).

We performed an experimental application of the Lake Maid™ at three marina docks in the San Joaquin River Delta to evaluate its efficacy in controlling the vegetation, cost-effectiveness, and environmental impacts. Paired treatment and reference stations were monitored for effects on water chemistry. The treated areas were sampled before and during treatment to assess the extent of fragment production, and a mesocosm study was set up to evaluate whether fragments in the treatment areas were viable. Finally, information was compiled to evaluate cost-effectiveness of the Lake Maid™ in relation to current chemical costs and NPDES permitting requirements for aquatic herbicides.

MATERIALS AND METHODS

Study Sites

Three marinas in the San Joaquin River Delta (hereafter, Delta) were chosen as study sites (Paradise Point Marina, King Island Resort, and Ladd's Stockton Marina) (Figure 1). The three locations were selected out of a larger group of marinas identified in the Delta (N = 30) based on suitability for this study (e.g., water level and plant infestation), and willingness of marina owners to cooperate with the research. They were all located on either the San Joaquin River or Disappointment Slough, within a six-mile radius of one another (within latitude N 37°58.616' and N 38°03.394' and longitude W 120°25.077' and W 121°27.518'). At each marina, two sites with comparable depth and plant density were identified and then randomly assigned to a treated site and a reference (untreated) site. The reference sites were solely established for comparison of water chemistry. The distance between treated and reference sites was 100-300 m. The sites were near frequently used boat slips and docks. The selected marinas had dense vegetation (more than 50% of the area covered by submerged plants). Shallow (<2 m) areas typically exhibited high macrophyte biomass during the summer months (>450 g/m^3 dry weight).

To determine plant composition, two areas of 1 m^2 were evaluated at each of the three marinas. All plants in each sample frame were collected, weighed, and keyed to compare biomass and species abundance within the marinas.

All treatment and sampling events took place in July and August of 2004. A week with moderate tides was selected for evaluation of treatment effectiveness and impacts.

Lake Maids™

One 20-foot and two 36-foot long Lake Maid™ units (Lake Restoration Inc., Rogers, MN) were deployed, one per marina. The Lake Maids™ operated 24 hours a day for ten consecutive days. Areas of 50 m^2 at Ladd's Stockton Marina, 130 m^2 at King Island Resort, and 200 m^2 at Paradise Point Marina were treated. The machines use a standard 110 V power outlet and draw 12.5 amperes. The life expectancy of the machines is estimated to be ten years by the manufacturer, with a shorter life-time in salt and brackish water. A P 4400 Kill A Watt™ Power Meter (P3 International Corporation, New York, NY) was used to determine the electricity consumed over the study period. The consumption per hour was determined to evaluate the cost of operating a Lake Maid™. The hourly rate was calculated for Stockton, CA, where Pacific Gas & Electric charges $0.11 per kilowatt-hour.

Water Chemistry

Water chemistry samples were taken 24 hours prior to the start of the treatment period, as well as 24, 72, and 240 hours into the treatment at the six different sites (three treated and three reference sites). Water quality parameters analyzed included total suspended solids (TSS), dissolved organic carbon (DOC), total organic carbon (TOC), total phosphorus, and dissolved ortho-phosphate, nitrate (NO_3), nitrite (NO_2),

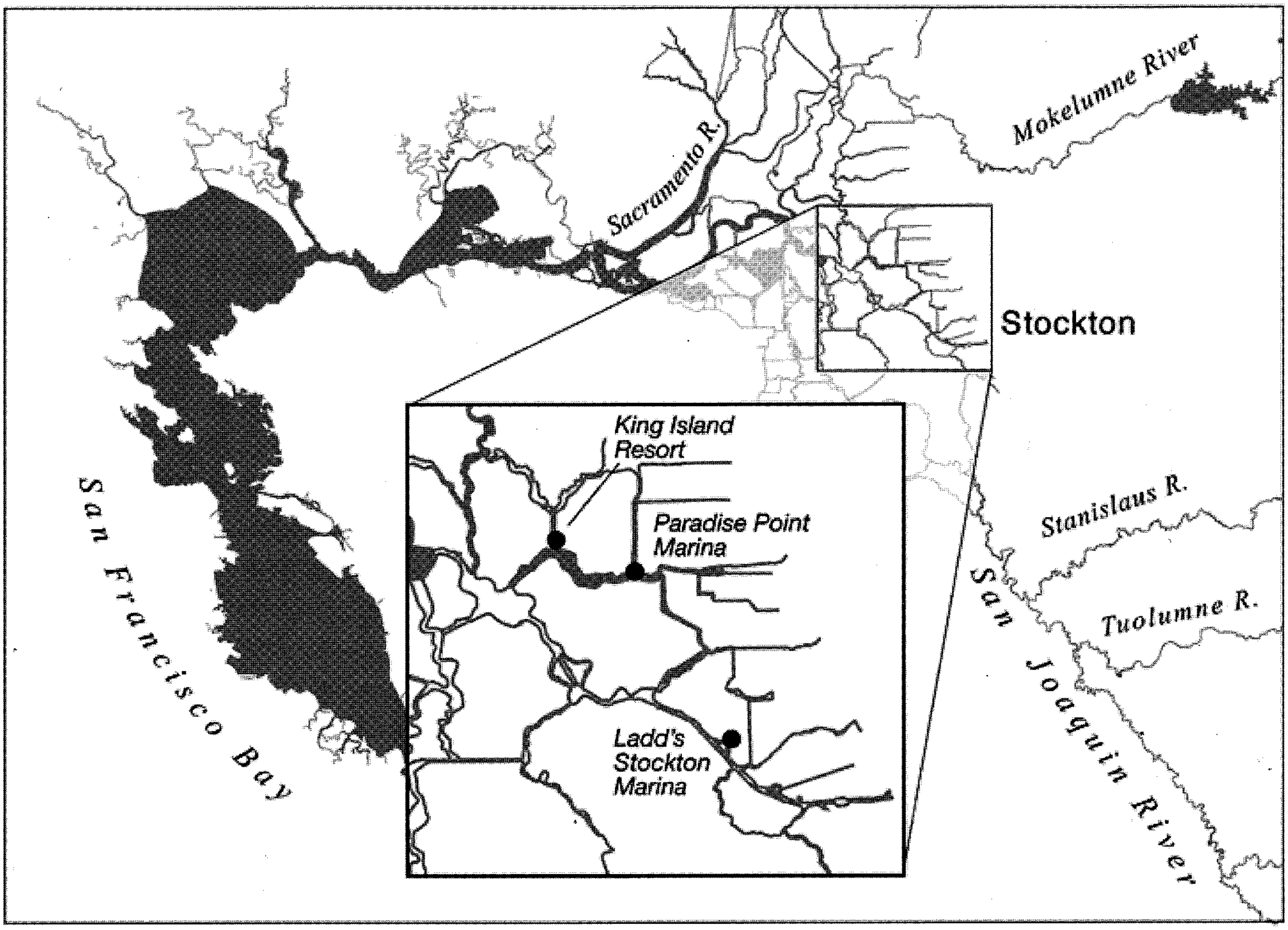

Figure 1. Study area in the Sacramento-San Joaquin River Delta, California. Circles indicate marinas at which Lake Maids™ were established.

and total Kjeldahl nitrogen (TKN). Total nitrogen was calculated as the sum of NO_2, NO_3 and TKN. These parameters were analyzed by the California Department of Fish and Game (Water Pollution Control Laboratory, Rancho Cordova, CA) and California Laboratory Services (Rancho Cordova, CA). Water samples were taken inside the treatment area at the midpoint rake radius, between sweeping cycles of the Lake Maid™ at 1 m water depth. Dissolved oxygen (DO), temperature, pH, electrical conductivity (EC), and turbidity were measured immediately below the water surface and at 1 m depth at all stations using a WTW Multi 340i multimeter.

Statistical analyses of the Lake Maid™ treatment and reference plots were performed using repeated measures analysis of variance (ANOVA). Repeated measures ANOVA models changes in environmental variables measured repeatedly over time in the same experimental sites. Repeated measures ANOVA was performed on each chemical parameter, with evaluation of overall changes over four measurement dates, in addition to the impact of the Lake Maid™ treatment on nutrient levels over time (i.e., a date by treatment interaction). For the nutrient evaluation, the experimental design followed a randomized block design, in which two plots (a Lake Maid™ treatment area and an untreated control area) were selected within each marina. Repeated measures ANOVA is an appropriate statistical method for evaluating differences between treatment and control in this randomized block design, provided that statistical significance is adjusted for sphericity (Von Ende 2001). All measurements were assessed for statistical significance by comparing the Huynh-Feldt Epsilon corrected p-value to an α value of 0.05. All statistical analyses were performed in SAS.

Density of Fragments

Plant fragment samples were collected for all three study areas about 24 hours before the Lake Maid™ operation (reference sample), three to six days into the operation, and ten days after the start. Within the treated area, a three-gallon bucket sieve (mesh openings 0.5 mm in diameter and bucket mouth 46 cm) with a flotation device was dragged for 10 m through the water with the mouth of the bucket perpendicular to the water surface. This method was repeated five times at random locations throughout the treatment area. Fragments were identified, counted, and measured for wet weight, number and length of stems (in ten centimeter size classes), and number of nodes. Changes in fragment characteristics were assessed over three measurement dates at the three different marinas using repeated measures ANOVA (Von Ende 2001).

Plant Biomass

At three dates (1 hr before Lake Maid™ treatment, 3-6 days into treatment, and 10 days into treatment), plant biomass samples were collected using a metal garden rake to evaluate changes in relative biomass over the treatment period (Treibitz et al. 1993). On each sampling date, three samples were collected, each 1 m in length, by dragging the rake along the bottom of the site parallel to the dock. Sample locations were randomly chosen within non-overlapping portions of the Lake Maid™ arc. The plant material, collected by the rake, was brought to the surface, dried, and weighed to evaluate the efficacy and progress of the sweeping operation. Since the size of the area sampled with each grab may have varied, the results were only used to estimate relative changes in plant abundance over the course of the experiment.

Control Costs

Information on purchase prices (http://www.lakerestoration.com), labor for installation and maintenance (Kevin Kretsch, Lake Restoration, Inc., pers. comm.), and fees for electricity (personal communication with PG & E Stockton, CA) were compiled to evaluate the control costs of the Lake Maid™. Chemical application cost included NPDES permit fees (U.S. EPA 1999), costs for herbicides and labor (Jay Kasheta, licensed applicator for Cygnet Enterprises West, Inc., pers. comm.), and costs for monitoring and reporting (based on an average of analytical costs for northern California laboratories) were calculated for comparison purposes. Frequency of equipment breakdown and necessity for repair (e.g., chemical sprayers, Lake Maids™, or application vessels) were not considered in either chemical or Lake Maid™ cost calculations. To obtain a qualitative understanding of the frequency of repair required for the Lake Maid™, a telephone survey was conducted with twelve Lake Maid™ owners (names provided by Kevin Kretsch, Lake Restoration, Inc.) regarding frequency and duration of operations and problems observed. Survey respondents were all Minnesota residents, and used the machine frequently on residential lake docks for two to five months per year. Respondents had operated the machine for either one year (N = 1), two years (N = 6) or three years (N = 5).

RESULTS AND DISCUSSION

Study Sites

Untreated areas at each marina where plants were identified, counted, and weighed showed that egeria comprised the majority of plant biomass (86% at Ladd's Stockton Marina, 74% at Paradise Point Marina, and 46% at King Island Resort). Coontail contributed 17% of the plant biomass at Paradise Point Marina, 11% at Ladd's Stockton Marina, and 44% at King Island Resort. Both species reproduce vegetatively by stem fragments. Additionally, *Lemna minuscule* (duckweed), *Cabomba caroliniana* (fanwort), *Cladophera* spp, *Myriophyllum hippuroides* (western water milfoil), *Hydrocotyle ranunculoides* (floating pennywort), and water hyacinth were present in minor amounts.

Water Chemistry

Repeated measures ANOVA yielded no significant differences between the three Lake Maid™ treated and the reference stations for any of the chemical parameters during the treatment period ($p > 0.05$ in all cases). Water chemistry parameters were generally similar before vs. after treatment (Table 1). When changes were observed over the experiment duration, they were generally similar for treatment vs. reference sites from the same marina (Figure 2), with no apparent difference resulting from the Lake Maid™ treatment.

The study results suggest that sweeping of small selected areas is unlikely to have significant impacts on water quality. In contrast, studies of the Weed Roller® by James et al. (2004a and 2004b) indicate substantial increases in turbidity and TSS, as well as an increase in soluble phosphorus due to the movement of the Weed Roller® arm. Few changes in water chemistry were observed at the Lake Maid™ experimental and reference sites. The difference between our find-

Table 1. Mean ± standard deviation of replicate samples for water chemistry parameters for all three treatment vs. reference sites in the Sacramento-San Joaquin River Delta, California. Pre = average of samples collected 24 hr prior to Lake Maid™ treatment. Post = average of samples collected 24 hr, 72 hr, and 10 d after Lake Maid™ treatment. Samples for 1 m depth and surface readings were averaged for conventional water quality parameters. DO = dissolved oxygen, EC = electrical conductivity, TOC = total organic carbon, TKN = total Kjeldahl nitrogen, TSS = total suspended solids.

Event	DO mg/L	EC µS	pH	TOC mg/L	Total Phosphorus mg/L	Dissolved ortho-Phosphate mg/L	Dissolved Nitrate + Nitrite mg/L	TKN mg/L	TSS mg/L
Treatment									
Pre (N =3)	5.5 ± 0.7	330 ± 270	7.6 ± 0.1	1.2 ± 1.1	0.08 ± 0.04	0.08 ± 0.03	0.58 ± 0.67	0.9 ± 0.9	4.4 ± 1.8
Post (N = 9)	6.3 ± 1.3	320 ± 220	7.8 ± 0.2	2.6 ± 1.2	0.09 ± 0.05	0.08 ± 0.04	0.53 ± 0.60	1.1 ± 0.9	4.8 ± 0.7
Reference									
Pre (N =3)	5.7 ± 0.6	320 ± 280	7.6 ± 0.2	1.1 ± 1.1	0.09 ± 0.03	0.07 ± 0.03	0.56 ± 0.67	1.0 ± 0.8	4.0 ± 1.3
Post (N = 9)	5.9 ± 2.0	320 ± 230	7.7 ± 0.1	2.7 ± 2.0	0.09 ± 0.05	0.08 ± 0.04	0.59 ± 0.68	1.1 ± 1.0	4.7 ± 1.8

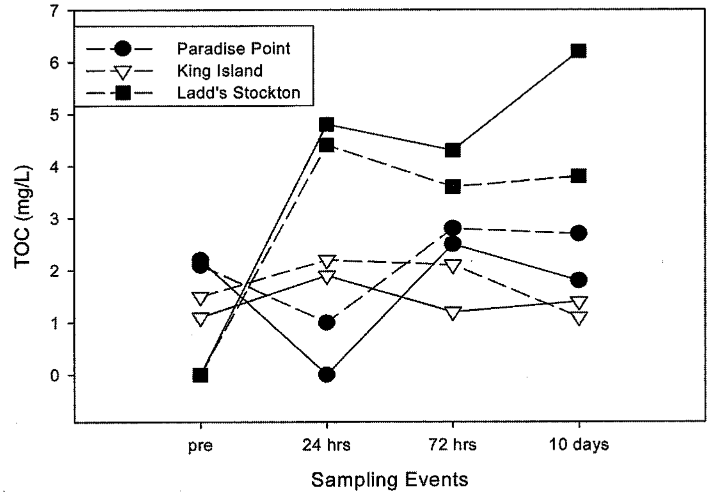

Figure 2. Total organic carbon concentrations in water samples at all three study sites over a 10-day period. Broken lines indicate treated site concentrations, solid lines indicate reference sites.

ings and those of James et al. (2004a and 2004b) may stem from differences between the two modes of operation. The Weed Roller® rolls directly on the benthic surface, resulting in substantial sediment disturbance and modification. In contrast, the Lake Maid™ uses loosely attached rakes to scrape through macrophytes, with limited to no direct sediment contact. The tidal influence at the Lake Maid™ sites could also have been a factor minimizing observed effects to water quality because of significant water exchange. Slight fluctuations in concentrations recorded were probably only due to tidal cycles, since the variations at the treated and reference sites were consistent (Figure 2). The majority of samples were taken during slack tide after high tide but the exact sampling time relative to tidal cycles varied slightly among samples. The absence of strong impacts on water chemistry may also be related to the small scale of the Lake Maid™ operation in comparison to larger scale mechanical harvesting projects (e.g., Carpenter and Adams 1976, 1978, Carpenter and Gasith 1978, Alam et al. 1996).

Density of Fragments

Repeated measures ANOVA indicated a significant increase in average fragment abundance (from 2 to 43 fragments) (Huynh-Feldt Epsilon corrected $p = 0.048$; $N = 3$) and mass (from 7 to 196 g) (Huynh-Feldt Epsilon corrected $p = 0.030$; $N = 3$) of egeria three to six days after the start of Lake Maid™ operation, with consequent decline in abundance (3 fragments) and mass (24 g) eight to ten days into treatment (Figure 3a). There was no statistical evidence of changes in egeria fragment average stem length or number of nodes, or in any coontail fragment attributes ($p > 0.05$; $N = 3$ in all cases) over the three sampling events. Fragments of egeria and coontail in all size classes were present in the samples taken within the treatment area. Fragments accumulated in bundles mostly around the dock where the Lake Maid™ swept them. Often fragments stuck to the rakes of the Lake Maid™ and were pulled along with the movement of the arm. Fragments of these plants are generally viable (Sabol 1987).

The results of the fragment tests suggest that over a period of two to nine days, fragmentation of plants in the treated area will increase dramatically, although plant fragments will be present at all times. In addition to fragments generated by the Lake Maid™, fragments can be generated by spontaneous fragmentation of plants, by boat traffic, or by other mechanical control operations, and these fragments, regardless of source, can potentially cause reintroduction of new plants (Olem and Flock 1990). The manufacturer of the Lake Maid™ recommends an operation time of initially seven days to clear submerged aquatic weeds from an area. According to our results, after that time period, the generated egeria fragments floating in the water seemed to have dispersed and only a slightly higher number of fragments remained in the treatment area after ten days (Figure 3a).

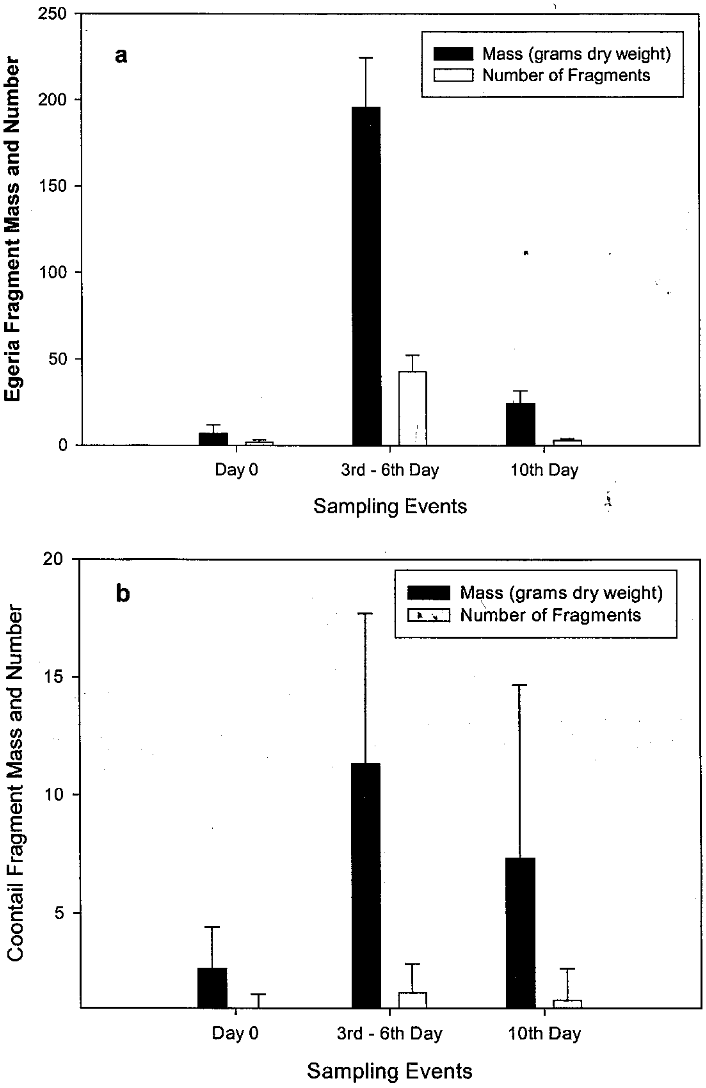

Figure 3. Fragment weight and stem density during the 10-day study period. Results were averaged for fragments at the three Lake Maid™ treatment sites in the Sacramento-San Joaquin River Delta. Error bars indicate one standard error. a. *Egeria densa*. b. *Ceratophyllum demersum* (coontail).

Plant Biomass

For Paradise Point Marina and King Island Resort, rake plant biomass in the treatment areas went down to almost zero at the end of the 10-day study period (Figure 4). In between day one and day six, an average of 397 g of plant material was brought up with a single rake sample (range of 78 g to 1,546 g). At day 10, treatment areas at both marinas showed almost no plants at the bottom. At Ladd's Stockton Marina, the weight of scooped up rake samples was similar over the sampling period with an average of 356 g for the nine samples taken (average on day 1 = 359 g, on day 5 = 313 g, and on day 10 = 397 g). At this marina, the vegetation was initially very thick throughout the whole water column, and the rakes of the machine had to be positioned closer to the surface in order for the machine to function. Progress was made by lowering the rakes of the Lake Maid™ over time, but the clean-up of this area was not accomplished within the period of this study. Further work may be necessary to determine plant densities that can impact Lake Maid™ performance.

Control Costs

The initial purchase cost for each Lake Maid™ was approximately \$2,000, installation and maintenance (two visits) were \$600, and the electricity costs for the machine were estimated at \$0.07 per hour (\$24 for the two-week treatment period). The cost for each Lake Maid™ operation thus totaled approximately \$2,624. The Lake Maid™ could also be repositioned within a marina to broaden the treatment area. For comparison, the current California aquatic pesticide NPDES permit fee is \$1,000, event-based monitoring, laboratory analysis, and reporting by a scientific consulting firm was estimated at \$4,000, and the cost for chemicals and labor was \$174, for a total cost of approximately \$5,174 (for an area of approximately 200 m^2). Both treatment types most likely would have to be repeated during the growing season, with additional chemical and monitoring costs for the pesticide treatment. The cost comparison was conducted for small treatment areas (e.g., to provide dock access in marinas or swimming access at recreational beaches) in natural waters within the state of California. For water bodies or regions where NPDES permits or similarly costly permitting and monitoring are not required, the cost of chemical treatment would be lower than Lake Maid™ treatment. An increase in treatment area would result in an increase in purchasing cost for Lake Maids™ while the permitting fees for chemical application would stay the same with a small incremental increase in chemical cost.

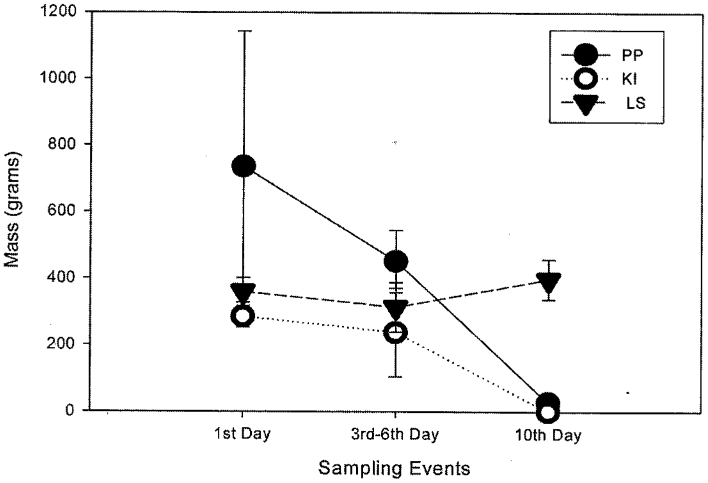

Figure 4. Rake samples. Mean and standard error of plant mass sampled (g dry weight) over the 10-day study period. All plant species were collected with a garden rake and were weighed as described in the results. PP = Paradise Point Marina, KI = King Island Resort, LS = Ladd's Stockton Marina.

Of the 12 separate Lake Maid™ owners surveyed, nine reported that no repairs were required during the entire duration of use. One reported that a single repair was required over three years, and two reported two separate repair instances each. All repairs were performed by the manufacturer under warranty and completed within three weeks of the breakdown event. All owners indicated that they incurred no monetary or labor costs, either in repair or routine maintenance of the Lake Maid™, and reported satisfaction with the product. Although we did not directly measure repair and maintenance over multiple growing seasons, this qualitative survey suggests that routine maintenance and repair would have negligible impact on the control cost for using the Lake Maid™.

The Lake Maid™ can provide effective plant control in small areas and it is comparable to other studied types of non-chemical macrophyte control techniques (e.g., James et al. 2004a). It controlled plant growth in the treatment plots for about half the estimated cost of NPDES permitting and application for Komeen (chelated copper) or Reward (diquat dibromide) in a similar sized area. In addition, amortization of the Lake Maid™ purchase costs over its ten year life span would result in considerably lower per anum costs.

In summary, results from three experimental treatments in the western Sacramento-San Joaquin Rivers Delta, California, suggest that the Lake Maid™ may be a viable option for small infested areas. In two of three locations, it significantly removed nuisance aquatic plants over a 10-day treatment period. Although the underwater rakes of the Lake Maid™ captured much of the up-rooted plants and the clean-up was effective in the treated area, the fact that reproduction and dispersal of these plants via fragments of shoots and rhizomes (rooted or free floating) occurred indicates the need to consider additional factors when evaluating the effectiveness of the Lake Maid™ method (Parsons 1997; Anderson 2000; Greenfield et al. 2004). In the Stockton area, an increased fragment production of egeria and coontail may not impose a higher risk for spreading the plant infestation, since these species are already widely distributed and cover about 3,900 acres in the Sacramento-San Joaquin Delta (Pennington 2004). In areas where there is little additional infestation, the increased fragment production by the Lake Maid™ could have significant consequences. No significant effects on water quality due to operation of the Lake Maid™ were detected. An earlier treatment start date (e.g., in April or May) could have minimized maintenance effort and shortened treatment time due to less plant growth and less density in plant mats in spring and the beginning of the summer. As seen in this study, extremely dense vegetation throughout the entire water column may reduce efficacy of the control device, and require treatment periods greater than 10 days. In comparison to chemical treatments and associated NPDES permitting and monitoring costs, the Lake Maid™ can be cost-effective for treating very small areas of plant infestations in California waterways.

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