INVASIVE POTENTIAL OF THE AQUATIC MACROPHYTE

CRYPTOCORYNE BECKETTII

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Florence M. Oxley, B.S., M.S.

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Committee Members Approved:

____
Paula S. Williamson, Chair

____
Mara Alexander

____
Tina M. Cade

____
Kathryn Kennedy

____
Thomas R. Simpson

____
Floyd W. Weckerly

Approved:

____
J. Michael Willoughby
Dean of the Graduate College

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ABSTRACT

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SUPERVISING PROFESSOR: PAULA S. WILLIAMSON

Invasive species are a major threat to global biodiversity, resulting in a need to understand characteristics that cause a species to be invasive and increasing pressure to control or eradicate invasive species in order to mitigate their impacts. *Cryptocoryne beckettii*, native to Sri Lanka, has been introduced to the U.S. and is known to occur in freshwater ecosystems in Florida and Texas. *Cryptocoryne beckettii*, a relatively new introduction, is listed as invasive by the USDA. New introductions should be carefully studied to determine their potential to invade habitats, and, should they prove to be invasive, determine whether or not the public will support management efforts. My study

objectives were to: 1) determine ability of *C. beckettii* to reproduce asexually; 2) determine environmental factors influencing vegetative growth in *C. beckettii*; 3) determine community awareness, perceptions, and attitudes towards invasive species and their control in the San Marcos River; and, 4) determine effectiveness of dredging to control *C. beckettii* in the San Marcos River. I found that *C. beckettii* is capable of vegetative reproduction, with 24-34% of rhizome segments producing plantlets over a 12-week period. While significantly more plantlets were produced at a cooler temperature, plantlets were also produced at both moderate and warm temperatures demonstrating tolerance for a range of temperatures. To assess public awareness of invasive species, I administered a survey instrument and found that the public's overall awareness of invasives in the San Marcos River was moderate. There was a high level of support for control and eradication programs, mainly among men. Proposed management methods influenced levels of support and projects involving chemical controls or animal death were least supported.

CHAPTER I

INTRODUCTION

Charles Elton's (1958) classic, *The Ecology of Invasions by Animals and Plants*, was the first book to document the spread of nonnative species through intentional or unintentional anthropogenic introductions (Crawley, 1986). It was an early warning to ecologists and biologists about what he believed would become an environmental crisis. As Elton predicted, we are now in the midst of what is rapidly becoming a global environmental emergency.

Biological invasions are now recognized as a major component of human-caused environmental change (Williamson, 1996; Vitousek et al., 1997a), particularly in cases where invasions have resulted in the disruption of entire ecosystems by altering community composition, nutrient cycling rates, or disturbance regimes (Vitousek et al., 1987; D'Antonio and Vitousek, 1992; Vitousek et al., 1997b). Invasive species are considered to be the second greatest threat to rare, threatened, and endangered native species and to the integrity of native ecosystems (Diamond, 1985; Williamson, 1996; Flather et al., 1998; Shiva, 1999).

As international trade increases and humans become more mobile, the transport of species and the risk of introductions into new areas will increase (Jenkins, 1999). As a result, there is an urgent need for the development of tools and methods to reduce this threat to natural biodiversity (Sandlund et al., 1999). These tools must be based on a thorough understanding of the ecology of invading species, the ecosystems being invaded, and the processes driving invasions (Sandlund et al., 1999). Practical and economical ways of predicting, stopping, controlling, and managing invasive species still need to be developed (Sandlund et al., 1999).

Ecologists ask fundamental questions such as why some communities are more invaded than others, or why a particular species becomes widespread and abundant (Kolar and Lodge, 2001; MacIsaac et al., 2001; Keane and Crawley, 2002). This lack of information continues to handicap our attempts to predict invasions and manage and control invasive species (Sandlund et al., 1999). Improved understanding of the characteristics of successful invaders and the interactions between them and resident species will allow us to develop the tools and management strategies necessary to counteract both invasions and their negative impacts on ecosystems (Mooney and Hobbs, 2000; Corbin and D'Antonio, 2004).

Many traits have been attributed to invasive species and invaded ecosystems, but none are universal. These traits include fast growth (Elton, 1958), rapid reproduction (Rejmanek and Richardson, 1996; Reaveley et al., 2009), high dispersal ability (Reaveley et al., 2009), phenotypic plasticity (Daehler, 2003; Richards et al., 2005), tolerance to a wide range of environmental conditions (Reaveley et al., 2009), asexual reproduction (Reichard and Hamilton, 1997; Rejmanek, 1989), and association with humans (Williams and Meffee, 1998; Kolar and Lodge, 2001; Maki and Galatowitsch, 2004). Most invasive species tend to possess several of these traits, but rarely possess all of them (Cronk and Fennessy, 2001).

It is unclear what makes an ecosystem invasible. A combination of many factors, some of which we probably do not recognize, may be responsible (Rejmanek, 1989). Elton (1958) argued that ecosystems with higher species diversity were less invasible because of fewer available niches. Since then, other ecologists have pointed to highly diverse, but heavily invaded ecosystems and have argued that ecosystems with high species diversity seem to be more susceptible to invasion (Stohlgren et al., 1999). Small-scale studies tend to show a negative relationship between diversity and invasion while large-scale studies tend to show a positive relationship. The latter result may be an artifact of invasive or non-native species capitalizing on increased resource availability and weaker overall species interactions that are more common when larger spatial scales are considered (Levine, 2000; Byers and Noonberg, 2003).

Invasion is more likely if a potentially invasible ecosystem is similar to the ecosystem in which the potential invader evolved (Williams and Meffee, 1998). Invasible ecosystems, while meeting fundamental habitat niche parameters of the invader, may lack the natural competitors and predators that keep introduced species in check in their native ecosystems. Finally, invaded ecosystems have often experienced disturbance, usually human-induced (Williams and Meffee, 1998). This disturbance may give invasive species, which are not otherwise coevolved with the ecosystem, a chance to establish themselves with less competition from species adapted to the environment (Tilman, 2004).

Freshwater ecosystems are among the most altered ecosystems worldwide (Moyle and Leidy, 1991; Allan and Flecker, 1993). They are subject to water diversions and intense human use of both the aquatic systems and the surrounding watersheds (Postel et al., 1996). As a result, native organisms, particularly ecologically important plant and fish species that inhabit these ecosystems are severely stressed and subjected to intense exploitation (Moyle, 1999). Adding to the stresses caused by environmental changes, freshwater ecosystems are also the most invaded ecosystems in the world (Hamilton, 1998; Nature Conservancy, 2010; United States Environmental Protection Agency, 2010). Human introductions of fish, invertebrates, plants, and pathogens have caused further alterations in already extremely stressed ecosystems (Moyle, 1999; Garcia-Berthou et al., 2005).

As a result of these many stresses, biodiversity is declining in freshwater ecosystems at rates far exceeding those in terrestrial ecosystems (Dudgeon et al., 2006). Introductions of nonnative plant species are one major source of biodiversity decline in freshwater ecosystems (International Union for Conservation of Nature, 2000; Rahel, 2002; Dudgeon et al., 2006; United States Environmental Protection Agency, 2010). Examples of introduced nonnative plant species that have adversely impacted freshwater ecosystems abound. Water hyacinth (*Eichhornia crassipes*), considered one of the world's most noxious freshwater weeds, fouls drinking water, impedes the natural flow of water in rivers and streams, obstructs navigation, interfers with agricultural crops, depletes oxygen in the water leading to fish kills, and harbors disease vectors (Gopal, 1987). Eurasian milfoil (*Myriophyllum spicatum*) forms thick dense colonies that can shade out and displace native species within three years of being introduced into new habitats (Aiken et al., 1979; Smith and Barko, 1990; Madsen et al., 1991; Boylen et al., 1999). Hydrilla (*Hydrilla verticillata*), another submersed introduced species, can be found in rivers, streams, and lakes from Florida to Connecticut and west to California and

Washington (Langeland, 1996; Center for Aquatic Invasive Plants, 2001; United States Department of Agriculture, 2010). Forming thick mats, it shades out or simply outcompetes native species, often resulting in their elimination in the invaded habitat (van Dijk, 1985).

Cryptocoryne beckettii Thwaites ex Trimen. (Figure 1.1), commonly called Beckett's water trumpet, is a relatively new introduction that is listed as invasive in the United States Department of Agriculture Plant Database (2010). The taxon is not yet listed on the United States Department of Agriculture Animal and Plant Health Inspection Service Federal Noxious Weed List (2006), nor does it appear on any of the Texas state lists of noxious weeds, including the Texas Parks and Wildlife Department (2010b) Invasive, Exotic, and Prohibited Species List or the Texas Parks and Wildlife Department (2010a) Ineligible Species List. It is one of the 13 *Cryptocoryne* species that is being considered for inclusion on Texas Parks and Wildlife's Proposed List of Approved Exotic Aquatic Plants (2010c). *Cryptocoryne* species are popular decorative plants for tropical aquaria (Rataj and Horeman, 1977). *Cryptocoryne beckettii* has been one of the most popular of the species for more than 60 years (Bastmeijer, 2001). It is hardy and vigorous (Rataj and Horeman, 1977; Miller, 1998). It is widely sold in pet stores and on the internet (personal observation).

It is believed that *C. beckettii* may have been introduced into North American aquatic systems as a result of dumping of aquaria (Jacono, 2002). Its potential range as an invader in North America is uncertain, but it is believed that it has the potential to easily expand throughout the Gulf coastal plain and the southern Atlantic coastal plain (Nature Conservancy, 2001).

In the United States, *C. beckettii* is found in karstic systems formed by artesian groundwater that is high in clarity, rich in soluble carbonates, and moderate in temperature. In these systems, it has been observed growing by rooting directly in limestone substrates or sandy and silty sediments that overlay rocky streambeds in clear, fast-moving water (United States Geological Survey, 1999; United States Geological Survey, 2000).

Cryptocoryne beckettii was first recorded in the United States in Marion County, Florida, in 1989. Originally observed in a shaded cove of a spring run along the Rainbow River on the Rainbow Springs Aquatic Preserve (Wunderlin, 1998), it was misidentified as *C. wendtii*. Recollection at the site 12 years later determined that three closely related species were growing together, *C. beckettii*, *C. wendtii*, and *C. undulate.* Specimens were identified and vouchered (Jacono, 2002). The invading colony consists of a dense, 130 m^2 stand ranging from 28 to 75 cm deep.

The Rainbow River is a site of exceptional scenic beauty and a popular destination for recreation. It was designated the Rainbow Springs Aquatic Preserve in 1986 (Florida Statute 258.39[32]). *Cryptocoryne beckettii* grows there at 1,480 plants per m^2, a high density that excludes native macrophytes and encroaches on adjacent stands of the endemic springtape (*Sagittaria kurziana*), twoleaf watermilfoil (*Myriophyllum heterophyllum*) and an unusual population of starrush whitetop (*Rhynchospora colorata*). Several meters downstream, annual wild rice (*Zizania aquatica*) and the endemic Florida watercress (*Rorippa floridana*) contribute to one of the few unspoiled plant communities remaining at the Preserve. The potential for dispersal of *C. beckettii* at Rainbow Springs Aquatic Preserve is significant (Jacono, 2002).

In 1996, *C. beckettii* was first documented in Hays County, Texas, as large colonies that were established in shallow riffles and shaded pools of the spring-fed San Marcos River (Rosen, 2000). Scattered patches had reportedly been observed since 1993, and monitoring studies carried out between 1998 and 2000 documented patch expansion at an average rate of 80% per year within a 1.7 km stretch of the upper San Marcos River (Doyle, 2001).

During this time, coverage consisted of many small and a few large colonies. During the monitoring period, the number of individual colonies increased from 11 to 63 and the total area covered increased from 171 to 646 m^2. Most colonies were located at depths of 30 - 90 cm, with none growing deeper than 120 cm (Doyle, 2001). Other researchers have observed the plant growing at depths of 5 m (Mara Alexander, personal communication). Plants continued to spread in the San Marcos River, and where small patches were once observed, stands extended bank-to-bank. At one point *C. beckettii* was observed to occupy a total area in excess of 1,950 m^2 (Biowest, 2005).

The upper San Marcos River supports a wide diversity of aquatic organisms and provides critical habitat for eight endangered species including the fountain darter (*Etheostoma fonticola*), the San Marcos blind salamander (*Eurycea rathbuni*) and Texas wild-rice (*Zizania texana*) (United States Fish and Wildlife Service, 1978). While it is typically found at depth and flow velocities similar to that of *Z. texana*, *C. beckettii* exhibits a more rapid rate of expansion and poses a threat to *Z. texana* by moving into and colonizing habitat that might otherwise be colonized by *Z. texana* and other native aquatic species (Doyle, 2001).

The ability of *Cryptocoryne* species to selectively use bicarbonate under alkaline conditions (Cheng and Mansor, 2000) may contribute to their successful colonization of karstic spring environments in Florida and Texas. Like many aroids, species of *Cryptocoryne* use contractile roots to adjust plant level after heaving or flooding (Bown, 2000). Rootlets sent deep into the rock use root pressure to contract in length and pull the roots farther into the substrate. This adaptation firmly anchors plants in swift currents and likely accounts for the deep rooting in limestone substrate at Rainbow Springs, Florida. In the San Marcos River, Texas, plants root deeply in sediment mounds resulting from streamside erosion, as well as in cement, clay, and loose sediment (Mara Alexander, personal communication).

Reproduction in *C. beckettii* appears to be primarily asexual in the San Marcos River (personal observation). The same situation was observed by Jacono (2002) at Rainbow Springs. Rhizomes and runners (stolons ending in a new plantlet) provide for expansion of populations in both Texas and Florida. According to Jacono (2002) at Rainbow Springs, basal shoots are most abundant in springtime. Disturbances such as wading dislodge the basal shoots, which immediately sink. Bottom currents then carry the shoots downstream. Dislodged rhizomes, on the other hand, simply float on the surface.

Dispersal of plants into uncolonized areas may be slightly different in the San Marcos River. Dislodged basal shoots may also sink to the bottom of the river and be carried downstream by bottom currents. Dislodged rhizomes, however, rather than simply floating on the river’s surface, may also be transported downstream (personal observation). This would potentially increase downstream colonization by the plant.

Public perception of invasive species can impact the spread and control of invasive species (Perrings et al., 2002; Bremner and Park, 2007). Perrings et al. (2002) point out that continued introductions and spread of nonnative invasive species can be attributed to human behavior and whether or not people are willing to change their behavior. According to Perrings et al. (2002), people can respond positively in one of two ways: by working to eradicate and prevent the continued spread of invasives (mitigation) or by changing their behavior to reduce the impact of an invading species (adaptation).

Public support of invasive species management programs is often dependent on how people feel about the species being targeted (Bremner and Park, 2007). Managers attempting to eradicate/control species that the public considers appealing or attractive, may not find the necessary support for their efforts (Bremner and Park, 2007). An excellent example of this is the trial eradication of a small population of the grey squirrel (*Sciurus carolinensis*) in Turin, Italy (Bertolino and Genovesi, 2003).

According to Bertolino and Genovesi (2003), a plan was developed for the eradication of the American grey squirrel, an introduced species that replaces the native red squirrel (*Sciurus vulgaris*). A trial eradication of a small population of the squirrel was scheduled to determine if the plan was feasible. The public strongly opposed the trial eradication and, led by members of three animal rights groups, took the project leaders to court, causing the project to be suspended during the legal proceedings. The time lost during the trial proceedings allowed the American grey squirrel to expand its range so much that eradication is no longer an option.

In order to make sound biological decisions about introduced species and to determine the most efficient and cost-effective methods of control and/or eradication, it is important to understand the biology and ecology of the targeted species. New introductions, especially those that are discovered early in their introduction, should be carefully studied to determine their potential to aggressively invade a new habitat, and, should they prove to be invasive, whether or not the public will support management efforts. The objectives of this study are to: 1) determine ability of *C. beckettii* to reproduce asexually; 2) determine environmental factors influencing vegetative growth in *C. beckettii*; 3) determine community awareness, perceptions, and attitudes towards invasive species and their control in the San Marcos River; and, 4) determine effectiveness of dredging to control *C. beckettii* in the San Marcos River.

Figure 1.1. Photograph of *Cryptocoryne beckettii*.

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CHAPTER II

POTENTIAL OF CRYPTOCORYNE BECKETTII TO BECOME A WIDESPREAD INVASIVE PLANT

Introduction

Cryptocoryne beckettii Thwaites ex Trimen., Beckett's water trumpet, is a popular aquarium species (Bastmeijer 2001) and is sold in pet stores throughout the United States and on the internet (personal observation). It is considered hardy and vigorous by aquarium enthusiasts (Rataj and Horeman 1977; Miller 1998).

The USDA has identified a number of invasive species that have become established in aquatic ecosystems after being introduced by the aquarium trade (United States Department of Agriculture Plant Database 2010). Among them are Hydrilla (*Hydrilla verticillata* L. f.), Brazilian waterweed (*Egeria densa* (Planch.) Casp.), Caulerpa (*Caulerpa taxifolia* (M. Vahl) C. Agardh), and Eurasian watermilfoil (*Myriophyllum spicatum* L.) (United States Department of Agriculture Plant Database2010). *Cryptocoryne beckettii* is now included in this group (Jacono 2002); the taxon is a relatively new introduction that is listed as invasive in the United States Department of Agriculture Plant Database (2010).

Native to Sri Lanka, where it grows submersed in fast moving freshwater springs and rivers (Mühlberg 1982; de Graaf and Arends 1986), *C. beckettii* is considered an invasive species in both Florida and Texas. Its potential range as an invader in North America is uncertain, but it is believed that it has the potential to easily expand throughout the Gulf coastal plain and the southern Atlantic coastal plain (Nature Conservancy 2001).

Cryptocoryne was first recorded in the United States in 1989 in Marion County, Florida in a shaded cove of a spring run along the Rainbow River on the Rainbow Springs Aquatic Preserve (Wunderlin 1998). Three closely related species, Beckett's water trumpet (*Cryptocoryne beckettii)*, Crypt Wendtii (*C. wendtii* de Wit), and undulate cryptocoryne (*C. undulate* Wendt), occur at the site (Jacono 2002). The plants occur in a dense, 130 m^2 stand at depths ranging from 28 to 75 cm. *Cryptocoryne beckettii* is found at a density of 1,480 plants per m^2, a high density that potentially excludes native macrophytes and encroaches on adjacent stands of the endemic springtape (*Sagittaria kurziana* Glück), twoleaf watermilfoil (*Myriophyllum heterophyllum* Michx.) and an unusual population of starrush whitetop (*Rhynchospora colorata* (L.) H. Pfeiffer).

Cryptocoryne beckettii was first documented in the San Marcos River ecosystem in Hays County, Texas, in 1996 (Rosen 2000), as established colonies in shallow riffles and shaded pools of the river (Rosen 2000). Monitoring studies carried out between 1998 and 2000 documented patch expansion at an average rate of 80% per year within a 1.7 km stretch of the upper San Marcos River (Doyle 2001). During the monitoring period, the number of individual colonies increased from 11 to 63 and the total area covered increased from 171 to 646 m^2. Most colonies were located at depths of 30 - 90 cm, with none growing deeper than 120 cm (Doyle 2001). Other researchers have observed the plant growing at depths of 5 meters (Mara Alexander, personal communication). Plants continued to spread in the San Marcos River, and where small patches were once observed, stands extended bank-to-bank. At one point *C. beckettii* was observed to occupy a total area in excess of 1,950 m^2 (Biowest 2005).

The expansion of *C. beckettii* in the San Marcos River ecosystem led to the plant's colonization of designated critical habitat of the federally listed Texas wild-rice (*Zizania texana* Hitchc.). Due to the threat *C. beckettii* poses to wild-rice and other native aquatic plants, attempts were made by the United States Fish and Wildlife Service (USFWS) in 2006 to curtail spread of the species through dredging. However, dredging does not appear to have been a completely successful means of removing the species from the ecosystem since plants continue to persist in the river seven years post-dredging.

Reproduction in *C. beckettii* appears to be primarily asexual in the San Marcos River (personal observation). The same situation was observed by Jacono (2002) at Rainbow Springs. Rhizomes and runners provide for expansion of populations in both Texas and Florida. Reproduction in many aquatic species is primarily asexual (Sculthorpe 1967; Barrat-Segretain 1996). One way asexual reproduction can occur is through fragmentation of the vegetative organs (Barrat-Segretain 1996). Because vegetative organs of aquatic plants tend to be very brittle, they are easily broken and fragmented during disturbance (Barrat-Segretain 1996; Barrat-Segretain and Bornette 2000) and these fragments can potentially disperse long distances (Owens et al. 2001) increasing the potential for establishment of colonies in new areas (Campbell 2003; Wright and Davis 2006).

The ability of this species to invade bodies of freshwater makes it compelling to study species' traits that may cause it to be invasive. The goal of our study was to examine traits, including ability to reproduce vegetatively and tolerance for a range of environmental conditions that may cause *C. beckettii* to be invasive. Specific objectives were to: 1) determine the potential for rhizome segments of varying sizes to produce new plants; 2) determine the effect of initial rhizome segment size on extent of vegetative growth; and, 3) determine the effects of different light intensities and temperatures on vegetative reproduction and growth.

Materials and Methods

We examined the effect of temperature, light intensity, and initial rhizome segment size on the vegetative reproduction and growth of *C. beckettii* using three experimental growth chambers. Each growth chamber was constructed using a 75.7 liter Topfin© aquarium outfitted with a Topfin© Power Filter, model 20 # 35903 (115 volts, 60Hz) that filters 303 liters of water every hour, a submersible Topfin© Powerhead 30 water circulator that circulates 360 liters of water every hour to simulate current flow, and a Central Garden & Pet© battery operated digital thermometer (Figure 2.1).

We used water collected from the United States Fish and Wildlife Service San Marcos Aquatic Resources Center wells, which comes from the same aquifer source as the San Marcos River in which *C. beckettii* grows, to fill the growth chambers. Each growth chamber contained 72 liters of water. We replaced water as needed to maintain a constant volume.

Water in each of the three growth chambers was maintained at a different temperature. The temperature in growth chamber 1 (cool treatment) was maintained at 15.5^{o}C ± 1.5^{o}C; growth chamber 2 (moderate treatment) was maintained at 22.5^{o}C ±1.5^{o}C; and, growth chamber 3 (warm treatment) was maintained at 28.5^{o}C ± 1.5^{o}C. Temperatures in the cool and moderate growth chambers were maintained using Current© Mini-Chillers, model # 2680. Temperature in the warm growth chamber was maintained using a Topfin© 100 watt aquarium heater.

Plants in each growth chamber (cool, moderate, warm) were exposed to three different light treatments; light intensities examined were full shade (FSh), dappled shade (DSh), and full sun (FS). In each growth chamber a subset of plants received the FSh treatment, a subset the DSh treatment, and the third subset received the FS treatment. Full shade was simulated by covering planted trays with woven shade cloth that filtered out 70% of light (DeWitt's Woven Shade, manufacturer's specifications). Dappled shade conditions were simulated by covering planted trays with woven shade cloth that filtered out 30% of light (DeWitt's Woven Shade, manufacturer's specifications). Full sun conditions were simulated by exposing planted trays to full light. Figure 2.2 shows the light treatment experimental design. The light source for each growth chamber was provided using a Marina© 15 w/120 volt clear aquarium light bulb. Lights were set on a 12/12 hour light-dark regime using a Brinks Temporizador© digital timer.

We cut twenty rhizome segments of each of four size classes (0.5 cm, 1.0 cm, 1.5 cm, and 2.0 cm), removed all roots and leaves, and weighed the rhizome segments to determine a beginning mean weight for each rhizome size class. We cut rhizome segments, measuring 0.5 cm (n=20), 1.0 cm (n=20), 1.5 cm (n=20), and 2.0 cm (n=20) and bearing at least one node, rinsed them in a 10% bleach solution to remove surface pathogens and rinsed them again in distilled water. Planting trays with 2 mm cells were cleaned using a 10% bleach solution, rinsed in distilled water, and air dried prior to planting. We filled each cell with 14.95 mm^3 of sterilized, sieved soil. We randomly planted rhizome segments in planting trays, with each segment planted to one-half its length. We completely submerged the trays and placed shade cloth on full shade and dappled shade trays. We began the study and allowed the experiment to run for a period of 12 weeks.

We treated growth chambers with Pimafix™ and Melafix® throughout the study period to control fungal and bacterial growth. To control algal growth, we used Advanced Algae Destroyer™ applied at three day intervals throughout the study. We changed filters monthly.

Rhizome segments were allowed to grow for 12 weeks. After 12 weeks, we harvested plants (Figure 2.3), rinsed them with tap water to remove excess soil, and then patted them dry with paper towels. We collected the following data: number of plantlets produced by each rhizome segment, total fresh biomass of plantlet (shoot and root systems combined) measured in grams, height of shoot system of each plantlet measured in centimeters, total number of leaves produced by each plantlet, and combined total length of adventitious roots produced by each plantlet measured in centimeters. We calculated the increase in biomass of plantlets by taking the final weight and subtracting the average initial weight of rhizome segment. We used fresh biomass because after data collection the rhizome segments were replanted in culture tanks for use in other studies. We measured the height of the shoot system of each plantlet from the tip of the longest leaf to the top of the initial rhizome segment. We measured the length of all adventitious roots produced by each plantlet and combined the data as total root length.

We analyzed data for the number of rhizome segments producing plantlets under each temperature treatment using a one-way ANOVA. Shoot system height and adventitious root length data were log-transformed to meet conditions for normality and homoscedascity before analysis. Total plantlet biomass and leaf number data met conditions of normality and homoscedascity. We analyzed shoot system height, adventitious root length, total plantlet biomass, and leaf number data with factorial ANOVA's ($\alpha = 0.05$) (Zar 1999) in program R, version 2.10.1 (R Development Core Team 2008).

Results

Rhizome segments (n=240) exposed to the cool treatment (15.5ºC) produced 81 plantlets (34%). Rhizome segments (n=240) grown under moderate temperature (23.5ºC) produced 66 plantlets (28%). Rhizome segments (n=240) grown in the warm treatment (28.5ºC) produced 58 plantlets (24%). The different temperature treatments did not produce any significant differences in number of rhizome segments producing plantlets ($F = 1.04$, $df = 2$, $p = 0.355$). Although the different temperature treatments did not produce any significant differences in number of rhizome segments producing plantlets, there were significant differences in the mean number of plantlets produced ($F = 11.28$, $df = 2$, $p = 2.50E-05$). Rhizome segments exposed to cool temperature produced a mean of 1.23 plantlets, while in both the moderate and warm treatments a mean of 1.0 plantlets was produced (Table 2.1).

The largest number of plantlets (mean=1.11) was produced by rhizome segments exposed to full shade and the lowest number of plantlets (mean=1.07) was produced under dappled shade conditions (Table 2.2). Under full sun, a mean number of 1.08 plantlets was produced (Table 2.2). Differences in mean number of plantlets produced were not statistically significant (Table 2.2).

There was a significant difference in the number of plantlets produced as a result of initial segment size ($F = 3.12$, $df = 3, 201$, $p = 0.028$). More plantlets were produced by 2.0 cm rhizome segments, than other segment size classes (Table 2.3). Two centimeter rhizome segments produced a mean of 1.15 plantlets, while 1.0 and 0.5 cm segments produced means of 1.11 and 1.07 plantlets, respectively. The 1.5 cm initial rhizome segments produced the fewest plantlets (mean=1.00).

The total amount of biomass produced under the different temperature treatments was significantly different ($F = 4.34$, $df = 2, 202$, $p = 1.47E\text{-}02$). Rhizomes grown under the warm temperature treatment produced greater total mean biomass (0.13 g) when compared to rhizomes grown under either the cool (0.08 g) or moderate (0.09 g) temperature treatments (Table 1). Differences in growth of the shoot system were also statistically significant ($F = 56.55$, $df = 2, 218$, $p = <2.2E\text{-}16$). The least growth in height (mean=1.52 cm) occurred in plantlets exposed to the cool treatment and the greatest growth in height (mean=3.46 cm) occurred in the warm treatment (Table 2.1). The mean height of the shoot system in the moderate treatment was intermediate at 2.71 cm (Table 2.1). The number of leaves produced in the different temperature treatments was significantly different ($F = 19.79$, $df = 2, 172$, $p = 2.630E\text{-}08$). Plantlets grown in the cool treatment produced fewer leaves (mean=2.12) when compared to plantlets in either the moderate (mean=3.44) or warm (mean=3.41) treatments (Table 2.1). There was a statistically significant difference in extent of adventitious root growth as a result of the different temperatures ($F = 137.20$, $df = 2, 162$, $p < 2.2E\text{-}16$). The least amount of adventitious root growth occurred in plantlets in the cool treatment (mean=0.61 cm), while the most adventitious root growth occurred in plantlets grown in the warm treatment (mean=4.54 cm) (Table 2.1). The mean length of adventitious roots produced by plantlets in the moderate temperature treatment was intermediate (mean=2.83 cm) (Table 2.1).

Light had a statistically significant effect on vegetative growth. The number of leaves produced under the different light treatments was significantly different ($F = 3.65$, $df = 2, 172$, $p = 0.029$). Plantlets grown in full sun produced more leaves per plantlet (mean=3.27) than plantlets in dappled shade (mean=3.20) or full shade (mean=2.57) (Table 2.2). The extent of adventitious root growth was significantly different ($F = 6.52$, $df = 2, 162$, $p = 0.002$). The greatest extent of adventitious root growth (mean=3.18 cm) occurred under full sun conditions, growth was intermediate in plantlets exposed to dappled shade (mean=2.64 cm) and the least amount of adventitious root growth (mean=2.30 cm) occurred under full shade conditions (Table 2.2). There was no significant difference in the mean biomass produced by rhizomes under the different light treatments (Table 2.2). Rhizomes exposed to full sun produced greater biomass (mean= 0.11 g) than rhizomes exposed to dappled shade (mean=0.09 g) or full shade (mean= 0.09 g) (Table 2.2). Shoot system height did not vary significantly under the different light treatments (Table 2.2). Plantlets grown in full sun produced the largest amount of shoot growth (mean=2.43 cm), while plantlets grown in dappled shade produced a mean shoot growth of 2.38 cm and those grown in full shade produced the least shoot growth (mean=2.33 cm) (Table 2.2).

There were no significant differences in the number of leaves produced by plantlets from rhizomes of differing initial sizes (Table 2.3). Plantlets from rhizome segments measuring 0.5 cm and 2.0 cm produced a mean number of leaves of 2.79 and 2.83, respectively (Table 2.3). Plantlets from rhizomes segments with initial sizes of 1.0 and 1.5 cm produced a mean number of leaves of 3.34 and 3.09, respectively (Table 2.3). For all other parameters of vegetative growth, including biomass, shoot height, and adventitious root length, results were not significantly different (Table 2.3).

The interaction between temperature and initial segment size produced a statistically significant difference in biomass ($F = 2.22$, $df = 6, 198$, $p = 0.04$). The 2.0 cm rhizome segments produced the greatest biomass (mean=0.08 g) at 15.5°C (Figure 1). At 23.5°C and 28.5°C the 1.5 cm rhizome segments produced the greatest biomass (mean of 0.12 g and 0.17 g, respectively) (Figure 2.4). There were no third order interactions among the three factors.

The interaction between light and initial rhizome segment size produced a statistically significant difference in the mean height of the shoot system ($F = 2.98$, $df = 6, 214$, $p = 0.01$). Under full shade, the 1.5 cm rhizome segments produced the tallest plantlets (mean=2.52 cm) (Figure 2.5). Under full sun, the 0.5 cm and 1.5 cm rhizome segments produced the tallest plantlets (mean of 2.79 cm and 2.87 cm, respectively) (Figure 2.5). Under dappled shade, the 1.0 cm rhizome segments produced the tallest plantlets (mean=2.54 cm) (Figure 2.5). There were no third order interactions among the three factors.

No statistically significant differences in number of leaves produced occurred due to interactions between temperature and light, temperature and initial rhizome segment size, or light and initial segment size. There were no third order interactions among the three factors. No statistically significant differences in the length of adventitious roots occurred as a result of interactions between temperature and light, temperature and initial segment size or light and initial segment size. There were no third order interactions among the three factors.

Discussion

Traits that have been attributed to a species' ability to become a successful invader include rapid growth and reproduction (Rejmanek and Richardson 1996; Reaveley et al. 2009), vegetative reproduction (Reichard and Hamilton 1997), high dispersal ability (Reaveley et al. 2009), and an ability to tolerate a wide range of environmental conditions (Reaveley et al. 2009). In addition, an increasingly mobile human population has introduced a number of invasive species into new ecosystems (Williams and Meffee 1998; Kolar and Lodge 2001; Maki and Galatowitsch 2004). While most invasive species tend to possess several of these traits, few possess all of them (Cronk and Fennessy 2001). Our study revealed that *C. beckettii* possesses several of the traits characteristic of a nuisance invasive species.

The plant is capable of rapid asexual reproduction, with 24-34% of the rhizome segments producing plantlets within twelve weeks. The plant is also able to reproduce vegetatively under a range of environmental conditions. Plantlets were produced under different light intensities, ranging from full shade to full sun. The ability to reproduce asexually under different light intensities has been noted in other invasive species such as Canadian waterweed (*Elodea canadensis* Michx.) (Mielecki and Pieczynska 2005; Riis et al. 2012), Brazilian waterweed (*Egeria densa*) (Riis et al. 2012), African elodea (*Lagarosiphom major* Ridl. Moss ex Wager) (Riis et al. 2012), parrot feather watermilfoil (*Myriophyllum aquatica* (Vell.) Verdc.) (Wersal and Madsen 2011), Eurasian watermilfoil (*Myriophyllum spicatum*) (Titus and Adams 1979; Smith and Barko 1990) and hydrilla (*Hydrilla verticillata*) (Miller et al. 1976).

A study of growth and biomass allocation of Crypt ciliata (*Cryptocoryne ciliata* (Roxburgh) Schott), a related species, found that plants in shady areas produced larger leaves than those growing in full sun (Simon et al. 2008). Simon et al. (2008) also found that Crypt ciliata plants grown under shade conditions were taller, healthier, and better developed than plants growing under other light conditions. In contrast, our study revealed that *C. beckettii* grows better under high light intensities. *Cryptocoryne beckettii* plants grown under full sun produced more leaves than plants growing under shady conditions. Plants also had more adventitious root growth when grown under full sun conditions. Light intensity, however, was not a significant factor in other aspects of plant growth including shoot height and overall biomass suggesting a tolerance to different light intensities.

The ability of submerged macrophytes to tolerate a wide range of temperatures has been demonstrated in Eurasian watermilfoil (Smith and Barko 1990), Canadian waterweed (Barko et al. 1982), longleaf pondweed (*Potomogeton nodosus* Poir.) (Barko et al. 1982), and wild celery (*Vallisneria americana* Michx.) (Barko et al. 1982). While significantly more plantlets were produced at the cooler temperature, plantlets were also produced at both moderate and warm temperatures demonstrating that *C. beckettii* can tolerate a range of temperatures.

Although the two bodies of water in which *C. beckettii* have been recorded, the Rainbow River in Florida and San Marcos River in Texas, have similar water temperatures (22.8 ^{o}C - 23.5 ^{o}C), the results of this study suggest that *C. beckettii* has the potential to expand into bodies of water at a variety of temperatures throughout the Gulf coastal plain and the southern Atlantic coastal plain as speculated by the Nature Conservancy (2001) and possibly even invade more northern regions where water temperatures are cooler. The ability of *C. beckettii* to vegetatively reproduce under a variety of light intensities also supports the idea that the plant may colonize other aquatic ecosystems.

Vegetative reproduction is a primary mode of reproduction in many aquatic plants (Sculthorpe 1967; Barrat-Segretain 1996). Vegetative reproduction can occur as a result of stolons, rhizomes, specialized structures such as turions, and fragmentation of individual plants (Barrat-Segretain 1996; Barrat-Segretain et al. 1998). All *C. beckettii* rhizome segment size classes produced plantlets in our study. Fragmentation of this plant may be an effective dispersal mechanism as fragments easily float on the water surface for a short period of time before sinking to the bottom (personal observation). The size of fragments dispersed as the result of recreational disturbance and turbulence during flood events may be an important factor in determining how quickly colonies of *C. beckettii* become established in new areas.

The ability of *C. beckettii* to reproduce vegetatively under a range of light intensities and temperatures increases the likelihood of a successful invasion since a population can be established with the addition of a single individual into a new ecosystem. Since *C. beckettii* is prevalent in the aquarium trade (Rataj and Horeman 1977), dumping of aquaria into other aquatic systems could result in an invasion as introduced plants increase in number through asexual reproduction, similar to what is thought to have occurred in the San Marcos River and Rainbow River ecosystems. Managers of aquatic systems should be aware of the potential for *C. beckettii* to be introduced into systems they are managing.

Table 2.1. Measurements of vegetative growth (mean ± standard error) in different temperature treatments. Parameters with significant differences denoted by *.

Temperature (ºC)	Mean Number of Plantlets Produced	Mean Biomass (g)	Mean Shoot System Height (cm)	Mean Number of Leaves Produced	Mean Adventitious Root Length (cm)
Cool (15.5ºC)	1.23±0.06	0.08±0.01	1.52±0.09	2.12±0.21	0.61±0.07
Moderate (23.5ºC)	1.00±0.00	0.09±0.01	2.71±0.13	3.44±016	2.83±0.21
Warm (28.5ºC)	1.00±0.00	0.13±0.02	3.46±0.17	3.41±0.15	4.54±0.31
F-value	11.28	4.33	57.70	19.79	137.19
$Df_{N,D}$	2, 202	2, 202	2, 218	2, 172	2, 162
p-value	2.50E-05*	1.47E-02*	<2.26E-16*	2.63E-08*	<2.20E-16*

Table 2.2. Measurements of vegetative growth (mean ± standard error) in different light treatments. Parameters with significant differences denoted by *.

Light Treatment	Mean Number of Plantlets Produced	Mean Biomass (g)	Mean Shoot System Height (cm)	Mean Number of Leaves Produced	Mean Adventitious Root Length (cm)
Full Shade	1.11±0.05	0.09±0.01	2.33±0.16	2.57±0.20	2.30±0.33
Dappled Shade	1.07±0.04	0.09±0.01	2.38±0.15	3.20±0.19	2.64±0.28
Full Sun	1.08±0.04	0.11±0.02	2.43±0.15	3.27±0.17	3.18±0.31
F-value	0.056	0.911	0.327	3.65	6.51
$Df_{N,D}$	2, 202	2, 202	2, 218	2, 172	2, 162
p-value	0.946	0.404	0.721	0.029*	0.002*

Table 2.3. Measurements of vegetative growth (mean ± standard error) in different rhizome segment size classes. Parameters with significant differences denoted by *.

Rhizome Segment Size (cm)	Mean Number of Plantlets Produced	Mean Biomass (g)	Mean Shoot System Height (cm)	Mean Number of Leaves Produced	Mean Adventitious Root Length (cm)
0.5	1.07±0.05	0.07±0.01	2.08±0.16	2.79±0.19	2.48±0.34
1.0	1.11±0.05	0.09±0.01	2.29±0.16	3.34±0.24	2.85±0.33
1.5	1.00±0.00	0.12±0.02	2.59±0.21	3.09±0.21	3.37±0.45
2.0	1.15±0.00	0.10±0.01	2.42±0.15	2.83±0.19	2.30±0.30
F-value	3.12	2.17	1.18	1.41	0.276
$Df_{N,D}$	3, 201	3, 201	3, 217	3, 171	3, 161
p-value	0.028*	0.094	0.318	0.242	0.842

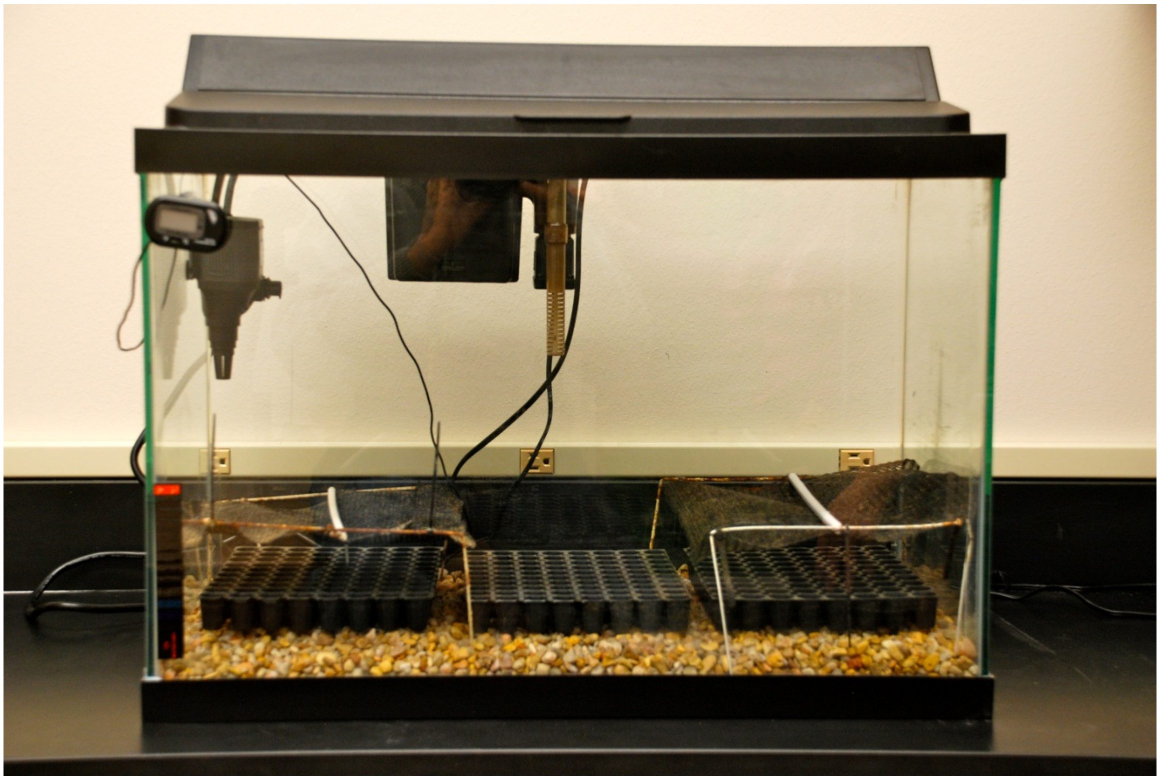

Figure 2.1. Experimental growth chamber.

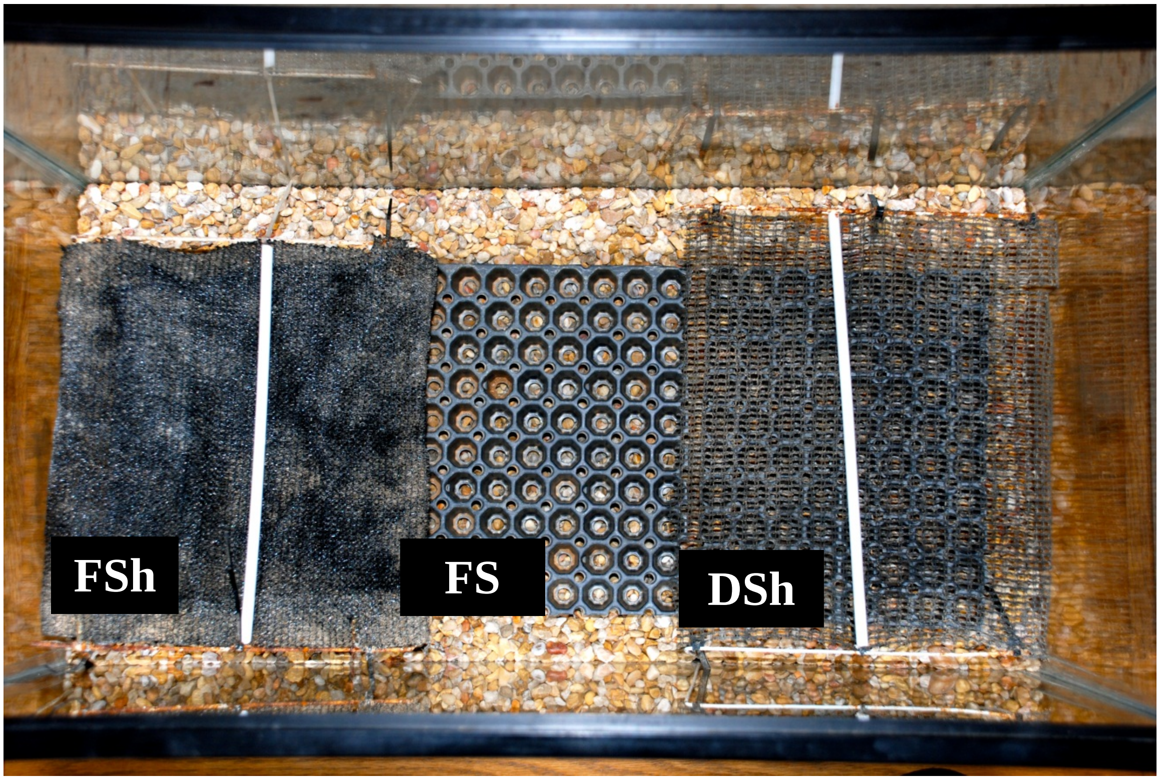

Figure 2.2. Light treatment design viewed from above. Full shade (FSh) was simulated by covering planted trays with woven shade cloth that filtered out 70% of light, dappled shade (DSh) was simulated by covering planted trays with woven shade cloth that filtered out 30% of light and full sun (FS) was simulated by exposing planted trays to full light.

Figure 2.3. Photograph of *Cryptocoryne beckettii* plantlet showing shoot system and adventitious roots.

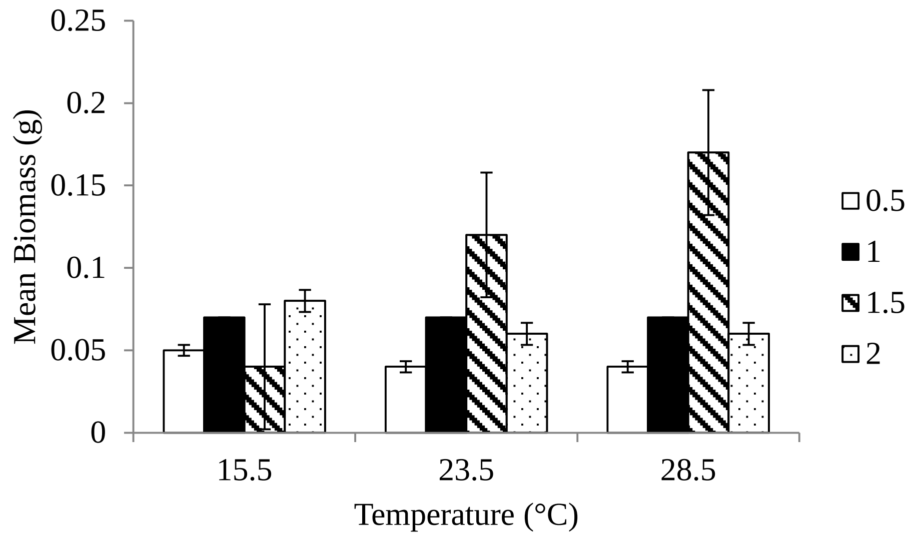

Figure 2.4. Mean biomass (g) of plantlets produced by rhizome segments of varying sizes under different temperature treatments. The interaction between temperature and initial rhizome segment size (0.5, 1.0, 1.5, 2.0 cm) produced statistically significant differences in plantlet biomass ($F = 2.22$, $df = 6, 198$ $p = 0.043$).

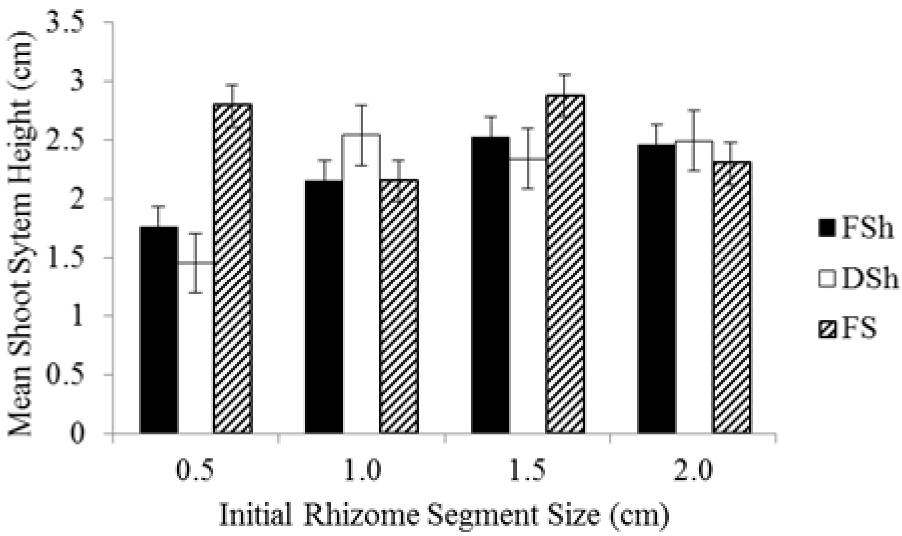

Figure 2.5. Mean shoot system height (cm) of plantlets produced by rhizome segments of varying sizes under different light intensities. FSh is full shade treatment, DSh is dappled shade treatment, and FS is full sun treatment. The interaction between light and initial rhizome segment size produced statistically significant differences in shoot height ($F = 2.98$, $df = 6, 214$, $p = 0.008$).

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CHAPTER III

PUBLIC PERCEPTIONS AND ATTITUDES TOWARDS INVASIVE SPECIES AND INVASIVE SPECIES MANAGEMENT IN THE SAN MARCOS RIVER, SAN MARCOS, TEXAS

Introduction

More than 50 years ago, Charles Elton (1958) warned of an impending environmental crisis resulting from the spread of nonnative invasive species. Today, nonnative invasive species are recognized as one of the largest and most serious threats to biological diversity (Mack et al., 2000). As Elton predicted, the world now faces what has been described as a global environmental emergency.

Colautti and MacIssac (2004) pointed out that trying to find common ground for terminology when talking about invasive species is difficult because different authors are often biased towards particular definitions. For example, Executive Order 13112 issued in 1999 defines invasive species as an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. The National Invasive Species Council (2008) defines invasive species as nonnative organisms known to cause or likely to cause negative impacts and that do not provide an equivalent or greater benefit to society. Lockwood et al. (2007) define an invasive species as one that is not native to a particular area and aggressively competes and sometimes displaces native species.

The inability to settle on a single definition or a common set of terms to define or describe invasive species is just one of the obstacles that hamper discussions about invasive species issues and undermines efforts to control and manage invasive species (Colautti and MacIsaac, 2004). Other obstacles include designing reliable and accurate methodologies to identify potential invaders (Reichard and Hamilton, 1998), developing and implementing regulations to control potentially invasive introductions (Burgiel et al., 2006), determining cost-effective and efficient control methods (Buhle et al., 2005), and determining public perceptions of what an invasive species is and role the public, itself, plays in the invasive species problem (Bertolina and Genovesi, 2003; Bremner and Park, 2007). For example, Bertolina and Genovasi (2003) documented the impact public opinion can have on the implementation of invasive species management. In 1997, a plan to eradicate the American grey squirrel, an introduced nonnative species that was rapidly replacing Italy's native red squirrel and damaging trees throughout the region, was proposed by the National Wildlife Institute and the University of Turin. The first part of the plan was to eradicate a small population of the grey squirrel to determine if the proposed methodology was effective. Preliminary results indicated that the eradication program was feasible, but was strongly opposed by animal rights groups which took the National Wildlife Institute to court. During the three years it took to resolve the case, the eradication program was placed on hold and the American grey squirrel expanded its range to the point that eradication was no longer feasible or practical (Bertolina and Genovasi, 2003). As a result, American grey squirrels are expected to continue to expand their range throughout continental Eurasia, presenting a major threat to the native red squirrel with major impacts on the forests and timber crops in the region (Bertolina and Genovasi, 2003).

Complications concerning the concept of invasive species arise from differing human values and perspectives (National Invasive Species Council, 2008). The public's perception of what is and is not an invasive species and their understanding of what types of impacts invasive species might have on the environment and them personally is influenced by each individual's social and cultural values (National Invasive Species Council, 2008). The attitude of many people towards invasive species depends on their perception of whether they believe a particular invasive species is harmful or beneficial. Public perceptions and attitudes regarding invasive species may impede or stop efforts to control or manage invasive species (Bertolina and Genovesi, 2003).

Archeological evidence indicates that the San Marcos River has been inhabited for more than 10,000 years (Smyrl, 2012). Today, the San Marcos River is one of the most popular and highly recreated rivers in Texas (Texas Parks and Wildlife Department, 1974). People come from all over the state and from around the world to swim and tube in its spring-fed waters and picnic and relax along its banks. It is also home to eight federally listed threatened and endangered aquatic species including the San Marcos Fountain Darter, Texas Blind Salamander, and Texas Wild-Rice (United States Fish and Wildlife Service, 1995; Bowles and Bowles, 2001).

The San Marcos River has been impacted for more than 100 years by introduced invasive species (Bowles and Bowles, 2001). Bowles and Bowles (2001) found that 48 species, including 16 plants and 18 fish species have been introduced into the San Marcos River. Thirty-two of the species have established populations in the river. Many of the plant species were introduced into the river as part of commercial production of plants for the aquarium trade (Bowles and Bowles, 2001). A number of the fish species were introduced for the purpose of sport fishing (Bowles and Bowles, 2001). The economic, ecological, and human health impact for many of these species is unknown (Bowles and Bowles, 2001).

Since community attitudes can potentially affect continued introductions and management of invasive species, it is imperative to understand the San Marcos community's level of knowledge and attitudes toward invasive species in the San Marcos River. This information will allow managers to design and implement appropriate educational programs to inform San Marcos River stakeholders of the issues and challenges of invasive species management. Additionally, this information will help river stewards/managers to develop management strategies to effectively deal with invasive species with support from the stakeholders.

In order to gain perspective on the San Marcos community's awareness of and attitudes toward invasive species in the San Marcos River ecosystem, a survey was conducted of San Marcos River stakeholders. The objectives of this survey were to determine San Marcos River stakeholders' general knowledge, perceptions, and attitudes regarding invasive species and invasive species management in the San Marcos River. In addition, demographic variables, such as gender, age, occupation, and residence were investigated in order to be able to target certain groups to compare differences.

Materials and Methods

Sample Population

Surveys were administered at multiple locations in an effort to have a diverse sample population from the region. The survey was administered to volunteers and docents at the Lady Bird Johnson Wildflower Center in Austin, Texas during February, March, and April 2011. Additionally, visitors to Sewell, City, and Rio Vista Parks in San Marcos, Texas were surveyed during May and July 2011. The survey was also administered to Texas State University-San Marcos students in September 2011. Finally, San Marcos Library patrons were surveyed during December 2011. To ensure that no one responded to the survey more than once, participants were screened prior to administering the survey. Those answering yes to the question, “Have you filled out this survey before?” were not surveyed. Upon completion of the survey, all participants were given a packet of wildflower seeds as a reward for their participation.

A total of 351 surveys were administered over the course of the six month survey period. The population sample used for this study cannot be considered random, as it was chosen because of convenience. Therefore, conclusions based on this study may not necessarily be generalizable to the overall population.

Instrumentation

The survey was modeled after a similar instrument developed by Bremner and Park (2007) used to measure the public’s awareness of invasive species in Scotland and, therefore, known to be valid and reliable. A series of questions was developed to establish a baseline of the participants’ familiarity with different aspects of invasive species issues (Sohan et al., 2002). Questions were not intended to conclusively assess the participants' knowledge of invasive species. Rather, they were used to measure the participants' awareness of invasive species issues in general, and specifically in the San Marcos River.

To establish validity, the survey was reviewed and evaluated by a team of academicians and U.S. Fish and Wildlife and Texas Parks and Wildlife Department personnel involved in invasive species management and research. The survey protocol and instrumentation were also reviewed and an exemption approved by the Humans in Research/Institutional Review Board at Texas State University-San Marcos before being administered (IRB EXP2008I6719/CON2010S2231).

The survey was divided into four sections and had a total of 21 questions. One section included four questions/statements designed to determine participants' familiarity with invasive species issues in general. Question 1 asked "Are you a member of any environmental organizations?" and was ranked using Yes/No responses. Question 2 asked "Where do you hear about invasive species?" and asked respondents to check all answers that applied, including options such as "TV," "Radio," and "Magazines". Questions 9 and 13, "Controlling some non-native species is necessary to help conserve the environment" and "Non-native species should be controlled or eradicated only where they threaten human health" were ranked using a five-point Likert scale with answers ranging from 1 indicating the participant strongly disagreed with the statement to 5 indicating the participant strongly agreed with the statement.

The second section, designed to determine participants' familiarity with invasive species in Texas (three questions), was tested with questions including, "Non-native species should be controlled or eradicated where they do damage to any native Texas species" and were ranked using a five-point Likert scale with answers ranging from 1 indicating the participant strongly disagreed with the statement to 5 indicating the participant strongly agreed with the statement.

Familiarity with invasive species in the San Marcos River (eight questions), the third section, was assessed with questions such as, "Are you familiar with any of the non-native species in the San Marcos River?" which was ranked using Yes/No responses, and "All invasive non-native species should be completely removed from the San Marcos River" which was ranked using a five-point Likert scale with answers ranging from 1 indicating the participant strongly disagreed with the statement to 5 indicating the participant strongly agreed with the statement. Finally, one question, "The most effective control strategies are different for different species. Would the chosen methods of control have any influence on your decision to support projects that would control or completely remove non-native invasive species in the San Marcos River?" was used to assess participants' attitude towards various methods used to control or manage invasive species. Methods of control for animals included shooting, poisoning, and egg destruction while methods of control of plants included cutting down, digging up, and use of herbicides.

The fourth section consisted of six questions aimed at gathering demographic information including targeting gender, age, time spent on the San Marcos River in the past year, ethnic group, highest level of education achieved, and employment status. On average, participants spent 8-10 minutes completing the survey.

All survey questions were pilot-tested on 88 individuals prior to final administration of the survey (Sheatsley, 1983) to refine the survey questions and to establish an adequate instrument reliability score.

To score the data for the first three sections, more positive answers to the statements were given more points. Negatively stated questions were reverse coded. Scores for the section determining participants' familiarity with general invasive species issues could range between 10 and 26. The median score for this section was 18. Scores that were greater than median indicated that participants were more familiar with general invasive species issues, whereas scores lower than median indicated that participants were less familiar with general invasive species issues.

Participants' familiarity with Texas invasive species issues scores could range from 3 to 15. The median score for this section was 8.5. Scores higher than the median of 8.5 indicated that participants were familiar with invasive species issues in Texas, while scores lower than 8.5 indicated that participants were less familiar with invasive species issues in Texas.

Scores determining participants' familiarity with invasive species in the San Marcos River could range from 7 to 26. The median score was 16.5. Scores that were higher than 16.5 indicated that participants knew about invasive species in the San Marcos River. Participants who did not know about invasive species in the San Marcos River scored less than 16.5.

Data were analyzed by using frequency and descriptive statistics and ANOVAS with the IBM SPSS 20 statistical package (Somers, New York).

Results and Discussion

Three hundred and fifty-one people completed surveys. Eighty-one (23%) of the participants were residents of Travis County and 270 (77%) were residents of Hays County. Surveys completed by residents of these two counties were selected for analysis because the participants live within 30 miles of the San Marcos River.

Demographic data indicated the majority of the participants were Caucasian (75.9%, 249) and predominately female (57%, 189). Hispanics comprised 17.1% (56) of the participants with the remaining 7% of participants designating themselves as African-American (2.1%, 7), Asian-American (2.1%, 7), and other (2.7%, 9). Forty-one percent of participants were 18-34 years of age. Fifteen percent (50) of participants were 55-64 and 14% (45) were 65-74. People ages 35-54 accounted for 20% (66) of the survey participants and ages 75 and older represented 5% (16) of participants. Overall, survey participants were well-educated with 35% (117) having earned a Bachelor of Science degree and 22% (72) a Master of Science degree. Four percent (12) of participants had earned a terminal degree, while 29% (96) had earned a high school diploma. Ten percent (32) of participants indicated they were currently enrolled in college and working toward a degree, had completed a trade school program, or been certified as a nurse's aide. Nearly 55% (160) of the participants indicated they were employed either full-time or part-time. Retirees accounted for 20% (66) of participants and students accounted for 19% (63).

Scores determining participants' familiarity with general invasive species issues ranged from a low of 9 to a high of 24 with a mean score of 18. Given that the median score of 16.5 was set to determine high versus low levels of knowledge, only 34% (119)

of scores were above the median indicating that participants were familiar with general invasive species issues while the majority, 52% (184), of the study participants' scores fell below the median indicating they were not familiar with general invasive species issues.

When asked about their familiarity with Texas invasive species issues, participants' scores ranged from a low of 0 to high of 15 with a mean score of 9. The median score for this section was set at 8.5 to determine high versus low levels of knowledge. Eighty-three percent (293) of participants scored above the median compared to 9% (32) of the participants who scored below the median. This indicated that the study participants were more familiar with invasive species issues in Texas when compared with invasive species issues in general.

Scores determining participants' familiarity with invasive species issues in the San Marcos River ranged from a low of 0 to a high of 32 with a mean score of 16.5. The median score of 16 was set to determine high versus low level of knowledge. Ninety-two percent (322) of the participants scored above the median while only 8% (29) scored below the median. This indicated that the study participants were most familiar with regional invasive species issues in the San Marcos River when compared to either invasive species issues in general or invasive species issues in Texas.

Questions Regarding Participants' Familiarity with Invasive Species in General

Participants were asked if they belonged to any environmental or conservation organizations. Of the participants responding, most, 58.6% (202), were not members of an environmental or conservation organization. Of the 41.4% (143) of participants responding that they were members of an environmental or conservation organization, 88

(62%) indicated they were members of a national environmental or conservation organization such as the Lady Bird Johnson Wildflower Center, Nature Conservancy, National Audubon Society, and National Wildlife Federation. Twenty-eight, or 20%, of the participants indicated that they were members of state environmental or conservation organizations including the Texas Master Naturalists, Native Plant Society of Texas, and Environment for Texas. Only 13 (9%) participants indicated they were members of local environmental or conservation organizations such as the San Marcos River Foundation, the Hill Country Conservancy, and the San Marcos Greenbelt Alliance.

Overall, participants who received invasive species information did so primarily via magazines (150, 42.7%), the internet (134, 38.2%) and by means other than printed and digital media (131, 37.3%). These other venues for information included word of mouth, lectures, classes, and workshops provided by state environmental organizations such as the Texas Master Naturalists and the Native Plant Society of Texas, and college courses. Only 49 (14%) participants indicated that they did not hear about invasive species issues. This indicated the majority of participants were engaged in some aspect of environmental conservation, if only passively.

When asked if controlling some non-native species is necessary to help conserve the environment, 286 (83.7%) of participants strongly agreed or agreed with the statement. Only 9 (2.6%) participants strongly disagreed or disagreed with the statement. Forty-seven (13.7%) participants were unsure if they agreed or disagreed with the statement.

Almost half of participants (167, 48.5%) strongly disagreed or disagreed when asked if non-native species should be controlled or eradicated only when they threatened human health. One hundred fourteen participants (33.1%) strongly agreed or agreed with the statement, while 63 (18.3%) were not sure if they agreed or disagreed.

Questions Regarding Participants' Familiarity with Invasive Species Issues in Texas

The majority of participants (256, 74.4%) strongly agreed or agreed that non-native species should be controlled or eradicated where they do damage to any native Texas species. More participants were not sure (68, 19.8%) if they agreed or disagreed with the statement when compared to the 20 (5.8%) participants that strongly disagreed or disagreed with the statement. This indicated an awareness of the importance of native Texas species to people who live in the survey area.

When asked if non-native species should be controlled or eradicated where they do damage to rare native Texas species, the majority of participants (302, 88.1%) strongly agreed or agreed. Only 3.5% (12) of the participants strongly disagreed or disagreed, while 29 (8.5%) participants were not sure.

Two hundred-twenty (63.9%) participants strongly agreed or agreed that native Texas species should be protected at all costs. Fifty (14.5%) participants strongly disagreed or disagreed with this statement. Twenty-one percent (74) of the participants were not sure.

Questions Regarding Participants' Familiarity with Invasive Species Issues in the San Marcos River

When asked if they were familiar with any non-native species in the San Marcos River, less than half of the participants (143, 41.8%) responded yes, while 57.9% (198) responded no. Those responding that they knew of non-native species in the river were then asked to list the non-native species with which they were familiar. Of the 143 participants responding yes to the question, 70 (49%) were able to name species that are recognized as being non-native in the San Marcos River. One individual (0.3%) did not respond to the question.

When asked if they knew of any invasive species in the San Marcos River, 142 (42.8%) participants responded yes and 190 (57.2%) responded no. Those responding that they knew of any invasive species in the river were then asked if they would object to them being eradicated from the river. Eighty-nine percent (126) said they would not object to the invasive species being eradicated from the river and 16 (11%) of the participants said they would object to the eradication of the invasive species.

Two hundred-ninety-four participants (86%) strongly agreed or agreed that protecting the San Marcos River from non-native invasive species was important. Only 3.2% (11) of participants strongly disagreed or disagreed with the statement, while 10.8% (37) of the participants were not sure if protecting the San Marcos River from non-native invasive species was important.

The majority of participants (197, 58.1%) strongly agreed or agreed that all invasive non-native species should be completely removed from the San Marcos River. Only 15% (51) of the participants strongly disagreed or disagreed with the statement. More than one-fourth of the participants (91, 26.8%) were not sure if all invasive non-native species should be completely removed from the San Marcos River. When asked if non-native species should be controlled or completely removed when they cause economic damage to the San Marcos River, 80% (272) of participants strongly agreed or agreed, 4.9% (17) strongly disagreed or disagreed, and 15.5% (53) were unsure.

An overwhelming majority (299, 87.2%) of the participants strongly agreed or agreed that non-native species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River. Nine (2.6%) participants strongly disagreed or disagreed that non-native species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River, while 10.2% (35) participants were not sure.

The majority of participants (251, 73.2%) had not heard about any projects to control non-native invasive species in the San Marcos River. Of the 91 (26.5%) who said that they had heard about projects to control non-native invasive species in the San Marcos River, when asked to provide details of those projects, only 32 (9.3%) participants were able to describe in the project in detail. The projects that were mentioned most frequently were elephant ear (*Colocasia esculenta*), hydrilla (*Hydrilla verticillata*), and water hyacinth (*Eichornia crassipes*) removal programs. Interestingly, four participants (1.2%) mentioned Texas wild-rice (*Zizania texana*), a federally listed endangered endemic, as an invasive species being removed from the river. One participant (0.3%) did not answer the question.

When asked if the chosen methods of control would have any influence on their decision to support projects that would control or completely remove non-native invasive species in the San Marcos River, 77.5% (252) responded that chosen methods of control would influence their support of projects. If the participants answered "YES" to the question, they were then asked to indicate which of several methodologies they would be against using. Methods of control of invasive animal species included shooting, poisoning, trapping and relocating, pesticides, sterilization or use of contraceptives, and egg destruction. Methods of control of invasive plant species included cutting down, digging up, herbicides, and dredging.

Methods of invasive animal control that resulted in the death of the animal were favored the least. These included shooting (122 against, 48.4%) and poisoning (198 against, 78.6%). The most favored method of controlling invasive animals was trapping and relocating the animal (36 for, 14.3%). One hundred eighty-seven (74.2%) participants indicated that the use of pesticides as a means to control invasive animal species was unacceptable.

Of the possible methods for the control of invasive plant species, the use of herbicides (149 against, 59.1%) and dredging (68 against, 27%) were the least acceptable. Cutting down plants (43 against, 17.1%) and digging up plants (32 against, 12.7%) were favored over the use of herbicides and dredging.

Demographic Comparisons

Demographic comparisons were made regarding participants' overall familiarity with invasive species in general, familiarity with invasive species issues in Texas, and familiarity with invasive species issues in the San Marcos River. These three broad topics each included a number of different questions that resulted in a score used to assess the participants' familiarity with the topic. There were no significant differences in overall scores based on comparisons of gender, age, ethnicity, education, and employment status.

Individual Statement Comparisons-Gender

Comparisons of responses to individual survey statements were then made among demographic variables and some differences emerged. There were significant differences in the number of men and women who identified as members of environmental organizations ($p = 0.018$, $\alpha = 0.05$). Forty-eight percent (89) of female participants indicated they were members of environmental organizations compared to 35% (49) of male participants.

When asked specifically if they were familiar in general with invasive species in the San Marcos River, men and women differed significantly in their responses ($p = 0.016$, $\alpha = 0.05$). Men (48.2%) were more familiar than women (36.6%) with invasive species in the river.

There were significant differences between men and women when asked if they knew of any invasive species in the river (0.006, $\alpha = 0.05$). Fifty-two percent of men indicated that they knew of invasive species in the river when compared with 36.7% of women who knew of invasive species in the river.

There were significant gender differences. Men and women were asked if they agreed that controlling some nonnative species was necessary to help conserve the environment ($p = 0.034$, $\alpha = 0.05$). One hundred and sixty-one (86.5%) female participants agreed or strongly agreed that controlling some nonnative species was necessary to help conserve the environment as opposed to 113 (80.2%) male participants.

Individual Statement Comparisons-Ethnicity

When individual response statement comparisons were made among ethnic groups, differences were found in the ethnic groups who were members of environmental organizations (Table 3.1). Post hoc comparisons (LSD) indicated that Caucasians were different from African-Americans and Hispanics. Fifty-eight percent (184) of all ethnic groups were not members of an environmental organization and fewer African Americans and Hispanics were members of an environmental organization (87%, 53).

Differences were found in those who received information about invasive species issues via newspapers, internet, and radio (Table 3.1). Hispanics were different from Caucasians with only 12.7% (7) of Hispanics receiving information about invasive species via newspapers compared to 37.4% (92) of Caucasians.

There were significant differences among ethnic groups when asked if they were familiar with invasive species in the San Marcos River (Table 3.1). More Caucasians (48%, 116) were familiar with invasive species in the San Marcos River compared to 24.1% (13) of Hispanics.

When asked if native Texas species should be protected at all costs, there were differences among ethnic groups (Table 3.1). More Hispanics (79.7%, 33) strongly agreed or agreed that native Texas species should be protected at all costs compare to 60.6% (146) of Caucasians.

Ethnic groups differed significantly in their opinions about whether nonnative species should be controlled or eradicated where they threaten human health (Table 3.1). Only 25.9% (63) of Caucasians strongly agreed or agreed that nonnative species should be controlled where they threatened human health compared to 53.7% (29) of Hispanics.

There were significant differences among ethnic groups when asked if they knew of any invasive species in the San Marcos River (Table 3.1). African-Americans and Hispanics were different from Caucasians. Fifty percent (121) of Caucasians, 27% (15) of Hispanics, and none of the African-Americans survey knew of any invasive species in the San Marcos River.

Individual Statement Comparisons-Age

When individual statement response comparisons were made, differences among age groups of people whom were members of an environmental organizations (Table 3.2). Post hoc comparisons (LSD) indicted participants younger than 18 years of age were significantly different from all other age groups except those ages 18-34 (Table 3.2). One hundred percent (16) of those younger than 18 and 78.9% (105) of those 18-34 indicated they were not members of an environmental organization. Participants ages 35-44 and 45-54 differed significantly from all other age groups but were the similar to each other. Forty-two percent (14) of participants ages 35-44 and 47% (15) of those ages 45-54 were members of environmental organizations. Participants ages 55-64, 65-74, and 75 and older were similar to each other and different from all other age groups. Seventy-two percent (36) of those ages 55-64, 80% (36) of those ages 65-74, and 62.5% (10) of those ages 75 and older indicated they were members of an environmental organization (Table 3.2).

There were significant differences in the ages of participants who received information about invasive species through newspapers, magazines, and other (Table 3.2). Participants less than 18 and ages 18-34 were similar to each other and different from all other age groups. Of the 16 participants less than 18 years of age, only 2 (12.5%) received information about invasive species through newspapers, 5 (31.3%) magazines, and 4 (25%) other sources. More participants ages 18-34 received information through newspapers (31, 22.6%), magazines (55, 40.1%), and other sources (48, 35%). Age groups 35-44, 45-54, 55-64, 64-75, and 75 and older were similar to each other and different from those ages less than 18 and 18-34. Of these age groups collectively, 42% (75) received information about invasive species through newspapers, 50% (89) received information through magazines, and 42% (75) received information through other sources (Table 3.2).

Comparisons among age groups showed a significant difference in the amount of time spent on the San Marcos River in the previous year (Table 3.2). Participants less than 18 years and ages 18-34 were similar to each other and different from all other age groups; participants ages 35-44 and 45-54 were similar to each other and different from all other groups; and, participants ages 55-64, 65-74, and 75 and older were similar and different from all other age groups. While 63% (331) of all participants indicated that they had spent time on the San Marcos River the previous year, significantly more younger participants (80%, 122) spent time on the river, followed by 65% (43) of those ages 35-44 and 45-54. Older participants (40%, 45), ages 55-64, 65-74, and 75 and older, spent the least amount of time on the river.

Participants' perceived familiarity with invasive species in the San Marcos River differed significantly among age groups (Table 3.2). Of all the participants, those ages 35-44 (17, 52%) and 55-64 (29, 58%) were most familiar with invasive species in the river. Participants who were ages 45-54 were the next most familiar with invasive species in the river (16, 48%), followed by those ages 65-74 and 75 years or older (21, 36%). The age groups least familiar with invasive species in the San Marcos River were those less than 18 years of age and those ages 18-34 (54, 34%).

There were significant differences among age groups when asked if protecting the San Marcos River from nonnative invasive species is important (Table 3.2). Participants less than 18 years of age were significantly different from all other age groups except those ages 35-44. Of the 54 participants ages less than 18 years of age and those 35-44 years of age, 67% (36) strongly agreed or agreed that protecting the San Marcos River from nonnative invasive species is important. Only 19% (10) strongly disagreed or disagreed that this was important and 15% (8) were unsure. All other age groups were similar, with 88% (246) participants age 18-34, 35-44, 45-54, 55-64, 65-75, and older than 75 years of age strongly agreeing or agreeing that protecting the San Marcos River from nonnative invasive species is important; 2% (6) strongly disagreeing or disagreeing that this was important; and, 10% (28) were unsure (Table 3.2).

Participants differed significantly in their opinion that all invasive nonnative species should be completely removed from the San Marcos River (Table 3.2). Participants less than 18 years of age differed significantly from all other age groups. Participants ages 18-34 were different from all other age groups except those ages 35-44, while participants ages 35-44 were similar to all other age groups except those less than 18 years of age. Of those less than 18 years of age, 63% (10) strongly disagreed or disagreed that all invasive nonnative species should be completely removed from the San Marcos River; 31% (5) were not sure, and 6% (1) strongly agreed or agreed all invasive nonnative species should be completely removed from the San Marcos River. The majority of participants ages 18-34 (48%, 65) strongly agreed or agreed that all invasive nonnative species should be completely removed from the San Marcos River, while 16% (22) strongly disagreed or disagreed that and 36% (48) were unsure. Seventy-one percent (122) of participants ages 35-44, 45-54, 55-64, 65-75, and 75 years and older strongly agreed or agreed that all invasive nonnative species should be completely removed from the San Marcos River and only 9% (16) strongly disagreed or disagreed. Twenty percent

(35) of participants in those age groups were unsure if all invasive nonnative species should be completely removed from the San Marcos River (Table 3.2).

There were significant differences among participants when they were asked if nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River (Table 3.2). The majority of participants less than 18 years of age (38%, 6) strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River. Only 25% (4) strongly disagreed or disagreed and 38% (6) were unsure. Likewise, the majority of participants ages 18-34 (77%, 105) strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River; 5% (7) strongly disagreed or disagreed; and, 18% (24) were unsure. Finally, of participants in the older age groups, 86% (151) strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River while 3% (50 strongly disagreed or disagreed. Only 11% (19) participants in the older age groups were unsure if nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River (Table 3.2).

There were significant differences among age groups when asked if they thought nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River (Table 3.2). Participants less than 18 years of age differed from all other age groups except those ages 35-44. All other age groups were similar to each other. Of the participants less than 18 years of age and ages 35-44, 73% (35) strongly agreed or agreed that nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River. Only 6% (3) strongly disagreed or disagreed and 21% (10) of the participants were unsure. Ninety-one percent of all other age groups strongly agreed or agreed that nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River while only 2% (5) strongly disagreed or disagreed and 7% (20) were unsure (Table 3.2).

When asked if controlling some nonnative species is necessary to help conserve the environment, significant differences among age groups were observed (Table 3.2). Participants younger than 18 years of age were different from all other age groups except those ages 35-44 and those older than 75. Participants ages 45-54 were similar to all other age groups except those younger than 18 years of age. Participants older than 75 years of age were similar to all other age groups. The majority of all age groups (87% of those ages 18-34, 45-54, 55-64, and 65-75; 81% of those older than 75; and, 67% of those 35-44 and younger than 18) agreed that controlling some nonnative species is necessary to help conserve the environment. Six percent (3) of participants 35-44 years of age and younger than 18 strongly disagreed or disagreed that that controlling some nonnative species is necessary to help conserve the environment while only 2% (5) of those 18-34, 45-54, 55-64, and 65-75 strongly disagreed or disagreed. No one older than 75 strongly disagreed or disagreed that controlling some nonnative species is necessary to help conserve the environment (Table 3.2).

Participants differed significantly in their responses when asked if nonnative species should be controlled or eradicated where they do damage to native Texas species (Table 3.2). Participants less than 18 differed in their responses from all the other age groups and all other age groups were similar to each other. Thirty-eight percent (6) of participants younger than 18 strongly agreed or agreed that nonnative species should be controlled or eradicated where they do damage to native Texas species, while an equal number were unsure. Twenty-five percent (4) of this age group strongly disagreed or disagreed. The majority of those in the older age groups (77%, 240) strongly agreed or agreed that nonnative species should be controlled or eradicated where they do damage to native Texas species, while only 5% (16) strongly disagreed or disagreed. A smaller percentage of this older age group (18%, 56) was unsure if nonnative species should be controlled or eradicated where they do damage to native Texas species (Table 3.2).

There were significant differences among age groups when they were asked if nonnative species should be controlled or eradicated when they do damage to rare native Texas species (Table 3.2). Nineteen percent (3) of participants younger than 18 strongly disagreed or disagreed that nonnative species should be controlled or eradicated when they do damage to rare native Texas species, while an equal number were unsure. Sixty-three percent (10) of this age group strongly agreed or agreed that nonnative species should be controlled or eradicated when they do damage to rare native Texas species. Ninety-one percent (132) of those in the older age groups (45-54, 55-64, 65-75, >75) strongly agreed or agreed that nonnative species should be controlled or eradicated when they do damage to rare native Texas species, while 3% (8) and 7% (22) strongly disagreed or disagreed or were unsure, respectively.

When asked if nonnative species should be controlled or eradicated only where they threaten human health, significant differences among age groups were observed (Table 3.2). Participants younger than 18 and those 18-34 years of age were evenly split when asked if nonnative species should be controlled or eradicated only where they threaten human health. Forty-two percent (64) strongly disagreed or disagreed, while 41% (63) strongly agreed or agreed. Fifty-six percent (98) of those in the older age groups (35-44, 45-54, 55-64, 65-75, >75) strongly disagreed or disagreed that nonnative species should be controlled or eradicated only where they threaten human health, while only 25% (44) strongly agreed or agreed. The same number of participants in the younger age groups (17%, 26) (<18, 18-34) and older age groups (19%, 33) (35-44, 45-54, 55-64, 65-75, >75) were unsure if nonnative species should be controlled or eradicated only where they threaten human health.

Individual Statement Comparisons-Education

When comparisons were made on individual statements differences were found among respondents of various education levels whom were members of an environmental organization (Table 3.3). Post hoc comparisons (LSD) indicted that participants with bachelor's, master's and Ph.D. degrees were similar to each other but different from those with HS diplomas or other types of education. Participants with high school diplomas or other types of education were similar to each other. Fifty-nine percent (114) of those who had bachelor's., master's, and Ph.D. degrees were members of environmental organizations. Only 17% (21) of those with high school diplomas or other types of education belong to an environmental organization.

There were significant differences in the education levels of participants who received information about invasive species via magazines, those who indicated they did not receive information about invasive species, and those who received information via other means (Table 3.3). Of participants who received information via magazines, those with bachelor's, master's and Ph.D. degrees were similar to each other. High school graduates and participants with other types of education were similar to each other. Participants with types of technical education in addition to or other than college degrees were different from those with master degrees and similar to all other groups. Only 30% (38) of participants with high school diplomas and other types of education received their information about invasive species through magazines, while 54% (106) of participants with higher degrees indicated they received information about invasive species from magazines.

Only 14% (45) of all participants, regardless of their education levels, indicated that they did not receive information about invasive species in some way. Of those participants with a Ph.D., only 8.3% (1) did not receive information about invasive species. Twenty-five percent (24) of high school graduates did not receive information about invasive species, while 22% (7) of participants with other types of education did not receive invasive species information. Seven percent (13) of those participants with a bachelor's or master's degree did not receive invasive species information.

Of participants who indicated that they receive information about invasive species through other means, those with a Ph.D. were similar to participants of all other education levels. High school graduates were different from those participants with bachelor's and master's degrees and similar to all other education levels. Participants with other types of education were similar to all other education levels except those with a bachelor's degree Twenty-five percent (3) of participants with a Ph.D. and 25% (24) of high school graduates indicated that they received information about invasive species through other means. Only 7% (13) of participants with a bachelor's and/or master's degree received information about invasive species through other means, while 38% (12) of those with other types of education received information about invasive species through other means.

Comparisons among education levels showed a significant difference in the amount of time spent on the San Marcos River in the previous year (Table 3.3). Those participants with high school diplomas and with other types of technical education degrees were similar to each other and different from all other education levels. Participants with a college degree and advanced degrees (bachelor's, master's or Ph.D.) were similar to each other. Eighty-two percent (106) of those with a high school diploma or with other types of technical education had spent time on the San Marcos River during the previous year. Fewer participants (55%, 109) with college degrees spent time on the San Marcos River during the previous year.

Participants' perceived familiarity with invasive species in the San Marcos River differed significantly among the different education levels (Table 3.3). Those with other types of technical education were similar to all other education levels. Participants with a college or advanced degree (bachelor's, master's or Ph.D.) were similar to each other. High school graduates were similar to those with other types of technical education and different from all the other education levels. Forty-four percent (14) of those participants with other types of technical education were familiar with invasive species in the San Marcos River compared to 27% (26) of those with high school diplomas. Participants with college degrees and advanced degrees (bachelor's, master's or Ph.D.) were equally split on familiarity with invasive species in the San Marcos River with 50% (98) being familiar and 50% (97) being unfamiliar.

There were significant differences among the different education levels when asked if protecting the San Marcos River from nonnative invasive species is important (Table 3.3). Participants with a Ph.D. and other types of technical education were similar to all other groups and each other. Participants with high school diplomas were similar to those with a Ph.D. and other types of technical education degrees. Seventy-eight percent (109) of those with high school diplomas, college or an advanced degree, and other types of technical education strongly agreed or agreed that it is important to protect the San Marcos River from nonnative invasive species, while 17% (23) were unsure and 5% (7) strongly disagreed or disagreed. Ninety-one percent (166) of participants with a bachelor's or master's degree strongly agreed or agreed that it is important to protect the San Marcos River from nonnative invasive species. Only 2% (3) strongly disagreed or disagreed that it was important while 7% (13) were unsure.

Participants of different education levels differed significantly in their opinion that all invasive nonnative species should be completely removed from the San Marcos River (Table 3.3). High school graduates and those with other types of technical education were similar to each other and different from other levels of education. Participants with college and advanced degrees were similar to each other and different from high school graduates and those with other types of technical education. The majority of participants strongly agreed or agreed that all nonnative invasive species should be completely removed from the San Marcos River. Forty-five percent (56) of high school graduates and those with other types of technical education and 66% (127) of those with college and advanced degrees strongly agreed or agreed that all nonnative species should be completely removed from the San Marcos River. Twenty-five percent

(31) of high school graduates and those with other types of technical education and 10% (16) of those with college degrees strongly disagreed or disagreed while 30% (38) of high school graduates and those with other types of education and 26% (50) of college graduates were unsure.

When asked if controlling some nonnative species is necessary to help conserve the environment, significant differences among education levels were observed (Table 3.3). Participants with a Ph.D. were similar to all other education levels while participants with other types of technical education were similar to all education levels except those with a bachelor's degree. The majority of participants (83%, 268), regardless of education, strongly agreed or agreed that controlling some nonnative invasive species is necessary to help conserve the environment. Only 2% (7) strongly disagreed or disagreed and 14% (46) were unsure. Seventy-five percent (24) of those with other types of technical education strongly agreed or agreed that controlling some nonnative invasive species is necessary to conserve the environment, compared to 88% (100) of those with a bachelor's degree.

Significant differences among different education levels were observed when participants were asked if native Texas species should be protected at all costs (Table 3.3). Participants with a Ph.D. were similar to all other education levels. Participants with college degrees were similar to each other but different from high school graduates and those with other types of technical education. Sixty-three percent (203) of all participants, regardless of education level, strongly agreed or agreed that native Texas species should be protected at all costs. Only 15% (48) strongly disagreed or disagreed and 22% (71) were unsure. Fifty-six percent (110) of those with college degrees strongly agreed or agreed that native Texas species should be protected at all costs compared to 73% (93) of those with high school diplomas and other types of technical education. Approximately twice as many college graduates (19%, 38) strongly disagreed or disagreed that native Texas species should be protected at all costs when compared with the 8% (10) of high school graduates and those with other types of education. Only 19% (24) of high school graduates and those with other types of education were unsure compared to 24% (47) of college graduates.

When asked if nonnative species should be controlled or eradicated only where they threaten human health, significant differences among education levels were observed (Table 3.3). High school graduates were similar only to those with other types of technical education. Those with other types of technical education were similar to all other education levels. The majority of participants (51%, 163), regardless of education, strongly disagreed or disagreed that nonnative species should be controlled or eradicated only where they threaten human health, while 32% (103) strongly agreed or agreed and 17% (56) were unsure. Of participants with high school diplomas or other types of education, 48% (61) strongly agreed or agreed that nonnative species should be controlled or eradicated only where they threaten human health compared to 22% (42) of those with college degrees. Thirty-seven percent (47) of high school graduates and those with other types of technical education strongly disagreed or disagreed compared to 59% (116) of college graduates. Roughly equal numbers of high graduates and those with other types of technical education (15%, 19) and college graduates (19%, 37) were unsure.

There were significant differences among the different education levels when asked if participants knew of any invasive species in the San Marcos River (Table 3.3). Participants with high school diplomas were different from all other education levels. All other education levels were similar to each other but different from high school graduate responses. Only 44% (141) of all participants knew of any invasive species in the San Marcos River. More participants with college degrees and other types of technical education (51%, 114) knew of any invasive species in the San Marcos River compared to 28% (27) high school graduates.

Individual Statement Comparisons-Employment

When individual statement response comparisons were made, differences were found in the employment status of people who were members of an environmental organization (Table 3.4). Post hoc comparisons (LSD) indicated that participants who were retired were different from all other groups. Part time students, those working in the home, and those who indicated their employment status as “Other” were similar to all other groups except those who were retired. Full time students were similar to all other groups except when compared to those who worked full time and who were retired. Full time workers were similar to all other groups except when compared to those who were unemployed, retired or full time students. Participants who worked part time were similar to all other groups except those who were unemployed and retired. The majority of participants (58%, 184) were not members of an environmental organization. The group with the most members of environmental organizations was retirees with 79% (51) indicating they were members of an environmental organization. The group with the fewest members of an environmental organization was those who were unemployed with only 5.6% (1) indicating they were members. Only 22% (13) of students, both full time and part time, were members of an environmental organization, while only 39% (65) of those employed were members.

There were significant differences in the employment status of participants who received information about invasive species via newspapers and via magazines (Table 3.4). Among those who received information about invasive species via newspaper, participants working full time and in the home were similar to all other groups. Those working part time, those unemployed, those who were full or part time students, and others were similar to all other groups except retirees. Retirees were different from all other groups and similar to those working from the home and employed full time. Only 33% (106) of the participants indicated they received information about invasive species from newspapers. Thirty-six percent (39) of those employed full time or in the home received information about invasives from newspapers, while 23% (35) of those employed part time, those unemployed, students, and other received information in this manner. Retirees were the largest group indicating that they received information about invasives species from newspapers with 49% (32) of participants responding yes to the question.

Among those who received information about invasive species via magazines, participants who were employed full time were similar to all other groups except retirees. Part time students and those responding “Other” were similar to all other groups. Forty-five percent (144) of participants indicated that they received information about invasive species from magazines. The largest group to receive information about invasive species from magazines were retirees (63%, 41), while the smallest groups to receive information in invasive species in this way were those who were unemployed (21%, 4). Forty-three percent (26) of students and 42% (70) of those who were unemployed received information about invasive species from magazines.

There were significant differences among employment groups when asked if they had spent time on the San Marcos River in the past year (Table 3.4). Retirees were different from all other groups. Participants who were unemployed, full time students, and those responding as “Other” were all similar. Participants who were employed part time and in the home and part time students were similar to all other groups except full time employees and retirees. Full time employees were different from all other groups except those unemployed, full time students, and those responding as “Other.” The largest number of participants (83%, 65) who spent time on the San Marcos River during the previous year included those who were unemployed, part time employees, those who worked in the home, and part time students. Seventy-nine percent (63) of those participants who were unemployed, full time students, and those who responded as “Other” spent time on the river in the last year compared to 60% (59) of those employed full time. Only 34% (22) of retirees indicated that they had spent time on the San Marcos River in the last year.

When asked if protecting the San Marcos River from nonnative invasive species was important, there were significant differences among employment groups (Table 3.4). Participants who worked in the home were different from all the other groups. All groups were similar to each other and different from those who worked in the home. Eighty-six percent (273) of all participants strongly agreed or agreed, 3% (10) strongly disagreed or disagreed that it was important to protect the San Marcos River from nonnative invasive species, and 11% (36) were unsure that it was important to protect the San Marcos River from nonnative invasive species. Forty percent (4) of those working in the home strongly agreed or agreed that this was important while 87% (269) of all the other groups strongly agreed or agreed. Of those working in the home, 30% strongly disagreed or disagreed that protecting the San Marcos River from nonnative invasive species was important and only 2% (7) of all the other groups strongly disagreed or disagreed. Of those participants who were not sure this was important, 30% (3) worked in the home and 11% (33) were in all the other groups.

There were significant differences among employment groups when asked if all invasive nonnative species should be completely removed from the San Marcos River. Participants who identified as “Other” were similar to all the other groups, while retirees were different from all other groups except full time employees and those who responded as “Other.” Part time employees, workers in the home, the unemployed, and full and part time students were similar to each other. Full time employees were different from those unemployed. The majority of all employment groups (58%, 182) strongly agreed or agreed that all nonnative invasive species should be completely removed from the San Marcos River. Only 15% (47) of all respondents strongly disagreed or disagreed, while 28% (87) were unsure. Of those participants employed part time and in the home, unemployed, and full or part time students, 50% (73) strongly agreed or agreed that all nonnative invasive species should be completely removed from the San Marcos River, 20% strongly disagreed or disagreed and 30% (44) were unsure. Seventy-one percent (46) of retirees strongly agreed or agreed that that nonnative invasive species should be completely removed while 8% (5) strongly disagreed or disagreed and 22% (14) were not sure. Eighty-six percent (30) of those who responded “Other” strongly agreed or agreed that nonnative invasive species should be completely removed from the San Marcos River, while 61% (58) of those employed full time strongly agreed or agreed. Only 6% (2) of those who responded “Other” and 12% (110 of those employed full time strongly disagreed or disagreed.

Significant differences were observed among employment groups when asked if nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River (Table 3.4). Participants working in the home were similar to those identifying as “Other” and different from all other groups. Part time employees, those who were unemployed, and full and part time students were similar to each other. Full time employees and retirees were similar to each other. Eighty-one percent (257) of the participants strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River, while 4% (12) strongly disagreed or disagreed, and 15% (49) were unsure. Of those participants employed in the home and who identified as other, 55% (11) strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River; 15% (3) strongly disagreed or disagreed; and, 30% (6) were unsure. Seventy-eight percent (68) of part time employees, part time students, and those who were unemployed strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River, while 1% (4) strongly disagreed or disagreed, and 14% (15) were unsure. Eighty-six percent (138) of participants employed full time and retired strongly agreed or agreed that nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River; 2% (3) strongly disagreed or disagreed while, 12% (19) were unsure.

When asked if nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River, there were significant differences among employment groups (Table 3.4). Full and part time employees, full and part time students, those who were unemployed, and retirees were similar to each other. Participants employed in the home and those who identified as “Other” were similar to each other and different from all other groups. Only 2% (7) of all participants strongly disagreed or disagreed that nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River, 88% (283) strongly agreed or agreed, and 9% (30) were unsure. The majority of participants (91%, 273) who were employed full or part time, full or part time students, unemployed, and retired strongly agreed or agreed that nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River, while 1% (4) strongly disagreed or disagreed and 8% (23) were unsure. Fifty-nine percent (10) of participants who worked in the home and identified as other strongly agreed or agreed that nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River. Eighteen percent (3) strongly disagreed or disagreed and 41% (7) were unsure.

There were significant differences among employment groups when asked if controlling some nonnative species is necessary to help conserve the environment (Table 3.4). Full and part time employees, full and part time students, those who were unemployed, and retirees were similar to each other. Those who identified as “Other” were similar to all other groups. Participants who worked in the home were similar to those who were unemployed and those who responded as “Other” and different from all other groups. Eighty-three percent (266) of all participants strongly agreed or agreed that controlling some non-native species is necessary to help conserve the environment, while 2% (7) strongly disagreed or agreed and 14% (46) were unsure. The majority of participants (85%, 255) who were employed full or part time, full or part time students, unemployed, and retired strongly agreed or agreed controlling some non-native species is necessary to help conserve the environment, while 2% (6) strongly disagreed or disagreed and 13% (38) were unsure. Fifty-eight percent (11) of participants who worked in the home and identified as other strongly agreed or agreed controlling some non-native species is necessary to help conserve the environment. Five percent (1) strongly disagreed or disagreed and 42% (8) were unsure.

Significant differences were observed among employment groups when asked if nonnative species should be controlled or eradicated where they do damage to rare native Texas species (Table 3.4). Full and part time employees, full and part time students, those who were unemployed, and retirees were similar to each other. Those who identified as “Other” were similar to all other groups. Participants who worked in the home were similar to those who were unemployed and those who responded as “Other” and different from all other groups. Eighty-nine percent (283) of all participants strongly agreed or agreed that nonnative species should be controlled or eradicated where they do damage to rare native Texas species. Three percent (9) strongly disagreed or disagreed and 8% (27) were unsure. Ninety-one percent (272) of those who were employed full or part time, full or part time students, unemployed, and retired strongly agreed or agreed that nonnative species should be controlled or eradicated where they do damage to rare native Texas species, while only 2% (7) strongly disagreed or disagreed. Seven percent (20) were unsure if nonnative species should be controlled or eradicated where they do damage to rare native Texas species. Of those participants who worked in the home and identified as “Other,” 55% (11) strongly agreed or agreed that nonnative species should be controlled or eradicated where they do damage to rare native Texas species, 10% (2) strongly disagreed or disagreed, and 35% (7) were unsure.

When asked if nonnative species should be controlled or eradicated only where they threaten human health, significant differences emerged among the different employment groups (Table 3.4). Part time employees, full time students, and those who work in the home were similar to each other and different from the other groups. Full time employees and those who identified as “Other” were similar to each other and different from the other groups. Those who were unemployed, retired, and part time students were similar to each other and different from the other groups. Overall, 30% (93) of participants strongly agreed or agreed that nonnative species should be controlled or eradicated only where they threaten human health. Fifty-two percent (161) strongly disagreed or disagreed, while 18% (56) were unsure. Among those participants who were part time employees, full time students, and who worked in the home, 35% (42) strongly agreed or agreed that nonnative species should be controlled or eradicated only where they threaten human health, while 47% (56) strongly disagreed or disagreed and 18% (21) were unsure. The lowest percentage (22%, 22) of participants that strongly agreed or agreed that nonnative species should be controlled or eradicated only where they threaten human health were those who were employed full time and identified as other. Fifty-seven percent (56) of these two groups strongly disagreed or disagreed and 20% (20) were unsure. Of participants who were part time students, retired, and unemployed, 31% strongly agreed or agreed that nonnative species should be controlled or eradicated only where they threaten human health, 53% (49) strongly disagreed or disagreed, and 16% (15) were unsure.

Discussion

A number of studies have examined the effects of public perception and attitudes towards invasive species and invasive species management issues (Bertolino and Genovesi, 2003; Jetter and Paine, 2004; Bardsley and Edward-Jones, 2006; Bremner and Park, 2007 García-Llorente et al., 2008). Because the San Marcos River has such a large number of nonnative invasive species, this study is significant in providing a broad overview of the public's perceptions and attitudes towards those species and their management in the San Marcos River, which can be used to make better informed management decisions.

The majority of survey participants were well-educated, employed Caucasian females between the ages of 18 and 34. This reflects 2011 census demographic data, which indicate that 50.2% of Hays County and 49.5% of Travis County residents are female (United States Census, 2011). Given that Hays and Travis counties are home to a number of universities, including Texas State University-San Marcos and the University of Texas at Austin, it is also not surprising that survey participants were well-educated. Both Hays and Travis counties have low unemployment rates, lower than the state or national averages (City-data.com, 2012a; City-data.com, 2012b), which is reflected in the number of survey participants indicating they were employed.

Survey participants were least familiar with general invasive species issues, more familiar with Texas invasive species issues, and most familiar with invasive species issues in the San Marcos River. This lack of familiarity with invasive species in general may be attributed to the fact that the majority of survey participants indicated they were not members of an environmental or conservation organization. Many environmental and conservation organizations provide, as a component of their organizational missions, education and information about invasive species and their impact on the environment. Nonmembers do not have access to that information and those educational materials and, therefore, would not be as informed as members who do have access. Of those survey participants who were members of an environmental or conservation organizations, 20% were members of state or regional groups such as the Texas Master Naturalists, Native Plant Society of Texas, and Environment for Texas. These groups focus on invasive species as major parts of their mission and members participating in the survey would explain why survey participants were more familiar with Texas invasive species issues. Members of local environmental and conservation organizations, such as the San Marcos River Foundation, Hill Country Conservancy, and San Marcos Greenbelt Alliance, would be most familiar with invasive species issues in the San Marcos River because these groups would have strongly local agendas focusing on issues in the immediate area, particularly the San Marcos River. Interestingly, when asked to name a nonnative species or an invasive species project in the San Marcos River, the majority of participants who said they were familiar with nonnative invasive species in the river were unable to do so. Equally interesting was the fact that a number of participants named Texas wild-rice (*Z. texana*), a federally listed endemic species, as an invasive and were quite adamant about the need for its removal. These results are similar to those of Andreu et al. (2009) who found that respondents to their survey were unable to accurately differentiate between invasive species and noninvasive species.

The majority of survey participants who indicated they received information about invasive species issues did so primarily through magazines, followed by the internet, and “Other” sources. Because of the age distribution (18-34) of the participants and the digital nature of modern information dissemination, one would expect more participants to use the internet as their primary source of information rather than what is now considered “traditional” print media. Also of note were the sources many participants indicated as “Other” including Texas Master Naturalists, the Native Plant Society of Texas, classes at the university, and, in one instance, a participant who responded, “I live here, I see it.”

In general, survey participants believed that controlling and managing invasive species was important regardless of the level of threat posed by the species in question and agreed that nonnative invasive species should be controlled or eradicated especially in order to conserve the environment. They agreed that they should be controlled or eradicated even if they did not threaten human health. These results are similar to those of Bremner and Park (2007) who found that respondents to their survey favored control and eradication programs. The majority of participants agreed that Texas native species should be protected at all costs and a higher percentage of participants believed that nonnative invasive species should be controlled or eradicated especially when they damage Texas native species. An even larger percentage of participants believed nonnative invasive species should be controlled or eradicated when they damage rare or endangered Texas species. Philip and Macmillan (2005) found similar views expressed by respondents to a survey conducted to determine willingness to pay for wildlife conservation.

In a study to determine public support for control methods, Barr et al. (2002) found that, while respondents generally supported control of the grey squirrel to help conserve red squirrel populations and prevent damage to timber crops, they did not support the poisoning of the squirrels as an acceptable method. This attitude toward the death of animals is also supported by the findings of Bremner and Park (2007). This was found in our study as well. Methods that involved the death of animals, including poisoning and shooting, were least supported, especially by females. Respondents were most supportive of methods that included trapping and relocation. In the case of plants, the use of herbicides and dredging as means of removal were least favored.

Results of this study will help managers make better informed management decisions. First, the study helps to understand perceptions and attitudes of people who use and value the San Marcos River regarding invasive species. As Bertolino and Genovesi (2003) illustrated, the public can be a huge impediment to the implementation of management programs. They can also provide incredibly valuable and meaningful information to policymakers and conservation managers (Fischer and van der Wall, 2007).

Survey participants value the San Marcos River not only as a recreational resource, but also as a natural resource. They are generally willing to support invasive species management programs and to be active participants in those programs as volunteers through membership in various state and local environmental and conservation organizations. When respondents were asked about invasive species projects in the river, those who were familiar with projects invariably responded that "We need more." What is severely lacking is public education about nonnative invasive species issues (Bremner and Park, 2007). García-Llorente et al. (2008) point out the positive impact of public awareness campaigns for gaining the support of the general public and making them more aware of invasive species issues. Studies such as Fischer and Young (2007) and Stokes, et al. (2006) illustrate the importance of public involvement in management decisions. Many studies support the importance of public involvement conservation initiatives and participation in management programs (Barr, et al., 2002; Philip and Macmillan, 2005; Stokes et al., 2006; Bremner and Park, 2007; Fischer and Young, 2007). Where an educated public has been involved in the decision-making process, success was achieved with little or no local resistance (Sheail, 2003). Educated and informed stakeholders are key to the success or failure of nonnative invasive species management projects (Bremner and Park, 2007).

Based on the results of this study recommendations to educate the general public about impacts of invasive species in the San Marcos River and actions the public can take to contribute to the solution include: creating interpretive signage for the San Marcos River; a media campaign covered by local news sources, such as the San Marcos Daily Record and University Star newspapers, that informs the public about local invasive species management projects and volunteer opportunities; incorporation of invasive species issues into class curricula at public schools and universities; and a collaborative effort by city entities such as the San Marcos Chamber of Commerce, San Marcos Parks and Recreation Department, Lions Club, San Marcos Convention and Visitor Bureau to develop and distribute educational brochures for the visiting public at prominent locations such as Aquarena Center, City of San Marcos Tourist Information Center, Nature Center, Lions Tube Rental, and local hotels and restaurants.

Table 3.1. Results of a one-way analysis of variance comparison of individual statements showing significant differences among different ethnic groups in the study of public perceptions of nonnative invasive species.

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Are you a member of an environmental organization?						
Caucasian	242	1.50	0.50	4	7.82	0.000*
Asian	7	1.29	0.49			
African-American	7	1.00	0.00			
Hispanic	54	1.15	0.36			
Other	10	1.40	0.52			
Where do you hear about invasive species issues?						
Newspapers						
Caucasian	246	1.37	0.48	4	3.87	0.004*
Asian	7	1.14	0.38			
African-American	7	1.43	0.53			
Hispanic	55	1.13	0.34			
Other	11	1.18	0.40			
Internet						
Caucasian	246	1.42	0.49	4	3.52	0.008*
Asian	7	1.86	0.38			
African-American	7	1.29	0.49			
Hispanic	55	1.24	0.43			
Other	11	1.27	0.47			
Radio						
Caucasian	246	1.16	0.37	4	2.65	0.034*
Asian	7	1.29	0.49			
African-American	7	1.00	0.00			
Hispanic	55	1.02	0.13			
Other	11	1.09	0.30			
Are you familiar with invasive species in the San Marcos River?						
Caucasian	244	1.49	0.52	4	3.92	0.004*
Asian	7	1.29	0.49			
African-American	7	1.14	0.38			
Hispanic	54	1.24	0.43			
Other	10	1.20	0.42			

*Statistically significant at $P \leq 0.05$.

Table 3.1 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Native Texas species should be protected at all costs.						
Caucasian	244	3.64	1.17	4	3.77	0.005*
Asian	7	3.43	1.13			
African-American	7	4.14	1.07			
Hispanic	54	4.26	1.01			
Other	11	4.00	1.10			
Nonnative species should be controlled or eradicated only where they threaten human health.						
Caucasian	244	2.52	1.42	4	8.22	0.000*
Asian	7	3.43	1.27			
African-American	7	3.86	1.21			
Hispanic	54	3.50	1.41			
Other	11	3.73	1.19			
Do you know of any invasive species in the San Marcos River?						
Caucasian	244	1.50	0.50	4	4.36	0.005*
Asian	7	1.29	0.49			
African-American	7	1.00	0.00			
Hispanic	55	1.27	0.45			
Other	11	1.27	0.47			

*Statistically significant at $P \leq 0.05$.

Table 3.2. Results of a one-way analysis of variance comparison of individual statements showing significant differences among different age categories in the study of public perceptions of nonnative invasive species.

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Are you a member of an environmental organization?						
<18	16	1.00	0.00	6	18.26	0.000*
18-34	133	1.21	0.41			
35-44	33	1.42	0.50			
45-54	32	1.47	0.51			
55-64	50	1.72	0.45			
64-75	45	1.80	0.40			
>75	16	1.63	0.50			
Where do you hear about invasive species issues?						
Newspapers						
<18	16	1.13	0.34	6	3.19	0.005*
18-34	137	1.23	0.42			
35-44	33	1.33	0.48			
45-54	33	1.42	0.50			
55-64	50	1.46	0.50			
64-75	46	1.41	0.50			
>75	16	1.50	0.52			
Magazines						
<18	16	1.31	0.48	6	2.27	0.039*
18-34	137	1.40	0.49			
35-44	33	1.33	0.48			
45-54	33	1.39	0.50			
55-64	50	1.58	0.50			
64-75	46	1.54	0.50			
>75	16	1.69	0.48			
Other						
<18	16	1.25	0.45	6	3.78	0.001*
18-34	137	1.35	0.48			
35-44	33	1.27	0.45			
45-54	33	1.27	0.45			
55-64	50	1.52	0.50			
64-75	46	1.61	0.49			
>75	16	1.19	0.40			

*Statistically significant at $P \leq 0.05$.

Table 3.2 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Have you spent any time at the San Marcos River in the past year?						
<18	16	1.88	0.34	6	7.53	0.000*
18-34	137	1.80	0.42			
35-44	33	1.70	0.53			
45-54	33	1.67	0.48			
55-64	50	1.54	0.54			
64-75	46	1.35	0.48			
>75	16	1.38	0.62			
Are you familiar with any of the nonnative species in the San Marcos River?						
<18	16	1.19	0.40	6	2.86	0.010*
18-34	136	1.38	0.49			
35-44	33	1.52	0.51			
45-54	33	1.49	0.51			
55-64	50	1.64	0.60			
64-75	44	1.37	0.49			
>75	15	1.27	0.46			
Protecting the San Marcos River from non-native invasive species is important.						
<18	16	3.81	0.98	6	4.19	0.000*
18-34	136	4.43	0.92			
35-44	32	4.09	1.06			
45-54	31	4.58	0.89			
55-64	50	4.68	0.62			
64-75	46	4.76	0.71			
>75	16	4.56	0.63			

*Statistically significant at $P \leq 0.05$.

Table 3.2 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
All invasive nonnative species should be completely removed from the San Marcos River.						
<18	16	2.25	0.86	6	8.30	0.000*
18-34	135	3.47	1.12			
35-44	31	3.81	0.95			
45-54	31	4.03	1.08			
55-64	49	3.92	1.10			
64-75	46	4.13	1.02			
>75	16	4.06	1.12			
All invasive nonnative species should be completely removed from the San Marcos River.						
<18	16	2.25	0.86	6	8.30	0.000*
18-34	135	3.47	1.12			
35-44	31	3.81	0.95			
45-54	31	4.03	1.08			
55-64	49	3.92	1.10			
64-75	46	4.13	1.02			
>75	16	4.06	1.12			
Nonnative species should be controlled or completely removed when they cause economic damage to the San Marcos River.						
<18	1632	3.31	1.08	6	4.53	0.000*
18-34	136	4.20	0.98			
35-44	32	4.19	1.00			
45-54	31	4.45	0.89			
55-64	50	4.40	0.78			
64-75	46	4.61	0.71			
>75	16	4.44	1.09			

*Statistically significant at $P \leq 0.05$.

Table 3.2 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River.						
<18	16	3.88	1.26	6	2.77	0.012*
18-34	136	4.60	0.71			
35-44	32	4.34	1.00			
45-54	32	4.41	1.04			
55-64	50	4.54	0.68			
64-75	46	4.72	0.72			
>75	16	4.56	0.63			
Controlling some nonnative species is necessary to help conserve the environment.						
<18	16	3.75	0.86	6	4.52	0.000*
18-34	136	4.40	0.83			
35-44	32	4.03	1.06			
45-54	31	4.42	0.89			
55-64	50	4.60	0.67			
64-75	46	4.72	0.62			
>75	16	4.31	0.79			
Nonnative species should be controlled or eradicated where they do damage to any native Texas species.						
<18	16	3.06	1.12	6	3.84	0.001*
18-34	137	4.20	0.98			
35-44	32	4.03	1.03			
45-54	31	4.19	1.01			
55-64	50	4.08	1.03			
64-75	46	4.35	0.87			
>75	16	4.31	0.79			

*Statistically significant at $P \leq 0.05$.

Table 3.2 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Nonnative species should be controlled or eradicated only where they threaten human health.						
<18	16	3.31	1.40089	6	3.35	0.000*
18-34	137	3.09	1.47470			
35-44	32	2.59	1.31638			
45-54	32	2.81	1.44663			
55-64	50	2.26	1.46817			
64-75	46	2.39	1.40599			
>75	15	2.47	1.18723			
Nonnative species should be controlled or eradicated where they do damage to rare native Texas species.						
<18	16	3.50	1.26	6	4.48	0.000*
18-34	137	4.54	0.74			
35-44	32	4.41	0.91			
45-54	31	4.52	0.85			
55-64	50	4.48	0.84			
64-75	46	4.65	0.74			
>75	16	4.60	0.63			

*Statistically significant at $P \leq 0.05$.

Table 3.3. Results of a one-way analysis of variance comparison of individual statements showing significant differences among different education levels in the study of public perceptions of nonnative invasive species.

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Are you a member of an environmental organization?						
High school diploma	96	1.14	0.34	4	17.86	0.000*
Bachelor’s degree	112	1.54	0.50			
Master’s degree	70	1.64	0.48			
Doctorate	12	1.67	0.49			
Other	30	1.27	0.45			
Where do you hear about invasive species issues?						
Magazines						
High school diploma	96	1.28	0.45	4	5.21	0.000*
Bachelor’s degree	115	1.51	0.50			
Master’s degree	70	1.56	0.50			
Doctorate	12	1.67	0.49			
Other	32	1.34	0.48			
I don’t						
High school diploma	96	1.25	0.44	4	5.55	0.000*
Bachelor’s degree	115	1.04	0.20			
Master’s degree	70	1.11	0.32			
Doctorate	12	1.08	0.29			
Other	32	1.22	0.42			
Other						
High school diploma	96	1.23	0.42	4	4.52	0.001*
Bachelor’s degree	115	1.49	0.50			
Master’s degree	70	1.46	0.50			
Doctorate	12	1.25	0.45			
Other	32	1.38	0.49			
Have you spent any time at the San Marcos River in the past year?						
High school diploma	96	1.82	0.44	4	7.23	0.000*
Bachelor’s degree	115	1.59	0.49			
Master’s degree	70	1.53	0.53			
Doctorate	12	1.42	0.51			
Other	32	1.88	0.34			

*Statistically significant at $P \leq 0.05$.

Table 3.3 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Are you familiar with invasive species in the San Marcos River?						
High school diploma	96	1.27	0.45	4	3.99	0.004*
Bachelor's degree	114	1.50	0.55			
Master's degree	69	1.51	0.50			
Doctorate	12	1.67	0.49			
Other	32	1.44	0.50			
Protecting the San Marcos River from nonnative invasive species is important.						
High school diploma	95	4.18	1.03	4	3.82	0.005*
Bachelor's degree	113	4.60	0.77			
Master's degree	69	4.58	0.76			
Doctorate	12	4.67	0.65			
Other	32	4.53	0.92			
All invasive non-native species should be completely removed from the San Marcos River.						
High school diploma	93	3.32	1.15	4	5.39	0.000*
Bachelor's degree	112	3.82	1.04			
Master's degree	69	3.97	1.03			
Doctorate	12	4.17	0.94			
Other	32	3.34	1.38			

*Statistically significant at $P \leq 0.05$.

Table 3.3 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Controlling some nonnative species is necessary to help conserve the environment.						
High school diploma	95	4.14	0.86	4	5.04	0.001*
Bachelor’s degree	113	4.57	0.80			
Master’s degree	69	4.57	0.70			
Doctorate	12	4.58	0.67			
Other	32	4.22	0.91			
Native Texas species should be protected at all costs.						
High school diploma	95	3.99	0.98	4	3.20	0.014*
Bachelor’s degree	115	3.57	1.23			
Master’s degree	68	3.59	1.17			
Doctorate	12	3.50	1.45			
Other	32	4.16	1.11			
Nonnative species should be controlled or eradicated only where they threaten human health.						
High school diploma	95	3.40	1.42	4	9.10	0.000*
Bachelor’s degree	115	2.53	1.37			
Master’s degree	68	2.26	1.31			
Doctorate	12	1.92	1.08			
Other	32	2.84	1.61			
Do you know of any invasive species in the San Marcos River?						
High school diploma	96	1.28	0.45	4	3.97	0.004*
Bachelor’s degree	115	1.50	0.50			
Master’s degree	67	1.48	0.50			
Doctorate	12	1.67	0.49			
Other	31	1.52	0.51			

*Statistically significant at $P \leq 0.05$.

Table 3.3 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Controlling some nonnative species is necessary to help conserve the environment.						
High school diploma	95	4.14	0.86	4	5.04	0.001*
Bachelor's degree	113	4.57	0.80			
Master's degree	69	4.57	0.70			
Doctorate	12	4.58	0.67			
Other	32	4.22	0.91			
Native Texas species should be protected at all costs.						
High school diploma	95	3.99	0.98	4	3.20	0.014*
Bachelor's degree	115	3.57	1.23			
Master's degree	68	3.59	1.17			
Doctorate	12	3.50	1.45			
Other	32	4.16	1.11			
Nonnative species should be controlled or eradicated only where they threaten human health.						
High school diploma	95	3.40	1.42	4	9.10	0.000*
Bachelor's degree	115	2.53	1.37			
Master's degree	68	2.26	1.31			
Doctorate	12	1.92	1.08			
Other	32	2.84	1.61			
Do you know of any invasive species in the San Marcos River?						
High school diploma	96	1.28	0.45	4	3.97	0.004*
Bachelor's degree	115	1.50	0.50			
Master's degree	67	1.48	0.50			
Doctorate	12	1.67	0.49			
Other	31	1.52	0.51			

*Statistically significant at $P \leq 0.05$.

Table 3.4. Results of a one-way analysis of variance comparison of individual statements showing significant differences among different employment categories in the study of public perceptions of nonnative invasive species.

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Are you a member of an environmental organization?						
Working full time	97	1.42	0.50	7	9.64	0.000*
Working part time	58	1.36	0.48			
Working in the home	10	1.30	0.48			
Unemployed	18	1.06	0.24			
Full time student	50	1.22	0.42			
Retired	65	1.78	0.41			
Part time student	10	1.20	0.42			
Other	10	1.40	0.52			
Where do you hear about invasive species issues?						
Newspapers						
Working full time	99	1.35	0.48	7	2.53	0.015*
Working part time	59	1.27	0.45			
Working in the home	10	1.40	0.52			
Unemployed	19	1.16	0.37			
Full time student	51	1.27	0.45			
Retired	65	1.49	0.50			
Part time student	10	1.10	0.32			
Other	10	1.10	0.32			
Magazines						
Working full time	99	1.39	0.49	7	3.26	0.002*
Working part time	59	1.51	0.50			
Working in the home	10	1.10	0.32			
Unemployed	19	1.21	0.42			
Full time student	51	1.45	0.50			
Retired	65	1.63	0.49			
Part time student	10	1.30	0.48			
Other	10	1.30	0.49			

*Statistically significant at $P \leq 0.05$.

Table 3.4 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Have you spent any time at the San Marcos River in the past year?						
Working full time	99	1.62	0.51	7	7.04	0.000*
Working part time	59	1.80	0.41			
Working in the home	10	2.00	0.47			
Unemployed	19	1.79	0.42			
Full time student	51	1.76	0.43			
Retired	65	1.37	0.52			
Part time student	10	2.00	0.00			
Other	10	1.90	0.32			
Protecting the San Marcos River from non-native invasive species is important.						
Working full time	96	4.52	0.94	7	1.27	0.003*
Working part time	58	4.43	0.80			
Working in the home	10	3.30	1.42			
Unemployed	19	4.58	0.69			
Full time student	51	4.43	0.85			
Retired	65	4.63	0.74			
Part time student	10	4.30	0.95			
Other	10	4.30	0.67			
All invasive nonnative species should be completely removed from the San Marcos River.						
Working full time	95	3.78	1.17	7	2.39	0.021*
Working part time	58	3.55	1.22			
Working in the home	9	3.11	0.78			
Unemployed	18	3.17	1.25			
Full time student	51	3.55	1.01			
Retired	65	4.03	1.02			
Part time student	10	3.20	1.32			
Other	10	3.50	1.08			

*Statistically significant at $P \leq 0.05$.

Table 3.4 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Nonnative species should be controlled or completely removed when they threaten rare or endangered species in the San Marcos River.						
Working full time	97	4.60	0.81	7	4.51	0.000*
Working part time	58	4.60	0.72			
Working in the home	10	3.50	1.27			
Unemployed	19	4.53	0.70			
Full time student	51	4.61	0.57			
Retired	65	4.60	0.68			
Part time student	10	4.50	0.85			
Other	10	3.70	1.42			
Controlling some nonnative species is necessary to help conserve the environment.						
Working full time	96	4.35	0.8	7	3.16	0.003*
Working part time	58	4.60	0.72			
Working in the home	10	3.50	1.27			
Unemployed	19	4.11	0.94			
Full time student	51	4.41	0.73			
Retired	65	4.55	0.73			
Part time student	10	4.30	0.82			
Other	10	4.20	0.92			
Nonnative species should be controlled or eradicated where they do damage to rare native Texas species.						
Working full time	97	4.56	0.72	7	2.85	0.007*
Working part time	58	4.59	0.68			
Working in the home	10	3.60	1.26			
Unemployed	19	4.26	1.15			
Full time student	51	4.49	0.70			
Retired	64	4.58	0.81			
Part time student	10	4.50	0.85			
Other	10	4.00	1.155			

*Statistically significant at $P \leq 0.05$.

Table 3.4 (continued).

Question	**Sample size (No.)**	**Mean**	**SD**	**df**	**F**	***P***
Nonnative species should be controlled or eradicated only where they threaten human health.						
Working full time	98	2.69	1.40	7	2.27	0.029*
Working part time	58	2.72	1.46			
Working in the home	10	3.30	1.49			
Unemployed	19	3.42	1.68			
Full time student	51	2.88	1.52			
Retired	64	2.34	1.34			
Part time student	10	3.70	1.42			
Other	10	2.40	1.43			

*Statistically significant at $P \leq 0.05$.

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VITA

Florence Marie Oxley was born in Ellsworth, Maine, on January 6, 1957. She is the daughter of Joseph Donald and Juliette Virginia McDougall. Flo spent the best part of her childhood traveling around the world with her father who was a career Navy Master Chief. She has lived in Turkey and Puerto Rico and all over the United States. Flo earned a Bachelor of Science degree and a Master of Science degree from Southwest Texas State University. She entered the Aquatic Resources Ph.D. program in the fall of 2003. During her graduate work, Flo worked as the Director of Plant Conservation at the Lady Bird Johnson Wildflower Center at The University of Texas Austin. As director, she was responsible for the Texas component of the Millennium Seed Bank Project. Under her leadership, the Wildflower Center collected more than 600 native Texas species for storage at the Millennium Seed Bank located at the Royal Botanic Garden, Kew. In recognition of her work in Texas plant conservation, Flo was awarded the 2013 Center for Plant Conservation STAR Conservation Award. She is now an Adjunct Professor of Biology at Austin Community College (ACC). She is the recipient of the 2013 Phi Kappa Theta Teaching Excellence Award at ACC.

Permanent Address: 2765 Old Seguin Road
San Marcos, Texas 78666

This dissertation was typed by Florence M. Oxley.