# Ludwigia Control Project
## Final Report

### Laguna de Santa Rosa, Sonoma County, California

**February 2008**

Laguna de Santa Rosa Foundation

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# Final Report: Ludwigia Control Project
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### Executive Summary
*Ludwigia* sp. is a non-native invasive aquatic plant from South America that has invaded the Laguna de Santa Rosa watershed. The scale of the invasion threatens water quality, biodiversity and channel capacity and hampers efforts to control mosquitoes. The Ludwigia Control Project (LCP) was a three-year effort to reduce the extent and density of the *Ludwigia* sp. in two of the worst affected areas of the Laguna de Santa Rosa. Spearheaded by the Laguna de Santa Rosa Foundation, the general approach included application of aquatic herbicide followed by mechanical removal of biomass. The total project area comprised 5.3 miles of channel and 99 acres of floodplain.

The results of the effort varied considerably by site and were strongly influenced by water depth and the ability to remove treated vegetation. Deeper channels treated with herbicide and subsequently cleared retained excellent control for two seasons. However, the dry winter of 2007 resulted in low water levels and some of these areas experienced strong late season regrowth as a result. Shallow channels experienced strong regrowth despite successive years of herbicide application and mechanical removal. Shallowly inundated floodplain areas did not have sufficient water during the project season to enable access for mechanical removal equipment. These sites could only be sprayed. Although the herbicide-only treatments reduced the biomass considerably each season, cover remained high throughout the project duration.

Although removal of dense *Ludwigia* mats can improve water quality, spraying plants without removing subsequent decaying biomass further reduces dissolved oxygen and should be avoided except under special conditions.

*Ludwigia* is symptomatic of underlying problems in the Laguna. These problems will be solved only through watershed-level efforts including reduction of nutrient, sediment and summer water inputs, as well as physical changes to the problem areas including large-scale restoration. Because these actions take considerable time, efforts should be taken to ensure that ground gained through the project period is not lost.

## Introduction

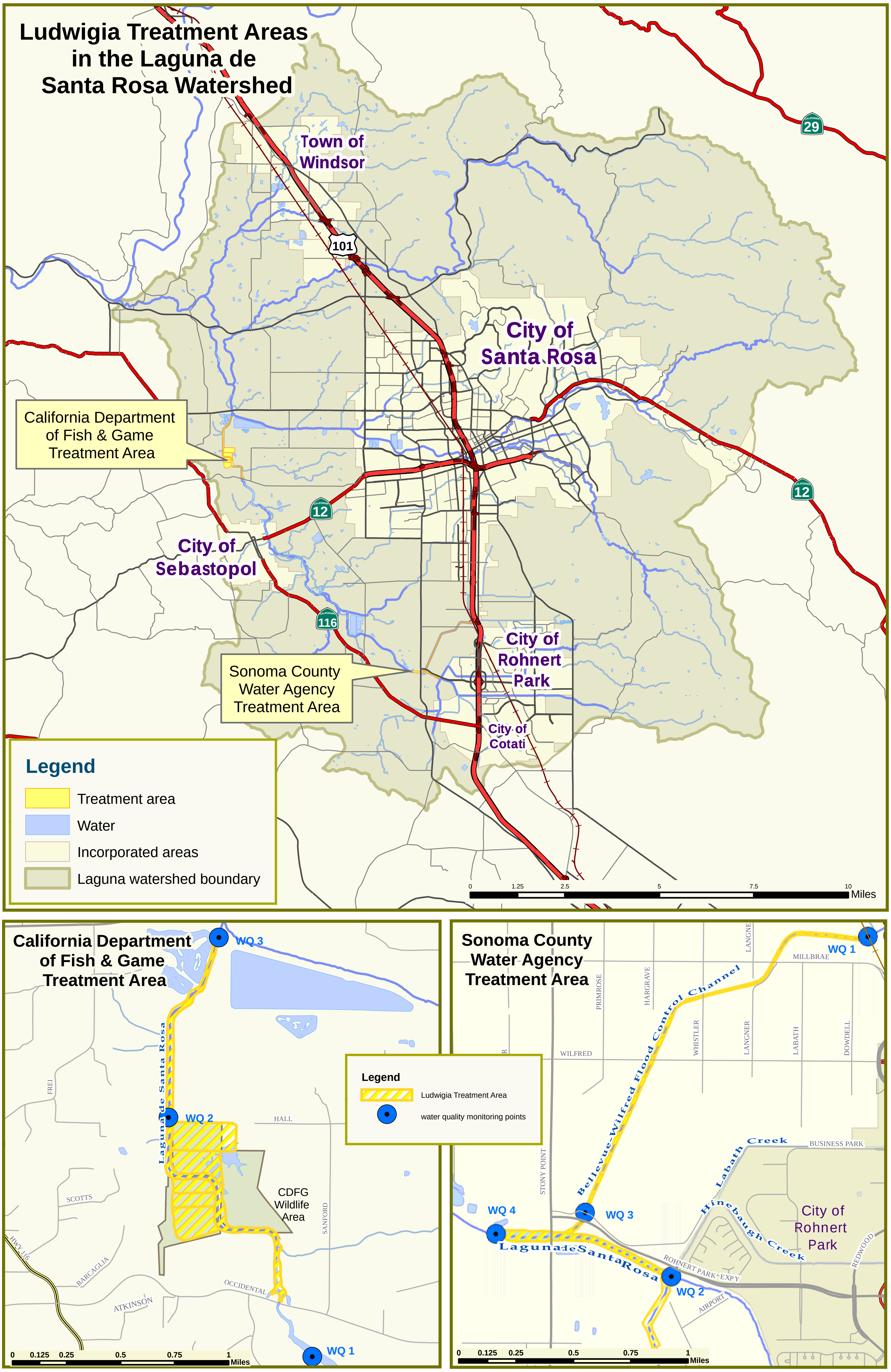
The Ludwigia Control Project (LCP) was a three-year effort to reduce the extent and density of the non-native aquatic plant *Ludwigia* sp. in two of the worst infested areas of Sonoma County's Laguna de Santa Rosa (Figure 1). The aggressive growth exhibited by *Ludwigia* negatively impacts the Laguna in numerous ways. As a strong competitor forming large dense mats over open water, *Ludwigia* contributes to a loss of biodiversity and may drive changes in ecological community dynamics including food webs. Its biomass reduces water holding capacity within the Laguna's channels and may contribute to more frequent and longer duration flooding. Decomposition of accumulated biomass can further depress already low dissolved oxygen levels. Finally, the presence of the thick vegetation mats hampers efforts to control mosquitoes in the Laguna. With the spread of West Nile Virus to Sonoma County, barriers to mosquito control are perceived as a public health threat.

The plan of action included treating *Ludwigia* with herbicide followed by mechanical removal of dead vegetation where feasible. The two field sites included 41 acres of Sonoma County Water Agency (SCWA) maintained channels and 111 acres of the Laguna Wildlife Area owned by the California Department of Fish & Game (CDFG).

The LCP was carried out by the Laguna de Santa Rosa Foundation (Laguna Foundation) and followed the recommendations of the Invasive *Ludwigia* Management Plan for the Laguna de Santa Rosa, Sonoma County, California 2005-2010. The plan was developed by the Laguna Foundation in consultation with the Ludwigia Task Force, a multi-agency group focused on *Ludwigia* issues in the Laguna. Funding for the project was provided by SCWA, California Wildlife Conservation Board, the Marin Sonoma Mosquito & Vector Control District, and the Santa Rosa Subregional Wastewater Treatment Plant. The term of the LCP was 2005-2007.

## Target Invasive Species

Appendix 1 provides a summary of the taxonomic status of the invasive *Ludwigia* species targeted for control as well as information on the *Ludwigia* genus. The summary was prepared by botanical expert Dr. Brenda Grewell of the USDA-ARS.




Laguna de Santa Rosa Foundation © 2008

Map ID: 470-A

# Figure 1

## General Locator Map for Ludwigia Control Sites

within the Laguna de Santa Rosa

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## Project Location

The first project site, owned by SCWA, is located west of Rohnert Park in unincorporated Sonoma County near the intersection of Stony Point Road and Rohnert Park Expressway. It includes a 4,000-foot section of the main Laguna channel (referred to hereafter as Laguna Main), the 11,000-foot Bellevue Wilfred flood control channel (referred to hereafter as BW channel), and a 1,600-foot section of Gossage Creek (Figure 1).

Laguna Main is part of the primary Laguna de Santa Rosa Channel but has been severely altered over the decades. The channel was straightened in the 1960s and widened in 1994. A narrow band of thirty-foot tall willows lines most of the 120-foot wide channel and provides some shading to the channel margins. The channel is fed by numerous tributaries. Although most of the tributaries contain water year-round, only one, Copeland Creek, is naturally perennial. The others are fed by urban and agricultural runoff during the dry season. The substrate is primarily silt with some areas of sand.

BW channel is a straight trapezoidal flood control channel that flows into Laguna Main. BW channel contains water year-round and is fed by urban and agricultural runoff in the dry season. During this time it averages 75 feet in width and 1-3 feet in depth. Some woody riparian vegetation has been planted but the channel is largely unshaded.

Gossage Creek is a tributary to Laguna Main. It retains water year round but is not naturally perennial. There is a well established but narrow riparian strip that provides significant shading to portions of the 40-foot wide channel. The substrate is silt and sand underneath an average depth of 2 feet.

All of the channels are characterized by low energy flow that increases substantially in depth during winter and stands virtually stagnant in summer. Taken together the site spans roughly 41 acres and is bordered by agricultural and rural residential properties. Approximately 90% of the site was covered with *Ludwigia* prior to project activities.

The second site, the CDFG-owned Laguna Wildlife Area, is located north of Sebastopol between Occidental Road and Guerneville Road in unincorporated Sonoma County (Figure 1). Included are 2.1 miles (11,300 feet) of Laguna channel and 99 acres of floodplain which together comprise a total of 111 acres. The channel was created in the 1960s to convey floodwater and to enable reclamation of the floodplain for agriculture. It was dredged regularly until the early 1980s. In 1994 SCWA sold the property to CDFG.

During the dry season the channel averages 46 feet in width and 2 feet in depth. The floodplain is divided by the channel into north and south sections. Previous reports refer to the floodplain area as “flooded fields” because of the former agricultural use and the current state of perennial inundation.

Aerial photos from 1942 depict the site as heavily forested with small ponded areas, channels and possibly emergent marsh. Today the riparian forest is limited to the western edge of the site. Whereas until recently the floodplain would drain each summer, it currently retains up to ½ - 3 feet of water during the dry season. Approximately 15% of the floodplain and 80% of the channel was covered with *Ludwigia* prior to project activities.

The Laguna Wildlife Area is bordered by private lands in the north, south and west. Substantial acreages of the private lands are also infested with *Ludwigia* but were not part of the project area. Landowners were generally interested in seeing the results of the project before including their own properties.

*Permitting*

The project operated under the following permits:

- *Statewide General NPDES Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States.* This permit is issued by the North Coast Regional Water Quality Control Board (RWQCB). A separate permit was required for each site in each of the three years. Each year the Laguna Foundation prepared Aquatic Pesticide Application Plans (APAP) on behalf of SCWA and CDFG. The APAP formed the basis of the NPDES permit.
- *Waiver of Waste Discharge Requirements for Minor Dredging and Fill Activities.* Also known as a 401 permit this RWQCB issued permit was required each year that vegetation removal occurred.
- *County of Sonoma 3836R roiling permit.* This was required at the CDFG Laguna Wildlife Area during years with mechanical removal. SCWA maintenance activities are exempt from this permit.
- *California Environmental Quality Act (CEQA).* The SCWA project site was administered under a Class 1 Categorical Exemption, pursuant to the California Environmental Quality Act, as a maintenance activity on an existing facility. The CDFG project site was also administered under a categorical exemption under Class 4(d), Section 15304 of the CEQA guidelines.

*Public Notification*

Prior to commencement of project activities each year, the Laguna Foundation mailed letters to 55 surrounding households, and issued press releases to the *Santa Rosa Press Democrat*, *West County Times* and the *Rohnert Park Community Voice.* Paid public notices were posted in the *Press Democrat*. During the active season, the Laguna Foundation emailed regular progress updates to over 100 individuals including members of the public, grantors, regulatory agency staff and local officials. Numerous interviews were given to local newspapers and local radio stations throughout the project.

## Methods

*Herbicide Application*

The first step of the two-step process intended to control *Ludwigia* was application of aquatic herbicide to all *Ludwigia* plants within the project area. To avoid any potential take of federally listed salmonids that may pass through the project area during winter and spring months, herbicide application was limited to the period between June 15 and September 30 of each year.

Two herbicides were used, glyphosate and triclopyr. Glyphosate is the active ingredient in several terrestrial and aquatic herbicides and was applied at a rate of 3 quarts per acre.[1] Limited efficacy of this herbicide prompted a switch to triclopyr in the latter half of the 2006 field season.[2] Triclopyr was applied at a rate of 1 quart per acre. Adjuvants included surfactant (Cygnet Plus), drift control agent (Sta-Put), blue dye and water. Herbicides were applied either by truck, airboat or Marshmog.[3] Because the density of the plant prevented the airboat from traveling at controlled speeds, a path had to be cleared using a machine called a cookie cutter. Appropriate best management practices were followed including cessation of application if wind speeds exceeded 10 miles per hour and spraying from downstream to upstream to avoid accumulation of herbicide.

*Vegetation Removal*

Three to five weeks following herbicide application, vegetation was mechanically removed from the sites where feasible. Wide channels were cleared using the cookie cutter and aquatic harvesters. Narrow channels with good access roads were cleared using a long-reach excavator. To reduce the amount of sediment removed by the excavator, a custom "skeleton" bucket was built by the contractor which allowed water and sediment to drain out before loading plant biomass into trucks for disposal.

A floating boom with a silt screen was erected downstream of the removal operations to prevent fragments from floating downstream and to reduce movement of turbid waters offsite. The most effective management practice for reducing turbidity during removal was to operate in an upstream to downstream direction. In this manner, standing *Ludwigia* biomass downstream helped filter sediment moving downstream.

Agreements were made to dispose of the materials in nearby farm fields where it was left to dry before being bulldozed and ultimately disked into the soil. Because significant amounts of trash were intermingled with the biomass, crews pulled out trash once the piles were bulldozed.

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[1] The product used was Glypro, a glyphosate-based herbicide registered for aquatic use. The U.S. Environmental Protection Agency rates glyphosate in its least toxic category for herbicides. Glyphosate is a broad spectrum herbicide and can kill both monocots and dicots.

[2] The product used was Renovate 3, a triclopyr-based herbicide registered for aquatic use. The U.S. Environmental Protection Agency rates triclopyr in its least toxic category for herbicides. Triclopyr is marketed as dicot-specific, it does not kill monocots.

[3] The Marshmog is similar to a snow cat used at ski areas but is designed to operate in up to 3 feet of water.

*Vegetation Monitoring*
Photo monitoring was used to provide a qualitative assessment of the project. A total of 48 photo points were established at the two sites. Photos were taken before herbicide application, after herbicide application and after mechanical removal in each of the three field seasons. An annotated subset of these photos is provided in Appendix 2.

The quantitative assessment was limited to the floodplain of the CDFG site. Four east-west bearing transects (43 plots) were established in the floodplain treatment area.[4] In 2006 one quasi-control transect (5 plots) was established in an adjacent untreated area of privately owned floodplain. Although the untreated area was hydrologically connected to the treatment area, particularly during winter high water, it was chosen because of the absence of physically similar sites upstream. Stagnant conditions in the floodplain helped ensure minimal water exchange between the treated and untreated control site. Transect plots were 4m x 5m and were established every 10-15m. The southwest corner of each plot was marked using a Garmin Vista GPS.[5] Within each plot the cover of each species observed was estimated and assigned a cover class (1: 1-5%, 2: 6-25%, 3: 26-50%, 4: 51-75%, 5: 76-95%, 6: 96-100%).

*Water Quality Monitoring*
Water quality monitoring was an integral part of the LCP as a condition of the NPDES permit and the Waiver of Waste Discharge permit. In response to public concerns about the use of herbicides and to a lesser extent mechanical removal, the RWQCB required substantial water quality monitoring, the intensity of which well exceeded that required by the general permit.

Grab sampling was carried out over the course of the field seasons to analyze multiple water quality parameters. Residual herbicide monitoring, a standard requirement under the NPDES permit, entailed taking grab samples upstream, within, and downstream of the treatment area before, immediately following and 3-7 days post-herbicide application. Samples were shipped on ice to a lab to analyze for residuals of the herbicides, metabolites, and water hardness. Grab samples were also taken at the same locations on a weekly basis and analyzed in the field for dissolved oxygen, temperature, specific conductivity and pH. Equipment included a handheld YSI 85 and a YSI Ecosense pH10 meter. Grab samples were also taken to monitor turbidity during mechanical removal. Turbidity data was collected using a Hach 2100P turbidimeter.

To capture diurnal patterns a continuous monitoring data sonde was deployed downstream of the SCWA project site and upstream and downstream of the CDFG project site. Sondes were deployed 2 weeks prior to herbicide and mechanical removal activities and continued for 2 weeks following completion of activities, though the timing varied from year to year. Sondes collected data every 15 minutes and were typically

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[4] In 2006 and 2007 three additional transects were sampled to better characterize the site. However, it was determined that because the transects had not been sampled prior to herbicide treatments in 2005, the data could not be used.
[5] Because the accuracy of the Garmin Vista GPS is limited to 15 feet, the plots may not overlap entirely in all cases.

deployed for 12-15 days at a time. Data parameters collected included dissolved oxygen, temperature, specific conductivity and pH. Figure 1 shows the sampling locations at each site.

## Results

*Herbicide Application*

At the SCWA site the total project increased in area by 21% from 2005-2007 while the total acreage sprayed with herbicide decreased by 9%. While this suggests herbicide effectiveness, it is likely more complicated. Deeper areas where mechanical removal was possible exhibited little regrowth, particularly in the Laguna Main, and these areas required limited herbicide application in later years. In contrast, the shallow BW channel experienced intense regrowth every year despite repeated herbicide application and mechanical removal. The relationship between regrowth and water depth was reinforced in late 2007 after an exceptionally dry winter left much of the Laguna Main at one third of its normal depth. Despite triclopyr applications, regrowth began at the margins and quickly spread to mid-channel where seeds and new sprouts were exposed to sunlight. By October 2007 much of the Laguna Main was covered with *Ludwigia* (see photo sequence Appendix 2).

At the CDFG site the total project area increased 4% in 2006 with no additional area added in 2007. The acreage treated over the same period decreased by 57%. Again, this appeared to be due largely to factors other than herbicide efficacy. Areas where mechanical removal was possible experienced very minor regrowth in both 2006 and 2007. Removal areas included the entire channel and roughly 5 acres of the floodplain where depth was sufficient to allow access for equipment. However, the rest of the floodplain where removal was impossible experienced strong regrowth after the herbicide application in 2006. In 2007 intense regrowth in this area prompted the Laguna Foundation and CDFG to call off herbicide application in the floodplain except where temporary biomass reductions were beneficial to mosquito control. The channel was treated where necessary.

The switch from glyphosate to triclopyr at both sites was prompted by a visual determination that the glyphosate was not working. Three weeks following the 2006 glyphosate application the majority of the plants showed little sign of impact and many began to flower. Potential reasons for the limited efficacy may have been the high density of *Ludwigia*, which could limit foliar coverage, timing of application, or, in the case of the Marshmog and airboat, the unavoidable coating of the plants in muddy water during application. Glyphosate binds readily to sediment and becomes inactive. It has also been suggested that the rate of application may have limited the efficacy of glyphosate but this is not verified.

Table 1. Summary of volume of herbicide applied, acreage treated, annual changes, and cost per acre, SCWA field site, 2005-2007.

| | Volume of glyphosate applied (gallons)[1] | Volume of triclopyr applied (gallons)[1] | Total acreage of project site | Acreage sprayed[1] | Percentage of site sprayed | % change in acreage of project site since 2005 | % change in acreage sprayed since 2005 | Cost per acre |
|---|---|---|---|---|---|---|---|---|
| **2005** | | | | | | N/A | N/A | $1,294.09 |
| Initial treatment | 17 | 0 | 34 | 23 | 68% | | | |
| Follow-up treatment | 10.4 | 0 | 34 | 14 | 41% | | | |
| **2006** | | | | | | +12% | +43% | $1341.45 |
| Initial treatment | 25 | 0 | 38 | 33 | 87% | | | |
| Follow-up treatment | 0 | 2.5 | 38 | 10 | 26% | | | |
| **2007** | | | | | | +21% | -9% | $1,773.51 |
| Initial treatment | 0 | 5.3 | 41 | 21 | 51% | | | |
| Follow-up treatment | 0 | 2.1 | 41 | 8 | 20% | | | |

[1]Values derived from herbicide use reports submitted by Clean Lakes, Inc.

Table 2. Summary of volume of herbicide applied, acreage treated, annual changes, and cost per acre. CDFG Laguna Wildlife Area, 2005-2007.

| | glyphosate used (gallons)[1] | Volume of triclopyr used (gallons)[1] | Total acreage of project site | Acreage treated[1] | Percentage of site sprayed | % change in acreage of project site since 2005 | % change in acreage sprayed since 2005 | Cost per acre |
|---|---|---|---|---|---|---|---|---|
| **2005** | | | | | | N/A | N/A | $531.96 |
| Initial treatment | 64.88 | 0 | 107 | 87 | 81% | | | |
| Follow-up treatment | 26.25 | 0 | 107 | 35 | 33% | | | |
| **2006** | | | | | | 4% | -28% | $997.74 |
| Initial treatment | 18.19 | 16.59 | 111 | 63 | 57% | | | |
| Follow-up treatment | 0 | 11.63 | 111 | 47 | 42% | | | |
| **2007** | | | | | | 4% | -57% | $636.16 |
| Initial treatment | 0 | 9.25 | 111 | 37 | 33% | | | |
| Follow-up treatment | 0 | 0.75 | 111 | 3 | 3% | | | |

In sharp contrast, the triclopyr, even at the low application rate, impacted the plants almost immediately with leaves wilting and stem strength deteriorating within 24 hours. This raised concerns that the herbicide would fail to act systemically. Systemic herbicides should act more slowly to enable translocation to the roots before the plant completely shuts down.

The average cost of herbicide treatment during the 3-year project period was $1,470 per acre at the SCWA site and $722 per acre at the CDFG site. Cost included the sum total of equipment mobilization, herbicide application, and materials, divided by the number of acres in the initial treatment. Touchup applications were not included because they are considered a re-treatment of the same initial acreage. While these figures can be used to calculate the cost of treating these sites in the future, they do not include the substantial associated costs of project management, reporting, water quality monitoring, and lab analysis. When extrapolating to other areas, local conditions such as access, water depth, vegetation density, economy of scale, and other factors should be considered.

*Vegetation Removal*

Over 12,000 cubic yards of biomass were removed from the SCWA site by the close of the 2005 field season (Table 3). Laguna Main remained virtually free of *Ludwigia* in 2006 and early summer 2007 with most regrowth limited to the channel margins. However, as described above, the shallow conditions prevailing in 2007 resulted in significant regrowth in Laguna Main by the close of the 2007 season.

Regrowth was strong each year in the BW Channel where shallow stagnant water enabled *Ludwigia* to root across the entire channel rather than just the margins. Dredging restrictions largely prohibited removal of sediment; therefore any roots not killed by the herbicide remained intact each year.

In 2007 a new and densely infested section of Gossage Creek was added to the project area bringing the total volume of biomass removed to 24,546 cubic yards.

The bulk of the mechanical removal in the CDFG Laguna Wildlife Area occurred in 2005 when 3,875 cubic yards removed from the channel and a 5-acre section of the floodplain (Table 4). This was the only portion of the floodplain accessible to floating equipment and, as a result, biomass in the rest of the floodplain was left to decompose in place. The cleared areas remained virtually free of *Ludwigia* in 2006 and the project area was extended downstream where another 1,401 cubic yards were removed. By early summer 2007 minor regrowth occurred in the shallower parts of the channel but not enough to justify the cost of removal. As in the SCWA site, shallow conditions prevailed by late 2007 and *Ludwigia* began to regrow in sections of the channel.

Table 3. Summary of mechanical removal in each year, SCWA field site, 2005-2007.

| | Method | Biomass removed (cubic yards) | Acres cleared (acres) | Avg biomass per acre (cubic yards) | Cost per acre of removal[1] |
|---|---|---|---|---|---|
| **2005** | | | | | |
| BW Channel: Millbrae Road to confluence with Laguna | Long reach excavator | 12,126 | 22.7 | 534 | $11,835 |
| Laguna Main from confluence of BW Channel to west end of project area | Cookie cutter and aquatic harvester | | | | |
| Laguna Main from confluence of BW Channel to east end of project area (north half only) | Long reach excavator | | | | |
| **2006** | | | | | |
| BW Channel: Millbrae Road to Rohnert Park Expressway | Long reach excavator | 3,840 | 14.6 | 263 | 4,462 |
| **2007** | | | | | |
| BW Channel: Millbrae Road to Rohnert Park Expressway | Long reach excavator | 8,580 | 17 | 505 | $6,054 |
| Gossage Creek: From confluence with Laguna Main extending 1,600 feet upstream | Excavator | | | | |
| **Total** | | **24,546** | **54.3** | | |

[1]The cost per acre in 2007 is based on 14.6 acres only. The additional 2.4 acres of Gossage Creek removal was carried out by the Sonoma County Water Agency under Laguna Foundation direction. Therefore the project budget was not charged.

Table 4. Summary of mechanical removal in each year, CDFG Laguna Wildlife Area, 2005-2007.

| | Method | Volume of biomass removed (cubic yards) | Acres cleared | Avg biomass per acre (cubic yards) | Cost per acre of removal |
|---|---|---|---|---|---|
| **2005** | | | | | |
| Main Channel: From Occidental Road to north end of north field | Cookie cutter and aquatic harvester | 3,875 | 13.9 | 292 | $17,187 |
| North field: 5-acre pond | | | | | |
| **2006** | | | | | |
| Main Channel: From north field to Gallo ponds | Cookie cutter and aquatic harvester | 1,401 | 3.4 | 350 | $30,627 |
| **2007** | No removal occurred | | | | |
| **Total** | | **5,276** | **17.3** | | |

The average cost of mechanical removal was $7,450 per acre at the SCWA site. When using only the long-reach excavator, as in 2006, the average cost dropped to $5,360 per acre. By comparison the $23,907 average cost of removal at the CDFG site was three times higher. The disparity is related to project size and conditions. A loaded aquatic harvester carries 4 cubic yards of biomass. The marshy conditions throughout most of the project area limited the number of haul out sites available to two. As a result, slow moving harvesters had to travel as much as ½ mile each way from the removal area to the haul out area. This contrasts with the much smaller SCWA site where travel distances were shorter and a substantial portion of the removal work was done with a long-reach excavator working from access roads.

Cost estimates inlcude mobilization of machinery, removal, hauling and disposal of biomass. The cost may be higher or lower depending on vegetation density and access. As with the herbicide application, the cost does not include associated project management and monitoring costs.

*Vegetation Monitoring*
In June 2005, prior to the onset of management efforts at the CDFG site, the cover of *Ludwigia* was extremely high with 79% of all plots sampled (n=43) having 96-100% cover and 91% of plots with greater than 50% cover. No plots were absent of *Ludwigia* in 2005 (Figure 2). By June 2007, following two years of herbicide treatment[6], only 12% of plots had 96-100% cover, 34% had greater than 50% cover and 14% of plots were absent of *Ludwigia*. Untreated control plots (n=5) showed nearly complete coverage by *Ludwigia* in 2006 and 2007 (Figure 3). Although biomass data is not provided, the observed density, stature, and height of *Ludwigia* in the control plots was markedly higher than in the treatment area.

Because *Ludwigia* tends to occupy all available space, the cover of open water was also monitored to help elucidate changes over the project period. In June 2005, only 9% of the sampled area had >50% open water cover (Figure 4). The majority of plots (77%) had 1-5% cover and there were no plots without open water. By 2007, 26% of plots had >50% cover of open water but the majority of plots (57%) had no open water. However, two factors besides the management actions may account for this change. First, the drought conditions of 2007 enabled some areas of the floodplain to dry out. Second, the cover of *Azolla filliculoides* (water fern) in otherwise open water areas increased dramatically. Whereas *A. filliculoides* was not recorded in 2005, it was present in 88% of plots sampled in 2007 (Figure 4). Of these plots, 33% had 96-100% cover of *A. filliculoides*. Whether the rise in *A. filliculoides* was a response to management actions, the low water levels, or some other factor is unknown but there were reports of large outbreaks elsewhere in California.

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[6] In the floodplain, mechanical removal was limited to a small area so the results presented here are primarily from herbicide application only.

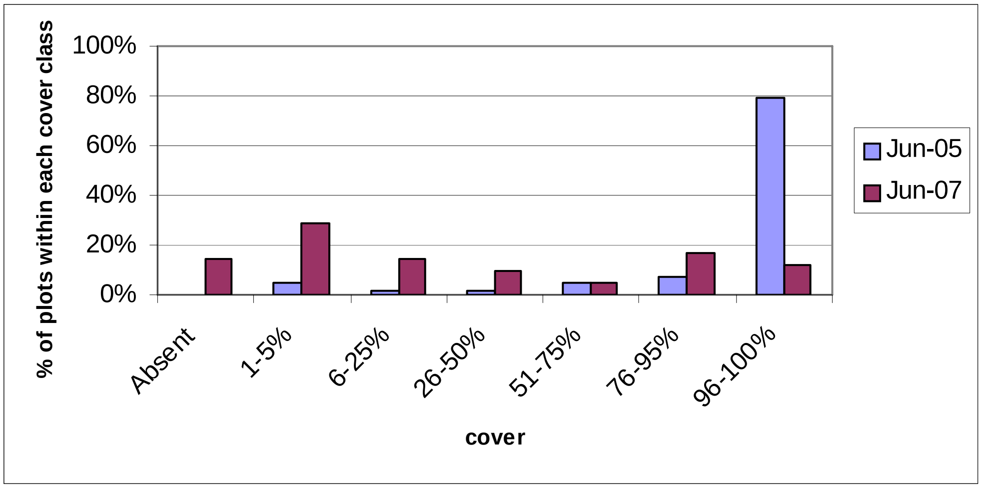


Figure 2. Comparison of the frequency of *Ludwigia* cover classes in the Laguna Wildlife Area floodplain in 2005 and 2007. The floodplain was treated with herbicide twice between the two sampling events. (n=43)

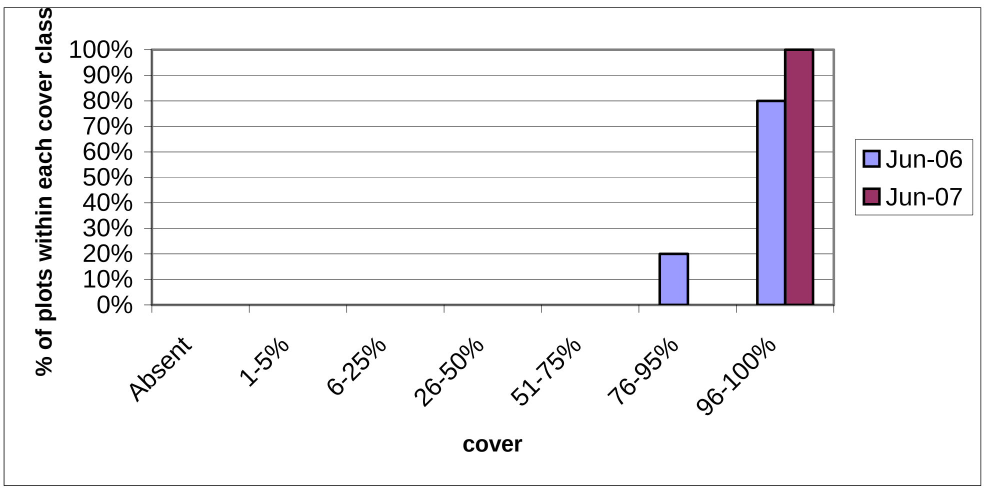


Figure 3. Comparison of the frequency of *Ludwigia* cover classes in the non-herbicide treatment area of the floodplain located adjacent to the Laguna Wildlife Area. (n=5)

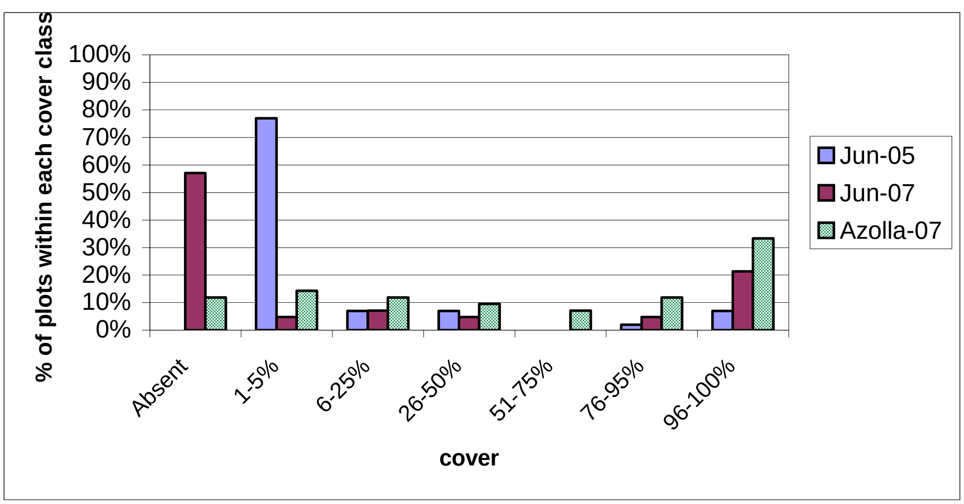


Figure 4. Comparison of the frequency of open water cover classes in 2005 and 2007 and *Azolla filliculoides* in 2007 in the Laguna Wildlife Area floodplain area. (n=43)

Although not reported here, numerous other species were present in the floodplain including *Alisma* sp., *Paspalum distichum, Cyperus eragrostis, Schoenoplectus americanus, Typha latifolia, Xanthium strumarium, Calystegia subacaulis, Lotus* sp., *Myriophyluum aquaticum, Lythrum hyssopifolia, Polygonum* spp., *Rumex crispus, Salix* spp., and several unknown graminoids. All of these species were present in low numbers.

*Water Quality Monitoring*

Residual herbicide monitoring throughout the three-year project period revealed traces of herbicide residue at sampling sites within and downstream of the project areas (Table 5 and 6). Concentrations detected were low in all cases. A summary of the results is presented here.

- **Glyphosate:** This is the active ingredient in the herbicide Glypro. The highest detection at the SCWA site was 59µg/L. The sample was taken at the downstream end of the BW Channel 3-7 days after herbicide application in 2006. The highest detection at the CDFG site was 27µg/L. The water sample was taken downstream of the treatment area 3-7 days after herbicide application in 2005. Glyphosate was also detected at the downstream sampling location prior to herbicide application indicating use by a neighboring landowner. The NPDES General Permit states that the water quality objective (WQO) is 700µg/L. The 96-hour LC50 (concentration lethal to 50% of test organisms) is 120,000 µg/L in bluegill sunfish and 86,000 µg/L in rainbow trout.[7] Glyphosate was not used in 2007.
- **Aminomethyl-phosphonic acid (AMPA):** This is the principal metabolite of glyphosate after it has broken down. Because glyphosate degrades rapidly in the environment, AMPA is an important measure of chemical persistence. The highest detected concentration of AMPA at the SCWA site was 54µg/L. The sample was taken at the downstream end of the BW Channel 3-7 days after herbicide application in 2006. AMPA was not detected in any of the sampling events at the CDFG site. No WQO has been established for AMPA.
- **Limonene:** This is the active ingredient in the surfactant Cygnet Plus. There were no detections of limonene in any sampling events.
- **Triclopyr:** This is the active ingredient in the herbicide Renovate 3. Triclopyr was applied in 2006 and 2007. The highest detection at the SCWA site was 100µg/L. The sample was taken at the downstream end of the BW Channel within 24 hours after application in 2007. The highest detection at the CDFG site was 17µg/L. The sample was taken downstream of the treatment area within 24 hours after the application in 2007. While the NPDES permit does not provide a WQO for triclopyr, the LC50 for this chemical is 117,000 µg/L for rainbow trout and 148,000 µg/L for bluegill sunfish.[8]
- **Oxamic acid:** This is a primary metabolite of triclopyr after breakdown and is an important measure of the persistence of the herbicide. There were no detectable levels of oxamic acid.

[7] http://extoxnet.orst.edu/pips/glyphosa.htm
[8] http://extoxnet.orst.edu/pips/triclopy.htm

Table 5. Summary of residual herbicide and metabolites, surfactant and water hardness in upstream, within and downstream project locations taken before, immediately following and 3-7 days following herbicide application at the SCWA field site, 2005-2007.

| | **glyphosate (µg/L)** | | | **aminomethyl phosphonic acid (µg/L)** | | | **triclopyr (µg/L)** | | | **oxamic acid (µg/L)** | | | **limonene (µg/L)** | | | **Hardness (mg/L)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 |
| **Before herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ1 (upstream) | ND | ND | - | ND | ND | - | - | ND | ND | - | ND | ND | ND | ND | ND | 330 | 340 | 380 |
| WQ2 (upstream) | ND | ND | - | ND | ND | - | - | ND | ND | - | ND | ND | ND | ND | ND | 300 | 300 | 280 |
| WQ3 (within) | - | ND | - | - | ND | - | - | ND | ND | - | ND | ND | - | ND | ND | - | 400 | 410 |
| WQ4 (downstream) | - | ND | - | - | ND | - | - | ND | ND | - | ND | ND | - | ND | ND | - | 330 | 320 |
| **Within 24 hrs following herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ3 (within) | - | - | - | - | - | - | - | - | 100 | - | - | ND | - | - | ND | - | - | 430 |
| WQ4 (downstream) | ND | 6.7 | - | ND | ND | - | - | 4 | 29 | - | ND | ND | ND | ND | ND | 240 | 260 | 370 |
| **3-7 days post herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ1 (upstream) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| WQ2 (upstream) | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| WQ3 (within) | 28 | 59 | - | 9.2 | 54 | - | - | - | 80 | - | - | ND | ND | - | ND | 310 | 400 | 430 |
| WQ4 (downstream) | ND | 9.2 | - | ND | 10 | - | - | 7.6 | 14 | - | ND | ND | ND | ND | ND | 330 | 290 | 350 |

ND indicates no detection
– indicates that no analyte was submitted for the given date or parameter, per the NPDES monitoring requirements

Table 6. Summary of residual herbicide and metabolites, surfactant and water hardness in upstream, within and downstream project locations taken before, immediately following and 3-7 days following herbicide application at the CDFG Laguna Wildlife Area, 2005-2007.

| | **glyphosate (µg/L)** | | | **aminomethyl phosphonic acid (µg/L)** | | | **triclopyr (µg/L)** | | | **oxamic acid (µg/L)** | | | **limonene (µg/L)** | | | **Hardness (mg/L)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 | 2005 | 2006 | 2007 |
| **Before herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ1 (upstream) | ND | ND | - | ND | ND | - | - | ND | ND | - | ND | ND | ND | ND | ND | - | 230 | 230 |
| WQ2 within) | ND | ND | - | ND | ND | - | | ND | ND | | ND | ND | ND | ND | ND | - | 190 | 190 |
| WQ3 (downstream) | 6.4 | ND | - | ND | ND | - | - | ND | ND | - | ND | ND | ND | ND | ND | - | 210 | 73 |
| **Within 24 hrs following herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ3 (downstream) | ND | ND | - | ND | ND | - | - | ND | 17 | - | ND | ND | ND | ND | ND | 140 | 190 | 240 |
| **3-7 days post herbicide application** | | | | | | | | | | | | | | | | | | |
| WQ1 (upstream) | - | ND | - | - | ND | - | - | ND | - | - | ND | ND | - | ND | ND | - | 220 | 210 |
| WQ2 (within) | - | ND | - | - | ND | - | - | ND | 1.6 | - | ND | ND | - | ND | ND | - | 150 | 74 |
| WQ3 (downstream) | 27 | ND | - | ND | ND | - | - | ND | 13 | - | ND | ND | ND | ND | ND | 240 | 190 | 160 |

ND indicates no detection
– indicates that no analyte was submitted for the given date or parameter

The physical characteristics of the grab sample locations within and between project sites were vastly different in terms of depth, width, flow, and canopy cover making it difficult to draw meaningful comparisons between them or to relate the data to project activities. Furthermore, grab samples were only taken during daylight hours so the strong diurnal fluctuations common to the Laguna were not captured.

In its Basin Plan, the RWQCB set numeric water quality objectives for dissolved oxygen (DO) and pH in the North Coast Region.[9] In 2007 the dissolved oxygen levels were frequently well below the minimum water quality objective, even at the upstream monitoring sites (Table 7). Minimum values typically occurred in the morning before photosynthesis caused the concentration to rise. Maximum DO concentrations often coincided with supersaturated conditions in the late afternoon when photosynthesis was at its peak. DO values at the downstream end of the CDFG site (WQ3) never rose above the minimum water quality objective of 7.0 mg/L. This held true even before management activities began for the season. However, continuous monitoring sondes did record values above the WQO at night. The extremely low 0.3 mg/L DO value at this site was recorded on October 26, 2007 following the flooding of a nearby field that had recently been disked. The field contained high *Ludwigia* cover but was not part of the project area. Water pH was mostly within the water quality objective at all locations.

Turbidity was the biggest water quality issue directly attributable to management activities in all years. Specifically, mechanical removal was responsible for temporary spikes in turbidity. Figure 5 compares turbidity levels at upstream and downstream sampling locations of the SCWA field site during the 2007 field season and identifies when removal operations occurred. At the downstream sampling location the average turbidity increased 39% during the Gossage Creek removal operations and 127% during the BW Channel removal operations. Background turbidity levels resumed within a week.

Although no mechanical removal took place at the CDFG site in 2007, Figure 6 provides a sense of background conditions upstream, within and downstream of the site based on a limited number of grab samples. The upstream sampling site, characterized by its 150-foot wide channel and 15-foot depth, averaged higher turbidity than the narrow and shallow downstream location. Turbidity values taken within the project site were highest. This was also the shallowest sampling location. Downstream values were, on average, lower than upstream turbidity values. Figure 7 provides a more detailed look at turbidity at the downstream location. The data sonde at this location was equipped with a turbidity probe. Figure 7a spans June 30-July 26, 2007. Turbidity values are concentrated between 25 and 55 NTU. The same concentration is evident during the period September 8-20 (Figure 7b). Outlying values occur frequently but are not correlated to any particular management actions or time of day. The largest outliers were eliminated from the data set.

[9] http://www.waterboards.ca.gov/northcoast/programs/basinplan/basin.html

The most effective measure taken to reduce turbidity was to work from upstream to downstream thus allowing the existing vegetation to filter turbid water moving downstream. Installation of a silt curtain also helped contain turbid waters.

Table 7. Maximum, minimum, and average values for daytime grab samples taken at monitoring stations WQ1-WQ4, June-October 2007, SCWA field site.

| | **DO%** | **DO (mg/L)** | **Temp (C)** | **pH** |
|---|---|---|---|---|
| *Basin plan water quality objective* | *none* | *7.0 minimum* | *none* | *6.5-8.5* |
| **WQ1** | | | | |
| max | 127.6 | 11.3 | 28.9 | 8.5 |
| min | 26.6 | 2.5 | 15.9 | 7.0 |
| avg | 90.0 | 7.6 | 22.7 | 8.0 |
| **WQ2** | | | | |
| max | 132.1 | 10.9 | 25.0 | 8.2 |
| min | 32.1 | 3.1 | 15.2 | 0.0 |
| avg | 58.9 | 5.4 | 19.5 | 7.8 |
| **WQ3** | | | | |
| max | 138.0 | 10.4 | 30.4 | 8.5 |
| min | 28.4 | 2.5 | 16.0 | 0.0 |
| avg | 84.4 | 6.8 | 24.9 | 7.8 |
| **WQ4** | | | | |
| max | 219.9 | 17.3 | 29.3 | 8.2 |
| min | 17.2 | 1.5 | 16.1 | 7.1 |
| avg | 78.4 | 6.5 | 23.0 | 7.7 |

Table 8. Maximum, minimum, and average values for daytime grab samples taken at monitoring stations WQ1-WQ3 June-October 2007, CDFG Laguna Wildlife Area.

| | **DO%** | **DO (mg/L)** | **Temp (c)** | **pH** |
|---|---|---|---|---|
| *Basin plan water quality objective* | *none* | *7.0 minimum* | *none* | *6.5-8.5* |
| **WQ1** | | | | |
| max | 171.5 | 14.0 | 28.9 | 8.7 |
| min | 34.0 | 2.9 | 18.4 | 7.0 |
| avg | 83.0 | 6.8 | 24.8 | 7.9 |
| **WQ2** | | | | |
| max | 105.4 | 8.5 | 30.8 | 7.8 |
| min | 9.5 | 0.9 | 14.3 | 6.6 |
| avg | 51.9 | 4.3 | 23.3 | 7.4 |
| **WQ3** | | | | |
| max | 76.8 | 6.3 | 34.9 | 8.3 |
| min | 2.6 | 0.3 | 16.0 | 6.9 |
| avg | 33.5 | 2.8 | 22.9 | 7.6 |

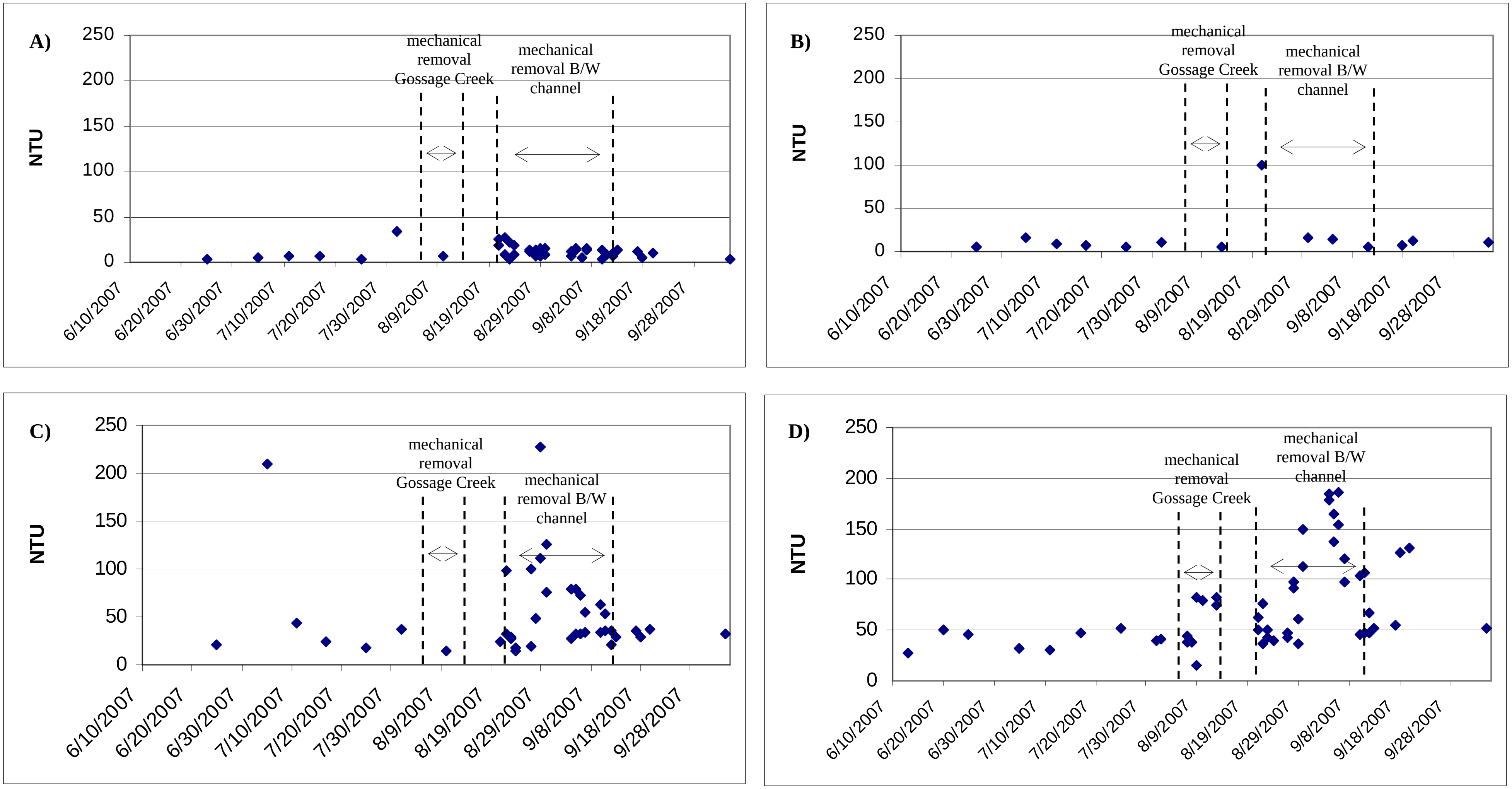


Figure 5. Turbidity grab sample monitoring at upstream and downstream locations at the SCWA field site, June-Sept, 2007. A) Sampling point WQ1 located upstream of project site in Laguna Main channel. B) Sampling point WQ2 located at the upstream end of the Bellevue Wilfred Channel. C) Sampling point WQ3 located at downstream end of Bellevue Wilfred Channel. D) Sampling point WQ4 located downstream of project site in Laguna Main channel. Mechanical removal activity occurred from August 6-13 in Gossage Creek and August 21-September 12 in Bellevue Wilfred Channel.

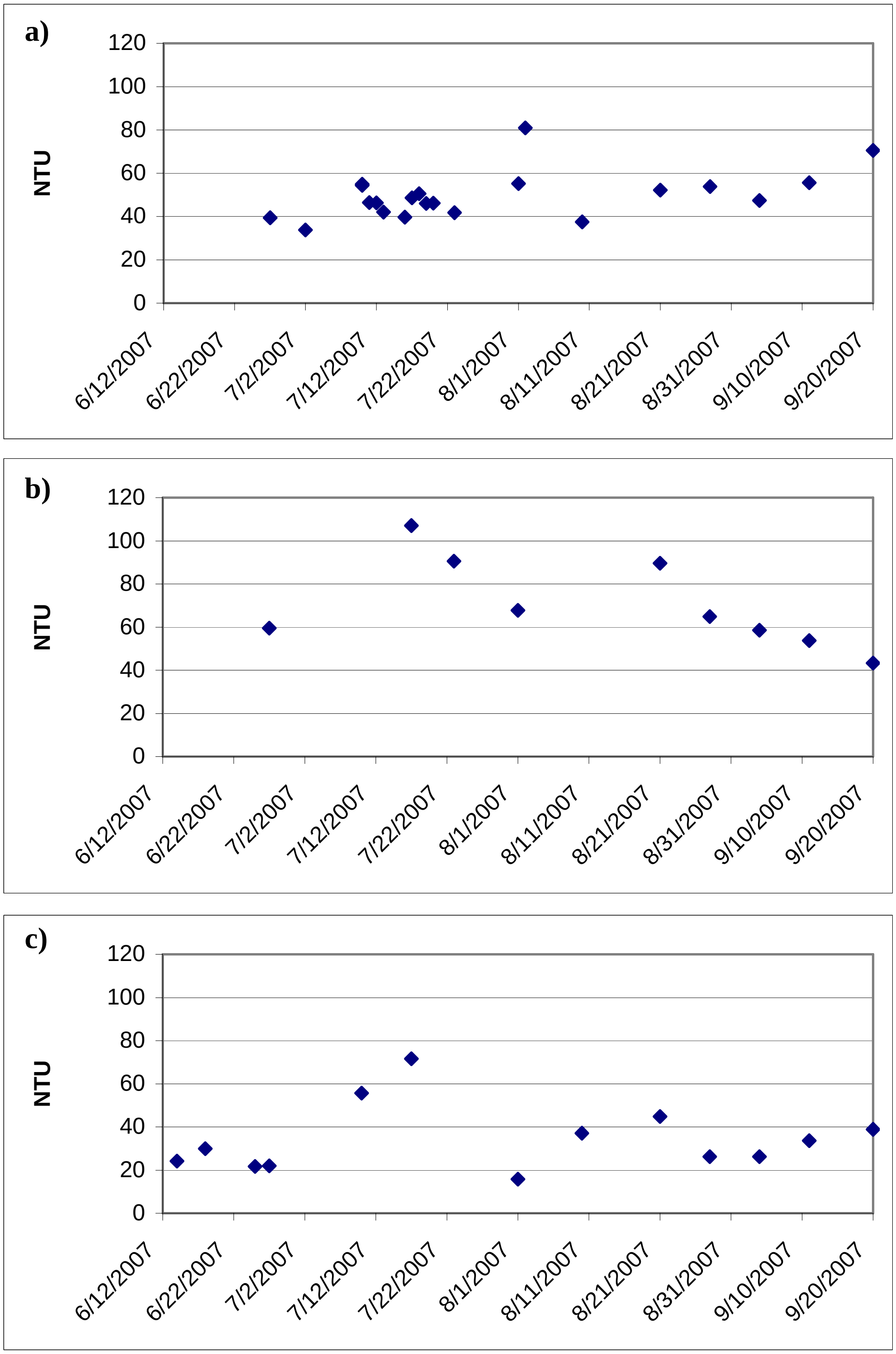


Figure 6. Turbidity grab sample monitoring, CDFG Laguna Wildlife Area, June-September, 2007. A) Sampling point WQ1 located upstream of the treatment area. B) Sampling point WQ2 located within the treatment area. C) Sampling point WQ3 located downstream of the treatment area.

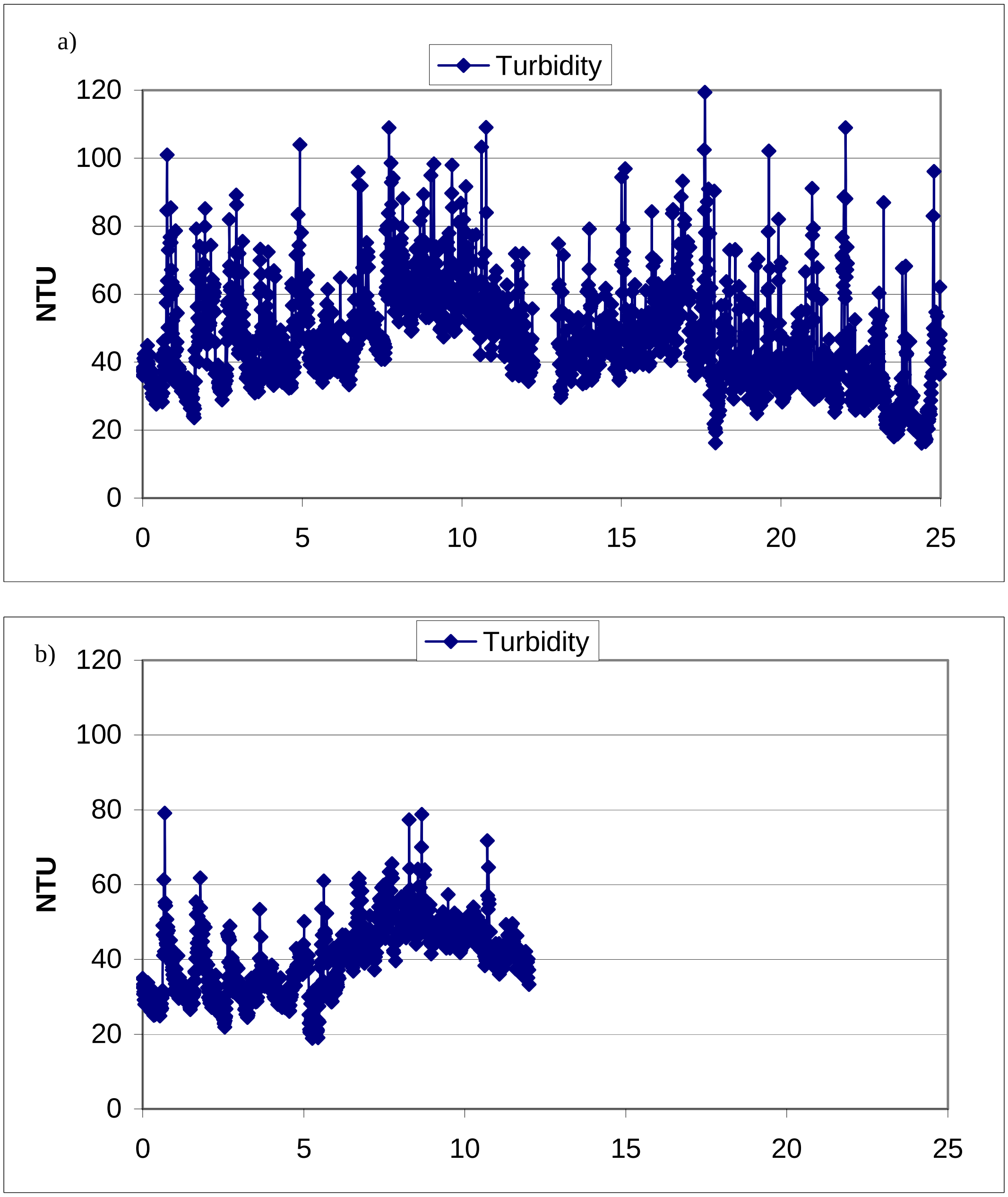


Figure 7. Turbidity monitoring data collected using data sonde at downstream sampling site (WQ3), CDFG Laguna Wildlife Area from a) June 30-July 26, 2007 and b) September 8-20, 2007.

As with turbidity, continuous monitoring sondes provided the largest data set for other water quality parameters and captured important diurnal fluctuations at the project sites. However, a combination of user error and frequent equipment malfunction during data sonde operations reduced the amount of usable data through the project period. For example, during much of the 2005 field season the sonde was deployed at a location downstream of the SCWA site that was not properly connected to the project site during low flow periods (i.e. summer). The site, chosen jointly by the Foundation, its consultants, and RWQCB staff, was relocated late in the season after the site dried. The 2005 data would have been the most informative year because it represented the before and after effects of herbicide and mechanical removal during the year in which the cover of *Ludwigia* was by far the largest.

Nonetheless, available data from 2007 reveals important patterns at both sites and provides a picture of the water quality response to herbicide application. Generally speaking, the Laguna exhibits typical diurnal patterns with regard to dissolved oxygen (DO) and temperature. However, the range between the high and low DO values is wide and lows are well below the Basin Plan objectives. Figure 8 illustrates continuous daily temperature and DO (% saturation and concentration) data collected by the data sonde at the downstream end of the SCWA site from June 26-July 3. The dissolved oxygen level rises from roughly 11 am to 10 pm and is consumed from 10 pm to 11 am. Peak concentrations occur from 6-9 pm while minimum concentrations occur from 8-10 am. Super saturation, a condition in which the dissolved oxygen level is greater than 100% of the water's oxygen holding capacity at a given temperature, occurs between 4 and 10 pm. Super saturation occurs in water bodies where water is agitated, as in a cascade, or water bodies in which algal production is high.

Herbicide applications made on June 27, June 29 and July 2 did not appear to disrupt the diurnal patterns. This suggests that two years after the removal of the large quantity of biomass in Laguna Main, *Ludwigia* was no longer the principal driver of photosynthetic oxygen production or the primary consumer of oxygen through respiration or decomposition. Although this seems likely given the low cover of *Ludwigia* and other aquatic vegetation in Laguna Main during the application period, the data is unavailable for the week following the herbicide application due to equipment failure. It is possible that a delayed impact would have been apparent. DO values later in the season were lower on average but this trend was observed in all monitoring locations including areas upstream of the project.

Downstream of the CDFG site the data sonde revealed a decline in both the high and low dissolved oxygen values beginning 3-5 days after herbicide application (Figure 9). The greater cover of *Ludwigia* in the channel at this site suggests that spraying *Ludwigia* and leaving the biomass in the water does lead to a measurable decline in DO and the downward trend continues through the season.

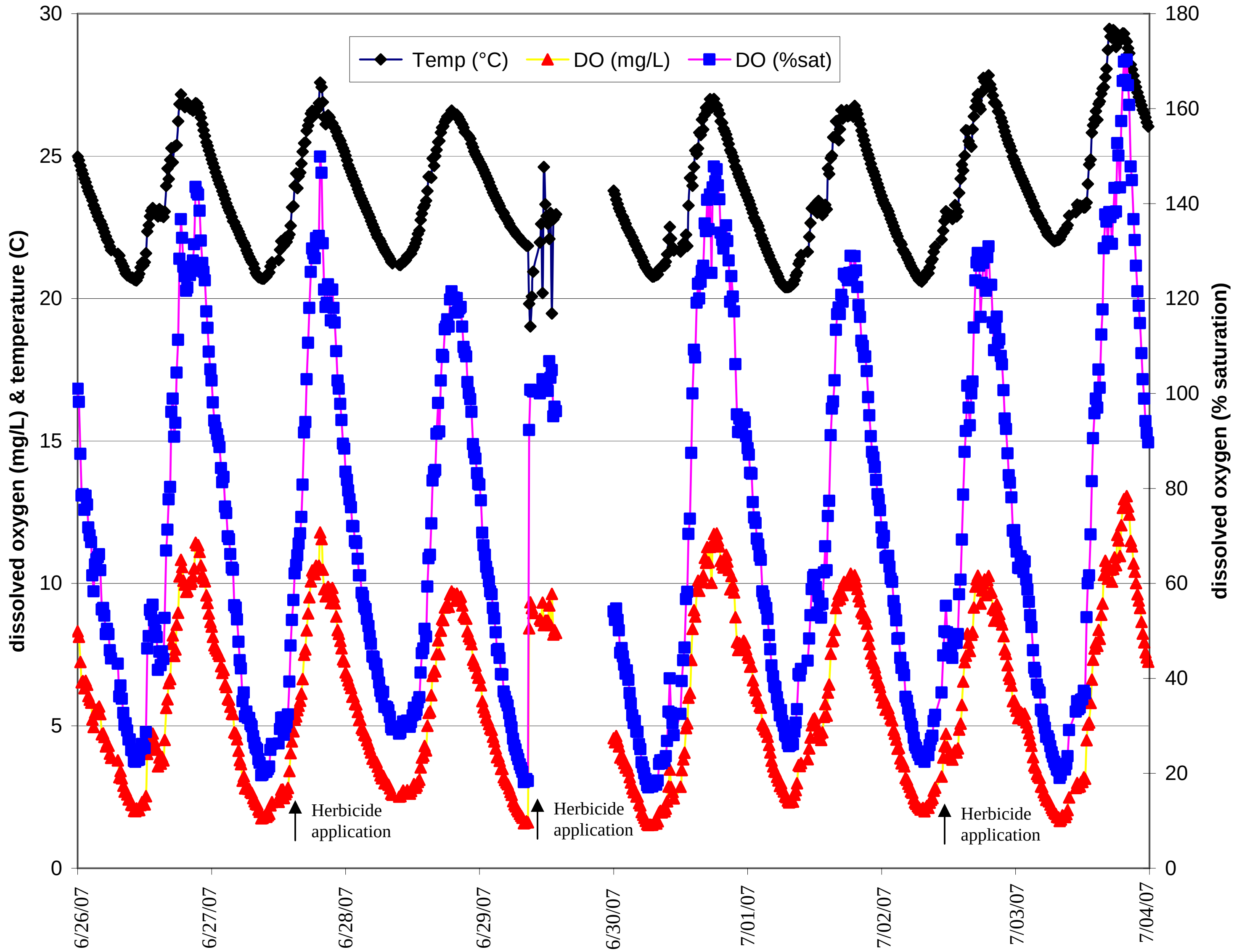


Figure 8. Continuous monitoring sonde data for the period June 26-July 3, 2007 located downstream of the SCWA site (WQ4). Three herbicide applications occurred during this period. The data sonde was pulled from the water for cleaning and calibration on June 29 resulting in a data gap.

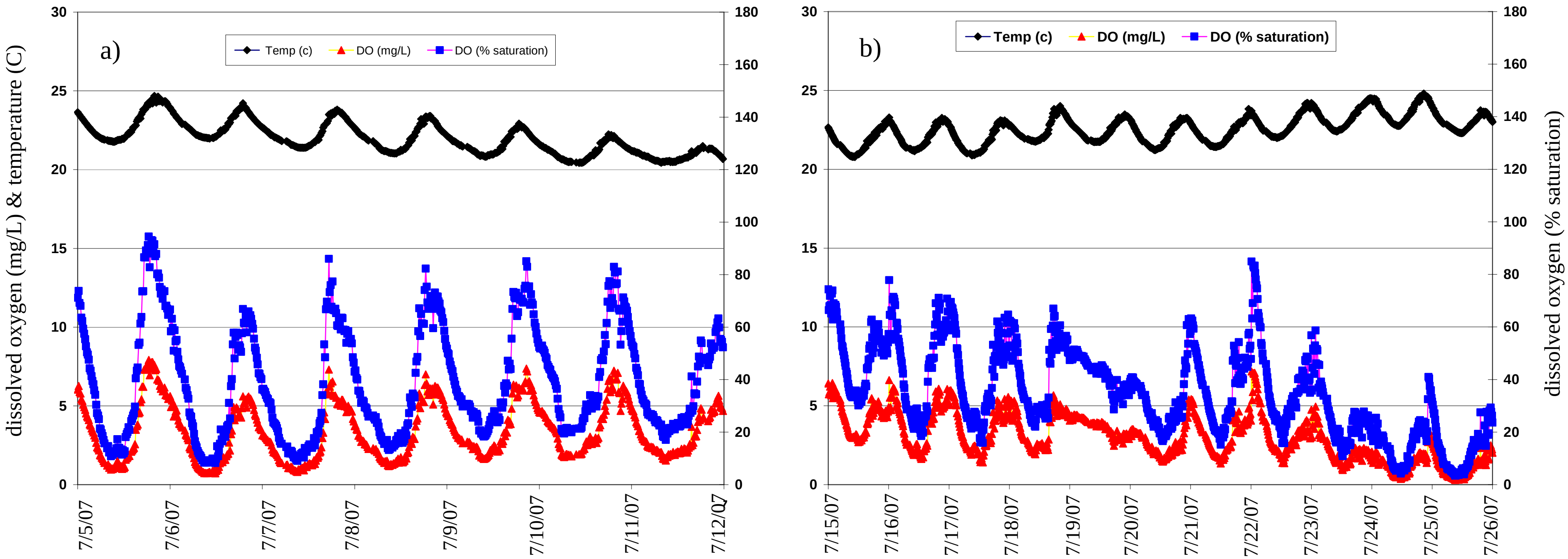


Figure 9. Continuous monitoring sonde data for the period a) July 5-12, 2007 and b) July 15-25. The sonde was located downstream of the CDFG site (WQ3). Herbicide application occurred on July 11 and July 12.

## Mosquito Control

A primary driver of this project was mosquito control. In 2002 the Marin Sonoma Mosquito & Vector Control District expressed concerns about the cost and difficulty of controlling mosquitoes in densely infested *Ludwigia* areas and the related public health threat posed by West Nile Virus, a mosquito borne disease. Although the issues of biodiversity, water quality, and channel capacity were equally important, the mosquito issue provided the most urgent call to action. Some community members even postulated that the presence of *Ludwigia* increased mosquito production though this has not been accurately tested or verified. It is more likely that *Ludwigia* areas appeared to have higher production because mosquito control operations were less effective there.

Table 9 summarizes data on adult mosquito abundance and larvicide operations from 2005-2007 at *Ludwigia* control sites. It is recognized that presence or lack of adult mosquitoes does not prove or disprove elevated or reduced larval levels; it is impossible to know the origin of the adults. What is clear, however, is that the acreage requiring larvicide treatments declined substantially over the project period. Although this may have been due to the LCP, other factors such as rainfall and temperature may also have contributed to decline.

Table 9. Summary of mosquito trapping and larvicide application at Ludwigia project sites, 2005-2007. Data submitted by Marin/Sonoma Mosquito & Vector Control District.

| | **Number of adults trapped** | **Number of larvicide applications applied** | **Total number of acres treated** |
|---|---|---|---|
| **SCWA: Bellevue Wilfred Channel** | | | |
| 2005 | 3,819 | unknown | 19.5 |
| 2006 | 314 | unknown | 10.8 |
| 2007 | 641 | 0 | 0 |
| **SCWA: Laguna Main Channel** | | | |
| 2005 | 4,022 | unknown | 14.3 |
| 2006 | 195 | 0 | 0 |
| 2007 | 1,200 | 1 | 0.2 |
| **CDFG: Laguna Wildlife Area** | | | |
| 2005 | 731 | 5 | 326.5 |
| 2006 | 1191 | 16 | 221.5 |
| 2007 | 531 | 4 | 15.2 |

## Discussion

Herbicide application provided mixed results, many of which are difficult to disentangle from other contributing factors including annual precipitation, spring air temperature, channel size and depth, herbicide application rate, and whether biomass was removed after spraying. However, in general, the pattern from the two sites is clear. Areas in which *Ludwigia* was sprayed and then removed provided control for 2 years *if* the water was deep, though minor touchup spraying was required. Under shallow water conditions these methods appear unable to provide effective control for even a single season. Application of herbicide to densely infested areas where biomass cannot be removed is not effective and contributes to poor water quality. Application of herbicide to small patches along channel margins may provide sustained control as long as applications occur every year.

Although both glyphosate and triclopyr are systemic herbicides, neither seemed to act systemically. The fact that glyphosate adsorbs readily to soil particles and becomes inactive makes it a poor choice of herbicide if conditions require the use of airboats or Marshmogs to drive over plants. This equipment causes plants to become coated with muddy water. However, this is not sufficient to explain its failure to provide control because large areas, such as the BW channel, were treated from the bank and therefore were not coated by muddy water during the application.

The label for Renovate 3, the triclopyr-based herbicide, recommends an application rate of 2-8 quarts per acre for aquatic and emergent weeds including water primrose (*Ludwigia*). Even at the greatly reduced rate of 1 quart per acre triclopyr acted too quickly on *Ludwigia* and generally failed to work systemically as a result. Therefore under shallow water conditions Renovate 3 also seems like a poor choice for control of *Ludwigia*, particularly if the biomass cannot be removed following the application.

It is important to repeat that the herbicides used may have been more effective at different application rates. For instance, glyphosate has been used effectively in other parts of California but there is little data reporting on the duration of control.

Each year herbicide applications occurred between June 15 and September 30 in compliance with NOAA Fisheries regulations. Yet in a typical year *Ludwigia* has already experienced significant growth and gained competitive advantage by June 15. This prompted discussion of an earlier application to young plants as soon as they emerge. This might work if the *Ludwigia* plants are directing more photosynthetic energy to root development at this time and if the herbicide truly works systemically. However, in areas where *Ludwigia* is well established, observations suggest that an early application might kill the early growth but as water levels drop through the growing season newly exposed banks will be open to a second wave of growth. This would require an additional application. If the water level dropped enough, as it did in 2007, *Ludwigia* could then begin to grow from the middle of the channel and require yet another application. Nonetheless, this approach may be worthy of a test. But if spraying occurs prior to June 15, a salmonid take permit would be required.

Although this discussion of herbicide use suggests that it is ineffective against *Ludwigia*, it should be acknowledged that different site conditions can yield very different results. For example, one area within the SCWA site dried out following the droughty winter of 2007. This was an area where mechanical removal had never been possible (southeast section of Laguna Main channel). Following one season of glyphosate treatment and two seasons of triclopyr treatment the site was nearly free of *Ludwigia*. Numerous other species quickly colonized the available mudflat including *Polygonum* spp. and various graminoids. This suggests that in addition to deep water, the absence of water can control or limit the growth of *Ludwigia*, particularly if it is sprayed with herbicide.

However, because most of the problem areas in the Laguna do not dry out, the continued use of herbicide (triclopyr), if any, should be limited to areas where biomass is low, areas where immediate control is needed (e.g. for mosquito control), or areas where it is part of an active restoration plan. Herbicide should not be applied to large patches unless it can be removed. In all cases herbicide should be considered a temporary fix while more effective solutions are planned. Efficacy trials using the herbicide Habitat (active ingredient imazapyr) to control *Ludwigia* are underway elsewhere in California and may yield better results.

As mentioned, herbicide application followed by mechanical removal provides longer lasting control in areas where the water is deeper. Although *Ludwigia* produces adventitious roots from its floating nodes, it must ultimately root in sediment. In deeper water the available rooting surface is limited to the channel margin. The plant must then “creep” across the surface. Although the minimum water depth required is unknown, observations over the three years suggest a minimum of 3 feet of water. Given time, however, *Ludwigia* will easily cover the water surface at this depth. Areas that had remained open prior to the onset of project activities were more on the order of 5 or more feet deep.

It is unclear whether spraying herbicide prior to mechanical removal increases control. The practice of spraying first is intended to reduce the threat of spreading fragments downstream. However, floating booms erected to prevent turbid waters from moving downstream should also serve to collect floating fragments. If so, it may be more effective to remove the vegetation first and then spray regrowth. This would also result in less volume of herbicide being used. Regardless of the order of operations, however, lasting control is unlikely with either spraying or mechanical removal alone though these actions may be an important component in larger restoration plans.

It is important to understand how water quality is affected by both the presence of *Ludwigia* and by efforts to control it. As a photosynthesizing macrophyte, *Ludwigia* helps boost dissolved oxygen levels each day just as it consumes oxygen each evening during respiration. As a dense mat it may even help mediate extreme temperature fluctuations in shallow water. But the effect of the decomposition on dissolved oxygen probably outweighs any benefits. Spraying *Ludwigia* without removing it amounts to a speeding up of this process and is detrimental to the system. Additionally, allowing the biomass to decompose in place releases all the stored nutrients back into the system, a process that may boost further *Ludwigia* growth. In all of this it is important to remember that although *Ludwigia* can affect water quality in both negative and positive ways, its presence is a response to poor water quality and ecosystem perturbation, not a cause.

## Conclusion

The three-year effort to control *Ludwigia* through herbicide application and mechanical removal has yielded mixed results at considerable cost. The degree and duration of control are closely linked to physical conditions at the site and annual variations in temperature and precipitation. Clearly there continues to be a need to address to the underlying conditions that promote *Ludwigia* growth in the watershed. Long-term *Ludwigia* control will require systemic approaches that address the primary stressors in the Laguna. Reducing inputs of nutrients and sediment is paramount. This process will begin when the Regional Water Quality Control Board completes its TMDL pollution plan, sometime around 2011. Although measurable differences may be more than a decade away, it is a positive step.

The focus in the shorter term should shift to manipulation of physical conditions as part of larger restoration plans. Perhaps the most effective action will be water level manipulation. This entails creating conditions that promote either deep water or the absence of water during summer months. Methods may include targeted sediment removal, creation of low flow channels, and reduction of summer irrigation runoff. Because accumulated sediment is very likely enriched with nutrients, its removal in key areas will also serve to remove accumulated nutrients from the system. Because sediment removal will create considerable disturbance, it should always be accompanied by restorative actions such as establishment of riparian forest.

## Recommendations

Management of *Ludwigia* within the Laguna watershed and within the current project sites will require sustained attention over the long term. This section begins with an update and recommendations for strategies to improve conditions and to prevent further introductions in the watershed. Following this are short and long term recommendations for both the SCWA field site and the CDFG Laguna Wildlife Area. Because some of the ideas presented here are under development and have not been approved by stakeholders, only general descriptions are provided.

<u>Watershed-level strategies</u>

*TMDL*
The Laguna provides ideal conditions for rampant growth of *Ludwigia* and other invasive aquatic species. Abating this threat will require reduction of future inputs of sediment and nutrients. This is the purpose of the TMDL pollution plan recently initiated by the RWQCB and expected to be completed by 2011. RWQCB will set numeric objectives for nitrogen, phosphorous, sediment, dissolved oxygen, temperature, and mercury and increase awareness of the specific actions needed to meet these objectives.

*Coordinated restoration and management*
Many agencies and organizations that work within the watershed are involved in restoration and management projects. There is a growing awareness of each other's work and increasing desire to collaborate. The Laguna Foundation convened its first Laguna Watershed Stakeholder Council meeting in October 2007 in which several agencies and organizations shared the work they were doing in the watershed. These meetings will continue to be held and it is hoped that smaller committee meetings on special topics will evolve out of this process.

*Public education*
The threat of new introductions of *Ludwigia* and other highly invasive species is omnipresent. Public education through interpretive signage can serve as a strong preventative measure at likely introduction points such as Spring Lake and Lake Raphine as well as at already invaded sites like Riverside Park. Outreach to local aquatic plant nurseries will also be important.

<u>Strategies for the SCWA field site – Short Term</u>

*Channel Maintenance*
It is important not to lose ground gained during the project period. This will require ongoing maintenance until physical conditions at the site are no longer conducive to *Ludwigia* growth. Recommended actions include mechanical removal followed by herbicide application to regrowth if needed. This reversal of the order of operations is derived from lessons learned and is intended to reduce the volume of herbicide used. Mechanical removal also serves to remove stored nutrients from the system. Because

live fragments will be created during removal, floating booms must be erected downstream to capture these potential propagules.

Channel maintenance is proposed every 2-5 years until longer term actions are accomplished. The frequency will be dictated by conditions. A long-reach excavator is recommended for removal in the BW channel and Gossage Creek and an aquatic harvester in the Laguna Main. Because the cost of contracting aquatic harvesters is very high, purchase of the equipment is strongly recommended. The most logical owner of the harvester would be SCWA or the Marin/Sonoma Mosquito and Vector Control District.

Strategies for the SCWA field site – Long Term

*Reduction or elimination of summer water inputs*

The only perennial stream entering Laguna Main is Copeland Creek yet summer flows occur in many local tributaries including Hinebaugh Creek and Gossage Creek. There is no perennial water source entering the BW channel yet it retains flow year-round. The likely sources are irrigation runoff into storm drains from agriculture, private lawns, golf courses, and car washing. This runoff is almost certainly rich in nutrients from fertilizers. Adding nutrient rich water to accumulated sediments in the infested areas perpetuates the ideal growing conditions for *Ludwigia* and other aquatic invasives in the Laguna. The first step in reducing or eliminating this input will be identification of sources through monitoring. This should begin immediately in summer 2008. Once major contributors of water are identified, essential efforts can be made to reduce or eliminate the input.

*Low flow channels and targeted sediment removal*

Although the elimination of *Ludwigia* is unlikely, containing its extent is possible by reducing the amount of channel available for colonization. Low flow channels can be created within the pre-existing channels to confine summer flow to a smaller area. In concept a low flow channel can be made deep enough to limit *Ludwigia* to its margins and the remainder of the channel would then dry out creating the two conditions that suppress *Ludwigia* growth, deep water and absence of water. Laguna Main is an excellent example of where a low flow channel is urgently needed. The roughly 120-foot wide channel is inundated by shallow water in the summertime. Excavation of a 15-foot wide by 8-foot deep channel would reduce the wetted area by 85%. Not only would the deeper water would be more resistant to *Ludwigia* growth, but it would have lower water temperature and higher dissolved oxygen as well.

Although the idea of a low flow channel is conceptually simple, implementation is not. Design, permitting, and maintenance costs could be high particularly if sedimentation is rapid or channel sides unstable. These issues are being studied by SCWA. Potential locations for low flow channels include the BW channel from Millbrae Avenue to the confluence with the Laguna, Laguna Main from the confluence of Gossage Creek and Hinebaugh Creek to the constriction point west of Stony Point Road, and Laguna Main from the constriction point and Llano Road. The process of constructing low flow channels would cause considerable disturbance and would necessarily be part of an active restoration project.

Strategies for CDFG field site – Short Term

*Mechanical Removal*

As described above and throughout this document, mechanical removal can provide effective short-term control of *Ludwigia*, particularly in deeper channels. In the coming years the channel through the CDFG Laguna Wildlife Area will gradually fill in with *Ludwigia* again. Mechanical removal should be used to clear the channel every 2-5 years until large-scale restoration begins. Herbicide may be used to stem regrowth along the channel margins following the removal if needed. As described above, it will be far more cost effective if a local agency purchases an aquatic harvester for the mechanical removal efforts.

*Ludwigia* will become worse in the floodplain without herbicide application but continued spraying without removal is not justified except under exceptional conditions such as emergency efforts to stem mosquito production following unusually high larval detection rates.

Strategies for CDFG field site – Long Term

The Laguna Wildlife Area is a highly disturbed site. The forested floodplain shown in the 1942 aerial photo was reclaimed for agriculture decades ago and the pilot channel that dissects the site is entirely artificial. Lack of drainage in the last decade has resulted in flooded conditions year round. Suppressing *Ludwigia* at this site will require large-sale, multi-objective restoration that includes participation by surrounding landowners. This process will be initiated in spring 2008. An expert team will be assembled to assess potential restoration options which will then be weighed against relevant ecological, social, and financial factors. A preferred alternative will be chosen with the participation of surrounding landowners. Implementation will follow.

**Appendix 1**
**Target Invasive Weed**
Prepared by Dr. Brenda Grewell, Ecologist, USDA-ARS

During project planning, the invasive *Ludwigia* species invading extensive areas of the Laguna was thought to be *Ludwigia hexapetala*, which is taxonomically described and considered a native California species in the Jepson Manual: Higher Plants of California (Hickman et al. 1993). Early in the project, botanical experts (Dr. Brenda Grewell and Dr. Cristina Hernandez USDA-ARS, and Keenan Foster, SCWA) carefully examined these plants in the field and determined that the primary invader in the Laguna consistently did not key to the taxonomic description of *Ludwigia hexapetala* in the Jepson Manual and did not key to the description of *Ludwigia hexapetala* by Zardini, the South American expert for the *Ludwigia* genus. However, the invasive *Ludwigia* species in the Laguna did fit the less-detailed description of *L. hexapetala* in the Flora of Sonoma County (Best et al. 1996). Chromosome counts can be used to differentiate among confusing *Ludwigia* species, and have been the basis for accurate taxonomic determinations elsewhere. Because precise identification of invasive weeds can be critical for the development of effective management strategies, USDA-ARS and UC Davis scientists launched a comprehensive cytological and morphometric evaluation of invasive *Ludwigia* taxa throughout the Laguna, the greater Russian River Basin, and the Pacific west states. Chromosome counts and morphometric analyses (Grewell et al. manuscript in review) confirm four *Ludwigia* taxa in the Laguna de Santa Rosa watershed, and companion molecular studies (Okada et al. manuscript in preparation) indicate hybrids are also present. All of these taxa co-occur in the project areas. Independent of this research, a global phylogenetic re-evaluation of the genus is underway. As results become available, nomenclature for taxa may change and taxonomic keys including the Jepson Manual will be revised. For now, as determined by ploidy levels, we can refer to the two primary invasive weeds in the Laguna as *Ludwigia hexapetala* and *Ludwigia peploides* ssp. *montevidensis*, and *L. hexapetala* is currently the more abundant of the two in both project locations. Both taxa will be treated as exotic invasive species from South America in taxonomic key revisions (Grewell, personal communication), and corrections to the taxonomic keys are in progress. The native *Ludwigia peploides* spp. *peploides* and *Ludwigia palustris* are also present, co-occur with the exotic species in the Laguna, and all four taxa are present in the management project areas. In addition, *Ludwigia peploides* hybrids have been confirmed in the Laguna.

# Appendix 2:

Select Photo Monitoring Series from the SCWA and CDFG Treatment Areas

2005-2007

**Bellevue Wilfred Channel, SCWA Field Site: Photo Point A-01**

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking southwest off the Millbrae Road Bridge. Prior to project activities *Ludwigia* covered roughly 75% of the channel. Following 2005 spray/removal activities the channel was clear. In spring 2006 regrowth was moderate. Following another season of spray/removal, regrowth was strong in 2007and Ludwigia reoccupied at least 75% of the channel though the density was reduced from pre-project levels. Note that much of the growth is occurring from the east (left) side of the channel where a mudflat provides ideal medium for germination, growth from fragments, and sprouting from existing roots. Removal of this sediment during the creation of a low flow channel could stem the regrowth in this section.

**Bellevue Wilfred Channel, SCWA Field Site: Photo Point D-07**

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking north toward the Wilfred Bridge. Photo taken from cross bridge within channel. Note the open water in the foreground following the first year. Although *Ludwigia* can easily creep across this deeper water (~36 inches), the time required to reoccupy it is greater than in uniformly shallow areas. The important point is that deeper water will limit *Ludwigia* growth for a period of time but not indefinitely as is obvious from the pre-spray July 2005 photo. Following the 2007 spray/removal activities, this section was once again clear.

**Bellevue Wilfred Channel, SCWA Field Site: Photo Point E-08**

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Pre-spray
June 2007

Bellevue Wilfred channel looking north from cross bridge within channel (just north of Rohnert Park Expressway). Dense infestation in July 2005 was growing on shallowly inundated mudflat. Regrowth in June 2006 was limited partly from cool wet spring. By mid-summer regrowth was more pronounced. Regrowth in June 2007 was stronger following a warm spring and drought winter. Note the natural low-flow channel in June 2007. If this were made deeper it is possible the soil on the adjacent mudflats would not be saturated and would be less conducive to *Ludwigia* growth.

## Laguna Main Channel, SCWA Field Site: Photo Point I-13

Pre-spray
July 2005

Post-removal
October 2005

Pre-spray
June 2006

Post-spray
September 2007

Main Laguna channel looking west from the Stony Point Road Bridge. Prior to project activities this relatively deep section was heavily infested. Following the first year of spray/removal the channel was largely clear and remained so in June 2006. No removal occurred in 2006. The drought of 2006/2007 resulted in shallow conditions in spring/summer 2007 allowing *Ludwigia* to root mid-channel. Despite two herbicide applications, the channel experienced significant regrowth in 2007 as well as large algal blooms. A low flow channel to contain summer flow would limit the area of the channel available for colonization.

**Laguna Main Channel, SCWA Field Site: Photo Point O-22**

Post-removal
October 2005

Pre-spray
June 2006

Post-spray
October 2006

Post-spray
September 2007

Main Laguna channel looking east of confluence with Bellevue Wilfred Channel. No photo available for June 2005. This section was treated with herbicide each year. Mechanical removal occurred only in 2005. Note that in September 2007 *Ludwigia* only occurs in the wetted channel and even here it is low density. The vegetation on the sides is not *Ludwigia* and the soil underneath is largely dry. This is the goal of a low flow channel, to contain water to a small area where *Ludwigia* can easily be contained and to keep the remainder of the channel dry during summer. Although water levels would be higher outside of a drought year, a constructed low flow channel would be deeper and the net result would likely be the same.

## Floodplain, CDFG Laguna Wildlife Area: Photo Point C-11

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

Pre-spray
August 2007

Looking south over the northern floodplain of the CDFG Laguna Wildlife Area. Because mechanical removal was not feasible in the floodplain, herbicide was the only management method used. Despite a promising appearance following spraying in 2005 and 2006, regrowth was strong by the following spring of each year. Although this portion of the floodplain was sprayed again in 2007, much of the floodplain was not sprayed in 2007 due to the limited efficacy of previous efforts. Decaying biomass left in place following spraying also degrades water quality by consuming dissolved oxygen and releasing stored nutrients.

**Floodplain, CDFG Laguna Wildlife Area: Photo Point Q-46**

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

August 2007

Looking west over the southern section of the Laguna Wildlife Area floodplain. As in the previous photo series, limited efficacy was achieved through spraying. Although the October 2006 photograph shows a strong component of non-*Ludwigia* species including *Polygonum* sp. and *Xanthium strumarium*, *Ludwigia* quickly regained a competitive edge by the following spring. This area was not sprayed in 2007.

## Channel, CDFG Laguna Wildlife Area: Photo Point L-38

Pre-spray
July 2005

Pre-spray
June 2006

Post-spray
October 2006

Post spray
August 2007

Channel through CDFG Laguna Wildlife Area. Spraying occurred each year. Mechanical removal occurred only in 2005. The channel remained quite clear until late 2007 when shallow water conditions prevailed following a low rainfall winter. Ongoing maintenance will be required to keep the channel clear. Mechanical removal is the preferred method and will need to occur every 2-5 years depending on the rate of regrowth. Maintenance will continue until the underlying issues that encourage rapid growth of *Ludwigia* are addressed. Planning efforts to restore the site will begin in spring 2008.

## Channel, CDFG Laguna Wildlife Area: Photo Point K-35

Pre-spray
July 2005

Pre-spray
June 2006

Post spray
August 2007

Channel through Laguna Wildlife Area. Spraying occurred each year. Mechanical removal occurred only in 2005. This deeper section of channel retained excellent control throughout the project period.