Appendix D:

Invasive Ludwigia Management Plan

for

The Laguna de Santa Rosa
Sonoma County, California

2005-2010

Prepared by
Anna L. W. Sears and Julian Meisler, Laguna de Santa Rosa Foundation; and Lily N. Verdone, Sonoma State University; and the Marin/Sonoma Mosquito and Vector Control District; on behalf of the Sonoma County *Ludwigia* Task Force.

Funding provided by the California Coastal Conservancy, the Sonoma County Community Foundation, the Marin/Sonoma Mosquito and Vector Control District, the Sonoma County Water Agency, the Wildlife Conservation Board, and the City of Santa Rosa Board of Public Utilities

Revised March 23, 2006

* Contact: anna@lagunafoundation.org; julian@lagunafoundation.org; verdone@sonoma.edu.

NOTE: Recent botanical evaluations have raised questions about the species designation of invasive Ludwigia in the Laguna system. Although it was initially identified as Ludwigia hexapetala, botanists now believe the invader to be either the non-native Ludwigia peploides subspecies montevidensis, a hybrid, or a species new to California. Until the taxonomic questions are answered, we will refer to this species as "invasive Ludwigia" to distinguish it from less aggressive members of the genus.

I. Preface

This plan is a summary of our current knowledge about invasive *Ludwigia* in the Laguna de Santa Rosa watershed, and the immediate and long-term strategies for *Ludwigia* management. It reflects contributions from the members of the Sonoma County *Ludwigia* Task Force, other stakeholders and interested parties in Sonoma County, and the science community. This is a work in progress. At this writing, *Ludwigia* is the subject of active scientific research, evaluating its ecology and the environmental triggers that promote explosive growth. As our knowledge evolves, this plan will also evolve.

II. Introduction

A. Site description and management goals

The Laguna de Santa Rosa (Laguna) is the largest tributary to the Russian River, and the second largest freshwater wetland in coastal California, draining a 254 mi^2 watershed. It is set in an open space/agricultural area of approximately 30,000 acres in a rapidly urbanizing portion of the North Bay Area, with more than 250,000 people residing within 10 miles of the principal channel. The central Laguna waterway is 14 miles long, with headwaters in the city of Cotati, emptying into the Russian River near Forestville. This channel is fed by more than 14 sub-tributaries, most entering the Laguna from the Santa Rosa Plain.

The Laguna ecosystem is a mosaic of open water, freshwater marsh, seasonal wetland, riparian forest, oak woodlands and grasslands. Some 232 bird species have been recorded in the Laguna, including many rare species with high conservation value. It is an important stopover for migrants on the Pacific Flyway, and the permanent home to a variety of wildlife, which are dependent on its diverse habitats. This ecosystem has been identified by local agencies and environmental groups as a focal point for environmental restoration, including restoration of the riparian corridor; improving water quality; and restoring fish, bird and wildlife habitats. The Sonoma County Agricultural Preservation and Open Space District (SCAPOSD) is acquiring land and easements and developing trail plans to increase public access in the Laguna. The Laguna de Santa Rosa Foundation (Laguna Foundation), has been funded by the Coastal Conservancy to develop a Laguna watershed restoration and management plan.

The wetlands of the Laguna naturally filter surface waters of nutrients, sediment and other impurities, before they enter the main channel of the Russian River. However, current inputs tax the natural capacity of this system. The US Environmental Protection Agency (EPA) has listed the Laguna as impaired for elevated nitrogen, phosphorus, sediment, temperature and low dissolved oxygen. These impairments arise from a combination of conditions: storm-waters from the cities of Santa Rosa, Sebastopol, Cotati, Rohnert Park and Windsor drain into the Laguna; the City of Santa Rosa also uses the Laguna channel as a seasonal discharge point for treated wastewaters from its Laguna Treatment Plant; and there are additional sources of nutrients and sediment from roads, construction, and run-off of agricultural operations on the plain.

Historic removal of riparian vegetation along the channels of the Laguna and its tributaries likely contributes to increased water temperatures and nutrient influx. The North Coast Regional Water Quality Control Board (NCRWQCB), which has regulatory authority for water quality, has given high priority to the development of a Total Maximum Daily Load (TMDL) pollution control plan for the Laguna. This process will quantitatively assess water quality impairments and sources of pollution, analyze the absorption capacity of the system, and evaluate actions to restore and protect beneficial uses of these waters. Many local community groups are concerned about water quality in the Laguna, and the TMDL process will likely be a broad-based effort.

Besides its value for conservation and regional water quality, the Laguna has an important role as a natural holding basin for seasonal floodwaters on the Santa Rosa plain, reducing localized flooding as well as down-stream floods along the Russian River. It is estimated that water levels in the city of Guerneville during the 1964 flood would have been 14 feet higher, if it were not for the Laguna floodplain's water-holding capacity[1]. However, a recent hydraulic analysis by the US Army Corps of Engineers (USACOE) found that the Laguna's flood control function is at risk from increased sedimentation in the channels and tributaries[2]. The study projects a 3 ft increase in Laguna flood levels over the next 40 years, with serious consequences to infrastructure in the surrounding area. The USACOE, in partnership with the Sonoma County Water Agency (SCWA) and the California Coastal Conservancy, is developing a plan for reducing sediment inputs and increasing hydraulic capacity in the Laguna system.

1 See refs, SCFCWCD

2 See refs, PW & A

The Santa Rosa Plain has been the home to human settlements for more than 11,000 years. Native Americans used the Laguna's abundant resources, including oaks, tule and wildlife, to develop large, thriving communities. Today, the area has substantial agricultural value, with vineyards, ranches, dairies and a variety of smaller operations; and is home to hundreds of thousands Sonoma County residents. Agricultural operations provide high-quality food and employment, as well as the benefit of unimpeded open space and natural beauty. The relatively healthy economy, quality of life and good jobs in the region make the Laguna watershed one of the most desirable residential areas of the state, and leading to a local housing shortage. Thus, there has been rapid urban growth in the last decade and continuing pressure to develop many of the upland areas.

B. How invasive Ludwigia interferes with management goals

Invasive *Ludwigia* is a rapidly growing aquatic shrub currently covering at least 150 acres of shallow-water areas in the Laguna ecosystem. *Ludwigia* creates a perceived public health threat as densely-growing patches create protective habitat for mosquito species that can carry West Nile virus (WNV), which reached Sonoma County in 2004. Several *Ludwigia*-infested areas have seasonal adult mosquito populations more than 100 times greater than normally acceptable[3]. The Marin/Sonoma Mosquito and Vector Control District (MSMVCD) expended more than $80,000 for 2003-04 alone for mosquito control in *Ludwigia* areas, diverting resources and energy from other parts of the County. Vector Control operators have stated that they have limited ability to control mosquitoes in these areas because dense *Ludwigia* growth inhibits larvacide applications. If larvacide cannot be properly applied, operators must use pyrethrin-based adulticides, which are less effective overall and tend to have greater negative impacts on fish. In addition, the stagnant eutrophic conditions associated with *Ludwigia* appear to favor 'foul-water' mosquito species that are superior vectors for West Nile virus (in the genus *Culex*).

Besides threatening public health, WNV has a potential to severely impact resident bird populations. The Laguna de Santa Rosa is a stopover on the Pacific Flyway, and hosts a very diverse bird community. More than a third of the permanent or seasonal avian residents of the Laguna are known to be susceptible to WNV, including the ecologically dominant herons, egrets, raptors, and corvids. Thirty-four of Laguna species

3 Marin/Sonoma Mosquito and Vector Control District, unpublished data

are given priority conservation status under the Riparian Habitat Joint Venture, the North American Wetlands Conservation Act (NAWCA) for Coastal California wetlands, and/or California Department of Fish and Game (CDFG) list of Species of Special Concern (see appendix B). Horses on surrounding farms are also vulnerable to the virus (one local fatality in 2004, and another in June 2005), which has unknown effects on other mammalian wildlife[4].

Ludwigia is also a direct threat to the diversity of native plant and animal communities, growing over surrounding vegetation to produce a thick mat of woody perennial stems and decaying plant matter. This mat inhibits the recovery and recruitment of other plants, and eliminates open-water habitats that are important foraging-grounds for birds and other wildlife. As *Ludwigia* tissue sloughs off and decomposes, microbial growth reduces dissolved oxygen in the water, impacting fish and invertebrate populations. Current efforts to protect and enhance Laguna wetland habitats for migratory birds and waterfowl on the Pacific Flyway are substantially limited by *Ludwigia* growth, especially in the CDFG's Laguna Wildlife Area where more than 100 acres of floodplain are covered with *Ludwigia*.

Ludwigia may also contribute to flooding in the Laguna system, as plant biomass fills in flood control channels, reducing its capacity for flood-retention and dramatically altering the characteristics of the wetland. Perennial *Ludwigia* mats slow the movement of water through the system, and likely act as a trap for fine sediments, further reducing capacity and degrading the wetland. Projecting current trends, with no remediation, *Ludwigia* will potentially lead to a decrease in shallow wetland areas overall, but with increased flooding during storm events.

C. Summary of Ludwigia biology

1. *General description:* The invasive *Ludwigia* found in the Laguna (believed to be *Ludwigia peploides* ssp. *montevidensis*) is an aquatic vascular plant; characterized by rapid growth; and occurring in transition zones of shallow, slow moving waterways. After establishing in the bank or channel bottom, prostrate stems grow laterally, rooting adventitiously at nodes. Once rooted, secondary shoots grow erect, up to 5 feet in height. This *Ludwigia* species is thought to reproduce primarily from asexual rooting plant fragments, dispersed by water currents or by birds and other wildlife; however, seedlings are also occasionally found.

4 http://www.audubon.org/bird/wnv/pdf/effects_on_wildlife.pdf

2. Taxonomy: The genus *Ludwigia* consists of 82 species worldwide, with the greatest diversity in South America, considered the center of origin for the *Ludwigia* genus and family (Onagraceae). The genus contains both herbaceous and woody species, as well as aquatic types. Many aquatic *Ludwigia* species are phenotypically plastic, such that their growth forms vary under different environmental conditions. This plasticity often complicates species-identification, and has led to a number of fluctuations in their taxonomic classifications. Chromosomal differences between species are sometimes used to aid taxonomy. *Ludwigia hexapetala* is a decaploid: 2n = 80 chromosomes; *Ludwigia peploides* subspecies *peploides*, *Ludwigia peploides* subspecies *montevidensis*, and *Ludwigia repens* contain 2n = 16, 16, and 32 chromosomes, respectively.

Recent botanical evaluations have raised questions about the species designation of invasive *Ludwigia* in the Laguna system. Although it was initially identified as *Ludwigia hexapetala*, botanists now believe the invader to be either the non-native *Ludwigia peploides* subspecies *montevidensis*, a hybrid, or a species new to California.

3. Distribution: Three species of *Ludwigia* have previously been documented in the Laguna watershed: *Ludwigia hexapetala*, and two native species, *Ludwigia peploides* subspecies *peploides*, and *Ludwigia palustris*. *Ludwigia hexapetala* is believed to have originated in Uruguay, as reflected by its synonym, *Ludwigia* uruguayensis, although there is still controversy among taxonomists as to whether it is also native to the United States. In Oregon, Southwestern Washington and California, these *Ludwigia* species, along with *Ludwigia peploides* subspecies *montevidensis*, are found at low elevations in rivers, streams, lakes, ponds, irrigation canals and other wet habitats – similar to the Laguna. Researchers at the University of California, Davis, are initiating a genetic analysis of invasive *Ludwigia* in California, to answer taxonomic questions, and better understand the biology and history of the invasion.

4. Biology: Invasive *Ludwigia* is identified by its tall upright stature, bright yellow five-petal flowers and lanceolate leaves, 5-10 cm long. The plants have deltoid bracteoles which align them with the *Ludwigia peploides* group, but emerging leaf tips are glandular, suggesting the exotic *Ludwigia peploides* subspecies *montevidensis*[5]. This *Ludwigia* species persists perennially in Sonoma County. Roots and rooting stem fragments, embedded in soil or mud, send out lateral shoots that root from nodes into submersed or seasonally exposed soils. Continued growth develops dense mats of emer-

5 Brenda Grewell, personal communication.

gent vegetation, covering shallow water areas and transitional margins. For *Ludwigia parviflora*, an abundant Asian rice-field weed, increases in soil-water content have been linked to increases in reproductive capacity and vegetative growth. This relationship has been observed, though not quantified in invasive *Ludwigia* in the Laguna. The amphibious character of this *Ludwigia* species allows for limited upland survival; dry soils appear to decrease survivorship and reproductive ability, making it a poor competitor with other riparian and upland plant species.

Invasive *Ludwigia* is adapted to submersed or temporarily exposed soils as well as low-oxygen (anaerobic) conditions, through the presence of two distinct specialized root structures that extract oxygen and nutrients from the water column. Porous, upward growing aerenchymous roots provide a conduit for atmospheric gases to transfer throughout the plant in anaerobic conditions. Tightly packed cells of downward-growing adventitious roots (arising from the stem) absorb nutrients in the water column, often without contact with the substrate.

Along with the ability to tolerate low oxygen, invasive *Ludwigia* appears to prosper in nutrient-rich water. *Ludwigia* species have been studied as potential bioremediation agents for constructed wetlands and wastewater holding ponds. Experimental data on *Ludwigia peploides* subspecies *peploides* reports growth increasing and leveling off with increased nitrogen concentrations. A similar study showed increased phosphorous and nitrogen concentrations in this species when exposed to effluent inundations. Initial research on invasive *Ludwigia* demonstrates a trend similar to that of *Ludwigia peploides* subspecies *peploides*: increased nitrogen and phosphorous concentrations result in greater plant biomass[6].

III. Overview of Weed Management Plan

A. General management philosophy

Weed control is a necessary part of any restoration and management plan, in order to protect and maintain native species and communities and the stability of the environmental system. The Laguna is home to a great diversity of wetland and upland plants, which provide food and shelter to a great diversity of invertebrates, fish and wildlife. The overall goal is to proactively prevent the establishment of new weed species, and to set priorities for control of established weeds according to their actual

6 Lily N. Verdone, unpublished data.

and potential impacts on ecosystem processes, and native species and communities, particularly the rare and ecologically important species that are specific targets for conservation (such as Sebastopol meadowfoam or steelhead trout). Action is recommended only after careful consideration indicates that leaving the weed unchecked will result in greater damage than risked by control efforts.

Weed control follows an adaptive management strategy. After establishing goals for the site, control areas are prioritized based on the severity of environmental impacts, and a control plan is developed based on this information. The plan is implemented in conjunction with a monitoring program, to evaluate the results of management actions. Methods are analyzed for effectiveness, and this information is used to modify and improve control priorities, methods and plans. Finally, the cycle is started again by establishing new or modified goals.

Ideally, priorities are geared toward minimizing the impact to non-target species, and minimizing the total, long-term workload. In general, the highest priority for weed control should be to prevent new infestations from taking hold, especially for species that are the fastest growing and most disruptive. However, large infestations of weeds with large environmental impacts, such as invasive *Ludwigia*, must also be given high priority. Lower control priority is given to weed species which are not rapidly increasing in numbers, that don't move into undisturbed habitats or impact recovery from disturbance.

B. Summary of planned control actions

Control plans for invasive *Ludwigia* were developed through a joint effort by the Sonoma County *Ludwigia* Task Force, convened in January 2003 to address the public and environmental health threats posed by *Ludwigia*. More than 50 local scientists, agency representatives, elected officials and representatives from environmental organizations have contributed to the planning effort. Control plans seek to follow an integrated pest-management (IPM) approach – based on the biology of the plant and on ecosystem-level restoration and management objectives. The integrated approach includes a variety of interim and long-term projects. Other aquatic weeds can also hinder control of mosquito populations; and the IPM approaches and Best Management Practices (BMPs) developed for invasive *Ludwigia* will inform the management of other problem species in the Laguna watershed.

1. Summary of interim control alternatives

There are eight general alternatives for interim control of invasive *Ludwigia* in the Laguna de Santa Rosa. The four most standard alternatives are (1) 'no action'; (2) remove biomass manually or mechanically; (3) use systemic herbicides to kill plants; (4) use a combination treatment of herbicides and removal. To this list could be added other no-spray methods for killing invasive *Ludwigia* plants, including (5) tarping; (6) flaming, or crushing; (7) techniques related to water-level management, such as flooding or draining; and (8) a more extensive biomass removal that includes mechanical excavation and dredging. Long-term control alternatives are described below.

a. No action: Because of invasive *Ludwigia*'s environmental impacts and accompanying risks to public health (described above), the 'no action' alternative is thought to have long-term negative impacts which would be difficult to mitigate. For these reasons, the first alternative is not desirable for the worst infested areas, although in Laguna locations where *Ludwigia* is now growing sparsely, the 'no action' alternative may be acceptable while other practices are being investigated. Leaving *Ludwigia* in place while attempting to manage mosquito levels may have ongoing negative impacts to resident fish species. Mosquito-control operators are not able to effectively apply larvacides in the presence of densely-growing *Ludwigia*. Gambusia fish and other natural predators that consume mosquito larvae in other parts of the Laguna, do not appear to be effective in *Ludwigia* areas – for reasons that are still unclear. Adulticide mosquito treatments are believed to be less effective for mosquito control, and as these sprays are pyrethrum-based, although relatively safe for humans, they are quite toxic to fish (with greater toxicity than proposed herbicides, below).

b. No-spray alternatives: Above-ground biomass removal is possible using manual or mechanical methods, and is similar in principle to flaming or mechanically crushing plants to kill above-ground parts. However, invasive *Ludwigia* is a perennial that re-sprouts readily from root and stem fragments. For this reason, biomass removals that do not completely eliminate the root system, or that are not done in conjunction with an herbicide treatment to kill the roots, can result in ready re-growth. This is similarly true of flaming and crushing methods, and ignition is likely to be difficult in this aquatic environment. Without killing the entire plant, at best these methods have limited effectiveness, and at worst they produce fragments that can spread *Ludwigia* to other parts of the Laguna system. A study performed on behalf of the State Water Resources Control Board by the San Francisco Estuary Institute found that shredding plant mate-

rial in stagnant water bodies (without removing shredded biomass) led to decreased dissolved oxygen, increases in nutrients, and an increased biochemical oxygen demand. Mechanical removal of above-ground plant material from shallow wetlands can also create substantial disturbance, and ideally should be minimized.

In 2005, 5388 tons of *Ludwigia* were removed from 44 acres at two Laguna sites. Researchers in France found that in the field, plants in the *Ludwigia* genus can double in mass in 15-90 days, depending on conditions[7]. The massive quantities of biomass in the worst-infested areas make manual removal difficult and expensive to sustain as a long-term control strategy. Workers at the City of Santa Rosa's Laguna Treatment Plant attempted to eradicate *Ludwigia* from their managed wetland by hand-pulling and raking in the worst infested areas for 2-6 person hours/week, and were only able to keep up with its growth. At the end of the season, *Ludwigia* covered 100% of the pond. However, hand pulling is likely to be a good option for smaller infestations in highly managed areas. Volunteers in 2004 were able to clear *Ludwigia peploides* subspecies *peploides* from the margins of a pond in the City of Sebastopol's Laguna Wetlands Preserve in approximately 150 person-hours of effort.

Mechanical excavation and dredging is a more comprehensive removal of invasive *Ludwigia* plants and roots, and would have better success in eliminating *Ludwigia* from waterways, especially if dredged channels are made too deep for *Ludwigia* to successfully re-establish. However, concerns remain about re-growth and fragmentation, and these methods represent a serious modification of the Laguna waterways. To excavate and dredge requires engineering and hydraulic analyses, and extensive oversight and permitting by the U.S. Army Corps of Engineers. As these studies take time, it is not likely that they could be implemented for the 2005 season, and perhaps not for several years. Tarping may be effective for killing *Ludwigia* plants down to the roots, although this technique has only begun to be tested on a small scale in the Laguna. It is likely that tarping extensive areas of wetland for an extended period of time would have great collateral damage on Laguna fish and wildlife populations.

c. Herbicide options: In response to the *Talent* decision, finding that discharge of pollutants from the use of aquatic pesticides must be covered by National Pollution Discharge Elimination System (NPDES) permits[8], the San Francisco Estuary Institute was commissioned to do a study of

7 Alain Dutartre, Hydrobiologiste, Cemagref, personal communication

8 See refs, SWRCB

the effectiveness of no-spray alternatives on various weed species[9]. One of these studies specifically compared the effectiveness of herbicide spraying (glyphosate), mechanical removal, and combined spray/removal treatment on *Ludwigia* in a Delta-area irrigation channel. This study found that mechanical removal alone had limited effectiveness, and that the combined treatment, though most expensive, gave the most lasting control. The Sonoma County *Ludwigia* Task Force has recommended this approach for controlling invasive *Ludwigia* in the Laguna.

2. Summary of interim control plans

To control invasive *Ludwigia* in the near-term, systemic herbicides will be used for three years in an active control and monitoring effort. Following herbicide application, residual biomass will be removed, where feasible, so that decomposing plant material does not create further adverse impacts, such as decreasing dissolved oxygen levels in the water. Control operations will be adjusted to site-specific conditions, and may vary among and within treatment areas. Overall, control efforts will be undertaken with sensitivity to the Laguna ecosystem – seeking to minimize effects on non-target plants and wildlife. Following adaptive management principles, fine-tuned planning and control efforts will be based on monitoring information.

Near-term control plans are being developed jointly with long-term plans to make the Laguna wetlands more resistant to aquatic weed infestation. The worst infestations appear to be associated with symptoms of wetland degradation: thick sediments in shallow, slow-moving, nutrient-rich waters in full sun. Thus, long-term control of *Ludwigia* will likely require restoration of riparian areas; improved water quality by reducing nutrient loads and sedimentation; and possible channel modifications (potentially including sediment removal) to encourage higher-quality habitat development. These restoration measures would have additional benefits to native flora and wildlife and the overall health of the Laguna ecosystem. Long-term control must also be pursued within an adaptive management framework: making adjustments based on the response of *Ludwigia*, mosquito populations, and associated plant and wildlife communities. Determining optimal *Ludwigia* control strategies will require a concerted research effort. Certain projects, such as riparian restoration of key areas, may be initiated in a relatively short timeframe. Others, such as potential modifications of the flood-control system, need further study to

9 See refs, SFEI

determine the most effective actions. See appendix D for a description of ongoing and proposed *Ludwigia* research projects.

IV. Specific Control Plans

A. Goals

Overall, the goal for invasive *Ludwigia* is to sharply reduce its population numbers to alleviate negative impacts on the Laguna ecosystem, and to reduce and stabilize its population growth rate, so that it no longer spreads invasively. Reducing *Ludwigia*'s abundance is the central objective of our near-term control plans. Stabilizing its population growth rate will likely require lasting changes in Laguna management practices that will complement the broader restoration goals for the Laguna ecosystem. After *Ludwigia* is brought to manageable levels, and following riparian restoration, the Laguna channel will likely have a higher habitat value. Mosquito control can be implemented more effectively, reducing the threat of WNV to humans and wildlife. Removal of invasive *Ludwigia* will restore open-water habitats and allow native vegetation to recover, providing feeding grounds for bird and wildlife populations. Riparian shading will reduce the vigor of *Ludwigia* and other invasive aquatic weeds, and stream-bank vegetation will buffer sediment and nutrients entering the Laguna. Water quality should measurably improve, and hydraulic processes may revert to somewhat more natural patterns, reducing sedimentation and local flooding.

B. Interim control plans

1. Project Description

The objective of near-term control plans is to control invasive *Ludwigia* in the two areas of the Laguna watershed that have the greatest infestations.[10] Invasive *Ludwigia* now covers close to 100 percent of these areas, comprising more than 150 acres of floodplain and waterways. Following the procedures described below, we expect to sharply reduce the abundance of *Ludwigia* from target sites over a two to three-year period. Treated areas will be monitored and mapped during and after this period for five years.

10 See maps, Appendix F

Implementation will follow adaptive-management principles, fine-tuning site-specific planning and control efforts based on effectiveness and monitoring data.

2. Project site

Target areas for short-term invasive *Ludwigia* control are the Laguna channel from approximately 200 meters west of Stony Point Road to the confluence of the Laguna and Gossage Creek in Rohnert Park; and the Wilfred/Bellevue flood control channel from Millbrae Avenue to its confluence with the Laguna channel; both managed by the SCWA; as well as the Laguna channel and flood-plain parcels of the Laguna Wildlife Area between Occidental and Guerneville Roads, managed by the CDFG.

3. Herbicide products

Ludwigia is a perennial species that regenerates readily from root and stem fragments. Therefore, systemic herbicides are required to effectively eliminate infestations. The two compounds that have had the greatest success in controlling *Ludwigia* species (including *L. hexapetala* and *L. peploides*), are glyphosate (trade names Aquamaster and Rodeo) and triclopyr (trade name Renovate), formulated for aquatic application. Glyphosate controls both broadleaf plants (such as *Ludwigia*) and monocots (e.g., grasses, reeds and sedges). Triclopyr controls only broadleaf plants, and is thus preferable in areas with desirable native monocots. Both of these products break down rapidly under the warm, standing-water conditions of *Ludwigia* areas during the proposed treatment time in the Laguna. Glyphosate adheres strongly to soil particles, with a low potential for runoff; and breakdown is primarily by microbes. Its half-life in pond water ranges from 12 days to 10 weeks. Triclopyr does not strongly adhere to soil particles. Its breakdown is primarily by microbes in soil, and by hydrolysis or photolysis in water. Triclopyr's half-life in water is from 2.8 to 14.1 hours, depending on season and depth. Another compound, imazapyr, may be a good option for the future, but has not yet been registered for use on *Ludwigia* in California. See EXTOXNET[11] (in reference section, below), for more information. Aquatic herbicide applications are regulated under the Environmental Protection Agency's Clean Water Act (CWA), and require an NPDES permit issued by the NCRWQCB.

During application, products are combined with surfactants or other adjuvants to improve their effectiveness as herbicides. Adjuvants are any product added to a spray solution to enhance or modify its performance.

11 See refs, EXOTOXNET

Surfactants are additives to improve the emulsifying, spreading, sticking and absorbing properties of liquids. These compounds are not always regulated under the CWA. Some surfactants have come under criticism for producing undesirable breakdown products. For this reason, the common aquatic herbicide surfactant Nonylphenol polyethoxylate (NPE) will not be used for *Ludwigia* control in the Laguna. Formulations will be chosen with the goal of limiting overall environmental impacts.

4. Permitting

Ludwigia herbicide applications are permitted under two separate Statewide General NPDES Permits for aquatic application of glyphosate herbicide (General Permit No. CAG 990005)[12] issued to the CDFG and SCWA for the two project sites by the NCRWQCB. CEQA is not required for herbicide applications under this permit, as glyphosate and triclopyr are not classified as priority pollutants. Biomass removal operations will be conducted under a CEQA Categorical Exemption. NOAA/National Marine Fisheries Service and CDFG biologists do not believe that this project will have negative impacts on salmonid species because the project is not occurring during spawning or out-migration season.

5. 2005 Project Report Summary[13]

The *Ludwigia* Control Project commenced in summer 2005 under the direction of the Laguna Foundation. *Ludwigia* plants within the two target areas were treated with herbicide and then removed by mechanical means. The Foundation made significant efforts to inform the public about the project including public workshops, mailed letters, email and website updates, press releases, and tours. Both quantitative and qualitative vegetation monitoring were done before and during the course of the project.

Application of a glyphosate-based herbicide began in mid-July 2005. A total of 115 acres of channels and flooded wetland were treated using a variety of equipment suited to local conditions. The kill rate achieved by the herbicide was approximately 75%. This was likely due to a combination of limited efficacy of both the herbicide and surfactant, method of application, density of existing plants, and timing.

In total 5,388 tons of *Ludwigia* were removed from a total of 44 acres at the two sites. Aquatic harvesters were used in the wider channels. Biomass

12 See refs, SWRCB

13 Adapted from the *Ludwigia* Control Project Year One Report. For further details see: http://www.lagunadesantarosa.org/RMP/Ludwigia/Ludwigia_Status.htm

from these channels averaged 55-60 tons/acre. In the narrower channels a long reach excavator was used to remove the vegetation. Biomass from these channels averaged 173 tons/acre. The vast difference in these values is probably due to the fact that the long reach excavator pulled out more of the sediment that was commingled with the *Ludwigia*. Site conditions in the flooded wetlands made biomass removal impossible. Vegetation disposal was successfully achieved at the CDFG site through drying, shredding and disking in nearby upland fields. The sediment-laden biomass from the SCWA site did not dry out and could not be disked in to the soil. The Laguna Foundation is working to convert the biomass into compost by late summer 2006.

Best management practices were implemented throughout the project to ensure that impacts to water quality and other natural resources were minimized. Intensive water quality monitoring revealed very low levels of glyphosate and aminomethyl phosphonic acid (a metabolite of glyphosate) present following the application. Heightened turbidity proved difficult to avoid despite efforts to reduce it. The Marin/Sonoma Mosquito and Vector Control District Annual Report observed a sustained drop in adult mosquito counts following *Ludwigia* removals in the SCWA project site.[14]

6. Recommendations for 2006

The 2005 *Ludwigia* Control Project provided important practical experience in controlling *Ludwigia* within two very different habitat types with the Laguna: channels and flooded wetland. Although the herbicide applications were largely successful in killing the plant, significant areas experienced incomplete kill and in some cases rapid regrowth. The method of application may have played a role (see below) but it does not account for incomplete kill in channel areas that were sprayed from shore. Undoubtedly the density of the canopy played a role by restricting herbicide penetration. Beginning earlier (i.e. June 15) in 2006 would ensure lower density in the canopy and is likely to enhance penetration. A second herbicide, Renovate (active ingredient triclopyr) is also being considered for use on an experimental basis in the flooded wetland area, compared against glyphosate. Significantly less mechanical removal is expected in 2006. This will depend on the level of regrowth but it is very unlikely that regrowth will reach the density experienced in 2005, which resulted from many years of accumulation. The following factors are likely to have contributed to the low kill-rate in 2005.

14 Marin/Sonoma Mosquito and Vector Control District unpublished data.

- *Efficacy of herbicide*. Although glyphosate provides a desirable balance between reasonably high efficacy and low mobility and toxicity, it is possible that it did not have the strength to kill the plant entirely. It would be useful to compare the efficacy of glyphosate against other herbicides such as triclopyr.
- *Efficacy of surfactant*. Cygnet Plus® may also have had limited efficacy. Again, it would be useful to try an alternative surfactant.
- Method of application. One of the most desirable qualities of glyphosate is that it adsorbs readily to soil particles and therefore is not at risk of leaching. However, in applying the glyphosate with terrestrial equipment, it was necessary to drive over the plants and cover some of them with muddy water. Because the spray hoses are located on the back of vehicle, the coating of muddy water occurred just before the spraying. In effect, the glyphosate may have been become bound up as soon as it hit the plant. This would have rendered a significant portion of the glyphosate ineffective. Although aerial application of the herbicide would avoid this problem, it is not being considered due to its controversial nature. This reinforces support for trying an alternative herbicide.
- *Canopy density*. *Ludwigia* has been accumulating for 10-15 years in these areas and has become particularly dense in the past 5 years. It is possible that a significant number of the plants were never hit by the glyphosate because it was intercepted by the tallest plants. The canopy is expected to be less dense next year as a result of this year's control effort.
- *Timing*. The first application of herbicide was July 18, 2005. By this point in growing season, *Ludwigia* had already added substantial biomass. If application can be made earlier in 2006 there will be less growth.

7. Project methods/timeline:

May–June 15 2006: Survey and map remaining invasive *Ludwigia* patches in control areas using GIS. Monitor response of plant community to *Ludwigia* control efforts. Revise site-specific control plans, based on areas of re-growth.

June 15–September 30 2006: Repeat applications of glyphosate herbicide to *Ludwigia* in flood control channels. Apply glyphosate and triclopyr herbicides to *Ludwigia* in floodplain areas, following an experimental methodology to evaluate product efficacy under these conditions. Products will be applied from airboats, ATVs, amphibious vehicles or other

ground or water-based equipment (no aerial spraying), according to site-specific application plans. Water-quality monitoring will take place prior to applications and repeated during and after treatments and removals, in accordance with permit requirements.

August–September 2006: Remove residual plant biomass from flood control channels where feasible, using small aquatic harvesters or long-armed excavators working from existing roads. Biomass will not be removed from floodplain to minimize impacts. Biomass will composted or tilled into the soil on fields above the annual floodplain. Institute erosion control methods where soil has been disturbed.

May-September 2007: Repeat surveys, revise site-specific control plans; repeat herbicide applications and remove residual plant material as necessary.

8. Monitoring and Evaluating Success

To support the long-term goals of this project, the plant community in the target areas will be surveyed before herbicide applications begin. During and after herbicide applications and dead plant material removal, water quality will be monitored to test for product residues (to comply with regulatory requirements), sediment and decreased dissolved oxygen. The percent cover of *Ludwigia* will be re-estimated in the year following treatments. Treatments effects on non-target native plant species will also be evaluated.

Invasive *Ludwigia* was first recognized as a serious environmental problem in the Laguna when the Marin/Sonoma Mosquito and Vector Control District reported that mosquito trap-counts in *Ludwigia* areas were found to be 100 times greater than normally acceptable levels (for example, 400 mosquitoes in a trap over a single night). Key indicators for project success will be (1) a sharp drop in mosquito trap numbers – showing a response to successful larvacide applications in the absence of *Ludwigia*; and (2) a species shift from foul-water *Culex* species to fresh-water mosquito species.

Project reports and monitoring results will be made available to project funders, the Sonoma County *Ludwigia* Task Force, and the general public.

9. Risks to Well Water

The California Department of Pesticide Regulation (DPR) has indicated that the risk of well-water contamination by label-rates of glyphosate or

15 http://www.cdpr.ca.gov/docs/gwp/index.htm

triclopyr applications is very low. In particular, glyphosate has a high affinity for soil particles and is broken down by microbes. As part of their Groundwater Protection Program, between 1986 and 2004 DPR tested for glyphosate contamination in 4685 wells, in 51 counties.[15] Of these, there was only one sample with traces of glyphosate, and follow-up tests did not confirm detection.

10. Public outreach and education

As there was public concern about the use of herbicide within the Laguna, the *Ludwigia* Task Force has made efforts to garner public input and keep the public informed of plans and decisions. In the fall of 2004, the Fifth District Supervisor, Mike Reilly, convened two meetings with Laguna Foundation, MSMVCD, public health officers and interested environmental representatives to discuss the potential public and environmental health threats posed by WNV and *Ludwigia*, and potential strategies to address the *Ludwigia* problem. The environmental representatives acknowledged the severity of the problem, and voiced strong concern that any *Ludwigia* control program be conducted within the context of long-term restoration of the Laguna ecosystem, including the need to address Laguna nutrient issues. There was also strong concern over the use of nonylphenol polyethoxylate surfactants, which were consequently eliminated from consideration for this project. The Laguna Foundation has developed a website with current information on the *Ludwigia* Control Project[16], and has acted as a nexus for information and questions from the public. The local press has given much coverage to the issues of *Ludwigia* and West Nile virus, and reporters have attended most *Ludwigia* Task Force meetings. Representatives from the Laguna Foundation have made presentations on *Ludwigia* to a wide variety of public gatherings, to share information and answer questions about control plans. Two public workshops were held during April and May 2005, to discuss *Ludwigia* Control Project plans and NPDES permit applications.

C. Long-term control through restoration

Although the project described above will likely control the worst *Ludwigia* infestations and relieve the immediate risks of West Nile virus and other mosquito-borne diseases, patches of invasive *Ludwigia* will remain, scattered throughout the watershed. Short-term approaches need to be accompanied by long-term restoration plans to make ecological changes

16 http://www.lagunadesantarosa.org/RMP/Ludwigia/default.htm

to the system that will prevent or reduce the impact of re-infestation. Thus, long-term control measures must also consider a broader geographic area. Native *Ludwigia peploides* subspecies *peploides* is also known to occur in the Laguna watershed, and it is often difficult to distinguish these species in the field. Because of the presence of this native, and the logistical considerations involved with systematically eradicating every individual of invasive *Ludwigia* from the lakes, ponds and waterways of Sonoma County, our goal is to lessen its invasiveness and environmental impacts – rather than seek total eradication. This approach requires extensive ecological research, likely over a 5-10 year time frame. As invasive *Ludwigia* appears to be a relatively new pest species, there is little material in the scientific literature to draw from (see Appendix D: Important Areas for *Ludwigia* Research).

A researcher at Sonoma State University has begun investigations on the response of invasive *Ludwigia* to excess nutrients in the Laguna. Researchers with the USDA Agricultural Research Service (USDA-ARS) are also conducting experiments on restoration-based methods for *Ludwigia* control. The Sonoma County *Ludwigia* Task Force will work together with these researchers to develop a long-term *Ludwigia* management strategy, based on the best available science. Potential control measures include water level management, shading portions of the channel with riparian vegetation, reducing nutrient availability, and using biological control organisms; see Appendix D. As *Ludwigia* species are creating serious environmental problems elsewhere in the country and in Europe, there is great potential for developing a broad *Ludwigia* research consortium. At this stage we are collecting baseline and preliminary data, initiating research, and a comprehensive GIS mapping effort. As part of this baseline mapping effort, the USDA-ARS has taken high-resolution aerial photos and hyper-spectral images of the Laguna channels. These images will help track the progress of the invasion, and evaluate the success of interim control measures, as well as develop a set of environmental correlates to *Ludwigia* distribution.

Restoration projects, for weed management and habitat enhancement, need to be designed within the context of broader planning efforts. The Laguna Foundation has been funded by the Coastal Conservancy to develop a Restoration and Management Plan for the Laguna watershed. As the Laguna represents some of the highest-quality habitat in an area of high species diversity, there is great community interest in ecosystem restoration in this area.

V. Acknowledgements

This plan is loosely based on a Weed Management Template developed by Mandy Tu and Barry Meyers-Rice for The Nature Conservancy's Wildland Invasive Species Program. We are grateful for this and the many other resources made available through TNC. We would like to thank the members of the Sonoma County *Ludwigia* Task Force and the many other interested parties who have contributed ideas and material to this plan. We are very grateful to the funders of this plan: the California Coastal Conservancy, the Sonoma County Community Foundation, and the Marin/Sonoma Mosquito and Vector Control District; as well as the funders of the Interim *Ludwigia* Control Project: The Sonoma County Water Agency, the Wildlife Conservation Board, the Santa Rosa Subregional Reclamation System, and the Marin/Sonoma Mosquito and Vector Control District.

VI. References

Baruah, M.; Saikia, L. R. 1999. Water stress on reproductive capacity of *Ludwigia parviflora* Roxb. Geobios (Jodhpur) 25 (2-3): 107-110.

Best, C., J. T. Howell, W. Knight, and M. Wells. 1996. A Flora of Sonoma County. California Native Plant Society. Sacramento, Ca.

Boyce, et al. 2004. Potential Impacts of West Nile Virus on Wildlife in California. Wildlife Health Center, University of California, Davis. http://www.wildlifehealthcenter.org.

Buckmann. 1991. Laguna Wildlife Area: Conceptual Area Acquisition Plan. Prepared for the Central Coast Region of the California Department of Fish and Game.

Burridge. 1995. Sonoma County Breeding Bird Atlas, Madrone Audubon Society. 216p.

Cadman. 2000. Stone Farm Ranch Plan. Report for the City of Santa Rosa.

California Department of Fish and Game; Bird Species of Special Concern; http://www.dfg.ca.gov/hcpb/species/ssc/sscbird/sscbird.shtml.

CDC West Nile Virus; List of Bird Species that have tested positive for WNV;http://www.cdc.gov/ncidod/dvbid/westnile/birdspecies.html.

DiTomaso and Healy. 2003. Aquatic and Riparian Weeds of the West. University of California, Agricultural and Natural Resources.

ECOTOXNET; Pesticide Information Profiles; Oregon State University; http://extoxnet.orst.edu/pips/ghindex.html.

Ellmore, G. S. 1981. Root Dimorphism in *Ludwigia peploides* (Onagraceae): Structure and Gas Content of Mature Roots. American Journal of Botany 68: 557-568.

Foster, Keenan. Fall 2005. Editorial: Thoughts on *Ludwigia* in the Russian River. The Russian River Bulletin 8(1): 8-10.

Greenway, Margaret. 1997. Nutrient content of wetland plants in constructed wetlands receiving municipal effluent in tropical Australia. Water Science Technology 35(5): 135-142.

Hickman, J.C. (editor). 1996. The Jepson Manual Higher Plants of California. University of California Press. Berkeley, Ca.

Laguna de Santa Rosa Resource Atlas and Protection Plan. 2003. Prepared by the Sonoma Land Trust and the Laguna de Santa Rosa Foundation

Miller, P. and P. Westra. How surfactants work. Colorado State University; http://www.ext.colostate.edu/pubs/crops/00564.htm

Philip Williams & Associates, LTD. 2004. Sediment Sources, Rate & Fate in the Laguna de Santa Rosa, Sonoma County, California. Report for the Sonoma County Water Agency and the U.S. Army Corps of Engineers.

PRBO Conservation Science; Partners in Flight; Riparian Habitat Joint Venture; Focal species; http://www.prbo.org/calpif/htmldocs/riparian2.html.

North American Bird Conservation Initiative; Bird Conservation Region 32: Coastal California; http://www.nabci-us.org/aboutnabci/nawcaspp.pdf.

Rejmankova, E. 1992. Ecology of creeping macrophytes with special reference to *Ludwigia peploides* (H.B.K.) Raven. Aquatic Botany 43: 283-299.

San Francisco Estuary Institute, et al. 2004. Field evaluations of alternative pest control operations in California waters. http://www.sfei.org/apmp/reports/PestAlternatives_field.pdf

Smith. 1990. History, Land Uses and Natural Resources of Sonoma County. Report for the Santa Rosa Subregional Water Reclamation System.

Sonoma County Flood Control and Water Conservation District (SCFCWCD). Ca.1965. Flood!! December 1964-January 1965, Santa Rosa, 65p.

State Water Resources Control Board. 2004. Fact Sheet: Water Quality Order No. 2004-0009-DWQ. Statewide General National Pollutant Discharge Elimination System Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States. General Permit Number CAG 990005 http://www.swrcb.ca.gov/resdec/wqorders/2004/wqo/wqo2004-0009.pdf

USGS National Wildlife Health Center; Species affected by West Nile Virus; http://www.nwhc.usgs.gov/disease_information/west_nile_virus/affected_species.jsp.

VII. Appendices

Appendix A. Index of Acronyms

BMP: Best Management Practice
CDFG: California Department of Fish and Game
CEQA: California Environmental Quality Act
DPR: Department of Pesticide Regulation
CWA: Clean Water Act
GIS: Geographic Information System
IPM: Integrated Pest Management
MSMVCD: Marin/Sonoma Mosquito and Vector Control District
NAWCA: North American Wetlands Conservation Act
NCRWQCB: North Coast Regional Water Quality Control Board
NOAA: National Oceanic and Atmospheric Administration
NPDES: National Pollution Discharge Elimination System
RRIIS: Russian River Interactive Information System
SCAPOSD: Sonoma County Agricultural Preservation and Open Space District
SCWA: Sonoma County Water Agency
TMDL: Total Maximum Daily Load
USACOE: United States Army Corps of Engineers
USDA-ARS: United States Department of Agriculture – Agricultural Research Service
WNV: West Nile virus

Appendix B. Sonoma County Ludwigia Task Force Members, June 2005

Allan Buckmann; Wildlife Biologist, California Department of Fish and Game

Dick Butler; Team Leader, National Marine Fisheries Service

Denise Cadman; Natural Resource Specialist, City of Santa Rosa

Caroline Christian, Ph.D.; Senior Scientist, Plant Ecologist, the Nature Conservancy

Gene Cooley; Botanist, California Department of Fish and Game

Bill Cox; Fisheries Biologist, California Department of Fish and Game

David Cuneo; Senior Environmental Specialist, SCWA

J. Hall Cushman, Ph.D.; Conservation Biologist, Sonoma State University Faculty

Keenan Foster; Botanist, Senior Environmental Specialist, SCWA

Brenda Grewell, Ph.D.; USDA-ARS Exotic and Invasive Weed Research, Davis CA

Leigh Hall, M.D.; Deputy Public Health Officer, Sonoma Co. Department of Health Services

Erik Hawk; Vector Ecologist, Mosquito Vector Control District

Andrew Jensen; Environmental Scientist, NCRWQCB

Ron Keith; Entomologist, Mosquito Vector Control District

Piper Kimball; Vector Ecologist, Mosquito Vector Control District

Chris Kjeldsen, Ph.D.; Aquatic Botanist, Sonoma State University Emeritus Faculty

Chuck Krause; Operations Manager, Mosquito and Vector Control District

Walter Kruse; Director, Sonoma County Environmental Health

Dan Logan; Fisheries Biologist, National Marine Fisheries Service

Bruce MacArthur; Deputy Ag. Commissioner, Sonoma Co. Agricultural Commission

Jake MacKenzie, Ph.D.; City of Rohnert Park, Aquatic Botanist, retired EPA regulator

Bob Rawson; Wastewater Management Consultant, Russian River Watershed Council

Jim Raisner; Agricultural Biologist, Sonoma Co. Agricultural Commission

Mike Reilly; Fifth District Supervisor, Sonoma County Board of Supervisors

Anna Sears, Ph.D.; Research Director, Laguna de Santa Rosa Foundation

Dan Schurman; Executive Director, Laguna de Santa Rosa Foundation
John Short; Senior Water Resource Control Engineer, NCRWQCB
Mike Thompson; Deputy Chief Engineer for Maintenance, SCWA
Joel Trumbo; Pesticide Use Coordinator, California Department of Fish and Game
Lily Verdone; Plant Ecologist, Biology Master's program, Sonoma State University
Jim Wanderscheid; Manager, Mosquito and Vector Control District

Appendix C. Bird species of concern

The following birds are residents of the Laguna de Santa Rosa within the vicinity of the project area and are Riparian Habitat Joint Venture focal species, CDFG species of special concern, or priority species under the North American Wetlands Conservation Act (NAWCA) for Coastal California freshwater wetlands. Susceptibility to West Nile Virus (WNV) is noted where known.

Riparian Habitat Joint Venture focal species
Common Yellowthroat (breeding)**
Song Sparrow (breeding)**
Wilsons Warbler (breeding)**
Yellow Warbler (breeding)* CSC
Warbling Vireo (breeding)**
Priority NAWCA Waterfowl species:
Mallards (breeding)**
Wood Duck (breeding)*
Lesser Scaup (winter resident)**
Greater Scaup (winter resident)**
American Widgeon (winter resident)
Ring-neck Duck (winter resident)
Priority NAWCA species
Northern Harrier (breeding)** CSC
American Avocet (breeding)
Allen's Hummingbird (breeding)
Violet-green Swallows (breeding)
Marsh Wren (breeding)
Warbling Vireo (breeding)*
Black-headed Grosbeak (breeding)**
Hooded Oriole (breeding)**
Bullock's Oriole (breeding)
Loggerhead Shrike (breeding) CSC

Cooper's Hawk (winter resident)** CSC
Short-eared Owl (winter resident)** CSC
Olive-sided Flycatcher (summer resident)**
Western Wood-peewee (summer resident)
Black-bellied Plover (migratory)
Short-billed Dowitcher (migratory)
Lazuli Bunting (migratory)
Lewis' Woodpecker (migratory)**
Other CDFG Species of Special Concern
Double-crested Cormorant (breeding)** CSC
Osprey (breeding)** CSC
Golden Eagle (breeding)** CSC
Bald Eagle (breeding)** FT, SE
American White Pelican (winter resident)** CSC

* – Species listed as affected by WNV by USGS National Wildlife Health Center

** – Species that have tested positive for WNV by the Federal Center for Disease Control

"CSC" – CDFG 'Species of Special Concern'

Note: Absence of positive test does not indicate that species are immune to WNV. Small or rare populations may not yet have been tested.

Appendix D. Important Areas for Ludwigia Research[17]

1. Overview: Information on *Ludwigia* species' biology is currently very limited, and its taxonomy is currently under revision, making it difficult to determine optimal control strategies. Understanding the basic ecology of invasive *Ludwigia*'s dispersal mechanisms, its taxonomy and ecosystem function in the Laguna, as well as its potential ecological interactions is essential for both long and short term watershed management planning. Initial research plans were developed in conjunction with the *Ludwigia* Task Force and have assisted with the interim planning process. There remain numerous unanswered questions requiring extensive research. These multifaceted questions affect a wide base of community, economic and natural resource management issues such as agriculture, water management and flooding and human health.

17 Research questions compiled from discussions with the *Ludwigia* Task Force, especially Keenan Foster (see ref.) and Dr. Brenda Grewell of the USDA-ARS.

2. Population biology and natural history: There is a strong need for better species identification tools: different *Ludwigia* species are very similar in physical appearance and habitat requirements, but may have very different ecological interactions. Molecular systematic analysis (studies of *Ludwigia* DNA) is needed to verify the taxonomy and origin of invasive *Ludwigia*. It can also be used to determine whether invasive populations are formed from *Ludwigia* hybrids, and whether the mode of reproduction in primarily clonal or through seed dispersal. What conditions stimulate germination? Understanding individual and population-level growth dynamics and dominant mechanisms of dispersal will be key for long-term management planning and modeling the rate of spread. Studies that quantify *Ludwigia* environmental constraints (e.g., water depth, nutrient availability) are needed to develop control plans for invaded areas and to predict potential invasion sites. What factors encourage *Ludwigia*'s proliferation?

3. Community ecology: It is important to understand how *Ludwigia* invasions affect surrounding plant and animal species. The primary competitive strategy of invasive *Ludwigia* is to overgrow neighboring plants, depriving them of space and light. Where *Ludwigia* plants form monocultures, birds, insects, fish and other wildlife may be affected, as well as surrounding wetland plants. Understanding these relationships will affect the specific planning of management practices, and potentially the prioritization of control actions. With regional efforts to protect habitat for endangered salmonids, it would be very useful to understand the effect of *Ludwigia* on juvenile fish, amphibians, and invertebrates. It would also be valuable to quantify the effects of *Ludwigia* on habitat quality for waterfowl and migrating birds in the Pacific Flyway. Physical, ecological, and physiological differences between local *Ludwigia* species may influence their interactions with insects, parasites and plant pathogens: providing avenues for potential species-specific biological control mechanisms. Are there native organisms that can help control the distribution of this species?

4. Ludwigia and mosquitoes: The need for effective mosquito control is a primary driver for *Ludwigia* control plans. Very high numbers of adult mosquitoes are found in *Ludwigia* areas. However, more work is needed to study the pattern of occurrence of larval mosquitoes in *Ludwigia* patches, and how different *Ludwigia* control methods affect larval abundance. Studies on rice fields have shown that leaving dead plants in place increases available nutrients and thus mosquito numbers. However, if field sites are regularly treated with mosquito control products, there may still be an

increase in mosquito control effectiveness, even if plants cannot be removed.

5. Interactions with hydrology and sedimentation: Water level and flow-rate appear to be central drivers of *Ludwigia* distribution patterns and reproductive success. Thus, water-level management is a potentially powerful tool for invasive *Ludwigia* control, manipulating levels by strategically draining or deepening areas of the Laguna. However, Laguna water-levels are dynamic, changing throughout the year, so it is difficult to quantify the specific conditions or regimes favoring *Ludwigia* growth as well as the growth and well-being of neighboring plant and animal species. Knowing which conditions favor different suites of species is absolutely necessary for evaluating the direct and indirect effects of water-level changes on the wetland community and abiotic processes. Thick, vegetative mats of *Ludwigia* potentially effect movement of sediment, water flow and flooding; and much more research is needed to understand these processes. *Ludwigia* appears to favor soft, sediment-rich soils. It is also likely that *Ludwigia* traps sediments moving through the Laguna waterways. This process of accretion and further growth may act as a positive feedback-loop, accelerating channel infill, and assist in *Ludwigia*'s habitat expansion.

6. Nutrient dynamics: While some initial research has investigated the growth of *Ludwigia* under different nitrogen and phosphorous nutrient regimes in the field and greenhouse, there are still many unknowns about the physiological ecology of *Ludwigia* and its response to nutrient availability in the sediment and water column.

7. Ludwigia control methods: There have been few published studies evaluating the effectiveness of different chemical and physical control treatments on *Ludwigia*. Also, different invasive *Ludwigia* species may respond differently to particular treatments. One study found that control success was much greater when herbicide treatments are combined with mechanical removals. However, in a number of situations, mechanical removal may not be possible. More research is needed to evaluate the relative effectiveness of different herbicide treatments with and without mechanical removals, and the relative effect of different herbicides on non-target plants and animals. Much more research is also needed to evaluate the feasibility of using tarps or grazing animals to control *Ludwigia*, and the non-target effects of these treatments.

Appendix E. MAP

Top priority sites for *Ludwigia* control in the Laguna de Santa Rosa see *Ludwigia* Control Project site: http://www.lagunadesantarosa.org/RMP/*Ludwigia*/*Ludwigia*_Status.htm

Appendix F. Herbicide Labels and Material Safety Data Sheets

1. Rodeo label (glyphosate product) http://www.cdms.net/ldat/ld4TN002.pdf
2. Rodeo Material Safety Data Sheet (MSDS) http://www.cdms.net/ldat/mp4TN006.pdf
3. Renovate label (triclopyr product) http://www.sepro.com/documents/Renovate_Label(REV).pdf
4. Renovate MSDS http://www.sepro.com/documents/Renovate_MSDS.pdf