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060381-EQ

An Assessment and Management Protocol for *Arundo donax* in the Salinas Valley Watershed

A Capstone Project

Presented to the Faculty of Earth Systems Science and Policy

in the

Center for Science, Technology, and Information Resources

at

California State University Monterey Bay

In Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science

by

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May 2001

Preface

This is an under-graduate student report. The opinions and conclusions presented do not necessarily reflect the final material to be presented as the outcome of the Salinas Sediment Study (2000-1 contract). Nor do they necessarily reflect the opinions or conclusions of the Central Coast Regional Water Quality Control Board, who funded the work, or any of its staff.

Having said that, I hope you enjoy the report. It is the product of an extra-ordinary level student dedication to the science of bettering the environment of the Central Coast while recognizing the social and economic importance of its agriculture and industry.

Dr. Fred Watson
Project leader.
Student Capstone Advisor

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Abstract

Arundo donax is an invasive non-native perennial grass indigenous to the Mediterranean region. *Arundo* was introduced to California by Spanish settlers in the 1800's and today is invading riparian habitats of North America, specifically in California. In fact, the California Exotic Plant Pest Council (CalEPPC) has included *Arundo donax* as one of the top five species of concern because of the associated environmental problems such as flood-control, fire-hazard, critical habitat loss, water quality, and water conservation. This study aimed: 1) to discuss the most effective management methods of *Arundo donax* infestations and the appropriate methods for restoring native vegetation in riparian areas, 2) to answer whether *Arundo* can be differentiated from similar riparian vegetation using remote sensing, which is the first step in any assessment protocol for the *Arundo* invasion in the Salinas Valley Watershed, and 3) to develop a policy recommendation for the *Arundo* invasion of Monterey County, California that is primarily based on ethics and history. Overall, this study is an assessment and management protocol for *Arundo donax* in the Salinas Valley Watershed.

This study found that the most effective methods in eradicating *Arundo* are the foliar 2-5% herbicide application method and the cut stump 100% herbicide application method. In developing a basis for an assessment protocol, this study found that *Arundo* can be differentiated from similar riparian vegetation on high-resolution digital Color-IR imagery. It appeared that after an unsupervised classification was completed on the Color-IR that *Arundo* was most similar to willow. Furthermore, from the supervised classification, this study found that *Arundo* is significantly different than willows in their designated reflectance properties. As such, remote sensing can be a useful tool in mapping the extent of the *Arundo* invasion in the Salinas Valley. The final result of this study concerning the policy recommendation is that before Monterey County can begin to deal with its *Arundo* environmental problems, there should be a complete understanding of why the county is even faced with *Arundo*. Also, there should be a collaborative effort, including the private and public sectors of Monterey County, in the management and eradication of *Arundo*. And finally, in determining the appropriate policy for Monterey County through collaborative action, look to examples as a guide where the implementation of *Arundo* policies have been successful. Since Monterey County has proposed a countywide Invasive Weed Management Plan, this study recommends that *Arundo* be included for immediate assessment and management before the *Arundo* invasion becomes problematic in the Salinas River and its Watershed.

Part I. Background: *Arundo donax* Management and Eradication in Riparian Systems

1.1 Introduction

Arundo donax, also known as giant reed, is an invasive non-native perennial grass that invades riparian habitats of North America, specifically California. *Arundo donax* was first introduced to California in the 1800's by western settlers and was primarily used for horticultural and medicinal purposes. More recently *Arundo donax* has been used as erosion control in drainage canals. Within the last 25 years, a number of problems have been associated with *Arundo donax* invasions in riparian habitats. Such problems include flood-control, water-conservation, habitat loss, water quality issues, and fire hazards.

The most immediate concern with an *Arundo donax* invasion is that it can out-compete native vegetation and therefore destroy the habitats of many native species, including a number of endangered species. An even larger concern is that the current management and eradication methods for *Arundo donax* are costly and labor intensive. This section of the protocol will discuss the most effective management methods that manage and eradicate *Arundo donax* and the restoration methods used to restore native vegetation in riparian areas.

1.2 *Arundo donax* Historical Facts

It is often stated that *Arundo donax* is indigenous to the Mediterranean region (Dudley, 1993) but different sources suggest that *Arundo* was introduced to the Mediterranean region either from India, or from eastern Asia. The uses of *Arundo* have been dated back to 5,000 B.C. where the Egyptians used *Arundo* leaves as lining for underground grain storage. In the 4th Century A.D., *Arundo* was used for medicinal purposes such as a sudorific, diuretic, anitlactant, and for the treatment of dropsy. Also, it has been stated that mummies were wrapped with *Arundo* leaves (Hoshovsky, date unknown).

The earliest time known for the intentional introduction of *Arundo* to California was in the early 1820's by the Spanish for erosion control (Douce, 1993). The Spanish also used *Arundo donax* for building material, firewood, and fodder (Frandsen, 1997). In addition, governmental agencies over time have encouraged farmers to plant *Arundo donax* for erosion control in drainage canals (Boose and Holt, 1998).

Figure 1.2A. *Arundo* as an ornamental plant
Source: http://www-bprc.mps.ohio state.edu/~bdaye/canestdc.gif

However, in more recent times *Arundo donax* has been commercially cultivated for the production of reeds for musical instruments. Interestingly enough this type of commercial cultivation has been traced back for nearly 5,000 years. Not only has *Arundo* been used for musical instruments it has been cultivated for ornamental plants (**see figure 1.2A**) and other horticultural purposes, such as garden fences and trellises. Unfortunately, *Arundo* has primarily invaded riparian habitats due to escapements from commercially and locally managed habitats.

1.3 Plant Biology of *Arundo donax*

Arundo donax is a rhizomatous perennial grass species. It reproduces by rhizomes and can essentially remain alive throughout the year. The adult plant resembles bamboo or corn and the young plant stems resemble large grasses such as ryegrass and common reed. *Arundo donax* is a member of the Poaceae family and has a number of common names associated with it, such as giant reed, bamboo reed, giant reed grass, *Arundo* grass, donax cane, giant cane, bamboo cane, and Canne-de Provence (Bell, 1993). It grows in a number of freshwater riparian habitats such as irrigation ditches, streams, lakes, and wetlands. Scattered colonies of *Arundo* can be found in moist sites like springs, along rice fields, and in residential landscaping. It prefers gentle sloping streams over steeper smaller stream channels and in California *Arundo* generally grows in regions below 1,000 feet.

Arundo is the largest of the herbaceous grasses. It has hollow, segmented culms that measure anywhere from 1 to 4 centimeters in diameter, which will branch in the second year of growth. The rootstock bears fibrous roots that grow into the soil up to 5 meters in depth (Frandsen, 1997). *Arundo* has the ability to survive in a number of different types of soils, ranging from heavy clays to loose sands and gravelly soils. Sandy soil is the most common type of soil in which it is found. *Arundo donax* can grow up to 6 to 8 meters tall and in optimal conditions it can grow between 5 to 7 centimeters a day (Frandsen, 1997). *Arundo* can grow year round but optimal growth occurs between February and October. It grows well when the water table is close or at the soil surface but will be retarded if there is lack of moisture in the first year of growth. Droughts have little effect on the established stands that are in the second or third year of growth. *Arundo* can survive extended droughts because of the drought resistant rhizomes and roots that

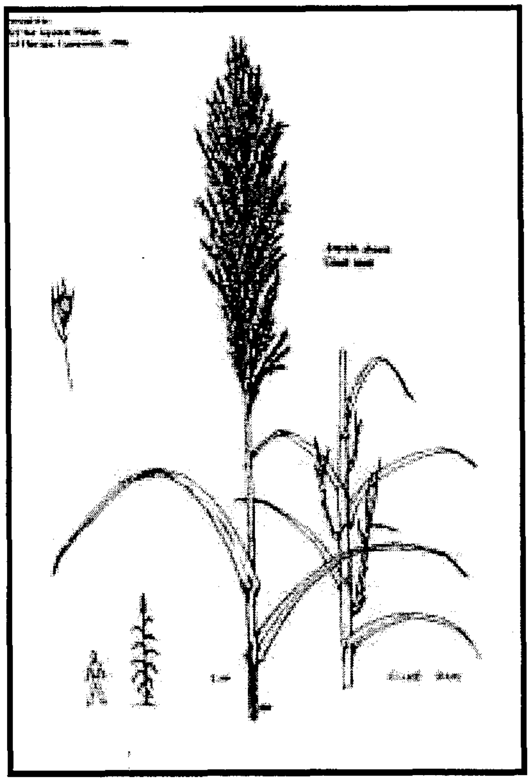


Figure 1.3. *Arundo* growth dimensions.
Source: http://aquat1.ifas.ufl.edu/*Arundon*2.jpg

can reach water supplies. It also can survive very low temperatures in the dormant winter season but is subjected to possible damage with frost events after the start of the spring growth.

Arundo donax reproduces vegetatively by rhizomes and also by stems, which will root at the nodes along the stalk (Jackson, 1993). Rhizomes in perennial grasses are underground stems that produce adventitious roots and shoots. Stems produce adventitious roots and shoots near the tips of branches or from sprouts at the stem base or stump (Radosevish, Holt, and Ghersa, 1997). It flowers in late summer and produces a plume-like flower. It has been observed that *Arundo* produces seeds, however, they are usually infertile.

1.4 Effects of Disturbance on the Viability of *Arundo donax*

Reproductive viability of *Arundo donax*

Because *Arundo* propagates vegetatively from both rhizomes and stems, it can become extremely invasive in highly disturbed environments. It is true that riparian areas have the potential to be highly disturbed due to flooding and occasional fires. Therefore, *Arundo* propagates most efficiently in riparian areas. *Arundo* becomes extremely invasive because of the viability of its reproductive means of stems and rhizomes. The ability to sprout roots is dependent on the size of the stem. The longer the stem, the longer it takes for the plant to sprout roots. The stem can sprout roots if the minimum length is 2 centimeters and it has been separated from the parent plant for less than 17 weeks (Boose and Holt, 1998). Stems can also sprout roots in soil depths of 10 centimeters. However, the ability to sprout roots is not dependent on the size of the rhizome (see figure 1.4A). The rhizomes can sprout up to 18 weeks after separation from the parent plant. Rhizomes can sprout in soil depths of 25 centimeters (Boose and Holt 1998).

Figure 1.4A. *Arundo* rhizomes
Source: http://www.smslrwma.org/

Flood as a disturbance

Arundo donax is a flood-follower, which indicates that it spreads by flood-fragmentation and vegetative propagules. Therefore water is the number one dispersal agent of *Arundo* in riparian habitats. Since flooding can break up vegetative cover and because *Arundo* responds quickly to disturbances (**see figure 1.4B**), the flood will break up large stands of already existing *Arundo* and carry it downstream for the stems and rhizomes to take root (Bell, 1993). Also, the root mass is easily undercut during high flow events and is washed downstream with the stems attached. Once transported downstream, *Arundo* has the potential to become invasive in new riparian areas.

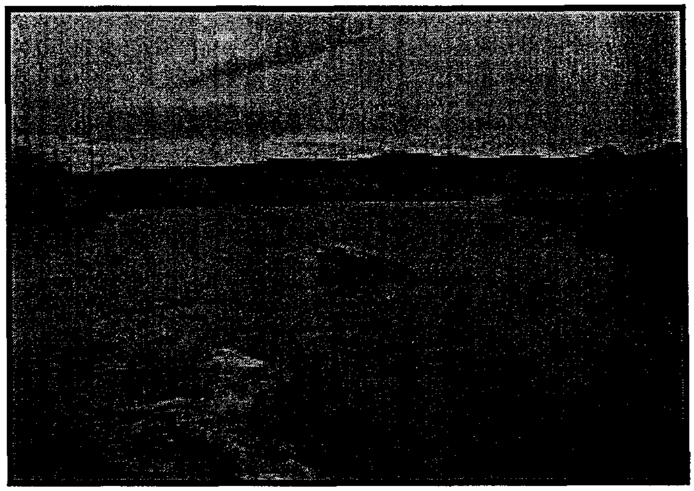


Figure 1.4B. Salinas River at the Greenfield Bridge. *Arundo* floating downstream during a winter rainstorm (photo taken by Alana Oakins, March, 2001).

Fire as a disturbance

Arundo donax is also a fire-follower, which means that *Arundo* rhizomes respond quickly after a fire and will outgrow native riparian vegetation (Bell, 1993). When fires occur during the drier part of the year, which is usually July through October, the existing stands of *Arundo* will increase the probability and the intensity of a fire occurring. *Arundo* is highly flammable during most of the year, which means it is a fire hazard for nearby vegetation, wildlife, buildings, and people. The existence of *Arundo* converts riparian areas from fire breaks to fire hazards and leaves agencies spending even more money to control fires. In post-fire regeneration in areas that *Arundo* exists, fires will promote even greater quantities of *Arundo*.

1.5 Problems Associated with *Arundo donax*

Effects on stream flow and stream morphology

The presence of *Arundo donax* in streambeds and along stream banks effects the stream flow and stream morphology. *Arundo* tends to form large continuous root masses that can stabilize stream banks and terraces. However, its root masses are brittle and large, and the shallow rhizomes provide little structural integrity to the stream banks. This results in undercutting of the bank, bank slumping, and sedimentation of the river or stream (Team *Arundo* del Norte, 1999). If the root masses break free from the streambed or banks, it will pull along with it debris from the streambed or banks which results in erosion. The *Arundo* and stream bank debris that washes downstream can form against the flood control and transportation structures such as bridges and culverts. This inhibits the stream flow of water. Also, *Arundo* debris constricts the flow and reduces the availability of stream navigation.

Arundo stands act as a filter and collect sediments that are carried downstream. As the surface under the *Arundo* stands rise, it can force the stream water in new paths, which then interact with other infestations downstream or across the stream (**see figure 1.5**). The result is accelerated erosion of stream banks, lost property, and expensive property repairs.

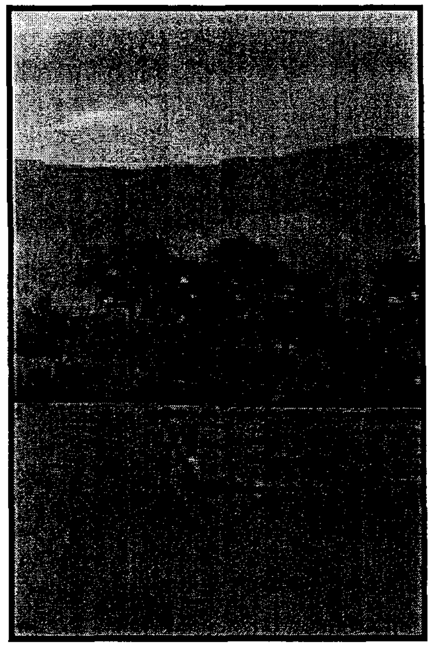


Figure 1.5. Salinas River near Gonzales. *Arundo* in the middle of the river. (photo taken by Alana Oakins, March 2000)

Loss of native riparian habitat

Native riparian vegetation predominately make up the largest habitat in California that *Arundo* infestations are threatening. *Arundo* can be found in nearly half of the US states and is of particular concern in Central California, Mexico, Arizona, Nevada, and Oregon. In the Santa Ana River of Southern California, it is estimated that 68% of the riparian vegetation in comprised of *Arundo* (Dudley, 1993). The native vegetation that *Arundo* has displaced is comprised of the Willow (*Salix*), Mulefat (*Baccharis salicifolia*), and Cottonwoods (*Propulus*). This native vegetation provides nesting for native species such as the Least Bell's Vireo (*Vireo bellii pusillus*), a federally endangered species, the Willow flycatcher (*E. traillii*), a federally threatened species, and the Yellow Cuckoo (Bell, 1993).

Competition mechanisms of *Arundo donax*

Firstly, *Arundo donax* uses three times more water than native riparian plants. In fact one meter of standing *Arundo* can use up to 2,000 liters of water (Bell, 1993). This results in the reduction of available water that is intended for agricultural use or urban use. Another way *Arundo* can reduce the amount of water in streams is by the debris build-up in the stream channel, which causes the water to flow at a much slower rate than normal. If the stream flow rate is reduced significantly, then the stream will have increased evaporation.

Secondly, *Arundo donax* interferes with the regeneration of native riparian vegetation by outgrowing or shading out the native species. *Arundo donax* grows in such tall, dense stands, that it can out-compete native vegetation for sunlight, soil moisture, and nutrients. The shade provided by the tallness of *Arundo* prevents the germination and development of emerging native riparian plants, such as trees, shrubs, and grasses.

Thirdly, the leaves contain a number of toxic and unpalatable natural minerals and chemicals, such as silica, cardiac glycosides, hydromaxic acids, and alkaloids that protect the plant from native insects that might attempt to feed or reproduce upon it (Bell, 1993). Therefore, even native insects become scarce with the invasion of *Arundo*. This could lead to the possibility of major reduction in all forms of wildlife because native vegetation supports many of the insects that wildlife depend on. With the invasion of *Arundo*, what was once a complex food web, becomes simplified, leaving fewer species that can survive in the presence of *Arundo donax*.

Unfortunately, little is known about predators of the U.S. that can kill *Arundo* (Frandsen, 1997). Diseases like root rot, lesions, crown rust, and stem speckle have been found on *Arundo donax* but they do not hinder the plant (Bell, 1993). However, in the Mediterranean, known natural predators have been the com-borers, spider mites, and aphids.

Inability of *Arundo donax* to provide habitat for native species

Not only does *Arundo* take away from the complex food web of riparian ecosystems it degrades riparian habitats and creates unsuitable habitats for a number of sensitive native species (Team *Arundo* del Norte, 1999). Native riparian habitats are some of the most diversified habitats in California in terms of the flora and fauna that it supports. *Arundo* stands are too thick for birds to fly and they lack the diversified structure needed for native bird species. Therefore, native bird species cannot find suitable habitats in *Arundo* infested riparian areas.

Arundo also lacks the canopy structure that provides shading for riparian habitats which results in warmer water temperatures, lower oxygen levels, and lower diversity of aquatic animals. These aquatic animals include the Arroyo Chub (*Gila orcuttii*), a species of concern, Santa Ana Sucker (*Catostomus santaanae*), a proposed threatened species, and the Unarmored Threespine Stickleback *(Gasterosteus aculeatus williamsoni*) (Bell, 1993). Many anadromous fish species previously mentioned require cool, clean water. Not only does *Arundo* alter aquatic habitat, *Arundo* stands also change the quality and timing of organic litter inputs that form the trophic base for Steelhead Trout (*Oncorhynchus mykiss*), a federally threatened species, Coho Salmon (*Oncorhynchus kisutch*), a federally threatened species, and Freshwater Shrimp (Team *Arundo* del Norte, 1999).

Other at-risk-protected species that are negatively affected by the invasion of *Arundo* in riparian habitats are the Arroyo Toad (*Bufo microscaphus californicus*), a federally endangered species, California Red-Legged Frog (*Rana aurora draytonii*), a federally threatened species, Western Pond Turtle (*Clemmys marmorata*), and the Tidewater Goby (*Eucyclogobius newberryi*), a federally endangered species (Dudley, 1993). *Arundo* is rapidly and catastrophically altering the ecological processes in riparian systems and moving diverse ecosystems into pure stands of *Arundo donax*.

However, it is important to note that a recent study from the Santa Margarita River, Marine Corps Base Camp Pendleton, San Diego County, California conducted by Bob Lovich (USGS) observed a macroinvertebrate community of *Arundo* in riparian habitats. They collected a total of 2,581 invertebrates and identified 140 exotic species in their sample. The study found that exotic species were more abundant than native species. Three of the 140 species exotic species found made up 41% of the total exotic species. This study has also reported that there were no sensitive species observed and therefore supports heavy machinery as a method for *Arundo* removal. This study also highlights that *Arundo* is poor habitat for native species and supports the existing and future management of *Arundo* in riparian habitats.

1.6 Management Methods of *Arundo donax*

Things to consider in managing *Arundo donax*

It is true that we might never be able to fully eradicate *Arundo* in our environment but effectively managing *Arundo* is possible. Management of *Arundo donax* in a riparian habitat means eradicating *Arundo*, protecting endangered species, water-conservation, flood and fire control, and increasing recreational use. The Office of Technology Assessment of the US Congress warn that by the Mid-21st Century biological invasions will become one of the most prominent ecological issues on earth (Douce, 1993). Therefore, a management plan must be developed that looks at riparian areas as an integrated system (Douce, 1993).

Managing *Arundo* is a multi-year effort, which means it can take up to five years of monitoring and re-treatment if necessary to fully manage *Arundo*. The methods used to manage and eradicate *Arundo* depends on the size of infestation, the amount of cane debris the must be dealt with, the terrain, the season, and whether *Arundo* canes are mixed with desirable native vegetation (Cornal, Dale, and Newhonser, 1999). The cost of management also depends on the slope of the site, the ease of access, who does the work, and the disposal method of leftover cane (Cornal, Dale, and Newhonser, 1999).

Managing *Arundo* in riparian areas or an entire watershed is obviously dependent on many factors. To determine these dependent factors, such as discovering that *Arundo* exists, or the total amount of *Arundo* in an area, one management approach is beginning with a mapping or remote sensing study. Mapping a riparian area can be conducted by acquiring aerial imagery and then groundtruthing what is seen on the image. This groundtruthing can serve as a base map for detecting *Arundo* through remote sensing applications. One question to ask in using remote sensing is, can *Arundo* be significantly differentiated from similar vegetation? If so, then an *Arundo* assessment using technology becomes more effective and efficient. "Mapping is essential to the planning of the ground removal (of *Arundo*) efforts" (Douce, 1993).

It is also important to consider the effects of the management plan on riparian zones on fish migration and bird nesting. Riparian birds will nest from May through July and anadromous fish with migrate from the ocean back to their home streams at various times of the year. It is suggested to consult the U.S. Fish and Wildlife Service, CA Department of Fish and Game, or the National Marine Fisheries Service to find out if protected species like salmon, steelhead or other anadromous fish are present at the proposed site of management. If these species are present, work should be carefully planned and executed according to any guidelines the agencies provide.

Mechanical methods of control

The first mechanical method that can be used to manage *Arundo* is called the cut-only method. It is appropriate to use this method with small infestations of *Arundo* where there is a concern with the use of herbicides. This technique requires the cutting of *Arundo* canes at the base of the plant and hauling the biomass away from the streambed and banks for disposal. This method can be applied any time of the year but it is preferred during the growing season. The side effects of this method include soil disturbance and erosion on steeper slopes. The cost of this method is minimal if the treatment is executed by the landowner but can be costly if outside laborers are contracted because constant follow up is needed. This method has poor results because *Arundo* propagates from its stems and will re-sprout new growth from its roots. However, removing the canes using this method can eliminate the spread of *Arundo* downstream. Without the combination of herbicide, this method can be costly and a waste of time and labor.

Figure 1.6A. An example of mechanical control of *Arundo*
Source: http://www.smslrwma.org/*Arundo*Photos.htm

The second mechanical method is called the root-removal method. This technique requires the digging up of roots and hauling the roots and canes away from the streambed and banks for disposal. This method can be applied at anytime of the year and is appropriate when roots are exposed due to erosion and when downstream areas are vulnerable to infestations. The side effects of this method include soil disturbance and erosion because the soil becomes vulnerable to being washed away. If some of the roots are missed, they can be uprooted and washed downstream during high water events. This will spread the infestation downstream. The cost of this method is minimal if executed by the landowner. The equipment and re-vegetation needed for this method is costly. This method reports a success rate that is mixed. The cost, soil disturbance and equipment costs make this method an unpopular choice (Cornal, Dale, Newhonser, 1999).

Chemical methods of control

The spray-only method technique includes spraying the stems and leaves with a systematic herbicide. A systematic herbicide like glyphosate is absorbed by the plant leaves and stems and is transported to the plant's root system where it kills the entire plant, roots and all (Cornal, Dale, Newhonser, 1999). If it is used properly it will not leave high residues in the soil or water. A minute amount of this type of herbicide can be measured after application and is environmentally insignificant. The glyphosate is absorbed by the organic matter in soil and water and becomes biologically inactive (Cornal, Dale, Newhonser, 1999). Studies have shown that there are no significant toxicological hazards to wildlife.

The herbicide that is currently labeled for wetland use by the Environmental Protection Agency (EPA) is called Rodeo, which is manufactured by the company Monsanto. Herbicides that are not labeled for wetland use and are specific to monocots like *Arundo donax*, are Fusilade-Dx (fluozapop-butyl) and Post (Sethoxidan). It is important to address that even though the EPA has proven that the herbicide glyphosate is safe to use by humans and in the environment for *Arundo* control, being cautious in its usage is strongly advised. We do not know the long-term environmental effects of herbicides. It is more important to be aware of how the different control methods may affect the other parts of the system then to use herbicides obliviously. Until other management methods are discovered, the herbicide application method has proven to be the most effective in *Arundo* eradication and management in riparian habitats.

If this method of herbicidal application is used, a permit is not required if the landowner is applying the herbicide but pesticide use safety training is recommended for all applicators. If outside labor is contracted to eradicate *Arundo* using herbicide, they must have pesticide training, a pesticide operator identification number, a pest control recommendation, obtain a letter of authorization from the landowner, and file a monthly report with the County Agriculture Commissioner's office (Cornal, Dale and Newhonser, 1999).

This method is most effective during the growing season and is optimal after the flowering season which is late summer or early fall before the plant enters dormancy. The most effective spray method is a foliar application of a 2-5 % solution of Rodeo to *Arundo* (**see Figure 1.6B**) after it has flowered and ready to go into its pre-dormancy state (Bell, 1993). The Santa Margarita River is an example of

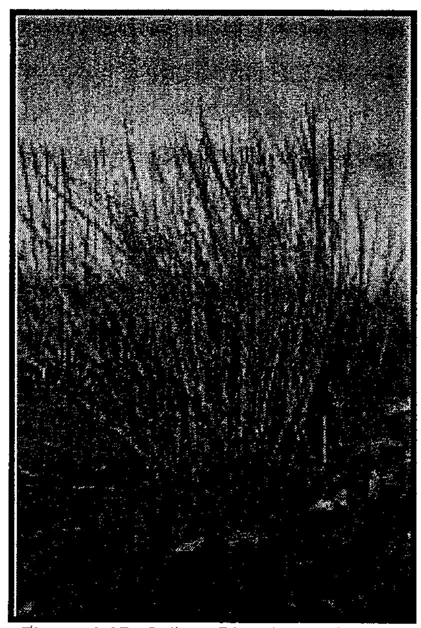


Figure 1.6B. Salinas River Levee Road Site
2% Rodeo Treatment on *Arundo*
(photo taken by Alana Oakins, March 2000)

where *Arundo* was controlled 100% versus a cut-stem treatment that resulted in a 5-50% control of *Arundo*. Within two to three weeks after the foliar treatment the leaves will turn brown and will soften making it easier to dispose of the biomass. In Figure 1.6C it is shown that a foliar treatment can be applied without negative effects on surrounding native vegetation. The side effects of this method are dependent upon the proper use of the herbicide. The greatest risk in spraying herbicides is spraying desirable native vegetation.

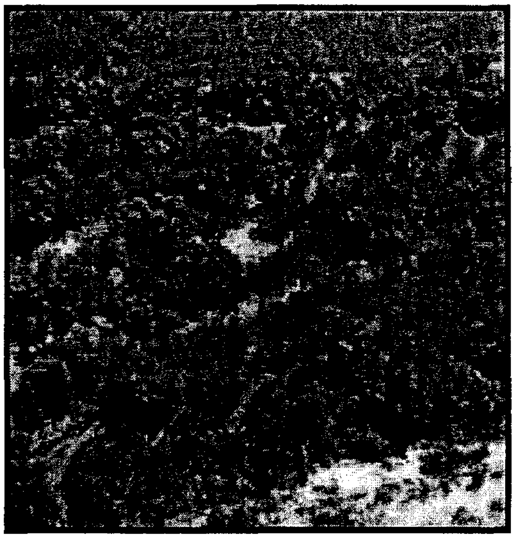


Figure 1.6C. Aerial image of successful foliar spray treatment of *Arundo*
Source: http://www.smslrwma.org/*Arundo*Photos.htm

Chemical and mechanical methods

The first combination of chemical and mechanical methods is called the cut-stump-herbicide application method (**see figure 1.6D**). This technique requires the cutting of the *Arundo* stalks and applying an undiluted glyphosate or other approved herbicide directly to the stump. "The cutting process has two steps. The first step is to cut the canes 1 to 2 feet from the base and remove the cuttings. Then, re-cut the stalks down to 2 to 3 inches and then apply the herbicide to the stumps within 2 to 3 minutes" (Cornwall, Dale, and Newhonser, 1999). This method can be applied throughout the growing season and is most effective in the early summer or early fall before the plant enters dormancy. It is appropriate in most proposed sites and best for mixed vegetation that is near water. The side effects include the risk of spillage of the herbicide and a slight risk of soil damage of disturbance and erosion when removing the cane. The cost of this method is moderate because there is very little herbicide wasted with precise application. Non-target losses are also avoided with this method and the follow up treatments is minimal. The success rate ranges from 50% to 95% in the first year and can take up to 3 to 5 years to fully eradicate *Arundo*.

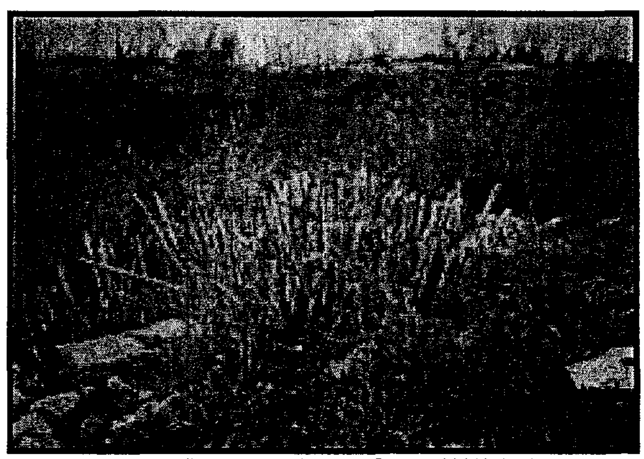


Figure 1.6D. Salinas River Site, Cut Stump 100% Rodeo Treatment to *Arundo* (photo taken by Alana Oakins, March 2000)

A second method of the combination of chemical and mechanical methods is the cut-stalk-re-sprout-spray method. First, the *Arundo* stalks are cut and then the biomass is removed. Then, allow 3-6 weeks to pass so that the plant can grow one meter tall and then the foliar application of the herbicide should be sprayed on the new growth. This method is appropriate to use in situations where *Arundo* is mixed with desirable native vegetation. The advantage of this method is that there is less herbicide applied to treat the new growth but the disadvantage is by cutting the stalks it results in the plant returning to the growth phase. This means it is drawing nutrients from the root mass and there is less translocation of the herbicide to the roots and therefore less root kill. Another disadvantage of this method is that it requires many follow-up treatments, which means more manpower and herbicide application and desirable vegetation may be effected by the spraying technique. "The success rate of this method is 50% in the first year and 75% in the second and third year of growth. It may take up to 3 to 5 years for full eradication of *Arundo*" (Cornwall, Dale, Newhonser, 1999).

An alternative approach that has not yet been tested on *Arundo donax* in the U.S. but has been effective in controlling *Fallopia japonica*, a similar species, has to do with depleting resources in the root mass. It involves repeated cutting of the shoots to deplete below ground carbohydrate storage in the rhizomes (Boose and Holt 1998). Another alternative approach that has not yet been tested in the U.S. is biological control using a variety of insects and pathogens. Tom Dudley from the University of California Berkeley and others traveled to Nepal and India in 2001 in search of these potential candidates. They discovered in Nepal a variety of candidates that have a negative affect on *Arundo*. They include a stem boring moth larva, a stem boring beetle larva, a moth that mines the leaves, leaf-hoppers, and other Hemiptera that feed on new tissue. In South Africa, they found that there was evidence of insects boring in the secondary shoots of *Arundo*. The introduction of non-native species as a biological control for eradicating *Arundo* poses a potential threat for the introduction of yet another invasive non-native species. From this discovery it appears that biological control of *Arundo* research will be conducted in the very near future. These future studies should take into consideration the potential risks of introducing a non-native species to eradicate another invasive non-native species.

Removal and disposal of *Arundo donax* debris

Lastly, the biomass removed after the treatments must be carefully dealt with to ensure that there is little chance for new invasions. The fresh cut stems and canes can be still viable and capable of re-sprouting and re-rooting, which means extreme care must be taken when removing stems and cane after cutting. There are four different ways in which *Arundo* debris can be dealt with after the removal method is applied.

Firstly there is composting, which includes letting the debris sit and rot in place. Usually it will decompose slowly in a pile above the high water line and out of the way of high water flow. This method is ideal for remote areas. Chipping is another method but it can be more costly due to the equipment and labor costs. Another method is dumping which is hauling the biomass away but this can be extremely expensive and many landfills are not willing to accept the biomass of *Arundo*.

Lastly, the most cost-effective method for removing the biomass is by fire as long as it does not threaten the native vegetation. There are restrictions when burning is considered that must be followed. A burn permit is required from the fire department during the fire season. The fire department requires the burn area to be confinable and far from the brush or overhanging trees. They also require the *Arundo* pile should dry for 60 days to meet the Air Quality Management District restrictions.

1.7 Restoring Native Vegetation in Invaded Riparian Areas

Passive re-vegetation

There is a desperate need for riparian habitat restoration in invaded areas by *Arundo donax* because of a few federally and state endangered species, such as Least Bell's Vireo, Western Yellow-billed Cuckoo, and the Willow flycatcher. It is estimated that one acre of restoration of riparian habitat costs $100,000 and one endangered bird requires a large number of acres of mitigation (Frandsen and Jackson, 1993).

Once the managed site is stripped of *Arundo* the land may look devastated. The cheapest way to restore riparian native vegetation is by natural succession and flooding. This re-vegetation is called passive re-vegetation, which may work if the site is left alone for one or two rainy seasons. Naturally the stream's high flow can carry fresh sediments and new native plants downstream and to the lower stream banks. Also, the nearby vegetation can fill the available space made by the removal of *Arundo*.

The disadvantage to this method is that it is periodic and my take several years to complete. Even though passive re-vegetation will re-vegetate the lower parts of the stream bank, it is active re-vegetation methods that are needed to re-vegetate higher riparian areas with native vegetation (Cornal, Dale and Newhonser, 1999).

Active re-vegetation

There are three things to consider before applying the active re-vegetation method in restoring native plants in riparian areas. First, active re-vegetation should be postponed until full eradication of *Arundo* is completed so that native vegetation will not be harmed when using herbicidal methods of control. Secondly, if the restoration site is downstream from other *Arundo* infestations, prompt vegetation is required to prevent re-invasion from the upstream invasions. Third, this method can be costly depending on the need of the restoration site, size of the area planted and the cost of the labor.

Active re-vegetation requires careful planning and seeking of advice when needed. First, develop a list of desired native plants species that are fast growing and can flourish. One example of a native California riparian species is the Willow (*Salix*), which establishes easily in most soils and grows rapidly. It is important to remember to plant the native species far enough from the stream banks so that they are not washed away. The second aspect to active re-vegetation is to maximize fish and wildlife habitats. The long term goal should include native plant species that can shade the stream, stabilize the ground surface, and provide a multi-level structure of greenery from trees to shrubs (Cornal, Dale, and Newhonser, 1999).

Part II. Problem Assessment:
A Study of *Arundo donax* in the Salinas River using Remote Sensing

2.1 Introduction

The first part of any successful invasive non-native species management plan is to map the distribution and location of the invading species. In the Salinas Valley there is a need for locating and quantitatively mapping *Arundo* in riparian habitats to determine the extent of the invasion. However, *Arundo* tends to grow along stream banks in large patches up to 10 square meters and can reach heights up to 6-8 meters tall. As such, traditional sensors (e.g. Landsat) may not work for mapping *Arundo*. This means the chances of detecting *Arundo* and differentiating it from other similar riparian vegetation may be improved with high resolution, multispectral or hyperspectral imagery acquired when *Arundo* is most productive (February through October). We can learn about successful types of imagery, classification schemes, and data analysis by investigation other invasive non-native species technological research using remote sensing applications.

Once *Arundo* is located and a complete quantitative study has been conducted, the concluding information would be useful for action plans to successfully manage and eradicate *Arundo* in the Salinas River. Also, the information would be useful to interested stakeholders, who want to understand how invasive *Arundo* has become in the Salinas River. The study would further offer how to apply effective management strategies to manage and eradicate *Arundo* before it becomes a severe environmental problem in the Salinas River. With the decrease of *Arundo* related environmental problems comes an avoided cost to many stakeholders. Some avoided costs include flood and fire hazards, water quality and conservation, and habitat loss.

Before a quantitative mapping study of *Arundo donax* in the entire Salinas River Watershed can be conducted, the question of whether *Arundo* can be detected and mapped from aerial imagery needs to be answered. In particular, can *Arundo* be differentiated from surrounding vegetation? What type of sensor would be the most useful? Finally, what is the most appropriate classification scheme for detection and mapping *Arundo* in the Salinas Valley Watershed?

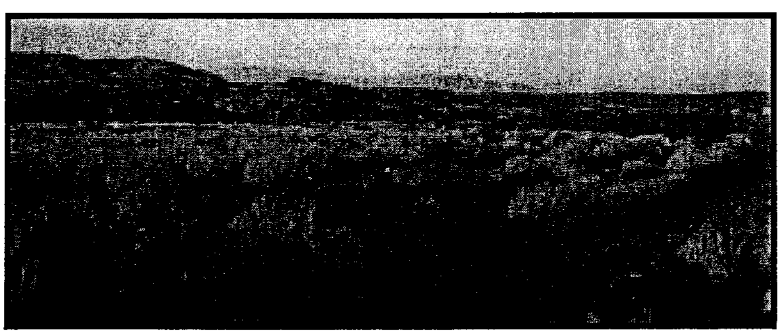


Figure 2.1 An *Arundo* Landscape
Source: http:// www.smslrwma.org/*Arundo*Photos.htm

2.2 Methods

Description of study site

The study site is located in Monterey County, California. It is a stretch of the Salinas River located 1 mile downstream and ¼ mile upstream from the Gonzales River Road Bridge near the city of Gonzales, California (**see figure 2.2A**). A levee road (**see figure 2.2B**) on the left bank of the Salinas River provided access to the site. The levee and levee road is maintained by an adjacent landowner, who currently farms the adjacent land. Since 1999, the landowner has been working in cooperation with the Watershed Institute in using native plant restoration techniques to stabilize the banks near his property.

This site was chosen because of the current intermixed riparian habitat of willows, both young and old, cottonwoods, oaks, shrubs, grasses, and various other weedy species. An intermixed riparian habitat provides a challenge for any remotely sensed based *Arundo* study. Also and most importantly, the site contains many accessible stands of *Arundo* for easy assessment and groundtruthing.

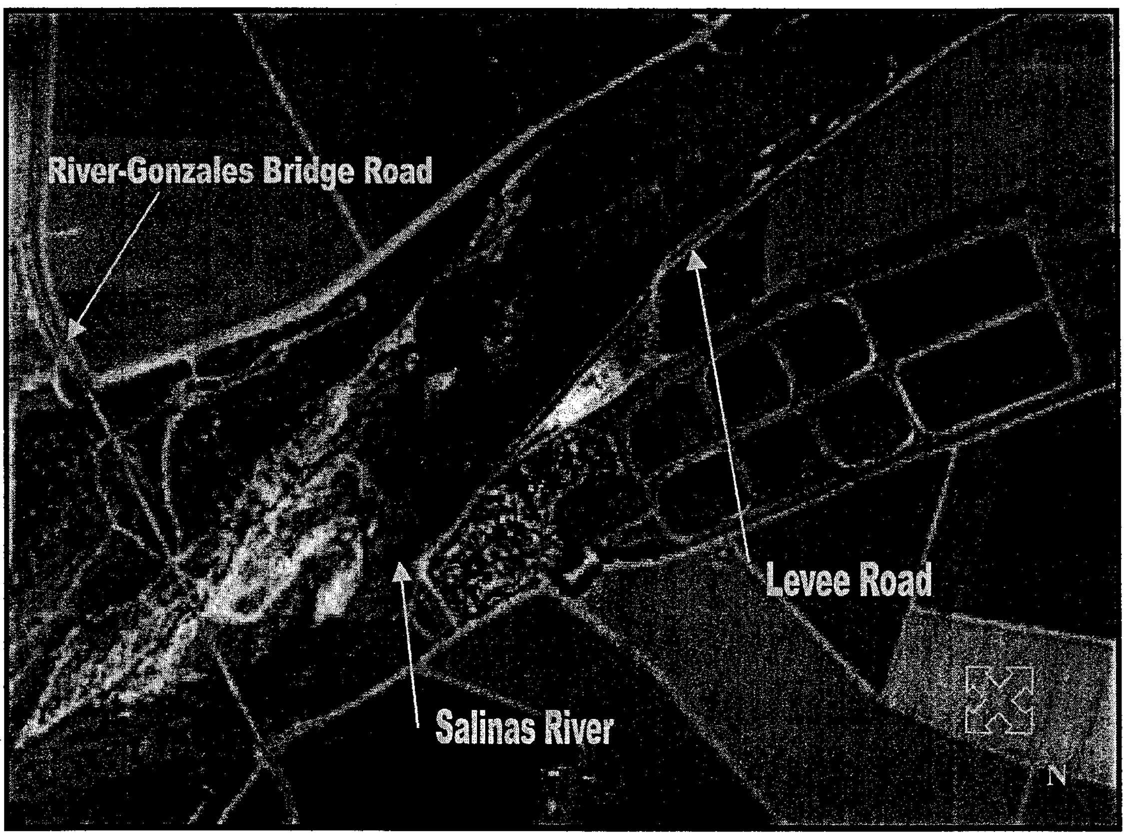


Figure 2.2A. Study Site Overview: Scale 1inch=250 meters (Source: Lee Johnson NASA Ames Research)

Figure 2.2B. Study Site Levee Road with treated *Arundo* on the left and untreated *Arundo* on the right. (photo taken by Alana Oakins, March 2000)

Image Analysis

In order to conduct an image analysis, materials and images were collected. A high altitude infrared aerial photograph (Color IR) scanned as a tiff image of the site of interest (near Gonzales) was obtained from Lee Johnson, NASA-Ames Research. The Color-IR was acquired in June of 1999. It has a 2-m resolution (2- 800 dpi) and was allocated multispectral information (Infrared, Red and Green light) from a NASA scanning device. The Color IR imagery was used because of its small nominal pixel size. Landsat and other satellite imagery, whose nominal pixel size is generally larger was not used because the resolution was not great enough. Since *Arundo* tends to grow in 10 square meter clumps the Color IR imagery is more adequate for successfully detecting individual *Arundo* clumps. Two Digital Ortho Photo Quads (DOQs), which represented the region of interest, were obtained from the SIVA Center in Seaside, California. These images were used as reference images for georeferencing the Color-IR. Lastly, to handle, manipulate, analyze, and display the geospatial information involved in this project, *TnTmips* (MicroImages, 1999) was used. Microsoft Office software (Word, Excel, Photo Editor) and Microsoft Paint were also used for some parts of this project.

The first step of the image analysis was to import the Color-IR tiff image into *TnTmips* as a Red-Green-Blue raster (RGB raster) using the Import Tool. It is important to understand that the Color-IR film records the green, red and the photographic portion (0.7 to 0.9 um) of the near infrared scene energy (Lillesand and Kiefer, 1994). The result is a "false color" image where blue images are objects reflecting green energy, green images are objects reflecting red energy, and red images are objects reflecting near infrared portion of the spectrum (Lillesand and Kiefer, 1994). Therefore, productive vegetation will reflect in the infrared energy and will appear in various tones of red on the Color-IR.

Secondly, the region of interest was extracted from the newly imported raster because the original raster was extremely large and hard to handle with the computer used. Next, the extracted image was saved as a *TnTmips* RVC file, which included the new RGB raster and was used for the classification analysis. After the Color-IR was imported into *TnTmips*, it was printed out for the purpose of groundtruthing the different vegetation, water, soil and ground types. Groundtruthing was completed in the first week of March of 2001 in order to create a vegetation map of the region of interest. Willows, both young and old, cottonwoods, oaks, shrubs, grasses, and weeds, including *Arundo* were all observed and their locations were documented on the printed RGB raster or base map. The groundtruthing of vegetation (*Arundo*, willows, cottonwoods, oaks, weeds, grasses, shrubs, bare soil, asphalt, deep and shallow water) was transferred from the base map as polygons onto the RGB raster using the Spatial Data Editor Tool in *TnTmips*.

After the groudtruthing was conducted, the RGB raster was then color enhanced using the histogram for each band under the Spatial 2-D Display Tool in *TnTmips*. The RGB raster was then georeferenced into UTM coordinates. However, it is important to note that the raster was not re-sampled because the raw data was required for the classification process. The agricultural lands adjacent to the region of interest were masked in case of spectral confusion between riparian vegetation and row crops. The Feature Mapping-Region of Interest Tool in *TnTmips* was used to complete this step.

Two types of image classification that were conducted in this analysis were unsupervised and supervised classifications. These classification schemes were used to see which scheme worked best in discriminating *Arundo* from other riparian vegetation. The purpose of image classification is to "automatically categorize all the pixels in the image into land cover classes or themes" (Lillesand and Kiefer, 1994). The data that is most commonly used in classification is multispectral imagery. The "spectral pattern" (the set of radiance measurements obtained in the various wavelength bands for each pixel) that is present in the data for each pixel is used as the numerical basis for categorization into individual classes (Lillesand and Kiefer, 1994). The different class types will have different combinations of digital numbers (DN) based on the spectral properties, like reflectance and emittance (Lillesand and Kiefer, 1994).

Unsupervised Classification

An unsupervised classification is useful for determining the natural spectral clusters present in the image being analyzed. The first step of the unsupervised classification was to decide the best clustering method to use. In this analysis the K-means clustering algorithm was used on the Color-IR with the agricultural lands masked out. This clustering method accepts from the analyst the number of spectral clusters to be located in the image. The algorithm evenly divides the reflectance of each band into 80 different spectral classes and each pixel in the image is assigned to the cluster whose mean reflectance it matches (Lillesand and Kiefer, 1994). In this analysis, 80 clusters or classes were used and it was conducted under the Auto-Classification Tool in *TnTmips*.

The final step of the unsupervised classification was to determine the identity of each spectral class produced by the K-means method. In this analysis 80 classes could essentially be identified the classes of concern were the groundtruthing of the vegetation and ground types. These classes were identified after layering the groundtruthed polygon vector on the newly classified image and identifying the class number(s) in the boundary of the polygon. Spectrally similar classes (under 15% separability) were combined using the dendogram, which is the graph of separability and assigned the same color.

Supervised Classification

A supervised classification is useful for training the classifier to produce a map of groundtruthed classes only. The first step of the supervised classification was to decide what method should be used once the classifier has been trained. In this analysis the Minimum-Distance-to-Means method was used, which determines the mean or average spectral value in each band for each trained class. This method is useful because if there is a pixel of unknown identity, it can be classified by computing the distance between the reflectance value of the unknown pixel and each of the trained class means. This method computes this value and assigns the pixel to the "closest" class (Lillesand and Kiefer, 1994).

However, before the Minimum-Distance-to-Mean method can be used, the classifier must be trained spectrally and statistically on the groundtruthed classes. Therefore, a training set raster was created using the Auto Classification-Training Set Editor Tool in *TnTmips*. This raster included polygons for each of the classes to be identified in the entire image. The polygons were created by highlighting all the pixels in the boundaries of the training polygons that were continued on the ground to be almost pure *Arundo*, willow, cottonwood, grass & shrubs, bare ground, water (deep), and water (shallow). Each of these polygons was then used to generate the means and standard deviations of each training class. These statistics are applied to the entire image when the Minimum-Distance-to-Mean method classifies all the pixels in the image.

Finally, the Minimum-Distance-to-Mean method was completed on the Color-IR using the set of trained classes. Again, the agriculture was masked out in the Color-IR in case of spectral confusion between riparian vegetation and row crops.

2.3 Results

Unsupervised Classification

The results of the K-Means unsupervised classification are shown in Figure 2.3B and in Figure 2.3C. In Figure 2.3B, most of the *Arundo* appears in the groundtruthed polygons of 100% *Arundo*. Also, most of the cottonwoods appear in the groundtruthed polygons of cottonwoods. However, it seems that the classifier is having difficulties distinguishing the spectral differences between the willows, cottonwoods and oaks because willow appears in polygons 3, 5, 7 which are only groundtruthed as 100% cottonwoods. This could be due to an edge effect when cottonwood and bare ground appear together. Then they are classified as willow.

In Figure 2.3C, cottonwoods appear in the groundtruthed polygons of cottonwoods. Oaks appear in the groundtruthed polygons of oaks. Willows appear in the groundtruthed polygons of willows. Again, it seems that the classifier is having difficulties distinguishing the spectral differences between the willows, cottonwoods, and oaks because willow appears in polygons 1 through 5 which was groundtruthed as 100% cottonwood or oak.

From observing the figures above and the groundtruthed classes it appears that an unsupervised classification may be able to detect *Arundo*. However, by observing the output statistics in Figure 2.3A, *Arundo* and Willow have the most similar means for their ranges of digital numbers in all three bands. Also, *Arundo* and willow have overlapping ranges in Band 1, the Infrared band. This means that we should look to the results of the supervised classification to uncover whether *Arundo* can really be differentiated from the surrounding vegetation.

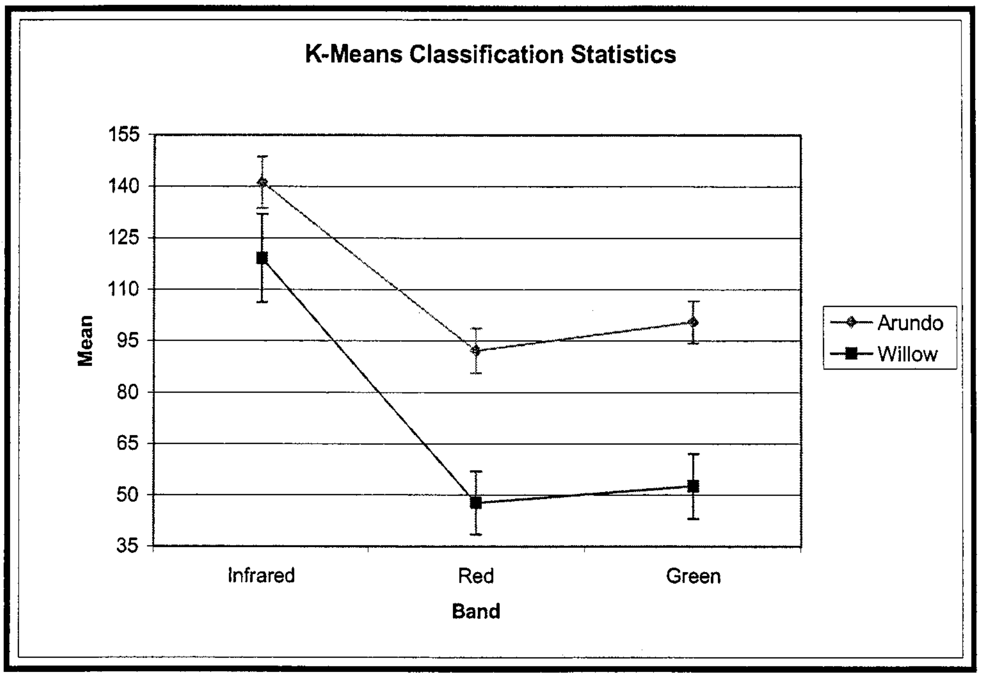


Figure 2.3A. K-Means Unsupervised Classification Statistics

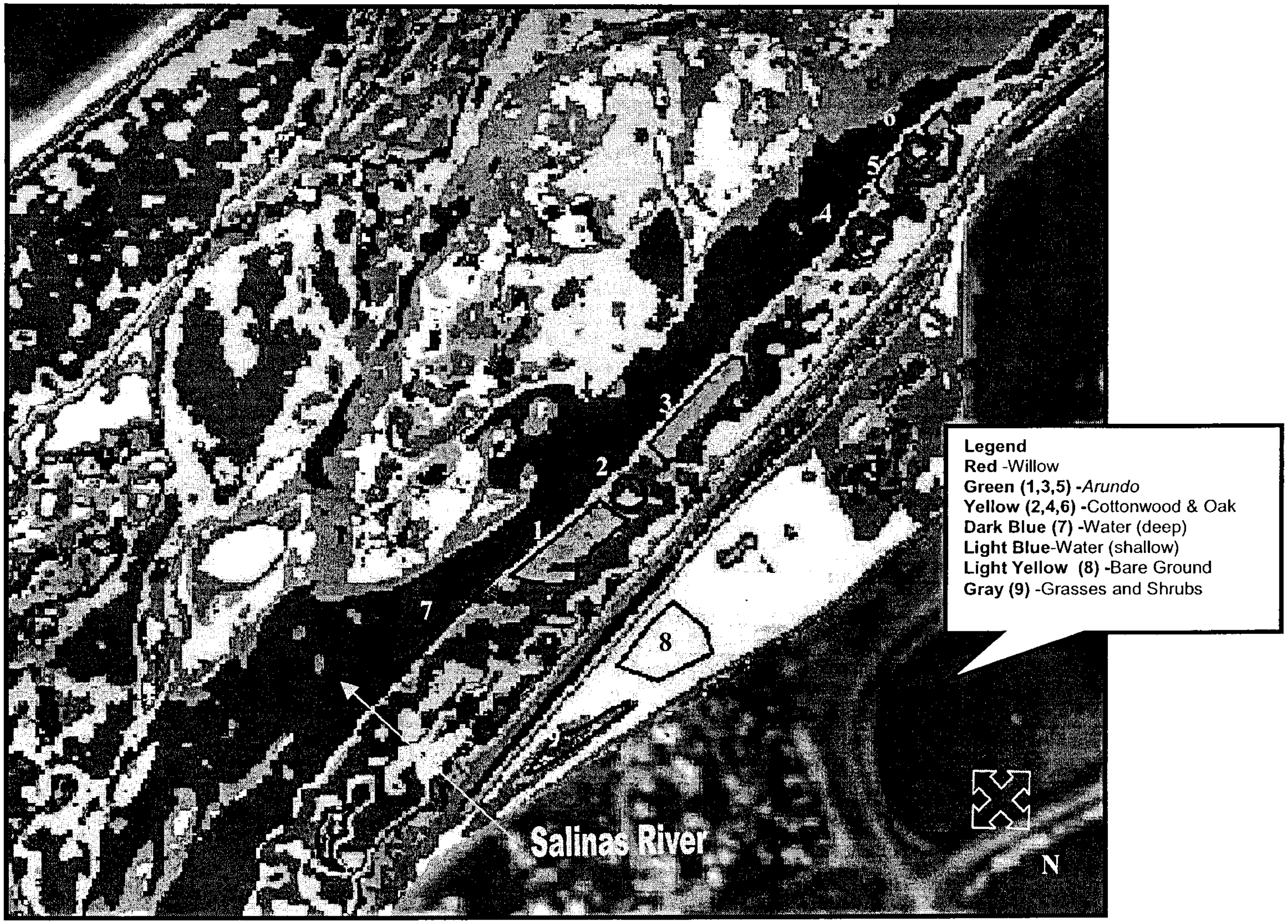


Figure 2.3B. K-Means Unsupervised Classification (Scale 1 inch = 85 meters)

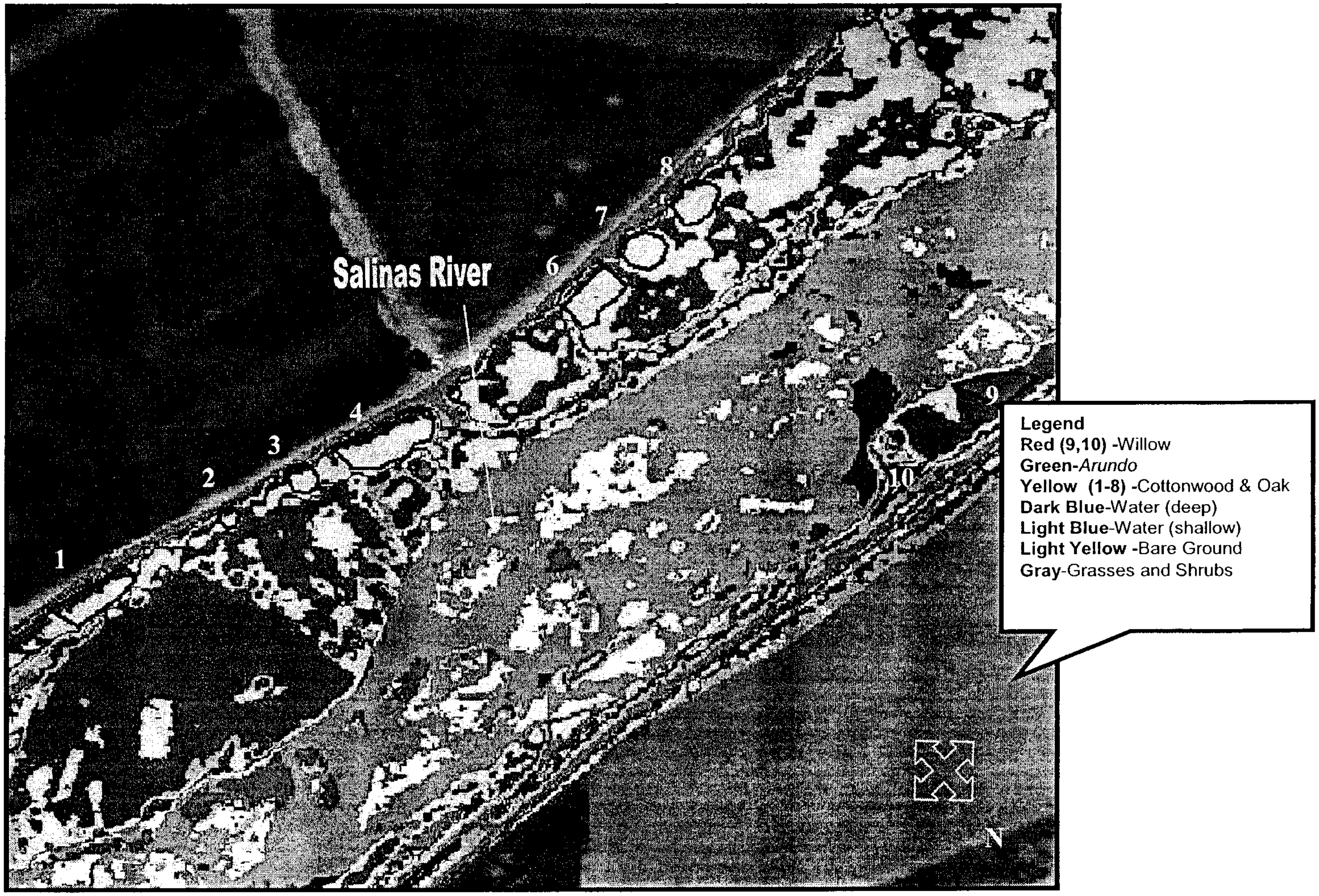


Figure2.3C. K-Means Unsupervised Classification (Scale 1 inch = 85 meters)

Supervised Classification

An unpaired pooled variance t-test with an alpha of 0.05 was performed on the training classes *Arundo* and willow of the supervised classification for all three bands. This was performed in order to determine whether or not *Arundo* is significantly different than willow since their means are similar and their ranges overlap (see **Figure 2.3D**). The result of the t-test was that *Arundo* is significantly different from willow in the Band 1, the Infrared light, Band 2, the Red light, and Band 3, the Green light. Therefore, we should be able to discriminate *Arundo* from other similar riparian vegetation.

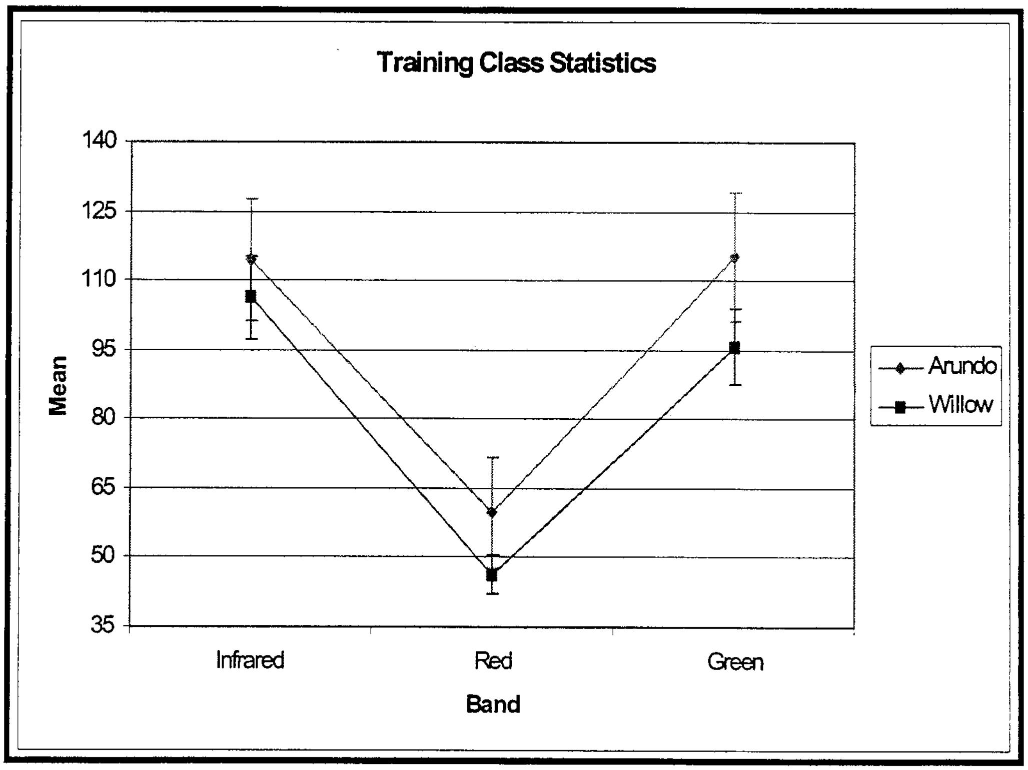


Figure 2.3D. Training Class Statistics for the Supervised Classification

	Ground Truth Data								
Name	Arundo	Willow	Grass/sh	Oaks	Cottonwo	Water(de	Bare gro	Total	Accuracy
Arundo	[illegible]	76	0	7	36	0	0	665	82.11%
Willow	29	[illegible]	0	2	55	0	0	664	87.05%
Grass/sh	0	34	[illegible]	3	1	0	76	387	70.54%
Oaks	0	76	0	10	[illegible]	0	0	285	68.82%
Cottonwo	0	0	0	23	[illegible]	0	0	1409	98.37%
Water(de	0	0	0	2	2	[illegible]	0	422	99.05%
Bare gro	0	0	0	0	0	0	[illegible]	400	100.00%
Water(sh	0	0	0	1	0	0	0	809	99.84%
Total	576	764	273	48	1679	419	476	4841	
Accuracy	94.96%	75.65%	100.00%	0.00%	94.40%	100.00%	84.03%		
Overall Accuracy = 91.06% Khat Statistic = 88.86%									

Figure 2.3E. Minimum Distance to Mean Supervised Classification Error Matrix

The results of the Minimum Distance to Mean supervised classification are shown in Figure 2.3F and Figure 2.3G (**see next page**). These figures show that *Arundo* and other vegetation classes were generally classified correctly. This means that the training class *Arundo* appeared in the groundtruthed polygons or the test sites. This is also true for the other vegetation classes, such as willow, cottonwoods, and oaks where the training classes of each vegetation class appeared correctly in the groundtruthed polygons or test sites. The error matrix explains the accuracy of the supervised classification.

Figure 2.3E represents the error matrix for the classifier (Minimum-Distance-to-Means Supervised Classification) and the ground truth data (training sites). From this matrix the errors of omission and commission can be deducted. The "error of omission is the amount of pixels that did not get classified and were known and the error of commission is the amount of pixels improperly included in the classification" (Lillesand and Kiefer, 1994).

The classifier classified 82.11% of the *Arundo* pixels as *Arundo* but 17.89% of the *Arundo* pixels were classified as something else. In fact, 11.42% of the *Arundo* pixels were classified as willow, 1.1% was classified as oaks, and 5.4% was classified as cottonwoods. Furthermore, the classifier classified 87.05% of the willow pixels as willow but 12.95% of the willow pixels were classified as something else. In fact, 4.37% of the willow pixels were classified as *Arundo*, 0.3% was classified as cottonwoods, and 8.2% was classified as oaks. This is the error of omission.

The classifier classified 94.96% of the *Arundo* pixels as *Arundo* but included 4.04% of the willow pixels and classified them as *Arundo*. Furthermore, the classifier classified 75.65% of the willow pixels as willow but included 9.94% of the *Arundo* pixels and classified them as willows. The classifier did the same for 4.45% of the grass and shrub pixels and 9.95% of the oak pixels. This is the error of commission.

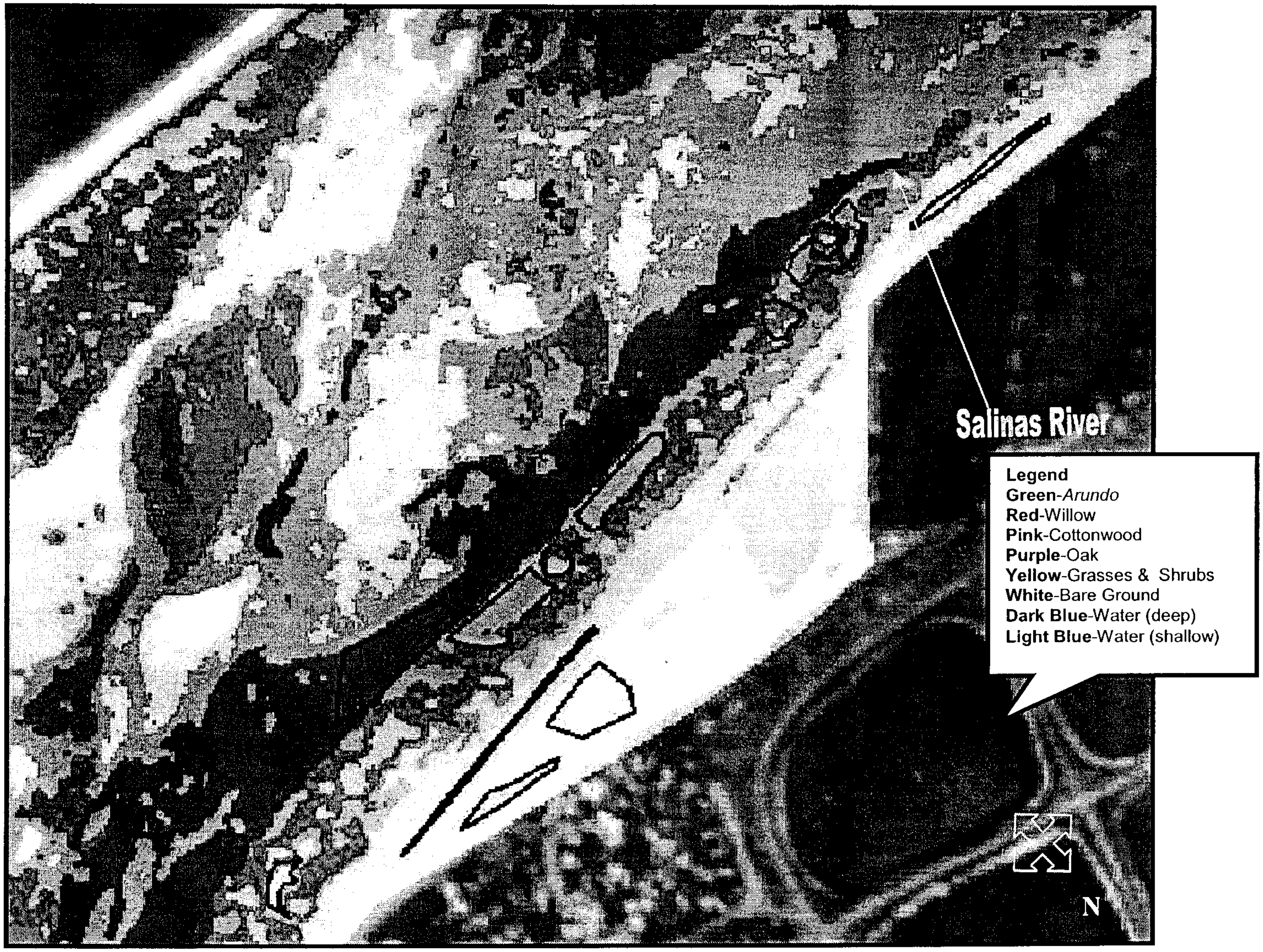


Figure 2.3F. Minimum Distance to Mean Supervised Classification (Scale 1 inch = 85 meters)

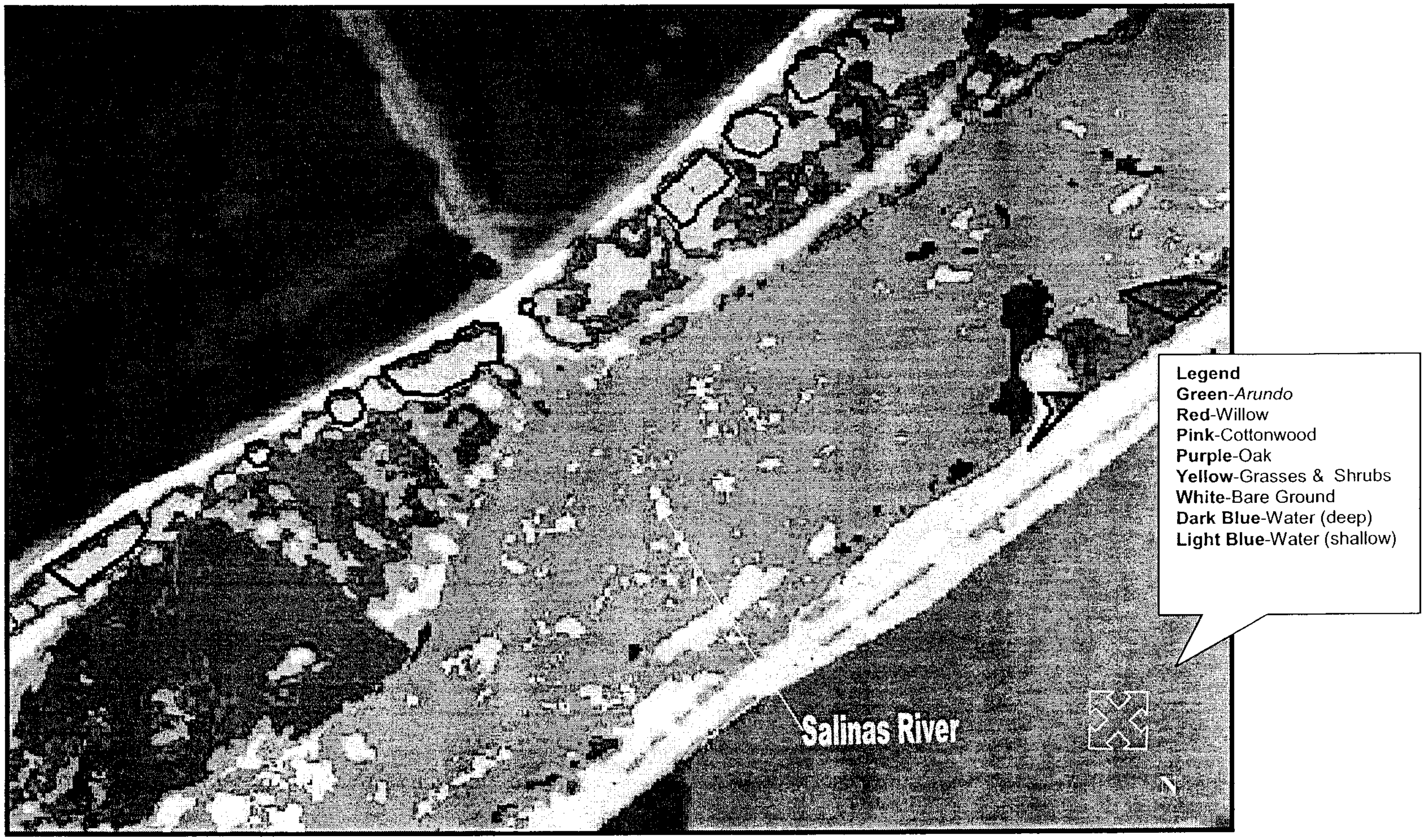


Figure 2.3G. Minimum Distance to Mean Supervised Classification (Scale 1 inch =85 meters)

2.4 Discussion

Can Arundo be differentiated from surrounding vegetation?

The results of the unsupervised classification show there is a possibility that *Arundo* can be differentiated from other similar vegetation classes, especially willow, which is the class most statistically similar. Furthermore, a first glance at the results of the supervised classification may seem like *Arundo* can not be differentiated statistically from other classes, especially willow. After performing an unpaired t-test with pooled variances on the training classes, there is a significant difference between *Arundo* and willow in their spectral information in all three bands, the Infrared, the Red, and the Green. *Arundo* was mapped with an overall accuracy of 94.96%.

What type of sensor would be the most useful?

The recommendation for the most useful reflectance bands in differentiating *Arundo* from other similar riparian vegetation would be Band 2(Red light) and Band 3 (Green light). Unlike Band 1(Infrared light), Bands 2 and 3 have the most significantly different spectral information.

Furthermore, there may be other spectral bands out there that are also useful for differentiating *Arundo* from other riparian vegetation such as a Thermal band or Mid-IR band. Deanne DiPietro from the University of California at Davis is currently conducting a remote sensing study of *Arundo* using AVIRIS hyperspectral data in the Santa Margarita River Watershed (DiPietro, 2001). This study should provide answers to which bands are useful in differentiating *Arundo* from other riparian vegetation.

Also, the study using AVIRIS imagery should be successful as long as the nominal pixel size is between 2-4 meters. With higher resolution data, the success in detecting *Arundo* is greatly increased because *Arundo* grows in clumps of up to 10 square meters. Any nominal pixel size over 4 meters will decrease the chances of successfully mapping *Arundo* in any remote sensing study.

What is the most appropriate classification scheme for detecting and mapping Arundo in the Salinas River Watershed?

Even though the unsupervised classification scheme provided some useful information about spectral differences in the groundtruthed vegetation, it did not provide confident answers to the questions of this study. For that reason, a supervised classification is the most appropriate classification scheme in detecting and mapping *Arundo* in the Salinas River Watershed. The supervised classification scheme allows the analyst to extensively groundtruth the image to create a base map. This base map can then be transferred to the image as training site polygons. By analyzing the training site polygon statistics, spectrally similar vegetation types can possibly be differentiated.

The supervised classification result of this study showed that *Arundo* is significantly different than other vegetation. With this finding, *Arundo* can now be mapped in the entire

Salinas River Watershed. Furthermore, the total amount of *Arundo* can now be calculated, which is important information for effective management and eradication. However, it is important to note that *Arundo* can be highly mixed with other vegetation like willow and cottonwoods. These dense mixtures might make the differentiating process difficult and therefore miscalculating the total amount of *Arundo* in the entire watershed. Most importantly, with findings of this study there is a potential to begin developing a basin-wide map of *Arundo* in the Salinas Valley Watershed.

Strengths and Weakness

Calibration of the raw data was not conducted, where the radiance values (digital numbers) were not translated into reflectance factors. The reason why the raw data was not calibrated was because the Color-IR imagery does not have a linear relationship between the radiance values and reflectance factors. Therefore, calibration is a difficult and time-consuming process where a relationship would have to be constructed. The disadvantage of not calibrating the raw data is that the results are not expressed in common reflectance factors. Therefore, it would be difficult to compare the results of this study with a similar study that did conduct the correct calibration or even a study that did not conduct the calibration. Digital numbers will vary depending on the imagery used and the sensor calibrations.

However, the advantage of using a Color-IR image, is that the imagery is usually inexpensive and easier for an agency or individual to acquire than other types of imagery. One strength of this study is that I was able to use a Color-IR image for image analysis, and therefore provide insight into spectral differences between *Arundo* and other similar riparian vegetation. This finding gives hope to others who are attempting to answer similar questions but may have tight budgets, like many agencies.

Future Studies

In future studies, calibrating the radiance values into reflectance factors should be conducted. A relationship between the radiance and reflectance must be developed in order to calibrate the image. Once the image has been calibrated then the statistics should be analyzed. The results of whether *Arundo* can be differentiated or not from other vegetation could be compared to results of other studies.

Future studies could also include using different types of imagery, such as high-resolution multispectral or hyperspectral satellite imagery. The advantages of using this type of imagery is that high resolution imagery makes it easier to identify vegetation clusters, such as *Arundo*, and multispectral satellite imagery includes more bands of light to be analyzed. Obtaining multispectral or hyperspectral imagery with a pixel size of 2-4 meters in future studies would be optimal. Furthermore, some additional types of multispectral and hyperspectral bands that could be used in future studies are the Thermal and Mid-IR bands. With increased number of bands, the likelihood of differentiating *Arundo* from other vegetation should increase.

Lastly, a suggestion made by Chad Hendrix, a member of Team *Arundo* del Norte, through a personal email, was to not only look at *Arundo*'s spectral information but to incorporate a texture band as well. This can be done by running a neighboring variance filter over the image to create an extra texture band.

Part III. Policy Recommendation:
How Ethics and History Inform Policy in Managing *Arundo donax* in Monterey County, California

3.1 Introduction

Today, there are a number of reasons why Monterey County is even faced with *Arundo* related issues. The history of invasive species migration largely follows the migration of humans. It is also the historical differences in attitudes toward land management of Native Americans and the European and Spanish settlers. The way in which one treats the land is dependent on how one views the land. In general, Native Americans lived "one with the land" while the European and Spanish settlers were "conquerors of the land." And lastly, globalization and the historical events that increased free trade between countries separated by oceans that lead to the increase of non-native species into regions they did not originate from. This paper proposes that before Monterey County deals with *Arundo* environmental problems, there should be a complete understanding of why the county is even faced with *Arundo*. Secondly, there should be a collaborative effort, including the private and public sectors of Monterey County, in the management and eradication of *Arundo*. Lastly, in determining the appropriate policy for Monterey County through collaborative action, look to examples as a guide where the implementation of *Arundo* policies have been successful.

3.2 History of Invasive Non-Native Species

Historically, a parallel existed between the migration of Europeans and the migration of exotic species. It has been said that in general, "human mobility has radically increased the rate at which large numbers of living things are moving from one ecosystem to another" (Bright (2), p. 10). In ancient times the introduction of species to foreign lands was made over great distances. In general there was a gradual increase in the amount of human interactions between foreign environments that led to the increase of species introduction around the world. This gradual increase began nearly 500 years ago when the Europeans colonized the Americas. European flora and fauna seemed to be colonizing the New World better than their own lands (Bright (1), p. 14). Bright continues to say that, "throughout the 19th Century, 'acclimatization societies' in North America and Australia, dedicated themselves to haphazard releases of exotics for various reasons – usually on the assumption that the local fauna was inferior to that of Europe" ((1) p. 14).

The success of the European settlers in New England heavily depended on these "weedy" non-native, "Band-Aid" species. The non-native species were prolific in heavily disturbed lands and kept in place topsoil that would otherwise blow away with the wind. This is the topsoil that settlers needed for the growth of their food supply. These exotic species became feed for their livestock, which was also a big part of the settler's food supply. Crosby states, "the colonizing Europeans who cursed their colonizing plants were wretched ingrates" (p. 170). Crosby implies that if the settlers did not promote their own European colonizing plants in the Americas, then the settlers success in the New World might not have been as great.

Along with the ideas of migrating species is the idea that Native Americans of [the New World] and the Europeans of the Old World that settled to the New World viewed the land very differently (Cronon, p.19). This meant that the Native Americans treated the land differently than the new European settler. In New England the European settlers saw the abundance of resources as merchantable commodities, which could be used, sold, and traded. Not only were they amazed with the abundance of resources and wildlife, they were also amazed at the lack of domestic animals, like sheep, cattle and dogs, for example. Bright supports this idea when he states, "it is also a consequence of the ancient and widespread practice of introducing exotic species for some tangible benefit: A bigger fish makes for better fishing, a faster-growing tree means more wood" (Bright (2), p. 51). One may extrapolate from this idea to include the settlers of California who viewed California landscapes, as did the European settlers of New England. The introduction of non-native species into the U.S. was largely due to the European attitude towards the land. In addition, the settlers did not understand why the Indians lived so poorly in a land of abundance. The Indians on the other hand viewed this very differently, in that they supported a stable human relationship to the environment.

Kat Anderson in her essay titled, "Native California Cultivators" also explores this different attitude the Native Americans had toward the landscapes, especially in California. Anderson assumes that the Native Americans had a "partnership with nature that left the resource base intact" (p. 42). "There is a common feeling among elders today that plants want to be used. This idea is similar to the concept that the fish and deer want to be caught and eaten. If not gathered they become scarce or disappear altogether. These examples suggest a respectful, attentive concern for the source of plant and animal abundance, a complete cooperation with nature's processes, and a yielding to its limits. They point to an intimacy and familiarity with the habits and requirements of valuable animals and plants that native peoples still continue to express daily" (Anderson, p. 45). With this attitude of respect and attentive concern for the source of plant and animal abundance comes the land management practices that does not deplete its resources. Anderson states, "Native Americans – through the pattern and timing of harvest, as well as through the burning, pruning, weeding, and planting of places – favored certain mixtures and frequencies of plant and animal species" (Anderson, p. 42). They "harvested resources in such a way that the plant communities continually thrived in the same locations" (Anderson, p. 42). The Native Americans claim that "many California native shrubs have benefited from being tended for centuries" (Anderson, p. 46).

Even though the Native Americans and settlers differed fundamentally in their attitudes toward the land, there was a commonality that the Spanish-Europeans and the Native Americans had. It was to a certain extent the ability to understand the land and therefore how to use the existing resources. However, a few ideas cannot be overlooked. The Europeans had the ability to migrate with all of their properties over miles of ocean waters while the Native Americans also had the ability to migrate. However, their migration patterns existed mostly within the boundaries of North America. The assumption here is that Native Americans *followed* their life-supporting resources in their migration whereas the Spanish-Europeans migrated *with* their life-supporting resources.

In the editorial letter titled, "A Traveller on Settling in California, 1873" by Charles Nordhoff, the author explains all the constituents one should "bear in mind" when selecting land in California. The most pertinent information relative to the commonality of understanding the land comes from this author's advice to plant certain vegetation in windy areas. It was surprising to read that this author's advice advises the interested settler to plant native plants in order to block the wind. "In many parts of the State, farms would be benefited by trees, planted as wind-breaks; and, fortunately, the willow or sycamore forms, in two years, in this climate, a sufficient shelter, besides furnishing fire-wood to the farmer" (Nordhoff, p. 11). This advice proves that settlers were able to understand the new lands they were settling on and therefore were able to use what resources were here, which is in essence what the Native Americans did. But it needs to be said again, in addition to using what existed, the settlers were able to use the their resources that was brought with them.

In more recent history, it was globalization and the opening of free trade in the 20th century that also contributed to the increase of migration of exotic species. Since 1950, the world-trading network has greatly expanded in value. In terms of migrating species, the volume of goods traded worldwide exacerbates the increase of exotic invasions. "The coalescence of a global trading network, with Europe at its hub, drew much of the world into the biotic mixing bowl. In seaports all over the globe, exotic flora sprouted in ballast heaps unloaded from ships. More and more organisms became objects of trade themselves " (Bright (1), p. 14). Bright continues to say that, "trade remains the most important factor overall, and among its many pathways, one is of special concern. Shipping containers, the big metal boxes that can be stacked on ships, then offloaded onto trucks and trains, have revolutionized shipping – and may do the same thing for the movement of exotics" (p. 15). Therefore, it is easy to say that the "world trade has become the primary driver of one of the most dangerous and least visible forms of environmental decline, thousands of foreign, invasive species are hitch hiking through the global trading network aboard ships, planes, and railroad cars, while hundreds of others are traveling as commodities" (Bright (1), p. 50). This begins the discussion of the environmental and ecological damages that exotic species have brought to the United States, but more specifically California.

For example, in the Tulare Basin, the native wildlife disappeared with the colonization of farmers in the area. In fact, the farmers viewed the wildlife as a threat to the crops and herds and therefore eradicated the wildlife (Preston, p.267). To my understanding in the 1800's the natural landscape of this region was transformed into a cultural landscape of "geometrical forms" and was the first time that human dominance was realized. To my surprise the author also notes that with the building of the railroad, came the realization of how humans could alter the face of the land. Preston said that, "...the cause and effect relationships between human practices and environmental degradation were recognized. Such observations helped people identify problems and formulate more conservative agricultural practices, and strengthened the conviction of settlers that the land could be altered still further" (p. 271).

In that, it is true that the introduction of non-native species in California, brought with it drastic ecological changes to the landscapes of California, especially in the Monterey Bay region. An excellent source for the history of ecological changes with respect to the introduction of non-native species in the Monterey Bay region is found in Monterey Bay Area: Natural History and Cultural Imprints by Burton L. Gordon. Gordon believes that the many existing non-native species that thrive in California today were due to the settlement of the Spanish and Europeans. The author states that,

> "More than a century and half passed between the Spanish discovery of Monterey Bay and the establishment of the first settlements in 1770, shortly after the arrival of Portola's expedition. Settlements brought about sweeping changes in landscape and ecology. New plants and animals, especially horses and cattle, were introduced (Gordon, p. 56). Livestock raising was the Spanish activity that had the greatest influence of the landscape (Gordon, p. 60). In association with the cattle industry, exotic plants and animals were introduced, particularly from the Mediterranean area, and the new species spread to other parts of the West Coast from Monterey, the main site of Spanish activity in northern California. Some of the grasses and weeds are now among the most characteristic plants of rural California: wild oat, for instance, and filaree, mustard, wild radish, foxtail, and bur clover (Gordon, p. 58). Within a century following the beginnings of Spanish settlement, coastal California had experienced a botanical transformation comparable in magnitude to that undergone gradually by Europe in its long transition from a Paleolithic (hunting and gathering) to a Neolithic (agricultural) economy" (Gordon, p. 62).

The historians were able to prove this idea of drastic ecological change in California by determining the dates of introductions of non-native species. This involves "ascertaining the presence or absence of their seeds in adobe samples taken from the Spanish mission buildings whose construction dates are known" (Gordon, p. 60).

3.3 Invasive Non-Native Species, "Weed" Laws

The role of the US Constitution

On the Federal, State and Local levels there exists a number of historical and recent invasive species policies. On the Federal level, the U.S. Constitution's Amendment 5 "Taking

Clause," in which the federal government cannot take private property for public use without just compensation does relate to weed laws in Monterey County. For example, when the Clinton Executive Order of 1999 on Invasive Species is implemented nationwide then it will ultimately affect federal lands, the states, and private landowners. It is true that the federal government has the power to control federal lands in different states but how do you tell a private landowner what they can and can't do with their private property, which is a right defended throughout the constitution.

If *Arundo*, a non-native species is displacing habitat along with endangered species, then how does the Endangered Species Act of 1973 (ESA), which is a federal act, do in this type of situation? Firstly, on a federal level the ESA "mandates that all federal agencies 'utilize their authorities to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved.' Under Section 7 of the ESA, it requires that any action funded, authorized, or carried out by a federal agency must not jeopardize the continued existence, or destroy the legally designated 'critical habitat' of a federally listed endangered and threatened species. If any action of a federally agency may affect a listed species and or its critical habitat the agency must consult the US Fish and Wildlife Service (FWS)" (Bartel and Knudsen, 1981). The FWS is the agency that determines if the federal agency action is jeopardizing a listed species. For example if an *Arundo* infestation were displacing critical habitat of an endangered or threatened species, it would be the responsibility of the federal agency who introduced *Arundo* to that riparian area to eradicate the infestation.

Secondly, the ESA can also be applied to both the state and private landowner. These groups are affected "via other federal legislation or authorities. For example, the federal highway dollars from the Federal Highway Administration going to a state transportation department" (Bartel and Knudsen, 1981) or the Executive Order on Invasive Species which promotes Invasive Species management plans from the federal to state level via the Department of Agriculture. "Another example would be the permits needed from the US Army Corp of Engineers that is required for certain projects affecting waterways. A state agency or a private landowner would have to comply with the ESA because of the federal involvement" (Bartel and Knudsen, 1981). For example, if a private landowner wanted to make any structural changes on or to their land, like using heavy machinery to remove *Arundo* in and along a stream, they would have to comply with the ESA because of the federal involvement. In other words, the landowner would first have to apply to the US Army Corps for a permit to remove the *Arundo* in the stream. Secondly if the US FWS determines that an endangered or threatened species exists, the landowner would have to comply with the ESA regulations so that no damage is made to the species or the critical habitat.

Furthermore, it seems as if the ESA could actually work against the management of *Arundo* infestations. If the *Arundo* infestation is so large that only heavy machinery can control the infestation then the US FWS may not agree to managing the infestation in fear of harming an existing sensitive species or critical habitat. Unfortunately, there is no legislation to date that can force a private landowner to eradicate invasive species like *Arundo* on their privately owned land. This means that there is no federal regulation that says if an invasive non-native species is threatening the viability of a native species, whether it be endangered or not, on privately owned land than the landowner is responsible for eradicating the invasive non-native species. Therefore, it is the cooperation of all three levels, the federal, state and local, that leads to the effective management of *Arundo* on private lands.

With the constraints mentioned previously, I truly believe that action against invasive non-natives can be most effective at the state and local levels because each invasive non-native species management plan is unique to its own location. The federal government can ask the states to comply with the federal laws by supplementing them with funding for implementation or they can develop federal committees that support invasive species management plans from the federal level to the state level. For example a committee comprised of 17 federal agency called the Federal Interagency for the Management of Noxious and Exotic Weeds (FICMNEW) supports state and local agencies in invasive species management. The goal of the FICMNEW is to "facilitate the development of biologically sound techniques to manage invasive plants on federal and private lands. The committee also forms partnerships with state and local agencies and non-governmental organizations to identify new ways to deal with invasive plants. These partnerships permit the public agencies to increase their expertise and resources and ensure a voice for private industry, landowners, and others who are directly affected by invasive plants" (Westbrook, 1998). This is the role of the Constitution in dealing with different states so that the federal government can implement policies that do not have to do with federal lands.

However, it up to the discretion of the individual state on how they will implement invasive species management plans. In some instances, "the state plant regulatory agencies can regulate the entry of invasive species into their state by prohibiting the sale and movement of plants and by regulating high risk vectors a such as potted nursery stock and seeds. In some western states, there are strict laws on invasive species and a County Weed Supervisor may be hired to enforce them. In certain cases when a landowner cannot or will not comply with the law, the County Supervisor will manage the infestation and bill the owner for the work" (Westbrook, 1998).

Federal "Weed" Laws

Other federal policies include the Federal Noxious Weed Act of 1975 and Clinton's Executive Order of 1999 on Invasive Species. The U.S. Department of Agriculture's Secretary implemented the Noxious Weed Act of 1975. The Act regulates the movement of noxious weeds into or through the U.S. or interstate. The Noxious Weed Act defines a noxious weed as "of foreign origin, is not new to or not widely prevalent in the US and can directly or indirectly injure crops, or other useful plants, livestock, or poultry or other interests of agriculture, including irrigation, or navigation of the fish and wildlife resources of the US or the public health." The Act also allocates the duties of federal agencies to manage noxious weeds on Federal lands throughout the U.S.

In 1999, Clinton signed an Executive Order on Invasive Species. The order prevents the introduction of invasive species, provides for their control and minimizes economic, ecological, and human health impacts caused by invasive species. The order defines an alien species as not native to that ecosystem. Native means the species that historically occurred or currently occur in that ecosystem. It also defines introduction as the intentional or unintentional escape, release, dissemination, or placement of a species into an ecosystem as a result of human activity. It defines an invasive species as an alien species that causes economic, environmental, and human health harm. The order describes the duties of the federal agency, in which an Invasive Species Council should be established. The Invasive Species Council consists of the Secretary of State, Treasurer, Defense, Interior, Agriculture, Commerce, and Transportation. The duties of the Council include implementation of the order, encourage planning and action at the local, tribal, state, and regional levels, to make a recommendation for international cooperation with invasive species, the prevention and control of invasive species, and to develop an Invasive Species Management Plan. The Secretary of the Interior will establish an Advisory Committee of representative stakeholders. The Advisory Committee will be funding by the Department of the Interior and will recommend plans and actions a local, tribal, state, regional, and ecosystem based levels.

California State "Weed" Laws

On the state level, there are two bills that have been passed in California legislation that directly relates to invasive species. The legislation includes the SB 1740 formed in September of 2000 (Leslie Bill) and the AB 1168 which was also formed in 2000(Funds Bill). Previous California state law designated the Department of Food and Agriculture (DFA) in Noxious Weed Management. The Secretary of the DFA is in charge of the DFA General Fund. The General Fund includes a Noxious Weed Management Account that appropriates $500,000 for three fiscal years. The funding is allocated for the management and eradication of noxious weeds through the local Weed Management Areas (WMA). A WMA is a local organization, usually within a county that coordinates the efforts and expertise against invasive weeds. WMA's function under the authority of a mutually developed memorandum of understanding (MOU). It is voluntarily governed and initiated by the County Agricultural Commissioner.

The newer bill, the SB 1740 appropriates $5 million from the DFA General Fund to the Noxious Weed Management Account for three fiscal years. The bill has a specified formula and criteria for the distribution of funds from the account to counties with established WMAs. In order for WMA's to receive the funding they must specify the purpose in which to spend the money. This is completed through the Agricultural Commissioner who submits a cost-share integrated Weed Management Plan with goals to aggressively control noxious weeds. The Oversight Committee should include livestock producers, agriculture crop producers, forest producers, Cal EPPC, research institutions, wildlife conservation groups, environmental groups, resource conservation district, general public, local government, and the Department of Fish and Game. The bill will also direct the Secretary of the DFA and WMAs to consider the use of California Conservation Corps, and local conservation corps in implementing the Weed Management Plans.

The Assembly Bill 1168, the Leslie Bill is implemented through the Integrated Pest Control Branch of the California State Assembly. It will distribute the funds in order to supplement existing budgets in WMA's collaborations and to initiate cooperation weed control projects. The WMA's must determine the targeted species for each county with the exception of A-rated species, which are a priority of all counties, like Yellow Star Thistle, for example. Just as the SB 1740 states, the County Agricultural Commissioner will allocate the funds to WMA's and therefore WMA's must submit proposals to receive the grants.

On the local level, Monterey County has two established WMA's, Big Sur and Ft. Ord. The Monterey County Agricultural Commissioner's assistant Bob Roach and BLM retiree, Jack Massera, are the WMA's primary contacts. They have developed a county wide noxious weed list, which includes Pampas Grass-Jubata Grass, Yellow Star Thistle, *Arundo*, Cape Ivy, and French Broom.

3.4 Examples of Implemented and Successful Invasive Weed Management Plans

Prior to the new Federal and State legislation, the implementation of Noxious Weed Management Plans (or policies), including action against *Arundo* were extremely successful in certain California regions. Team *Arundo* del Norte, founded by Paul Frandsen seven years ago, was one of the first coalitions of 20 groups to declare war on *Arundo*. In ten years they have brought back almost 500 acres of natural riparian habitat, which include cottonwoods and willows. In turn the habitat is back for the endangered bird, the Least Bell's Vireo. Team *Arundo* del Norte created an *Arundo* Management and Eradication Plan for the rivers, creeks, and watersheds in Central and Northern California, which are threatened by *Arundo* invasions. They proposed the plan to an agency called CAL-FED for funding in their efforts. CAL-FED formed in 1994 as a federal and state cooperative management and regulatory agency of the Bay Delta Estuary (Sacramento region of California). One of their four objectives is to "improve and increase aquatic and terrestrial habitats, improve ecological function in the Bay Delta (of California), and to support sustainable populations of diverse and valuable plant and animal species" (http://calfed.ca.gov). Team *Arundo* emphasized two pressing needs in regards to *Arundo*, on the ground eradication, and the need for coordination of a regional effort. CAL-FED approved the plan and funded projects in six watersheds including Putah Creek, Big Chico Creek, Sonoma Creek, Walnut Creek, Napa River, and the San Francisquito Creek. CAL-FED distributed $818,045 to reduce *Arundo*'s negative impacts to valuable riparian and aquatic habitats, water supply, natural stream morphology, fire risk, and flood risks. The funds were allocated for immediate eradicate, monitoring, technical coordination, planning future eradication work, and to organize and disseminate *Arundo* related information.

Other examples include, Santa Rosa's Russian River where the Sonoma County Water Agency has allocated $100,000 to the Sonoma Ecology Center to eradicate *Arundo*. Also, on the Santa Clara River, the California House of Representatives have approved a $100,000 appropriation to remove non-native weeds, including *Arundo*. US Representative, Howard P McKeon, a Republican of Santa Clarita, announced this approval in July of 2000 (Associated Press, 2000). Lastly, in the Sepulveda Basin, the Regional Park and Open Space District of Los Angeles County is deciding on whether to fund the Los Angeles Conservation Corps and the Audubon Society of $200,000 from Proposition A to manage *Arundo* between Victory Blvd and the LA River, a 5-acre site. A majority of the funds will go to the Los Angeles Conservation Corp, a non-profit agency that employs at risk youths to do the eradication work.

3.5 A Continuum Scale of Solutions and their Economic and Ethical Implications

There are many stakeholders concerned with the *Arundo* issue. The Property Owners and Homeowners of Monterey County are a major stakeholder because they are the owners of property that may or may not include *Arundo*, and may endure the costs of *Arundo* associated problems, like fire and flood damages. The Agricultural Commissioner and the Agricultural Community are stakeholders because they own a large portion of the land adjacent to the Salinas River, which currently contains *Arundo*. This community is also a major user of the water from the river for their agricultural crops. They also may bare the brunt of the *Arundo* problems like flooding, fires, and intensive use of water by *Arundo* (therefore, lack of water for the farmer). The Nurseries are a stakeholder because they are the distributors of *Arundo* for various reasons, like landscaping, ornamental, erosion control, and for musical reeds. If they are restricted to not selling *Arundo*, they are economically affected. Environmentalists are stakeholders because they include the scientists and land managers like the Watershed Institute or the Bureau of Land Management, the activists like Team *Arundo*, or passionate individuals like myself who are concerned about the health of the their local ecosystems. And lastly, the riparian habitats and endangered/threatened species of the Salinas River are stakeholders because they may be lost and gone forever in the Salinas River Watershed.

One may think of the solutions to the problem of *Arundo* on a continuum scale. At one end of the continuum the solution is to take no action on the *Arundo* problem in the Salinas River. At the other end of the continuum, the solution is to intensely regulate the sale, purchase and distribution of *Arundo* and to spend the entire state or county budget in eradicating existing *Arundo* infestations on the Salinas River. If the policy suggests to take no action on the *Arundo* problem then here would many be ethical and economic implications to the major stakeholders.

For example, the stakeholders that would be ethically affected by taking no action would be the nurseries of the agricultural community and the environmental-conservation-preservation groups. A Pomona nurseryman, John Greenlee, would support no action against *Arundo* because he feels it is his right to sell *Arundo* in California from his nursery. Greenlee states, "These plants aren't big, evil villains that have invaded nature. They are indicators of disturbance. The river has already been trashed and turned into a channel. Native plants have already been removed" (Raver, 1999). On the other hand, groups like Team *Arundo* del Norte, CA Native Plant Society, the Army Corps of Engineers, the Coalition to Save Sepulveda Basin, and the Sonoma Ecology Center would not support this policy. "*Arundo* has no value whatsoever, it's very prone to fire and soaks up a lot of water. It's a real problem," (Schnaufer, 1994) says Ted Carr, the Army Corps project manager. Most of the environmental groups value healthy, diverse, and native environments and they believe that something should be done about invasive non-native species like *Arundo* to ensure that.

There are many economic implications to certain stakeholders who decide to do nothing. As mentioned above, well-established *Arundo* infestations on rivers soon becomes an issue of economics. Property owners are faced with flood and fire damages. Also, California counties face economic challenges when *Arundo* causes flooding on public lands adjacent to rivers infested with *Arundo*. Team *Arundo* del Norte believes that removing *Arundo* early is the only way to avoid expensive, disruptive large scale eradication efforts. They believe that lessons were learned from the experience of *Arundo* in Southern California streams where there was estimated thousands of acres of *Arundo*. From that they said that early eradication and prevention is the most cost effective approach because once *Arundo* becomes heavily established, the problem shifts from biodiversity issues to one of economics and public safety. On the other hand, nursery owners would support this policy for economic reasons. No policy on controlling *Arundo* means continued sale and purchase of *Arundo* and therefore the continue disbursement of *Arundo* throughout California. The nurseries continue a profitable business.

If the policy suggests taking complete action to intensely regulate the sale, purchase and distribution of *Arundo* and to spend the entire state or county budget in eradicating existing *Arundo* infestations on the Salinas River there would also be ethical and economic implications to certain stakeholders. For example the stakeholders that would support this policy of full regulation might be the environmental groups who are extremely concerned with *Arundo*'s negative impacts on threatened and endangered species. A biologist from CA Fish and Game, Joel Trumbo says, "They don't call it 'the plant from hell' for nothing" (Associated Press, 1999). On the other hand, those that would not support this are the stakeholders that are concerned about having too many regulations put upon them. These might include individuals, landowners, and homeowners involved in the agricultural community of the Salinas Valley. It has been my experience when working with the agricultural community in the Salinas Valley that the threat of more regulation makes them more reluctant to take any action on any given issue. This assumption stems from working as a student assistant on a project, the Salinas Sediment Study, that will be developing a Total Maximum Daily Load (TMDL) for sediment in the Salinas River by 2002.

Therefore if the policy suggests taking complete action to intensely regulate the sale, purchase and distribution of *Arundo* and to spend the entire state or county budget in eradicating existing *Arundo* infestations on the Salinas River there would be economic implications to certain stakeholders. For example, the nursery owners are scared of exotic plant regulation for fear that it would negatively affect their business transactions. Craig Regelbrugge, the senior director of the American Nursery and Landscape Association would rather see voluntary compliance instead of mandatory regulation in banning certain exotics. "The last thing a nursery industry wants is an absolute balkanized marketplace where every little village has its own plant list and the market place becomes so fragmented you can't even keep up with it and do business," (Raver, 1999) Regelbrugge states.

I would like to propose a management policy for *Arundo* that falls somewhere in the middle of the continuum scale of solutions. The policy solution to the *Arundo* problem in the Salinas River is highly dependent on my personal environmental ethics in which healthy and diverse ecosystems are highly valued. I also believe like Team *Arundo* that it is important to address an environmental issue before it is out of control. The area in which science, technology, ethics and policy overlap is important to how this alternative solution will unfold. Science has shown that *Arundo* is an environmental problem. In other words, scientist have the knowledge to understand or assess a situation that appears to be disturbed and therefore can make the judgement of whether or not the disturbance is an environmental problem. Many scientists have made this judgement for the *Arundo* invasion. However, others could argue that a disturbance is an environmental problem only when defined as such. When defining a situation as problematic or not, personal ethics will greatly affect this decision. Therefore, I, as a scientist with my own personal ethics, believe that *Arundo* invasions in riparian systems are environmental issues because *Arundo* is threatening the health and diversity of riparian ecosystems. Furthermore, technology is going to help assess the problem and ethics will guide this project in determining the alternative solution or policy that lies on the continuum scale of solutions.

3.6 A Proposed Policy

The proposed policy for the *Arundo* problem on the Salinas River is in cooperation with the state bills AB 1168 and SB 1740. The proposed policy is asking that the funds allocated to

Monterey County for invasive weed management should be used to develop a management plan for *Arundo* and other top invasive species of concern in the county. It is important that *Arundo* management be included in the overall Invasive Weed Management Plan for Monterey County because addressing the problem before it is out of control will save future economic and environmental costs to many stakeholders. The *Arundo* Management, Eradication and Restoration Plan should be a collaborative effort of different private and public agencies to ensure that all stakeholders needs are met. Also, the funds should be allocated for additional research to fully understand the *Arundo* infestation in the Salinas River. The additional research should include mapping *Arundo* in the Salinas River, researching *Arundo*'s geomorphic ecological effects, bio-control methods, and outreach to those that are affected by *Arundo* infestations. The outreach to the community and other local organizations would enable these people to see that there is existing support and hope that they would want to join the collaborative action to make sure there needs are met. Also, the additional research would in hopes continue more funding in the future towards the *Arundo* management plan to fully eradicate *Arundo* on the Salinas River and restore the riparian habitat to a healthy and functioning system. To do nothing about the *Arundo* infestation is only securing future costs to many stakeholders. The full regulation on *Arundo* only ensures the lack of cooperation of certain key stakeholders and ignoring other invasive non-native species problems in Monterey County.

Part IV. Conclusion

In conclusion, this assessment and management protocol for *Arundo donax* provides a number of recommendations for the successful and effective management of *Arundo donax* in the Salinas River and its Watershed. What are the recommendations of this protocol?

The invasive non-native species, *Arundo donax* has been defined as an environmental issue. An *Arundo* infestation in a riparian system is an environmental issue because the infestation proposes many associated costs to the different stakeholders of the issue. These associated costs might include, flood and fire damage to landowners property, loss of sensitive habitat for sensitive species, and water quality issues to all users, whether it be drinking, irrigation, or recreation. However, there are proven effective management techniques for *Arundo* in riparian systems but the recommended effective management technique will be site dependent. In a site that contains a large amount of native riparian habitat, the foliar herbicide application of 2-5% solution may not be the best method. This method has proven to be one of the most effective in fully eradicating *Arundo*. It has a success rate of 100% in most *Arundo* infestations. In a site that is easily accessible and where mechanical mechanisms are provided, then the cut-stump-100% herbicide application is the other recommended effective management technique. The success rate of this method is 50-95% in the first year of management and full eradication by the fifth year.

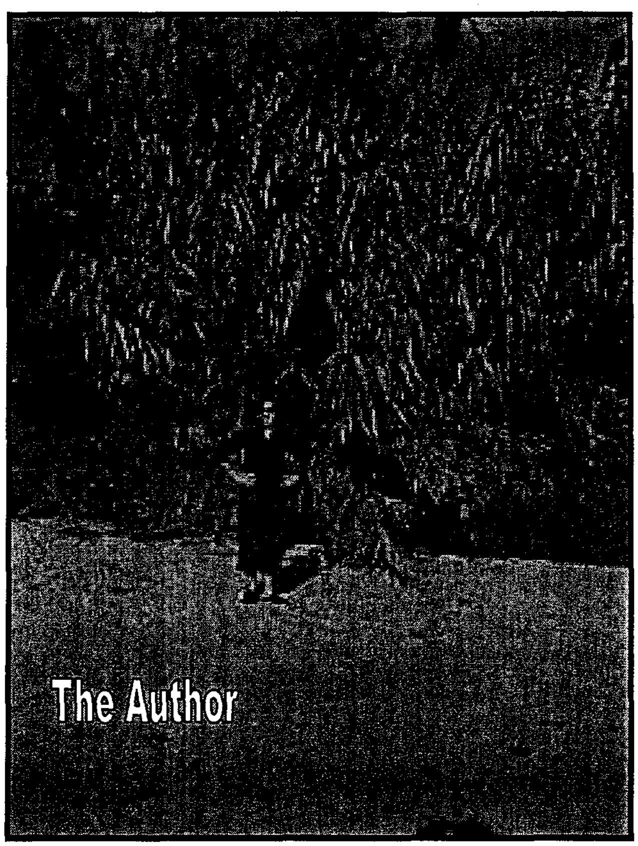
Once there is a general understanding of the biology of *Arundo*, its associated environmental costs, and the effective management techniques, then the detection and assessment of an *Arundo* invasion can be conducted. This protocol recommends that technology must be used in order to detect and assess *Arundo* in a riparian system. Technology, such as remote sensing is an effective tool to assess environmental issues such as *Arundo* because it is a technique most adequate for understanding the spectral information provided by *Arundo*. In addition, analyzing an image using a remote sensing classification scheme, like a supervised classification can answer the question whether or not *Arundo* can be differentiated from similar riparian vegetation. This study showed that *Arundo* can be differentiated from other vegetation, especially willow, which was the most similar type of vegetation to *Arundo*. Provided this finding, *Arundo* can now be mapped in the entire Salinas River Watershed. Determining the total amount of *Arundo* is important information for successful and effective management of *Arundo*.

Before a large-scale management effort of *Arundo* in the Salinas River Watershed can be developed, the protocol recommends that *Arundo* should be included in the overall Invasive Weed Management Plan for Monterey County. *Arundo* should be included in the county-wide policy because addressing the problem before it is out of control will only save future economic and environmental costs to many stakeholders in Monterey County. The *Arundo* Management, Eradication and Restoration Plan that this protocol recommends should be a collaborative effort of public and private entities to ensure all needs are met by participating stakeholders. The funds provided by the county-wide Weed Management Plan should not only develop an *Arundo* plan, it should also fund further *Arundo* research, including *Arundo* mapping studies similar to those addressed in this protocol. With findings such that *Arundo* can be differentiated from other vegetation is necessary information to map *Arundo* in the entire Salinas River Watershed and therefore, successful and effective management.

Part V. Acknowledgements

I would like to thank Scott Hennessy and the Watershed Institute for introducing me to the *Arundo* issue in the Salinas Valley and supporting me through the entire process of this capstone. I would also like to thank Dr. David Takacs and Dr. Daniel Shapiro, my environmental ethics and policy professors for motivating and inspiring me to create a real-world solution to the *Arundo* issue. Throughout the entire creating and writing process, I received some of the greatest feedback and support. Their feedback was greatly appreciated. My thanks also go out to Lee Johnson from NASA Ames Research who gave me the imagery I used in the remote sensing portion of this project.

I would like to thank Dr. Lars Pierce, my academic advisor for his four years of advisement and being there for all my questions and concerns throughout my undergraduate career. I would also like to thank Bruce Delgado and the Weed Warriors for inspiring and motivating me to care for native plants, their health and function. If I would have never met this group of people I may have never discovered my affinity for native flora and fauna. One Weed Warrior I would particularly like to thank is Garrett Chase Jones for his love, support, and of course editing skills. Finally, a huge thanks goes out to my family, my Dad, Mom, Angie, Cheri, and Andy for their support, love, and faith in me.



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