MEASURING THE EFFECTIVENESS OF INVASIVE SPECIES EDUCATION CURRICULA ON STUDENT KNOWLEDGE OF AND ATTITUDES TOWARD INVASIVE SPECIES

by

Kathryn M. Parsley, B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Biology
August 2017

Committee Members:

Paula S. Williamson, Chair

Tina M. Cade, Co-Chair

Florence M. Oxley

FAIR USE AND AUTHOR'S PERMISSION STATEMENT

Fair Use

Duplication Permission

ACKNOWLEDGEMENTS

I want to acknowledge my family, for supporting me throughout my academic career and my life. I would also like to acknowledge my mentors, Dr. Lila Peal, Dr. Michael Dunn, Dr. Paula Williamson, and Dr. Jaime Sabel, for your continued support and encouragement. Lastly I would like to thank the rest of my Master's committee, Dr. Tina Cade and Dr. Florence Oxley, for supporting and encouraging me during this process. I would not have been able to do any of this without the support of all of you.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

I. INTRODUCTION

Invasive species cost the United States 120 billion dollars every year, without factoring in the loss of species biodiversity and the damage done to our ecosystems (Pimentel, Zuniga, & Morrison, 2005). Recognition of threats posed by invasive species has led to increasing pressure to control or eradicate them in order to mitigate their impacts (Mack et al., 2000). Understanding public opinion can help guide educational outreach to gain public support for eradication projects (Bertolino & Genovesi, 2003). The attitude of many people towards control of exotic pests depends on their perception of whether they believe a particular species is harmful or beneficial (National Invasive Species Council, 2008). Obstacles impeding invasive species management would likely be alleviated given a well-informed public (Bertolino & Genovesi, 2003). Since public opinions and attitudes can potentially affect continued introductions and management of exotics, it is imperative to understand the public's level of knowledge and attitudes toward these pests.

In a study conducted by Oxley, Waliczek, and Williamson (2016) about the San Marcos River in Hays Co., Texas, a survey was administered to gauge the public's general knowledge, perceptions, and attitudes regarding non-native species and invasive species management. The San Marcos River is a highly invaded ecosystem with over 48 non-native species (Bowles & Bowles, 2001). The results indicated that participants who claimed they knew of invasive species in the river were more supportive of control measures being taken when compared to participants who claimed they did not know of any invasive species in the river. The study also found that young adults who had not received as much college education knew less about invasive species and were less likely to be involved in environmental organizations that could inform them about invasive species. These results indicate there is a need to determine and understand attitudes of college-aged youth about impacts of invasive species and their control (Oxley et al., 2016). This information will allow educators to design and implement appropriate educational programs to inform this segment of the public of the issues and challenges of exotic pest management.

Problem Statement

Lack of public education and knowledge of public opinion regarding invasive species limits invasive species management programs and their effectiveness. A more well-informed public will positively affect efforts to manage the spread of invasive species.

Purpose and Objectives

The purpose of this study is to determine if a lecture and/or a lecture and laboratory learning model influences college student learning gains and attitudes about invasive species.

The specific objectives of this study are:

1. To determine students' baseline knowledge of invasive species.
2. To determine students' pre-existing attitudes toward invasive species.
3. To investigate the effects of a lecture and a lecture and laboratory curriculum on students' knowledge of and attitudes toward invasive species.
4. To compare learning gains among students offered different learning opportunities.
5. To compare attitude changes among students offered different learning opportunities and among different demographic groups.

Definition of Terms

Invasive species: An "invasive species" is defined as a species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Federal Register, 1999).

Native species: with respect to a particular ecosystem, a species that, other than as a result of an introduction, historically occurred or currently occurs in that ecosystem (Federal Register 1999).

Hypothesis

The students who receive invasive species curricula will change their attitudes about invasive species and significantly increase their knowledge of invasive species.

Limitations

The limitations of this study include the following:

1. Any research conducted on humans will have extraneous factors that can influence the outcomes of the study.
2. Non-experimental research that is based on “real-life” scenarios cannot completely neutralize all controls.
3. The sample population for this study came from one large university in Texas and one community college in Texas, and thus is not generalizable to the entirety of university students, but only to those within these specific universities.
4. The students responding were those who were enrolled in the classes selected specifically for this study.

5. The sample size was further limited by the number of experienced researchers available to administer the curricula.

II. REVIEW OF LITERATURE

Over 50 years ago, a prediction was made that a global environmental crisis was imminent due to the spread of invasive species (Elton, 1958). Global trade and movement have only increased the number of invasive species introduced worldwide, compounding the problem (McGeoch et al., 2010). Not all introductions result in successful establishment in the new ecosystem. A study by Kolar and Lodge (2001) found that the probability of introduced bird establishment increases with the number of individuals released and the number of release events. Very few ecosystems anywhere in the world are completely free of introduced species, and an increasing proportion of biomes, ecosystems, and habitats are becoming dominated by them (Pysek & Richardson, 2010).

There are two types of introduction of invasive species: intentional and unintentional. Intentional introduction is an introduction made deliberately by humans, involving the purposeful movement of a species outside of its natural range and dispersal potential (Invasive Species Specialist Group, 2000). Unintentional introduction is an introduction made unknowingly by humans as a result of a species utilizing humans or human delivery systems as vectors for dispersal outside its natural range (Invasive Species Specialist Group, 2000). Most intentional introductions of plant species are for use in the horticultural industry by nurseries, botanical gardens, and individuals (Reichard & White, 2001). Unintentional introductions are difficult to diagnose and can arise from contaminanation, stowaway, corridors and unaided pathways particularly due to global trade (Hulme, 2009). Zebra mussels (*Dreissena polymorpha*) were unintentionally introduced to the Great Lakes by a Caspian Sea tanker dumping its ballast water (Griffiths, Schloesser, Leach, & Kovalak, 1991). The species was likely introduced in 1986 and has now spread as far south as Louisiana (Johnson & Carlton, 1996). Japanese kudzu vine (*Pueraria lobata*) was introduced to the United States from Japan in 1876 at the Centennial Exposition in Philadelphia (Forseth & Innis, 2004). Japanese kudzu was intentionally planted in the southern United States in the 1930s and 1940s to control soil erosion (Blaustein, 2001). Today, kudzu is estimated to cover 3,000,000 hectares (7,400,000 acres) of land in the southeastern U. S. (Forseth & Innis, 2004). Clearly, invasive species can spread out of control whether intentionally or unintentionally introduced.

As predicted by Elton, invasive species are now one of the largest and most serious threats to biological diversity (Mack et al., 2000). In fact, there are currently approximately 50,000 non-native species in the U.S. alone and 42% of endangered and threatened species are listed because of invasive species impacts (Pimentel et al., 2005). One example is the endangered Key Largo wood rat (*Neotoma floridana smalli*) that is preyed upon by Burmese pythons (*Python bivittatus*) in Florida (Dorcas et al., 2012).

Invasive species are decreasing species diversity, with their impacts increasing over time (McGeoch et al., 2010). For example, the brown tree snake (*Boiga irregularis*), introduced to Guam in WWII in the 1950s, has caused a near complete extinction of Guam's native forest birds (Lowe et al., 2000). Eight of 11 native bird species are now extinct as a result of this arboreal predator (Wiles, Bart, Beck, & Aguon, 2003). There are even examples of invasive species altering the evolutionary pathways and trajectories of native species through competitive exclusion, niche displacement, hybridization, and introgression which sometimes result in extinction (Mooney &

Cleland, 2001). The invasive fire ant (*Solenopsis invicta*) has out-competed native fire ants in Texas to the point that their total numbers have decreased by 90%. Gray squirrels (*Sciurus carolinensis*) have displaced the native red squirrel (*Sciurus vulgaris*) in Britain through niche displacement due to a difference in food availability (Mooney & Cleland, 2001). If scientists can understand these patterns of invasive species impacts, they can focus on the most effective ways to mitigate and reduce these extinction effects (Gurevitch & Padilla, 2004).

Other known impacts of invasive species include damage to crops, livestock, and property, transmission of dangerous diseases, and limits to recreation. Feral pigs (*Sus scrofa*) are known to uproot crops, attack livestock, and trample property (Lowe et al., 2000). Feral pigs are also known to transmit diseases (Lowe et al., 2000). Nutria (*Myocastor coypus*) damage sugarcane and rice crops (Evans, 1970). European starlings (*Sturnus vulgaris*) cause a billion dollars a year in crop damage in the U.S. (Pimentel, Lach, Zuniga, & Morrison, 2000). These introduced birds also carry histoplasmosis, a disease which can infect humans resulting in severe cough and flu-like symptoms, as well as oral lesions that can calcify as they heal (Johnson & Glahn, 1994). Water hyacinth (*Eichhornia crassipes*) forms dense floating mats that block waterways limiting boat traffic, swimming and fishing (Lowe, Browne, Boudjelas, & De Poorter, 2000).

Although humans actually rely on alien species for food and other basic requirements (Pysek & Richardson, 2010), humans are also threatened by invasive species. Invasive species jeopardize native plants humans use for food, medicinal or hygienic purposes all over the world (Burgiel, Foote, Orellana, & Perrault, 2006). Additionally, invasives compromise aesthetic and spiritual values of natural wonders and sacred spaces important to humans (Burgiel et al., 2006). Invasive species also damage the economy. Invasive species and their cumulative damage cost the U.S. almost $120 billion per year (Pimentel et al., 2005).

Damage caused by invasive species is well documented, yet scientists still lack a standard approach to defining and addressing the problem of invasive species (Bardsley & Edwards-Jones, 2006; Bertolino & Genovesi, 2003; Brenner & Park, 2007; Shine & Doody, 2011). Attempting to find a common definition for invasive species is challenging due to the fact that authors are biased toward certain definitions, and articulating ecological concepts cannot be described well using simple terms (Colautti & MacIsaac, 2004). Another challenge is determining which biological traits characterize invasive species.

Ecologists have identified traits that tend to be common to invasive species, such as rapid growth rates (Elton, 1958), rapid reproduction (Reaveley, Bettink, & Valentine, 2009; Rejmanek & Richardson, 1996), asexual reproduction (Reichard & Hamilton, 1997;), and high dispersal ability (Reaveley et al., 2009). A study by Kolar and Lodge (2001) found the probability of plant invasiveness increases if the species has a history of previous invasions and reproduces vegetatively. Another study found that certain structural, reproductive, and biogeographical attributes of woody plants can help determine whether they are invasive or not (Reichard & Hamilton, 1997). Characteristics such as the plant species' native ranges, whether or not they had invaded elsewhere outside of the U.S., what kind of reproduction system they had, leaf longevity, presence or absence of asexual reproduction, presence or absence of polyploidy, flowering season, length of flowering period, etc. were analyzed using discriminant analysis and classification and regression models (Reichard & Hamilton, 1997). Traits were selected based on the likelihood that they would directly or indirectly affect invasiveness based on previous literature found by the authors and herbarium specimens. The authors compared these analysis techniques and determined that discriminant analysis was better at determining what characteristics classify species that have and have not invaded. Predictive models based on the discriminant analysis technique correctly classified 86.2% of the species as invaders or non-invaders, whereas those models based on classification and regression trees classified 76% correctly (Reichard & Hamilton, 1997).

Marchetti, Moyle, and Levine (2004) found that successful invasive species generally do have distinguishable characteristics from species that failed to establish by examining fish invasions within California catchment areas. They found that fish species with narrow physiological ranges do not establish as well as species with higher physiological tolerance to changes in water quality. Examples of potential physiological changes include temperature, dissolved oxygen, turbidity and salinity. Fishes with prior invasion histories elsewhere are more likely to become invasive in new habitats. Furthermore, the authors found that certain characteristics are more favorable during establishment while other characteristics are more favorable during species spread (when they invade more catchment areas) or integration (abundance of that species within the catchment area). Traits favored during establishment include increased parental care, greater size of native range, and a higher level of physiological tolerance. During the spread stage, favored traits include being long-lived, of regional origin, and not being an herbivore (Marchetti et al., 2004). During the integration phase, being small, of regional origin, and not utilizing invertebrates as their primary source of food seems to be advantageous (Marchetti et al., 2004).

Van Kleunen, Weber, and Fischer (2010) performed a meta-analysis of 117 field or experimental garden studies to test whether invasiveness is associated with performance-related traits including physiology, leaf area allocation, shoot allocation, growth rate, size and fitness. They found that invasive plant species had significantly higher values for these traits when compared to non-invasive species. Furthermore, they suggested that these traits could possibly be used as a means of predicting future plant invasions (Van Kleunen, et al., 2010).

However, disagreement among authors exists in whether or not a profile for invasiveness can be produced, and if so, what is the best method of producing one. A study by Devin and Beisel (2007) found that invasiveness cannot be predicted from a limited number of criteria, but is the result of several characteristics and should be seen more as an ecological profile rather than a biological one.

In addition to predicting which introduced species will become invasive, predicting which ecosystems are likely to be invaded is also problematic. Invasive species surveillance is typically targeted to areas where the species is most likely to occur, but spatially-varying environmental characteristics and land use can affect actual occurrence (Hauser & McCarthy, 2009). Even with the ability to predict invasions, environmental variability and land use can influence the likelihood of successful eradication management programs (Hauser & McCarthy, 2009).

Larson et al. (2011) argue that sustainability of invasive species management programs must be considered. Management programs can be cost prohibitive once invasives are well established and eradication programs are generally less expensive if implemented in the early stages of an introduction (Pimentel et al., 2005). Mehta, Haight, Homans, Polasky, and Venette (2005) pointed out that previous literature on invasive species management focuses on preventing introduction of invasive species and post-introduction strategies. However, detection is just as important because, if detected in time, the invasive species population could be controlled for less money and with less damage.

Kim, Lubowski, Lewandrowski, and Eiswerth (2006) developed a conceptual model for determining the optimal use of resources to balance prevention and control strategies for invasive species with an uncertain discovery time. The model is designed to determine how best to allocate limited resources between activities before and after the species was discovered. This would be a great help in determining the methods of management that are most cost-effective, but it is still a model and has not been attempted in a real world invasion. Strategies for controlling invasives can be aimed at any or all of the stages in their life cycle, so control costs and efficiency of control method must be taken into consideration when deciding what stage to attack first (Buhle, Margolis, & Ruesink, 2005).

Larson et al. (2011) state that invasive species management rests on three pillars: environmental, economical, and social. The environmental pillar is likely the most studied. In order to manage invasions, it is crucial to understand the mechanisms that facilitate or inhibit invasions. These methods of management include identifying likely pathways of invasion, monitoring and attempting early detection of invasive species, eradicating newly-introduced invasives as early as possible, preventing the spread and impacts of invasives, and attempting to minimize effects of control on native species (Larson et al., 2011).

The economic pillar is also studied extensively and centers on how invasive species impact the economy. Management procedures that fall under this pillar include executing cost-benefit analyses that include data on non-market values, expanding the temporal and spatial range of cost-benefit analyses, incorporating efficiency when considering what strategies to employ, and securing sufficient funding for completing an entire management project (Larson et al., 2011).

Finally, the social pillar, which is critical to the success of these management plans, suggests focusing efforts on increasing collaboration and building support with a broad range of stakeholders, as well as increasing community education, involvement, and support for individuals who contribute to invasive species management. Local political advocacy is also important, so that changing attitudes toward invasive species ultimately translate into policy changes (Larson et al., 2011).

Much research on invasive species has focused on the ecological component, but knowledge of the social component is necessary to effectively target the problem (Garcia-Llorente, Martin-Lopez, Gonzalez, Alcorlo, & Montes, 2008). Mckneely (2001) proposed that, although the issue of invasive alien species has important biological components, the human dimensions deserve much greater attention. People can assist with eradication plans through citizen science and volunteer projects, or cause them to fail due to misunderstanding why invasives are problematic

The management of invasive species is a frequent cause of conflict in biodiversity conservation because perceptions of costs and benefits differ among stakeholder groups

(Stokes et al., 2006). Prinbeck, Lach, and Chan (2011) emphasized that understanding stakeholders' beliefs can help inform the creation of effective campaigns to engage stakeholders in finding solutions that halt the spread of invasive species. Schüttler, Rozzi, and Jax (2011) also pointed out that we need more studies that focus on the public's perceptions of invasive species management. If the public does not approve of an invasive species management plan, the plan is less likely to be successful.

Bertolino and Genovesi (2003) noted the impact public opinion has on the success of invasive species management, citing the failure of a plan to eradicate the invasive American grey squirrel from Italy. Shortly after a small test of the eradication plan in May 1997, a radical animal rights group took the National Wildlife Institute to court in June 1997. This halted the project altogether due to the tremendous time delay from ongoing litigation. By the time the lawsuit was over, the population of squirrels had already spread beyond the scope and capability of the original management plan (Bertolino & Genovesi, 2003).

Understanding the reasons for disagreements about conservation issues can facilitate effective engagement between the people involved in them (Shine & Doody, 2011). Bremner & Park (2007) asserted that pubic support can be critical to the success of invasive species management projects and understanding the attitudes of the public can help inform outreach and education activities. Estevez, Anderson, Pizarro, and Burgman (2014) recommended integrating environmental issues into invasive species research and management to promote trust and confidence between stakeholders and decision makers. One study suggested including broader public participation in design and management of responses to biological invasions by considering local knowledge, providing the public with scientific information, evaluating tolerance toward invasive species, clarifying the perspectives of economic income through invasive species management, and employing compromises on the basis of suggestions from the public (Schüttler et al., 2011).

One strategic goal of the 2008 National Invasive Species Council is to prioritize maximizing organizational effectiveness and collaboration on invasive species issues among all stakeholders including international, federal, state, local and tribal governments, private organizations, and individuals (National Invasive Species Council, 2008). Understanding all of these institutions' perceptions of invasive species and attitudes toward invasives is required in order to achieve the goal.

Understanding attitudes of stakeholders is necessary to develop effective invasive species management programs. Several factors can influence attitudes. Ecologists and environmentalists typically regard invasives as detrimental and undesirable, but invasive species are often compatible with recreational interests and not perceived as a public threat (Foster & Sandberg, 2004). People who consider a particular invasive species an economic asset can be major barriers to eradication or management programs (Marshall, Friedel, van Klinken, & Grice, 2011). Management costs and official policies can affect public perceptions of invasives and cause attitudes to vary greatly when mixed with personal experiences, media, and other sources of information (Veitch & Clout, 2001). Some individuals think invasive species are a natural occurrence, suggesting that a turnover in local species are an inherent part of their region (Bardsley & Edwards-Jones, 2006). A misunderstanding of what a non-native species is can lead to neutral attitudes toward invasive species, eliminating the desire to eradicate them by the general public (Selge, Fischer, & van der Wal, 2011).

Prinbeck et al. (2011) discovered six attitudes that acted as barriers to invasive species management: (1) behaviors such as using pesticides may be worse for the environment than invasive species, (2) the fight against invasives is a losing battle, (3) invasive species management is a low priority for many institutions, (4) the general public does not know or care about invasive species, (5) one does not know enough about invasive species prevention to be effective, and (6) recommended preventative behaviors are too difficult to perform.

People often bring ornamental plants to new places because they like to have floristic diversity in their immediate vicinity and they overlook that the plant is or can become invasive (Mack, 2001). Studies have shown that humans want to be able to travel the world without spreading invaders in the process (Low, 2001). This implies that human attitudes regarding their own travel and freedom differ from their attitudes about the ability of other species' freedom. Even government attitudes can be misplaced, as they were when introducing Japanese kudzu in the U.S. and calling it a 'wonderplant' (Blaustein, 2001). Now it is one of the most difficult invasive species to manage in the U.S.

Despite some attitudes against control of invasives, knowledge of invasive species and proposed management strategies can lead to increased public support for invasive control. For example, studies have found that people who had prior knowledge of invasive species control and eradication programs and who were also members of conservation organizations showed greater levels of support for invasive control programs (Bremner & Park, 2007; Oxley et al., 2016). Therefore, it is important to educate the public in a way that is scientific but clear and reflects an understanding of current public attitudes.

Calls for invasive species education have been put forth for all levels of learning. One study calls for educating the public, especially inspectors at airports and seaports, concerning the threat of invasive species and microbes to the U.S. environment and economy (Pimentel et al., 2005). Larson et al. (2011) suggests a need for education and outreach programs that address misconceptions about the impacts of invasive species. Undergraduate and graduate level coursework at 94 Canadian universities and colleges was reviewed and education regarding invasive species was found lacking (Smith, Bazley, & Yan, 2011). The authors called for incorporating training on invasive species into the university curricula in Canada. A study by Waliczek, Williamson and Oxley (in press) found a large gap in student knowledge about invasives, citing that college students did not feel informed or educated about invasive species and were unable to distinguish native species from invasive ones.

One of the most popular ways to educate the public about invasives is through citizen science. Such programs allow the general public to assist scientists in their research. Citizen science can make major contributions to informal science education by targeting participants' attitudes and knowledge about science while changing human behavior towards the environment (Crall et al., 2012). The Invaders of Texas program is a successful citizen science program in which volunteers survey and monitor invasive plants throughout Texas (Gallo & Waitt, 2011). Citizen science programs are emerging as an efficient way to increase data collection and help monitor invasive species (Newman et al., 2010). These programs are often touted as useful for advancing conservation literacy, scientific knowledge, and increasing scientific-reasoning skills among the public (Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). However, these programs show mixed results in how efficient or successful they are at educating the public about invasive species and their impacts because most of them only focus on identification or skill-building (Crall et al., 2011).

Educational programs have been put into action at the elementary school level to help increase awareness of invasive species and teach children about their impacts. In one example, fourth grade elementary students visited the Great Smoky Mountains National Park for an educational field trip that involved environmental science and education regarding ecosystems and invasive species (Farmer, Knapp, & Benton, 2007). The authors' findings suggest that one year after the experience, many students remembered what they had seen and heard and had developed a perceived pro-environmental attitude.

High schools have also implemented various teaching strategies in environmental science courses, which address the issue of invasive species. One study compared the use of constructivist learning theory methods and traditional teaching methods in an environmental education setting in high school (Dienno & Hilton, 2005), and another used project-based learning as a teaching model that combines elements from other learning strategies (Baumgartner & Zabin, 2008).

Dienno and Hilton (2005) found that the group of students exposed to constructivist teaching methods had significantly increased knowledge scores when given pre- and post-tests regarding invasive plant species, suggesting that constructivist learning theory is a good method to use for environmental education involving invasive plant species. Baumgartner and Zabin (2008) found that high school students participating in an intertidal monitoring project based on a project-based learning model increased their knowledge about the ecology of the intertidal zone, including impacts of invasive species and improved their scientific investigation skills. This model appears to be an effective way to engage students in learning about invasive species.

Vanderhoeven et al. (2011) suggest well-designed educational programs targeting particular groups could be effective tools to teach the public about invasive species. Waliczek et al. (in press) noted that college education seems to be more important in developing positive attitudes toward invasive species management. The study also found that students rate college classes as highly reliable sources of information about invasives, second only to environmental organizations. The authors called for the incorporation of invasive species biology into college curricula for these reasons. Given the need for education about invasive species at all levels, it is important that a curriculum for invasives be developed and tested to measure knowledge and attitude changes among college student populations.

III. METHODOLOGY

The purpose of this study is to determine if a lecture only curriculum and/or a lecture and laboratory curriculum increases student knowledge and/or changes student attitudes concerning invasive species.

Institutional Review Board

Dr. Tina M. Cade submitted an exemption request (EXP2015T8055334) to conduct this research project and it was approved by the Texas State Institutional Review Board. My request to use the data for this thesis was also approved (2017385).

Test Instrument

We developed an instrument to measure students' baseline level of knowledge about invasive species, as well as their attitudes toward them. The instrument consisted of a pre-test and a post-test, which were identical. The tests included Likert scale items and multiple choice questions focused on invasive species, and included both plant and animal examples. We also collected demographic data. There were a total of 37 questions and statements in the instrument (Appendix 1). We developed the questions using information obtained from the Texas invasives website (2017), the Texas Parks and Wildlife Department (2017), the U.S. Fish & Wildlife Service (2017), and a similar study instrument (Oxley et al., 2016). As recommended by Davis (1992), a panel of experts reviewed the instrument to determine validity.

Knowledge Questions

We used fifteen questions (questions 4-17, 20) to assess knowledge of invasive species. The knowledge questions were multiple choice with an option to select "I don't know." Examples of knowledge questions included "How many invasive species occur in the U.S.?," "Which of the following is an example of an invasive plant found in Texas?," and "Which of the following invasive animal species was unintentionally introduced into the continental U.S.?" We assigned each multiple choice question a value of one point. Correct answers (Appendix 2) received one point and incorrect answers including "I don't know," did not receive a point. There was a possible perfect score of fifteen points, with higher scores indicating more knowledge. I coded the answers to record the students' choices.

Attitude Items

We used five questions (questions 1-3, and 18-19) and ten statements (statements 21-30) to assess student attitudes toward invasive species (Appendix 1). The five questions measuring student attitudes were multiple choice or yes/no answers. The ten statements were ranked responses 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. Examples of attitude questions included, "How informed do you think you are about invasive species?," "Which of the following methods do you believe would be the best to control an invasive animal species?," and "Which of the following methods do you believe would be the best to control an invasive plant species?". Examples of attitude-related Likert statements included "I know how I can help stop the spread of invasive species," "Controlling some invasive species is necessary to help conserve the environment," and "Invasive species should be controlled when they cause damage to agricultural crops." I coded the answers to record the students' choices.

Demographics Questions

The test instrument included seven demographic questions (questions 31-37) (Appendix 1). Demographic information collected included gender, age, ethnicity, academic classification, major, international student status, and membership in environmental/conservation groups. We used the demographic data to determine similarity between students at Texas State University and Austin Community College, as well as the samples' similarity to the overall population of these schools. I collected the demographic information for Texas State University and Austin Community College by visiting their websites online.

Test Administration

We administered the pre-test and post-test in the 2016 spring semester. At least two weeks elapsed between the administration of the pre-test and the post-test in each course. Only researchers administered the tests, and we offered an incentive of extra credit points to each participant. The survey length was such that, on average, students spent 10-15 minutes completing the test instrument. The instrument was administered in Modern Biology II (BIO 1421), Economic Botany (BIO 3406), Organic Gardening (AG 3308), and Woody Plants (AG 3305) classes at Texas State University, as well as Biology Fundamentals (BIOL 1308), Human Physiology (BIOL 2305), and Introduction to Anatomy and Physiology (BIOL 2404) at Austin Community College. Not every respondent answered every single question.

Treatment Groups

There were three groups of respondents. One group received a lecture and laboratory curriculum between the pre-test and post-test (the lecture and laboratory treatment group); one group received a lecture between the pre-test and post-test (the lecture only treatment group), and one group received no instruction between tests (the control group). The lecture and laboratory treatment group (n=42) consisted of the Economic Botany lecture and laboratory sections. The lecture only treatment group (n=105) consisted of Modern Biology II, Woody Plants, and Organic Gardening. The control group (n= 50) consisted of Biology Concepts, Human Physiology, and Introduction to Anatomy and Physiology.

Curriculum

The curriculum we delivered to the students between pre-and post-tests included information on both invasive plants and animals in Texas, the U.S., and other countries. The lecture we presented was a PowerPoint presentation (Appendix 3). We presented the same PowerPoint to the lecture only group and the lecture and laboratory group. The curriculum addressed such issues as defining what an invasive species is, giving examples of intentional vs. unintentional introduction of invasive species, and cost of invasive species management plans. Other topics addressed included how to report an invasive species when spotted, appropriate agencies and organizations to report invasive species to, and general biological characteristics of invasive species.

The laboratory curriculum, delivered exclusively to the lecture and laboratory group, included several pedagogical techniques including a case study, a scavenger hunt, and a chart visual aid to help students understand invasive plant and insect species (Appendix 4). I designed the case study to adhere to the standards set forth by the National Center for Case Study Teaching in Science (2017). It featured two plant species that students were to identify as either invasive or native, and explain their reasoning for their answers, as well as what agency or organizations they could report the species to if necessary. The scavenger hunt led students on a walk to find invasive species on campus. This could be modified by showing the students pictures of invasive species instead. The visual chart aid addressed invasive insect species and their mouthparts, as well as how to identify an invasive insect that does damage to agricultural crops using mouthparts and leaf damage characteristics (E. Arnold, personal communication, Aug. 8, 2016)

Data Analysis

I ran a repeated measures ANOVA to determine if the difference between pre- and post-test scores were significantly different for each treatment group. I calculated the reliability of the knowledge portion of the instrument using Cronbach's alpha and found that it was reliable (α=0.804). I conducted an independent samples t-test to compare post-test knowledge scores between the lecture only and lecture and laboratory treatment groups. I then used frequency counts to compare answers between the pre-test and post-test for each treatment group on question 18 ("Which of the following methods do you believe would be the best to control an invasive animal species?") and question 19 ("Which of the following methods do you believe would be the best to control an invasive plant species?"). I performed exploratory factor analysis (EFA) to determine what factor(s), if any, the Likert scale attitude items were addressing. After identifying and naming the factor, I computed average scores on the items for that factor for each participant, and performed a repeated measures ANOVA to determine differences in factor scores among the three treatment groups. Reliability was calculated for the attitude factor using Cronbach's alpha and resulted in an adequate level of reliability at (α=

0.823) (Gall, Gall, & Borg, 2007). Three Likert scale items (23, 26, and 30) did not load onto the factor that was identified, so I used repeated measures ANOVAs again to determine significant changes in the answers to these questions between pre- and post-test for each treatment group. I then separated the ANOVAs that were significant and ran independent samples t-tests between the lecture only and the lecture and laboratory treatment groups on their pre-test scores. If those were not significantly different, I repeated the process for post-test scores to determine if the type of treatment had a significant effect on post-test attitude scores.

Samples

Target Population

The target population consisted of Texas State University and Austin Community College students. Texas State had a total of 38,808 students enrolled in Spring 2016. At the time of the study, 58% of the student population was female and 42% was male. Fourty-eight percent of students were Caucasian, 35% were Hispanic, 11% were African-American, and 5% consisted of students of Other descent. At Austin Community College, the total enrollment was 41,543 students. At the time of the study, 54.92% were female and 45.08% were male. The student population consisted of 44.54% Caucasian students, 35.72% Hispanic students, 7.37% African-American students, 5.23% Asian students and 7.14% students of Other descent. I collected the demographic information for the target populations using the Austin Community College and Texas State University websites.

Overall Sample

The sample was reasonably representative of the target population. Sixty-nine percent (135) of the respondents identified as female and 31% (62) as male. The sample was of primarily a traditional college student age with 93% (184) being in the 18-34-year-old range, 5.6% (11) were in the 35-44 age range, and 1% (2) were in the 45-54 age range. Forty-two percent (83) were Caucasian, 38% (74) Hispanic, 10% (20) African American, 3% (6) Asian and 7% (14) of Other descent. The sample was approximately distributed amongst grade classifications. Thirteen percent (26) of respondents were freshman, 30% (60) sophomores, 18% (36) juniors, 33% (65) seniors and 4.5% (9) graduate students. Two (1%) international students responded. Most students (88%, 174) said they were not part of any school, community or national environmental organization, while 11% (21) did claim an association with a group of this kind.

Control Group Sample

The control group consisted of 88% (44) females and 12% (6) males. Most respondents were in the 18 to 34 age range (82%, 41), 14% (7) were in the 35-44 age range, and 4% (2) were 45-54 years old. Forty-two percent (21) were Caucasian, 36% (18) were Hispanic, 8% (4) were African American, and 7% were of Other descent. Most students (56%, 28) were sophomores, with 10% (5) freshman, 12% (6) juniors, 2% (1) seniors, and 18% (9) graduate students. One student (2%) chose not to answer the classification question. Most students (88%, 44) indicated they were not part of any school, community or national environmental organization, while 8% (4) did claim an association with a group of this kind, and 4% (2) of students chose not to answer this question.

Lecture-Only Treatment Group Sample

The lecture-only treatment group consisted of 61% (64) females and 39% (41) males. Most respondents (96.2%, 101) were in the 18-34-year-old age range, and 3.8% (4) were in the 35-44 age range. In terms of ethnicity, 43.8% (46) were Caucasian, 38% (40) were Hispanic, 8.6% (9) were African American, 5.7% (6) were of Other descent and 3.8% (4) were Asian. Among respondents, 30.5% (32) were sophomores, 26.7% (28) were juniors, 22.9% (24) were seniors and 20% (21) were freshman. Most students (85.7%, 90) indicated they were not part of any school, community or national environmental organization, while 14.3% (15) did claim an association with a group of this kind.

Lecture and Laboratory Treatment Group Sample

The lecture and laboratory treatment group consisted of 64.3% (27) females, and 35.7% (15) males, all of whom (100%, 42) were 18 to 34 years of age. In terms of ethnicity, 38.1% (16) were Caucasian, 38.1% (16) were Hispanic, 16.7% (7) were African American, 4.8% (2) were Asian, and 2.4% (1) were of Other descent. Most students (95.2%, 40) were juniors, and 4.8% (2) were seniors. No students (100%, 42) reported being part of any school, community or national environmental organization.

IV. RESULTS

Knowledge of Invasive Species

Control Group Knowledge

The control group (n=50), which did not receive any curricula between pre- and post-test, had a mean score of 1.5 on the pre-test and 1.7 on the post-test out of a possible 15 points. The descriptive data indicate that the group did not improve their scores. When asked the question "How informed do you think you are about invasive species?," on the pre-test most students indicated they felt they were "not very well informed" (50%, 25) or "not informed at all" (38%, 19). On the post-test again most students answered "not very well informed" (44%, 22) or "not informed at all" (48%, 24).

Lecture-Only Treatment Group Knowledge

The mean knowledge score for the lecture-only treatment group (n=105) was 3.9 on the pre-test and 8.0 on the post-test. The instructional intervention in the form of a lecture curriculum apparently improved the group's knowledge of invasive species. When asked the question "How informed do you think you are about invasive species?," on the pre-test most students indicated they felt they were "somewhat well informed" (37%, 39) or "not very well informed" (46%, 48). On the post-test, most students answered "somewhat well informed" (73%, 77) or "very informed" (17%, 18). These results indicate a shift in confidence of knowledge in students.

Lecture and Laboratory Treatment Group Knowledge

The lecture and laboratory treatment group (n=42) had a mean score of 3.9 on the pre-test and 9.6 on the post-test. When asked the question "How informed do you think you are about invasive species?," on the pre-test most students indicated they felt they were “somewhat well informed” (57%, 24) or “not very well informed” (40%, 17). On the post-test, all students answered “somewhat well informed” (79%, 33) or “very informed” (21%, 9).

Comparison of Knowledge among Treatment Groups

A total of 197 respondents completed the pre-and post-test. The repeated measures ANOVA indicated that all three groups were significantly different in regards to change in knowledge scores (see Figure 1). There was a significant effect of type of treatment on pre- and post-test scores (Wilks' Lambda= 0.625, F [2,194] = 58.25, $P <$ 0.001) (see Table 1). The independent samples t-test indicated a significant difference in post-test knowledge scores for lecture only (M= [8.02], SD= [3.24]) and lecture and laboratory treatment groups (M=[9.62], SD= [1.75]); t (145)= -3.02 , P<0.001). The mean score on the pre-test for the lecture-only group was 3.90 and lecture and laboratory group was 3.88 points. On the post-test, the increase in mean score in the lecture-only treatment group was 4.12 points (3.90 to 8.02) and the increase in mean score in the lecture and laboratory treatment group was 5.74 points (3.88 to 9.62). Both a lecture-only curriculum and a lecture coupled with a laboratory curriculum appear to be feasible and appropriate learning interventions to increase student knowledge about invasive species. However, since the lecture and laboratory treatment group's mean post-test score was significantly greater than the lecture-only treatment group's mean post-test score, the combination of a lecture and a hands-on laboratory should be considered a more successful type of instruction.

Opinions of Invasive Species Control Methods

Control Group Opinions of Control Methods

Control group opinions of invasive animal species control methods shifted between the pre- and post-test (see Figure 2). Question 18 asked, "Which of the following do you believe would be the best to control an invasive animal species?" More students chose to respond "I don't know," on the post-test (44%, 22) when compared to responses on the pre-test (32%, 16). The number of students reporting "shooting" as their answer increased from 2% (1) on the pre-test to 14% (7) on the post-test. Poisoning decreased from 2% (1) on the pre-test to 0 on the post-test, and the answer "trapping and relocating" decreased from 60% (30) on the pre-test to 42% (21) on the post-test. The answer "take no action" decreased from 4% (2) on the pre-test to 0 on the post-test.

Considering the question "Which of the following do you believe would be the best to control an invasive plant species?" there were also changes in opinion from the pre-test to the post-test (see Figure 3). The percentage of students answering "herbicides" decreased from 14% (7) on the pre-test to 10% (5) on the post-test, and those answering "manual removal" also decreased from 28% (14) on the pre-test to 24% (12) on the post-test. The answer "dredging" decreased from 10% (5) on the pre-test to 6% (3) on the post-test. The percentage of the answer "take no action" stayed the same at 2% (1). The only answer that increased in frequency was "I don't know" which changed from 46% (23) on the pre-test to 58% (29) on the post-test.

Lecture-Only Treatment Group Opinions of Control Methods

Before the administration of the curriculum, in the lecture only group, student responses regarding methods that would be the best to control an invasive animal species were “trapping and relocating” (71.4%, 75), “I don’t know” (15.2%, 16), “poisoning” (5.7%, 6), “take no action” (4.8%, 5), and “shooting” (2.9%, 3). After receiving the curriculum, fewer students replied “I don’t know” (3.8%, 4) and fewer students selected “take no action” (3.8%, 4). A greater number of students selected fatal control measures such as “shooting” (25%, 26) (see Figure 4).

A shift also occurred with invasive plant species management in the lecture only group (see Figure 5) when asked “Which of the following methods do you believe would be the best to control an invasive plant species?” student responses on the pre-test were “manual removal” (38.1%, 40), “I don’t know” (33.3%, 35), “herbicides” (14.3%, 15), “dredging” (7.6%, 8), and “take no action” (2%, 1). After receiving the curriculum, there was a decrease in those selecting “I don’t know” (7.6%, 8) and “take no action” (3.8%, 4). There was also an overall increase in acceptance of all control methods. Post-test responses were “manual removal” (59%, 62), “herbicides” (19%, 20), and “dredging” (10.5%, 11).

Lecture and Laboratory Treatment Group Opinions of Control Methods

In the lecture and laboratory group, when asked “Which of the following methods do you believe would be the best to control an invasive animal species?,” there was a shift of opinions (see Figure 6). Before the curriculum, student responses were “trapping and relocating” (66.7%, 28), “shooting” (11.9%, 5), “poisoning” (7.1%, 3), “take no action” (7.1%, 3) and “I don’t know (7.1%, 3). After receiving the curriculum, the number of students selecting “shooting” increased (31%, 13). No students selected “take no action” or “I don’t know”.

In the lecture and laboratory treatment group when students were asked "Which of the following methods do you believe would be the best to control an invasive plant species?" pre-test answers consisted of 5% (3) "take no action," and "I don't know," 17% (8) "herbicides,", 9% (4) "dredging," and 64% (27) "manual removal." On the post-test, the frequencies changed to 2% (1) "take no action," 24% (10) "dredging," 38% (16) "herbicides," 36% (15) "manual removal," and no answers of "I don't know."

Attitudes about Control of Invasive Species

An exploratory factor analysis to determine which Likert items on the attitude portion of the instrument were related to one another showed seven of the ten items loaded onto a single factor that I termed "Appreciating and Understanding Impacts of Invasive Species" (see Table 2). The other three items (23, 26, and 30) did not load onto a factor and were analyzed separately. A repeated measures ANOVA revealed that changes in the "Appreciating and Understanding Impacts of Invasive Species" attitude factor were significant among all three groups (see Table 3). The control group scores decreased slightly for the attitude factor between the pre- and post-test, but this change was not significant. However, the lecture only and the lecture and laboratory treatment group scores for the attitude factor both increased significantly ($P < 0.001$) after their respective treatments were administered (see Figure 8).

Items 23, 26, and 30 did not load onto a factor at all. Item 23 on the instrument states, "I know how to report an invasive species that I encounter to the proper authorities." A repeated measures ANOVA to determine if there was a significant difference in mean scores among the three groups for this question indicated that there was (see Table 4) ($P < 0.001$). Both the lecture only and lecture and laboratory treatment groups increased in their average score, while the control group remained the same (see Figure 9). The lecture and laboratory treatment group did not have a significantly different pre-test score when compared to the lecture only treatment group pre-test score ($P = 0.586$), but they did increase their score significantly more than the lecture only group on the post-test ($P < 0.001$).

Item 26 states, “All invasive species should be completely removed from the environment.” The repeated measures ANOVA for this question also revealed a significant difference ($P = 0.020$) among the three groups (see Table 5). Both treatment groups increased their mean scores for this question on the post-test, but the control group did not increase significantly (see Figure 10). The lecture and laboratory treatment group did not have significantly different pre-test scores for item 26 (P = 0.716). This group also did not increase their score significantly over the lecture only treatment group ($P = 0.473$).

Item 30 states, “Invasive species should be controlled only when they threaten human health.” The ANOVA for this item revealed a different result than the previous items. There was no significant difference ($P = 0.592$) among the three groups for this item between the pre- and post-test (see Table 6). All three groups increased their agreement with this item on the post-test (see Figure 11).

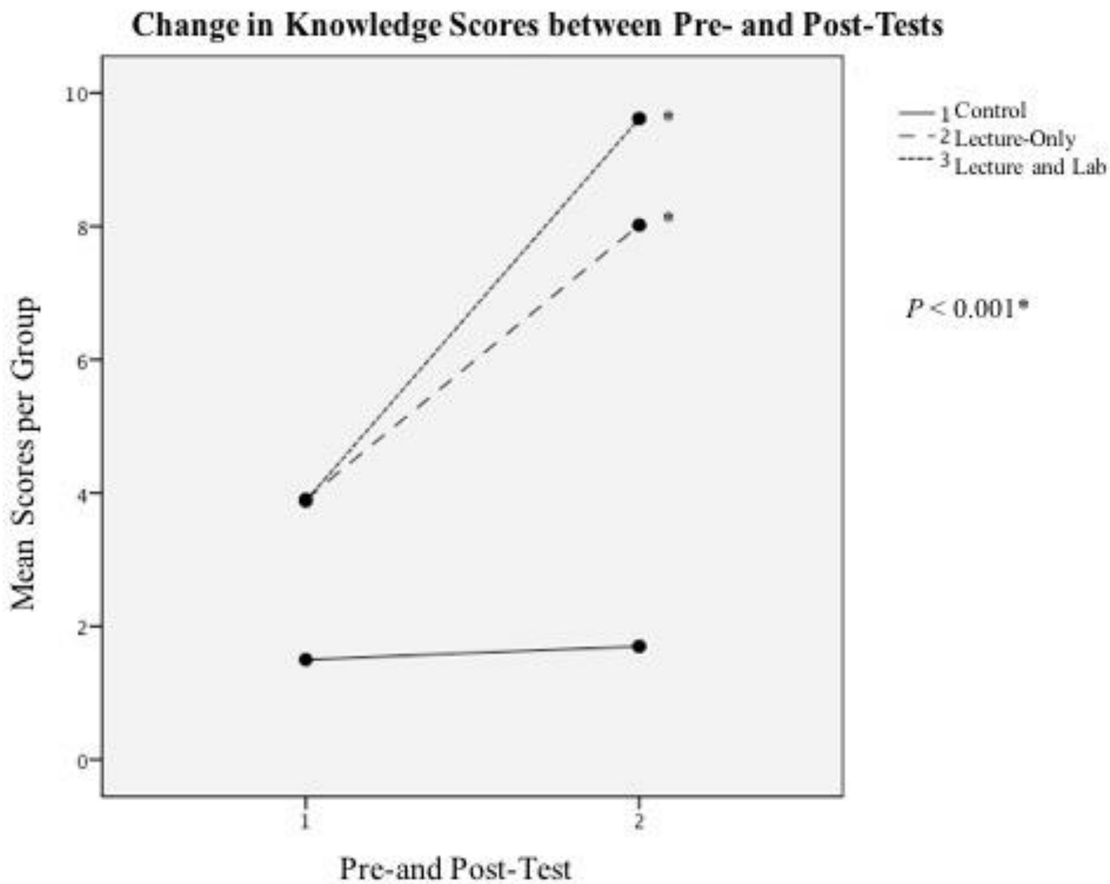
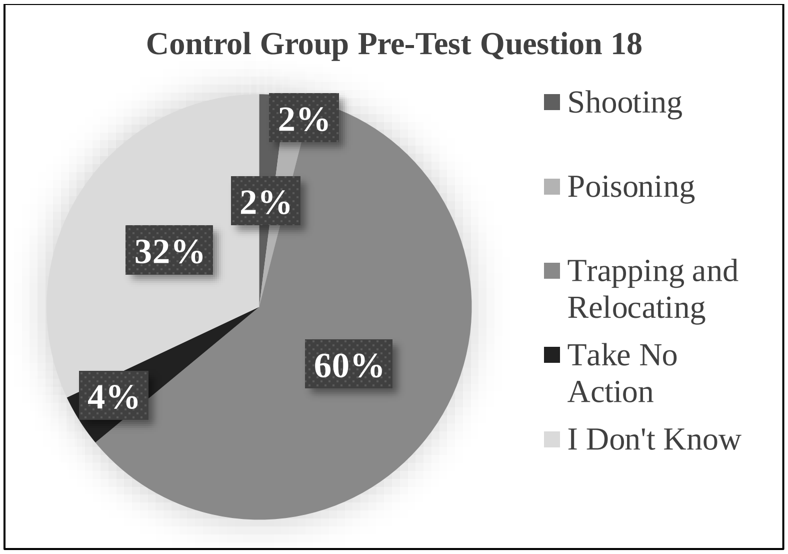


Figure 1. Results of repeated measures ANOVA to determine change in knowledge mean scores for each treatment group. * * represents significantly different post-test scores at the $P < 0.05$ level. * represents significance at the $P < 0.05$ level.



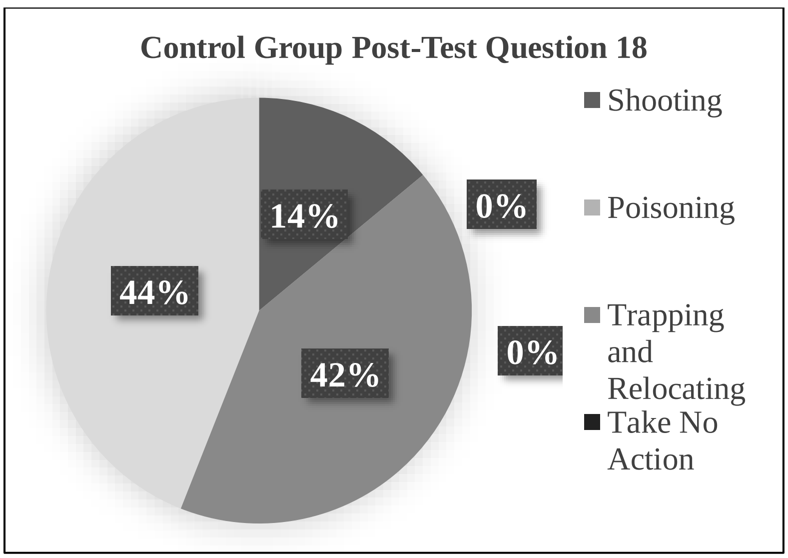


Figure 2. Comparison of control group opinions regarding invasive animal species control methods.

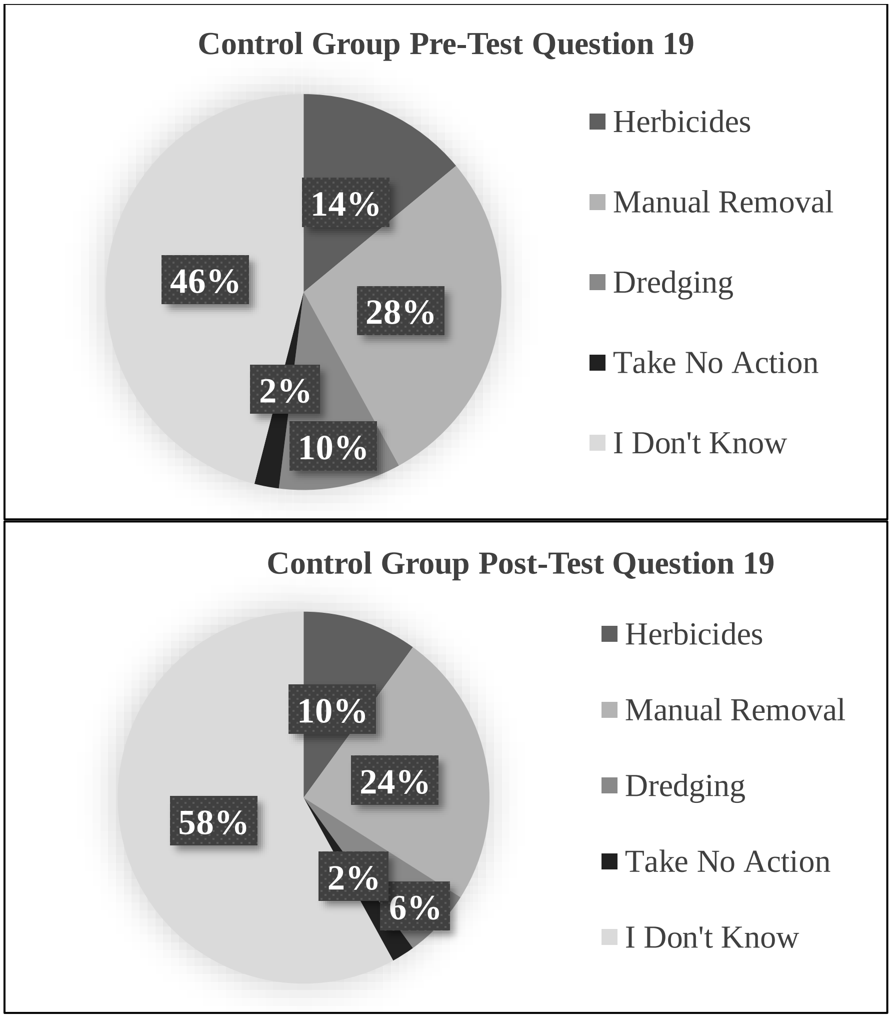


Figure 3. Comparison of control group opinions regarding invasive plant species control methods.

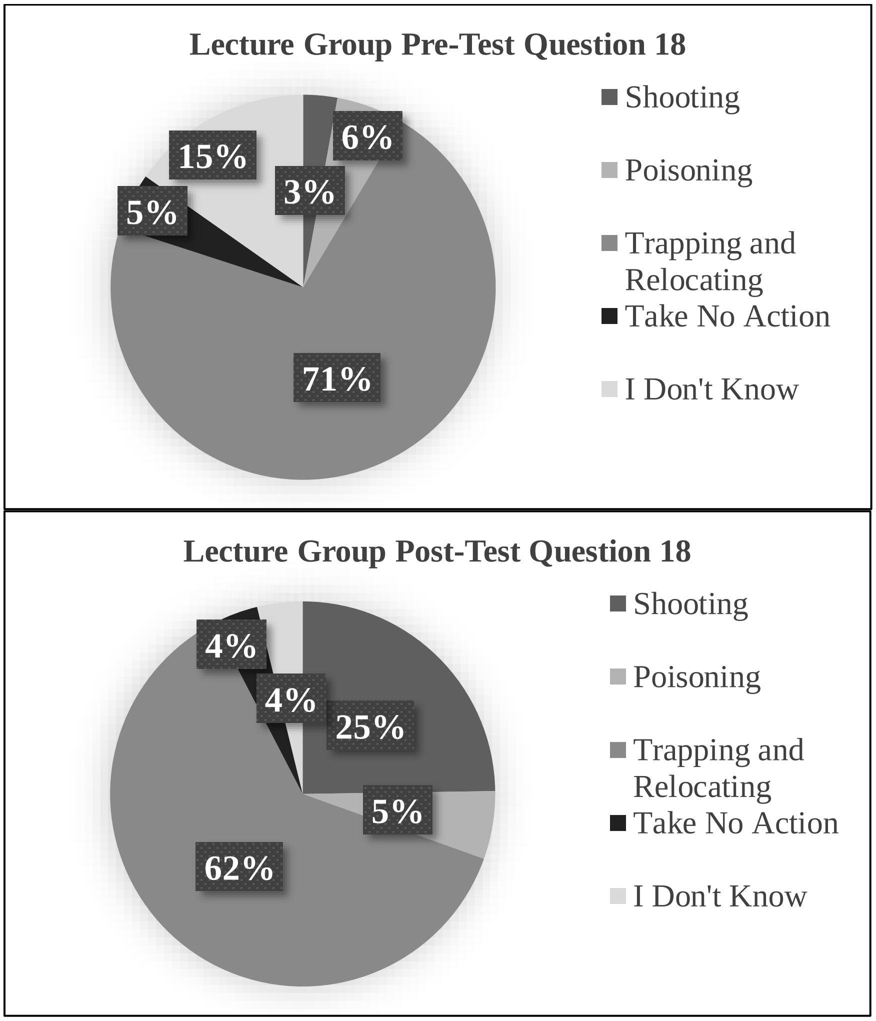


Figure 4. Comparison of lecture only treatment group opinions regarding invasive animal species control methods.

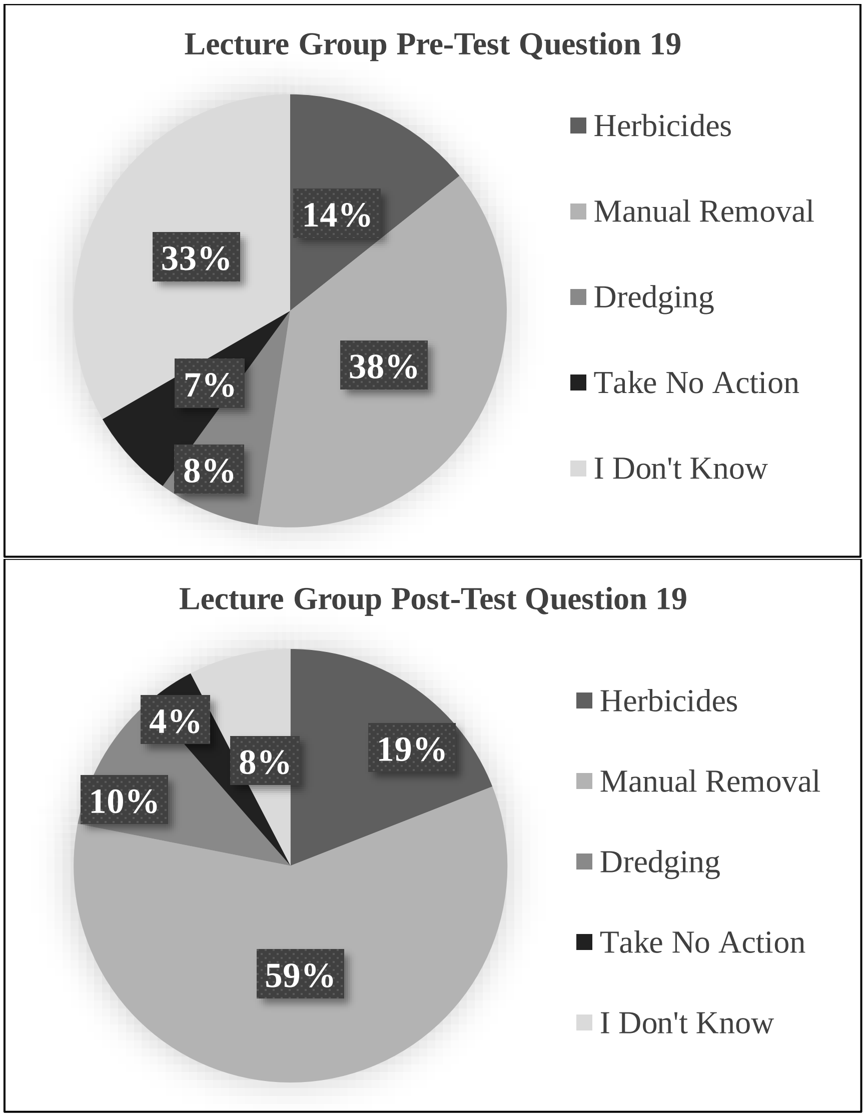
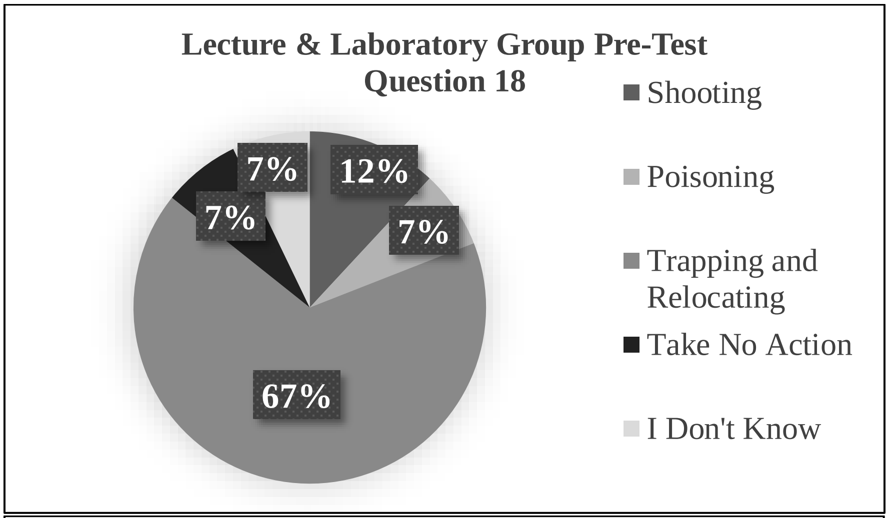


Figure 5. Comparison of lecture only treatment group opinions regarding invasive plant species control methods.



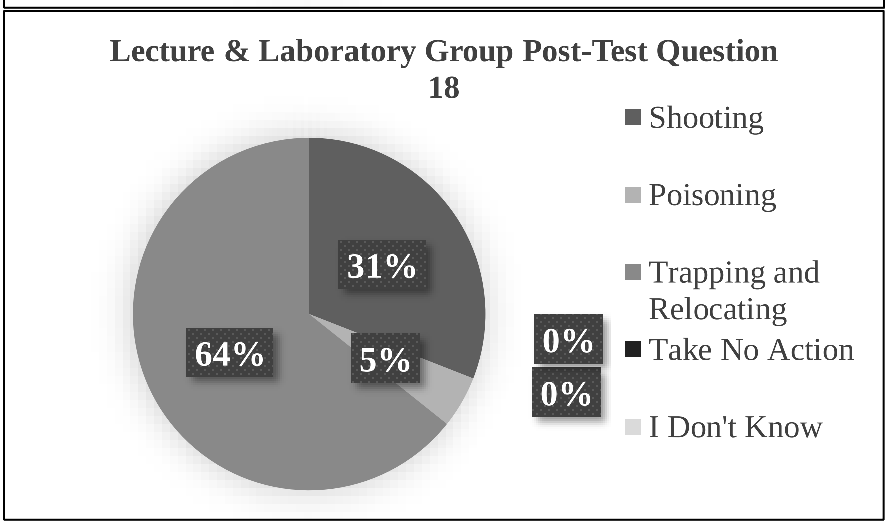


Figure 6. Comparison of lecture and laboratory treatment group opinions regarding invasive animal species control methods.

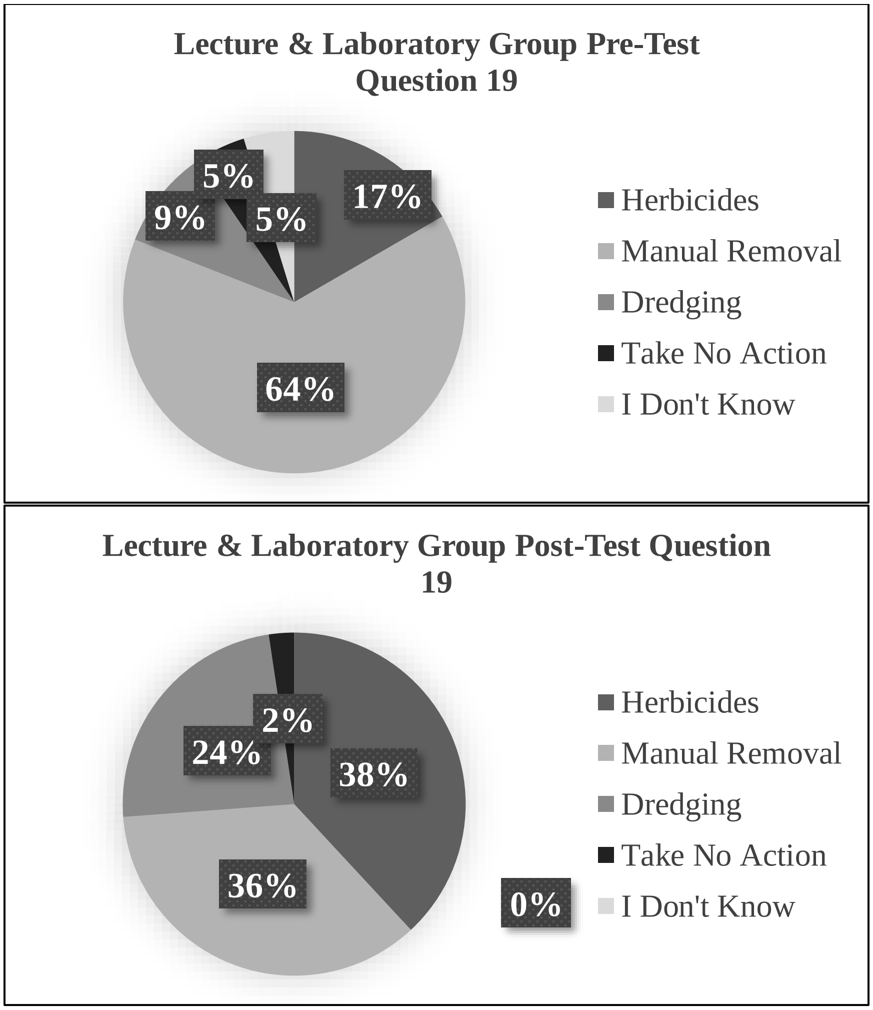


Figure 7. Comparison of lecture and laboratory treatment group opinions regarding invasive plant species control methods.

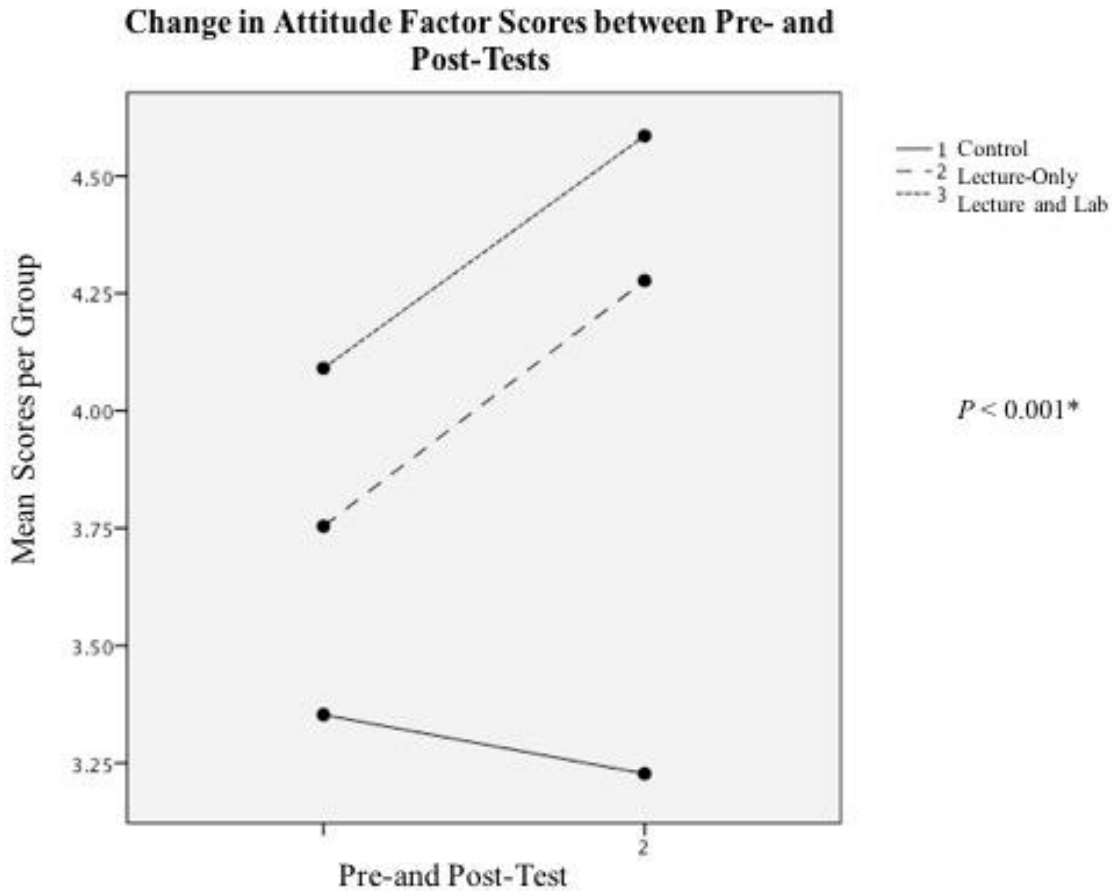


Figure 8. Results of repeated measures ANOVA to determine change in attitude factor mean scores for each treatment group. * represents significance at the $P < 0.05$ level.

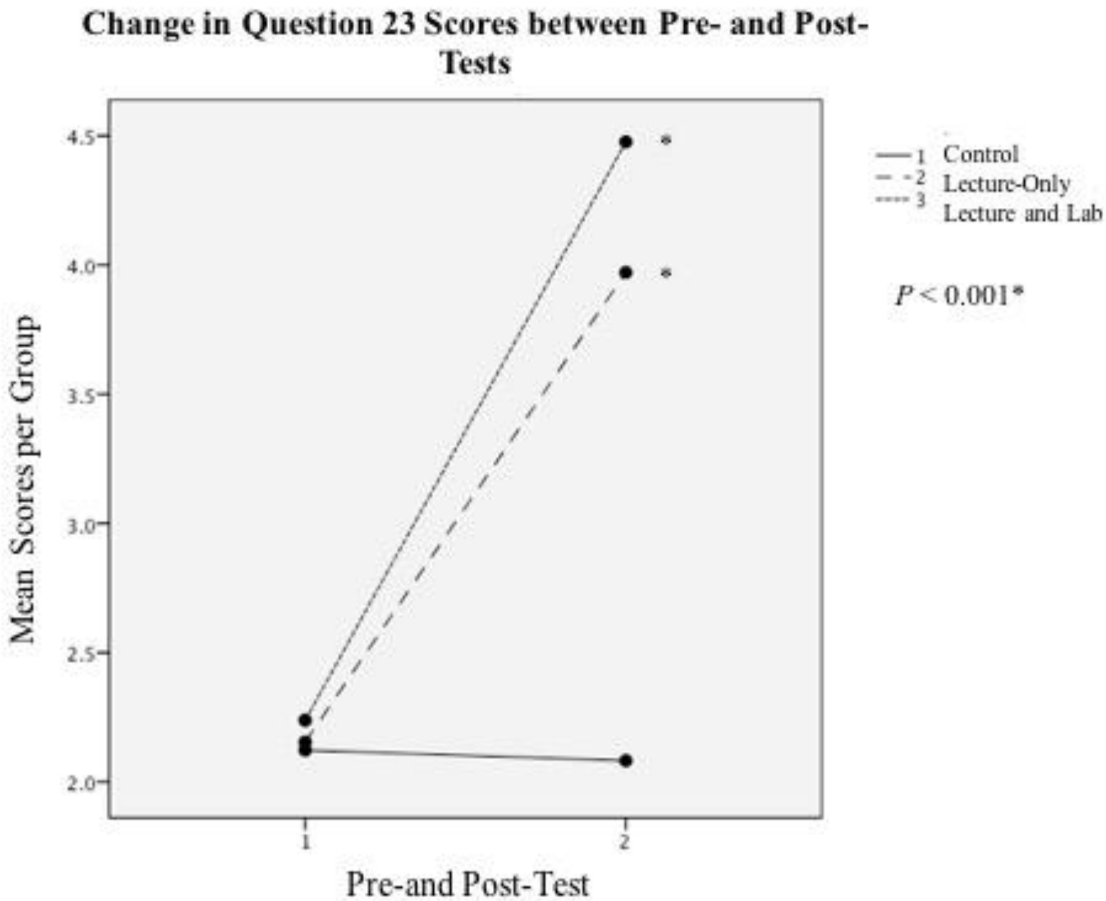


Figure 9. Results of repeated measures ANOVA to determine change in Question 23 mean scores for each treatment group. * * represents significantly different post-test scores at the $P < 0.05$ level. * represents significance at the $P < 0.05$ level

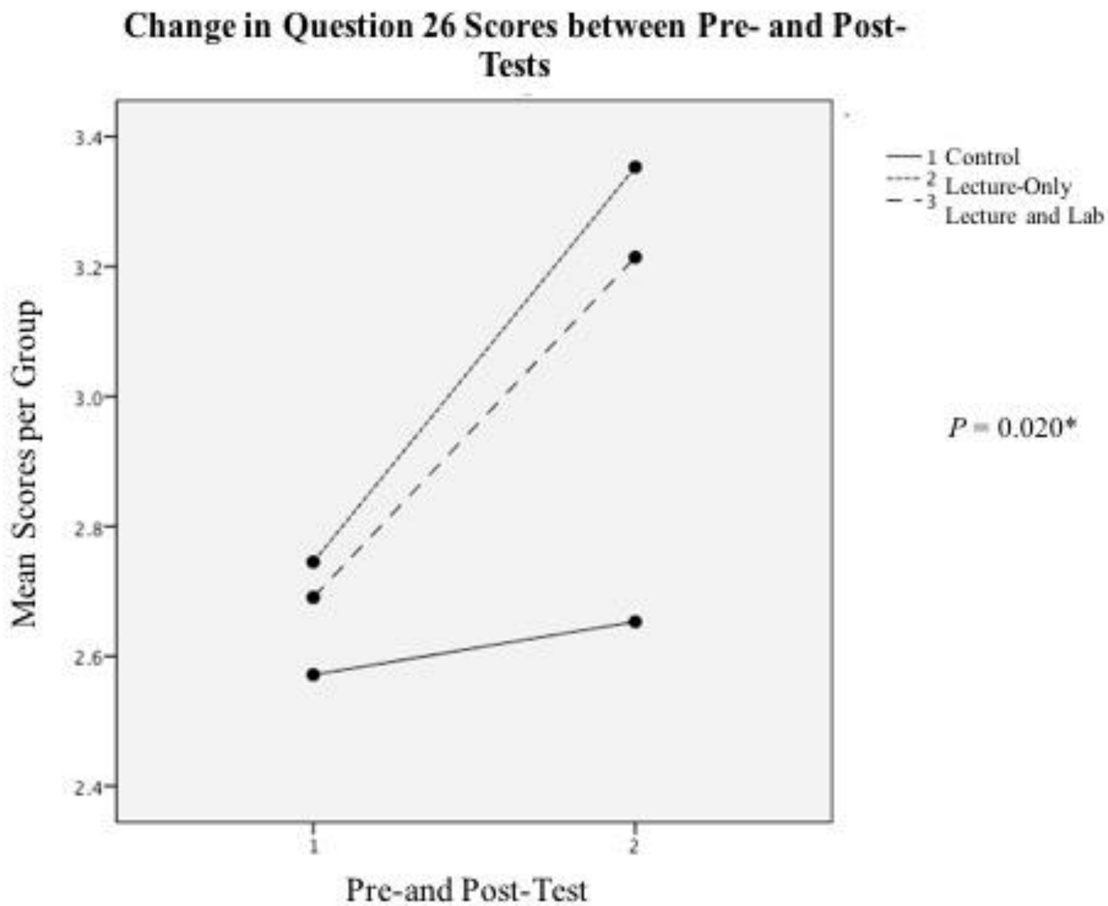


Figure 10. Results of repeated measures ANOVA to determine change in Question 26 mean scores for each treatment group. * represents significance at the $P < 0.05$ level.

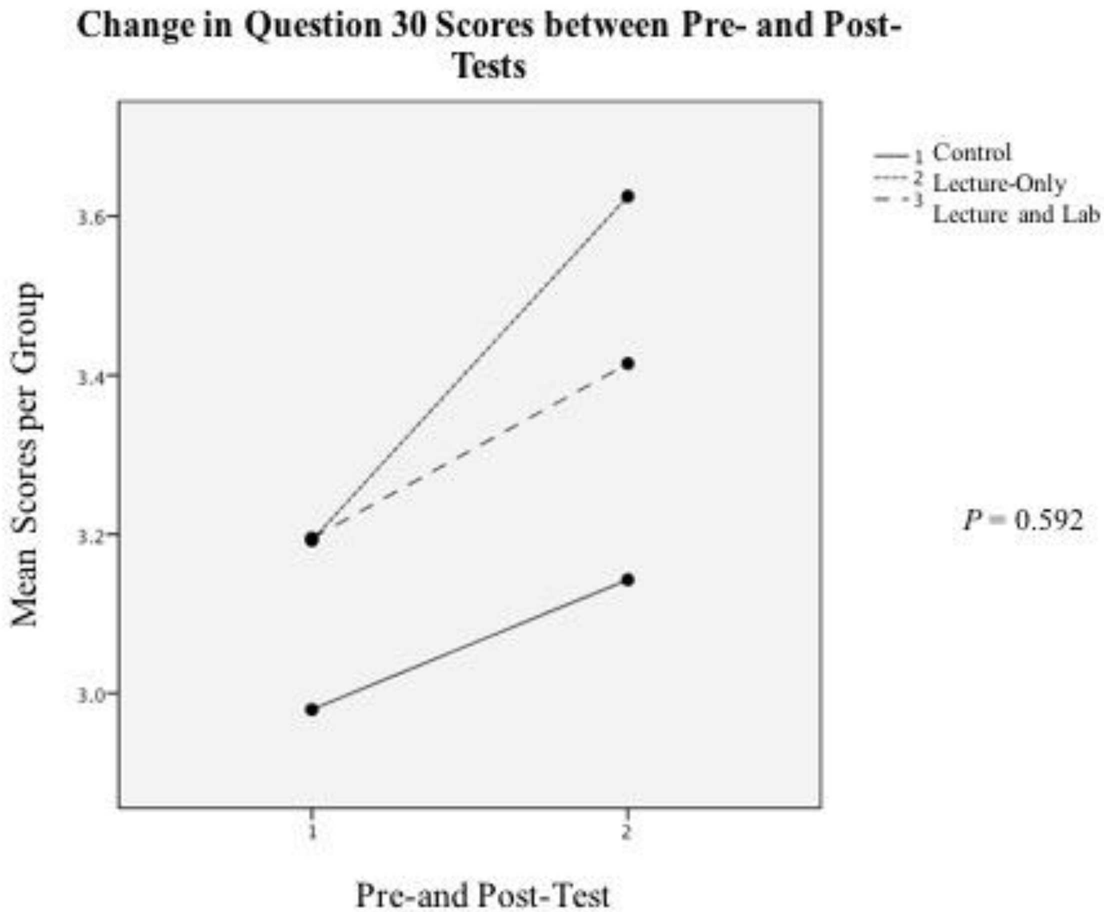


Figure 11. Results of repeated measures ANOVA to determine change in Question 30 mean scores for each treatment group.

Table 1.

Repeated Measures ANOVA for Knowledge Scores among Treatment Groups at Pre-test and Post-test Time Points

Effect	*MS*	*df*	*F*	*P*	Greenhouse-Geisser	Huynh-Feldt
Time	947.35	1	277.88	<0.001	<0.001	<0.001
Time x Treatment Group	198.57	2	58.25	<0.001	<0.001	<0.001
Error	3.41	194				

Note. P is significant at 0.05

Table 2.

*Factor Loadings and Communalities based on Principal Axis Factoring for Seven Items from the Invasive Species Knowledge and Attitudes Instrument (*N*=197)*

Questions	Appreciating and Understanding Impacts of Invasive Species	Communalities
I know how species can be introduced from their native ecosystem into a new one.	0.518	0.268
I know how I can help stop the spread of invasive species.	0.473	0.224
Protecting the environment from invasive species is important to me.	0.566	0.320
Controlling some invasive species is necessary to help conserve the environment.	0.744	0.553
Invasive species should be controlled when they cause economic damage to the environment.	0.708	0.501
Invasive species should be controlled when they cause damage to agricultural crops.	0.708	0.502
Invasive species should be controlled when they cause damage to rare or endangered species.	0.802	0.644

Table 3.

Repeated Measures ANOVA for Attitude Factor among Treatment Groups at Pre-test and Post-test Time Points

Effect	*MS*	*df*	*F*	*P*	Greenhouse-Geisser	Huynh-Feldt
Time	7.26	1	40.05	<0.001	<0.001	<0.001
Time x Treatment Group	7.46	2	20.57	<0.001	<0.001	<0.001
Error	0.18	187				

Note. *P* is significant at 0.05

Table 4.

Repeated Measures ANOVA for Question 23 among Treatment Groups at Pre-test and Post-test Time Points

Effect	*MS*	*df*	*F*	*P*	Greenhouse-Geisser	Huynh-Feldt
Time	149.69	1	201.65	<0.001	<0.001	<0.001
Time x Treatment Group	37.25	2	50.18	<0.001	<0.001	<0.001
Error	0.74	192				

Note. P is significant at 0.05

Table 5.

Repeated Measures ANOVA for Question 26 among Treatment Groups at Pre-test and Post-test Time Points

Effect	*MS*	*df*	*F*	*P*	Greenhouse-Geisser	Huynh-Feldt
Time	13.63	1	23.27	<0.001	<0.001	<0.001
Time x Treatment Group	2.35	2	4.02	0.02	0.02	0.02
Error	0.585	190				

Note. P is significant at 0.05

Table 6.

Repeated Measures ANOVA for Question 30 among Treatment Groups at Pre-test and Post-test Time Points

Effect	*MS*	*df*	*F*	*P*	Greenhouse-Geisser	Huynh-Feldt
Time	6.11	1	4.38	0.038	0.038	0.038
Time x Treatment Group	0.74	2	0.53	0.59	0.59	0.59
Error	1.40	191				

Note. P is significant at 0.05

V. DISCUSSION

Several authors suggest negative attitudes towards invasive species control methods become obstacles to managing invasive species (Andreu, Vila, & Hulme, 2009; Bardsley & Edward-Jones, 2006; Marshall et al., 2011; Shine & Doody, 2011). Waliczek, McFarland & Holmes (2016) point out that higher education can influence college students' attitudes toward environmental issues. Public education plays a vital role in developing positive attitudes and securing support for invasive species management (Bremner & Park, 2007; García-Llorente et al., 2008; Oxley et al., 2016). The college classroom has been suggested as a useful resource for educating students about invasive species biology, although it has been underutilized (Waliczek et al., in press, "College student knowledge and perceptions of invasive species").

Our results indicate the curricula delivered to college students in this study were effective at increasing student knowledge about invasive species. Both the lecture only and the lecture and laboratory treatment groups showed a significant improvement in knowledge following the learning intervention, while the control group that was not exposed to a curriculum did not exhibit an increase in knowledge scores. Additionally, the lecture and laboratory group performed significantly better on the post-test when compared to the lecture only group.

One of the seven principles for good practice in undergraduate education is emphasizing time on task (Chickering & Gamson, 1987). One possible explanation for the lecture and laboratory group exhibiting significantly higher post-test knowledge scores is that they had more time on task. Since the lecture and laboratory group spent an additional two hours learning about invasive species in the laboratory setting, this increased time on task may have resulted in higher knowledge scores.

Another explanation is that active learning techniques were the primary influencer of student outcomes (Freeman et al., 2014; Taraban, Box, Myers, Pollard, & Bowen, 2007; Prince, 2004). The laboratory curriculum in our study used hands on techniques that could be categorized as active learning. Taraban et al. (2007) found that active-learning–based laboratory units can lead to enhanced content knowledge and process learning for students. Prince (2004) found that different techniques in active learning had different levels of effectiveness in improving student learning outcomes, but across the board all techniques improved student achievement more than the traditional lecture setting.

The combination of active learning techniques and time on task together may better explain the increased performance by the lecture and laboratory treatment group. Astin (1984) suggested that student involvement in general is a key factor in learning outcomes, and that this aspect involves both a quantitative time-based element and a qualitative element related to the amount of effort the student expends. The quantitative element in this situation is time on task, and the qualitative element would be increased student engagement due to active learning techniques that capture and hold their attention.

Kidron & Lindsay (2014) conducted an analysis of 30 educational studies for K-12 math and reading students that involved increasing instruction time beyond that of the regular school day in various ways. They found certain programs that included hands-on activities, project-based learning, and field trips consistently increase student learning outcomes. The laboratory exercise delivered in our study included a scavenger hunt, which equates to a field trip. The laboratory also included a case study that was project-based. The variety of learning methods and hands-on laboratory instruction in addition to increased time on task appeared to have affected students' learning positively.

Our curricula also influenced student opinions and attitudes regarding control methods of invasive species. Frequency counts of answers to the questions asking the best methods to control animal and plant invasive species (questions 18 and 19), revealed in both treatment groups the frequency of the answer "I don't know," decreased on the post-test. This suggests an increased confidence in their knowledge of appropriate control methods.

Attitudes toward lethal control methods tend to be value-based and formed early on in life (Treves & Naughton-Treves, 2005). This can be particularly problematic in the case of trying to control invasive species. Bertolino and Genovesi (2003) cited an entire eradication plan failing due to an animal rights group filing a lawsuit against the National Wildlife Institute for using lethal control methods against American grey squirrels. Results of our study indicate that the more educated a population is regarding lethal control methods, the more accepting they are of such methods.

Considering the question regarding control methods of invasive animals (question 18), on the post-test, all three groups showed an increase in respondents selecting "shooting," as an appropriate control method. Shooting was presented in the curricula as an effective method to control nutria, which might explain increased support for this control method in the two treatment groups. Although students in the control group did not receive formal instruction, F. Oxley (personal communication, May 1, 2017) indicated that some of the control group students became interested in learning more about invasives after exposure to the pre-test. If they chose to do more research on their own, this could have influenced their opinions on the post-test.

Student attitudes toward invasive species were also influenced by the curricula. The shift in the attitude factor termed "Appreciating and Understanding the Impacts of Invasive Species," was significant among the three groups. The control group displayed virtually no change in attitude, while both treatment groups increased their appreciation and understanding of the impacts of invasives following the learning interventions. The scores of both treatment groups increased for this factor on the post-test. However, the lecture and laboratory treatment group started with a higher pre-test score as compared to the lecture only group. Therefore, it is not possible to attribute the higher post-test score for the lecture and laboratory group to the curriculum alone.

Different types of instruction have been found to have varying effects on student attitudes (DiEnno & Hilton, 2005). Future studies measuring the effectiveness of different types of active learning techniques in the context of invasive species education, both in the lecture and the laboratory, would be very informative. The laboratory has long been regarded as an essential part of learning science (Hofstein, & Lunetta, 1982). Freedman (1997) also found that being involved in a laboratory results in higher science proficiency and a better attitude toward science as a discipline.

Three of the Likert items (23, 26, and 30) used to measure attitude did not load onto the "Appreciating and Understanding the Impacts of Invasive Species," factor and were evaluated separately. Item 23 stated, "I know how to report an invasive species that I encounter to the proper authorities." There was no change in attitude for this item in the control group between pre- and post-test, but both treatment groups increased their scores for this item on the post-test. This indicates that after receiving learning interventions, both treatment groups felt better prepared to report an invasive species to the proper authorities. Comparing treatment groups, the lecture and laboratory group scored significantly higher on this question on the post-test. This indicates that receiving both curricula influenced scores on this question to a greater extent when compared to receiving the lecture alone. The lecture portion of the curricula did include a segment on reporting invasive species, and the laboratory component of the curricula further emphasized appropriate methods to report invasive species. The additional reinforcement from the laboratory experience may explain the increased confidence found in the lecture and laboratory treatment group.

Our findings support the result of another study by Lee, Liu, and Yeh (2016). Their case study indicated that students involved in hands-on activities about sharks increased their attitudes toward sharks both immediately and two years after the instruction took place. Another study found that cooperative learning where students work together to complete an educational task gives them a more internal locus of control, and increases student achievement (Johnson, Johnson, & Scott, 1978). This could help explain why students who received the lecture and laboratory answered significantly higher on item 23 regarding invasive species. Receiving the laboratory curriculum may have internalized their locus of control regarding the reporting of invasives to authorities.

Item 26 stated, “All invasive species should be completely removed from the environment.” Again there was no change in attitude in the control group between pre-and post-test, but both treatment groups increased their scores for this factor on the post-test. However, when considering this question, the lecture and laboratory treatment group scores did not increase significantly more than the lecture only treatment group scores.

Verbrugge, Van den Born, & Lenders (2013) conducted a study in the Netherlands using a survey to evaluate lay-person perspective of invasive species and how involved or invested they were in eradicating invasives. They found that overall, respondents were not particularly concerned about non-native species, but that they did recognize the need for invasive species management when invasives posed a threat to nature, the economy, or human health. Item 30 in our study stated, “Invasive species should be controlled only when they threaten human health.” Although the change was not significant, the control group as well as the two treatment groups increased their positivity toward this statement on the post-test. Exposure to the federal definition of an invasive species, which specifically mentions a threat to human health, on the pre-test may have influenced student attitudes on the post-test.

Next steps should include testing different aspects of the laboratory separately to determine their individual effectiveness, incorporating a lab activity into the lecture to see the effect of active learning without the extra time on task, and testing different lecture approaches like the 5E and 3E teaching methods. The 5E instructional model is a way of organizing a lesson plan so that it includes the following 5 steps: engage, explore, explain, elaborate and evaluate (Tanner, 2010). Each of these 5 steps can be modified to use active learning techniques and can be applied to a simple lecture in order to involve the students more in the lesson. The 3E version is an abbreviated model that only includes engage, explain, and evaluate, which may be useful if lecture time is limited.

The control group did not exhibit an increase in knowledge scores, yet both the lecture only and the lecture and laboratory treatment groups showed a significant improvement in knowledge following the learning intervention. With the exception of item 30, responses to all other attitude items contained in the survey instrument changed significantly in the two treatment groups from pre-test to post-test. Attitudes of the control group did not change significantly. A study by Davis (2015) involved a pre- and post-test that took place before and after an evidence-based learning intervention about breastfeeding designed for nurses. Their results indicated that such an intervention not only improved knowledge, but also attitudes toward the subject being taught. Our findings mirror their results in attitude change and increased knowledge resulting from learning interventions.

Clearly the curricula developed in this study are effective in changing student knowledge and attitudes in varying degrees, depending upon the treatment. Our study supports previous findings (Waliczek et al., in press, "College student knowledge and perceptions of invasive species"; Smith, Bazley, & Yan, 2011) that college is an appropriate forum to increase knowledge about invasive species biology.

APPENDIX SECTION

APPENDIX A: Pre/Post-tests

TEST OF KNOWLEDGE AND ATTITUDES TOWARDS INVASIVE SPECIES

This test asks about your knowledge of invasive species and opinions about their control in the environment.

Please select the best answer to the questions below:

1. How informed do you think you are about invasive species?
a. Very well informed
b. Somewhat well informed
c. Not very well informed
d. Not informed at all

2. Did you learn about invasive species in high school?
a. Yes
b. No

3. Have you received instruction about invasive species in your college classes?
a. Yes
b. No
If yes, please list the class(es) in which you learned about invasive species.

4. What is the best definition of an "invasive species"?
a. a species whose introduction does or is likely to cause economic or environmental harm or
harm to human health
b. any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem
c. a species that, other than as a result of an introduction, historically occurred or currently
occurs in that ecosystem
d. a plant or animal out of place
e. I don't know

5. How many invasive species occur in the U.S.?
a. 1,500
b. 6,500
c. 20,000
d. 100,000
e. I don't know

6. What is the approximate cost to control invasive species and the damages they cause to property and natural resources in the U.S. annually?
a. 50 million dollars
b. 236 million dollars
c. 137 billion dollars
d. 350 billion dollars
e. I don't know

7. Which of the following is an example of an invasive plant found in Texas?
a. Live oak
b. Mountain laurel
c. Bluebonnet
d. Buffelgrass
e. I don't know

8. Which of the following is an example of an invasive animal found in Texas?
a. Brown tree snake
b. Asian zebra mussel
c. Texas horned lizard
d. Prairie dog
e. I don't know

9. Which of the following invasive animal species was intentionally introduced into the continental U.S.?
a. European starling
b. Brown tree snake
c. Asian zebra mussel
d. Red imported fire ant
e. I don't know

10. Which of the following invasive animal species was unintentionally introduced into the continental U.S.?
a. European starling
b. Brown tree snake
c. Asian zebra mussel
d. Burmese python
e. I don't know

11. Which of the following invasive species was introduced into the U.S. through the aquarium trade?
a. Asian zebra mussel
b. Purple loosestrife
c. Kudzu
d. Hydrilla
e. I don't know

12. Which of the following statements about invasive Africanized bees is correct?
a. Africanized bees were introduced into south Texas to increase honey production and have
since spread to many U.S. states
b. Africanized bees were introduced into Brazil to increase honey production and have spread
from there to the United States
c. Africanized bees were unintentionally introduced to the Americas
d. Africanized bees do not occur in Texas
e. I don't know

13. Which of the following invasive species was originally imported for the fur trade industry?
a. Nutria
b. European starling
c. Feral pig
d. Red lionfish
e. I don't know

14. Which of the following invasive species was originally introduced from Southeast Asia into the U.S. for soil stabilization?
a. Buffelgrass
b. Congograss
c. Golden bamboo
d. Elephant ear
e. I don't know

15. Which of the following is an aquatic invasive species that occurs in the San Marcos River?
a. Purple loosestrife
b. Giant salvinia
c. Water hyacinth
d. Texas wild rice
e. I don't know

16. Which of the following governmental agencies is responsible for safeguarding agriculture and natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds?
a. Unites States Fish and Wildlife Service (USFWS)
b. Texas Parks and Wildlife Department (TPWD)
c. Department of Health and Human Services (HHS)
d. Animal and Plant Health Inspection Service (APHIS)
e. I don't know

17. Which of the following is NOT a characteristic of an invasive species?
a. reproduces rapidly

b. has several natural predators in the ecosystem
c. causes or is likely to cause environmental or economic harm
d. is not native to the ecosystem in which it occurs
e. I don't know

18. Which of the following methods do you believe would be the best to control an invasive animal species?
a. shooting
b. poisoning
c. trapping and relocating
d. take no action
e. I don't know

19. Which of the following methods do you believe would be the best to control an invasive plant species?
a. herbicides
b. manual removal
c. dredging
d. take no action
e. I don't know

20. Citrus greening, which kills citrus trees, is caused by which of the following agricultural pests?
a. wasp
b. fungus
c. bacterium
d. virus
e. I don't know

For the next set of questions, please provide your opinion using the scale provided.

21. I know how species can be introduced from their native ecosystem into a new one.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

22. I know how I can help stop the spread of invasive species.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

23. I know how to report an invasive species that I encounter to the proper authorities.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

24. Protecting the environment from invasive species is important to me.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

25. Controlling some invasive species is necessary to help conserve the environment.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

26. All invasive species should be completely removed from the environment.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

27. Invasive species should be controlled when they cause economic damage to the environment.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

28. Invasive species should be controlled when they cause damage to agricultural crops.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

29. Invasive species should be controlled when they cause damage to rare or endangered species.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

30. Invasive species should be controlled only when they threaten human health.

Strongly disagree	Disagree	Not Sure	Agree	Strongly agree
1	2	3	4	5

The next set of questions asks for information about you.

31. How do you self-identify?
a. Male
b. Female
c. Different identity

32. What is your age?
a. 18-34
b. 35-44
c. 45-54
d. 55-64
e. 65 or older

33. What is your ethnicity?
a. Caucasian
b. Asian
c. Hispanic
d. African-American
e. Other

34. What is your current academic classification?
a. Freshman
b. Sophomore
c. Junior
d. Senior
e. Graduate student

35. What is your major?

36. Are you an international student?

a. Yes
b. No

If you answered **Yes**, please list your home country.

If you answered **No**, please list the **ZIP CODE** of your hometown.

37. Do you belong to any school, community, or national environmental or conservation organization(s)?
a. Yes
b. No

If yes, please list the organization(s) below.

APPENDIX B: Pre/Post-test Answer Key

Knowledge questions with correct answer shown in bold.

4. What is the best definition of an “invasive species”?
a. a species whose introduction does or is likely to cause economic or environmental harm or harm to human health
b. any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem
c. a species that, other than as a result of an introduction, historically occurred or currently occurs in that ecosystem
d. a plant or animal out of place
e. I don't know

5. How many invasive species occur in the U.S.?
a. 1,500
b. 6,500
c. 20,000
d. 100,000
e. I don’t know

6. What is the approximate cost to control invasive species and the damages they cause to property and natural resources in the U.S. annually?
a. 50 million dollars
b. 236 million dollars
c. 137 billion dollars
d. 350 billion dollars
e. I don’t know

7. Which of the following is an example of an invasive plant found in Texas?
a. Live oak
b. Mountain laurel
c. Bluebonnet
d. Buffelgrass
e. I don’t know

8. Which of the following is an example of an invasive animal found in Texas?
a. Brown tree snake
b. Asian zebra mussel
c. Texas horned lizard
d. Prairie dog
e. I don’t know
9. Which of the following invasive animal species was intentionally introduced into the continental U.S.?
a. European starling
b. Brown tree snake

c. Asian zebra mussel
d. Red imported fire ant
e. I don’t know

10. Which of the following invasive animal species was unintentionally introduced into the continental U.S.?
a. European starling
b. Brown tree snake
c. Asian zebra mussel
d. Burmese python
e. I don’t know

11. Which of the following invasive species was introduced into the U.S. through the aquarium trade?
a. Asian zebra mussel
b. Purple loosestrife
c. Kudzu
d. Hydrilla
e. I don’t know

12. Which of the following statements about invasive Africanized bees is correct?
a. Africanized bees were introduced into south Texas to increase honey production and have since spread to many U.S. states
b. Africanized bees were introduced into Brazil to increase honey production and have spread from there to the United States
c. Africanized bees were unintentionally introduced to the Americas
d. Africanized bees do not occur in Texas
e. I don’t know

13. Which of the following invasive species was originally imported for the fur trade industry?
a. Nutria
b. European starling
c. Feral pig
d. Red lionfish
e. I don’t know

14. Which of the following invasive species was originally introduced from Southeast Asia into the U.S. for soil stabilization?
a. Buffelgrass
b. Congograss
c. Golden bamboo
d. Elephant ear
e. I don't know

15. Which of the following is an aquatic invasive species that occurs in the San Marcos River?
a. Purple loosestrife
b. Giant salvinia
c. Water hyacinth
d. Texas wild rice
e. I don't know

16. Which of the following governmental agencies is responsible for safeguarding agriculture and natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds?
a. Unites States Fish and Wildlife Service (USFWS)
b. Texas Parks and Wildlife Department (TPWD)
c. Department of Health and Human Services (HHS)
d. Animal and Plant Health Inspection Service (APHIS)
e. I don't know

17. Which of the following is NOT a characteristic of an invasive species?
a. reproduces rapidly
b. has several natural predators in the ecosystem
c. causes or is likely to cause environmental or economic harm
d. is not native to the ecosystem in which it occurs
e. I don't know

20. Citrus greening, which kills citrus trees, is caused by which of the following agricultural pests?
a. wasp
b. fungus
c. bacterium
d. virus
e. I don't know

APPENDIX C: Notes for Curriculum Delivered as PowerPoint Lecture.

Impacts of Invasive Species Handout
2016

Species Terminology
Executive Order 13112

Native species

- A native species is a species that, other than as a result of an introduction, historically occurs/occurred in that particular habitat

Exotic species

- Any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that habitat
- Other terms sometimes used for exotic species include "non-native," "non-indigenous," and "alien"
-

What is an Invasive Species
Legal Definition

A species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (*Executive Order 13112*)

European Starlings Introduced in U.S.

In 1890, Eugene Schieffelin released 60 starlings he had imported from Europe into NYC Central Park
In 1891, he released 40 more
He hoped to introduce into North America every bird mentioned by Shakespeare

- Henry IV Part I
-

European Starlings are Invasive

200 million occur in U.S.
Enormous flocks reside all across North America
They displace native birds and devour crops

- Cost U.S. agriculture one billion a year in crop damage

Carry histoplasmosis
In 1960, 10,000 starlings flew into plane taking off at Logan Airport, plane crashed killing 62 people

Do All Non-native Species Become Invasive

Vast majority of introduced species do not survive in new ecosystem
Only about 15% of those that do survive go on to become invasive

How Many Invasive Species Occur in the United States

Pimentel (2004) estimated that there are 50,000 non-native species in U.S.
According to the U.S. Geological Survey (2015) there are over 6,500 invasive

species established in the U.S.
About 42% of threatened and endangered species in U.S. are at risk primarily due to invasive species

Some Introduced Species are Beneficial

European honeybees

- Brought to U.S. in 1622 by English colonists for honey production
- They pollinate one third of food crops we eat

Some Introduced Species are Harmful

Africanized honey bee

- From Africa, they were imported into Brazil in 1956 with idea of cross-breeding them with European honey bees to increase honey production
- Escaped into wild and began moving north at rate of 100-200 miles per year

Spread 1990-2009

Reached south Texas in 1990

Killer Bees

- Highly aggressive
- Will chase a person a quarter of a mile
- July 2014, bees sting man 1,000 times
- Wichita Falls city worker mowing grass disturbed a hive, provoking defensive response

Invasive Species have an Economic Impact

- It is costly to prevent, monitor and control the spread of invasive species
- Invasive species cost the United States $137 billion annually

How are Non-native Species Introduced to New Ecosystem

- Humans intentionally & unintentionally transport species outside their native range

The Best Intentions

Kudzu Intentionally Introduced

- Japanese kudzu vine planted in southern U.S. in 1930s & 1940s to control soil erosion
- Rapid growth rate
  - About 1 foot per day
- Can rapidly cover entire trees & small buildings
- Now present in Texas

Brown Tree Snake

Unintentionally Introduced to Guam

- Brought as stowaway in cargo from Admiralty Islands to Guam in 1950s by U.S. military ships during WWII
- Arboreal predator has caused disappearance of nearly all Guam’s native

forest birds (9 of 11 species lost)
- In new habitat snake lacks predators
- Native species tend to lack defenses against snake

Pets Escape/Released into Wild

Burmese pythons arrived in Florida as exotic pets

Reported in Everglades since 1980s, presumably the result of escaped or released pets

Burmese Pythons in Florida

Feed on native species, including endangered species such as Key Largo wood rats

Potential to Spread

Listed as conditional species in Florida
- Can no longer be acquired as pets

Listed as Injurious Species by USFWS
- Prevents importation of pythons into U.S. & prevents transportation of snakes across state lines
-

What Makes Non-native Species Invasive

Invasive species:
- Grows & spreads rapidly
- Establishes over large areas
- Persists

Invasive species threaten survival of native plants & animals

Introduced species and native species did not co-evolve
- In new habitat invasive species lacks predators
- Native species lack defenses against invasive

Traits of Invasive Species

Traits that enable species to become invasive:
- Reproduce rapidly
- Plants often reproduce asexually
- Disperse widely
- Grow quickly
- Habitat generalists that tolerate wide range of environmental conditions
- Animals often eat wide variety of food
- Human commensalism

Common Control Methods

Invasive Animals:
- Shooting
- Poisoning
- Egg destruction
- Pesticides

- Trapping & relocating
- Biological

Invasive Plants:

- Mechanical
    - Cutting/digging up
- Herbicides
- Dredging
- Biological
-

Invasive Animals Found in Texas

Red imported fire ant

Displace native ants

Eat newly-hatched chicks and destroy eggs of ground-nesting birds, including Bobwhite quail

Cause painful sting

- To insects, lizards, birds, amphibians, and humans & other mammals

Red Imported Fire Ants Damage Crops

Feed on buds & fruits of numerous crop plants

- Corn, soybean, okra, citrus

Large nests in fields interfere with & damage equipment during cultivation and harvesting

Red Imported Fire Ant Spread

Native to Brazil and introduced into Alabama in 1930s

- Accidental, likely in dunnage in cargo ships

Prolific breeders & aggressive feeders

Spread to infest more than 260 million acres

Potential to spread to state of Washington

Invasive Animals Found in Texas

Asian zebra mussel

Disrupts entire food webs by feeding on phytoplankton

Threatens 140 native mussel species

Clogs pipes in dams & power plants

Zebra Mussel Spread

Unintentionally introduced to Great Lakes by Caspian Sea tanker dumping its ballast water

Likely introduced in 1986

Discovered in Lake St. Clair in 1988

Species has rapid growth rate

Avoid Spreading Zebra Mussels

CLEAN, DRAIN AND DRY YOUR BOAT, TRAILER AND GEAR EVERY TIME YOU LEAVE A BODY OF WATER!

Invasive Animals Found in Texas

Nutria

- Digging destroys banks of ditches, lakes, marshes & other wetlands
- Eat vegetation and are opportunistic feeders with an extremely varied diet
  - consume about 25% of their body weight daily
- Damage sugarcane & rice crops

Nutria Spread

- Native to South America
- First introduced into California in 1899
- Imported for fur trade, many released into wild when businesses failed in late 1940s
- Established in 16 states

Nutria Eradication

- Eat Em Up
- Even Though They're Not CATS

Invasive Plants Found in Texas

Buffelgrass

- Grows densely
- Crowds out native species
- Dense roots and ground shading prevent germination of seed
- Can kill most native plants by these means
- Can fuel wildfires

Buffelgrass Spread

- Native to Africa, Asia & Europe
- Introduced into U.S. in 1930s as livestock forage
- Soil Conservation Service experimented with for soil improvement
  - Ultimately found it not useful & stopped planting it
- Has proliferated and poses sizeable threat to desert ecosystems

Invasive Plants Found in Texas

Giant Salvinia

- Dense mats shade out native aquatic species & reduce dissolved oxygen levels
- Agricultural water use is impacted when plants obstruct intake pipes for Irrigation

Giant Salvinia Spread

- Native to Brazil
- Introduced to U.S. by aquarium trade
- First detected outside of aquaria in South Carolina in 1995
- Reached Texas in 1998
- Fast growth

- Infestation can double in size in just one week

Invasive Plants Found in Texas

Hydrilla

Dense stands raise water pH & temperature and lower dissolved oxygen
- Result in large fish becoming more rare
- Promotes mosquito habitat

Clogs waterways & irrigation intake pipes

Fast growth rate
- Can grow up to 1 inch a day
- Stems can reach 30 feet in length

Reproduces vegetatively from fragmented stems

Occurs in San Marcos River

Hydrilla Spread

Native to Indian subcontinent

Introduced from Europe into North America in mid- to late 1950s by the aquarium trade

Spread by people dumping aquarium contents into bodies of water

Spread through boating and fishing activities and by waterfowl

Invasive Plants Found in Texas

Water hyacinth

Forms dense mats that shade out submerged vegetation

Depletes oxygen in water leading to fish kills

Occurs in San Marcos River

Water Hyacinth Spread

Native to S. America

First introduced to U.S. in Louisiana at World's Industrial & Cotton Centennial Exposition in 1884-1885

Visitor from Florida took some home and released into St. John River

Spread to other states

Using Water Hyacinth to Make Compost

Invasive Plants Found in Texas

Elephant Ear

Native to Africa

Originally brought to N. America as food crop for slaves

Introduced to San Marcos River in early 1900s

Forms dense stands along shore crowding out native vegetation

Impact of Exotic Pests to Agriculture Crops

Agriculture industry has a $100 billion economic impact on the state of Texas

Pests of Agriculture Crops
Asian citrus psyllid

- First found in Florida in 1998
- Causes serious damage to citrus crops through feeding on sap
- Burned tips and twisted leaves result from infestation on new growth
- Acts as carrier of bacterium that causes citrus greening disease

Pests of Agriculture Crops
Citrus greening disease

- Once a tree is infected there is no cure
- Signs include visible psyllids or waxy psyllid droppings
- Plants & plant material can spread infection

Pests of Agriculture Crops
Citrus greening disease Symptoms

- Yellowing of leaves called blotchy mottle
- Hard fruit with aborted seed
- Fruit remains green when ripe

Top 8 Ways Pests Get Around

Government Regulation

- APHIS (Animal & Plant Health Inspection Service) is part of the USDA
- Responsible for safeguarding agriculture & natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds

Halt Invasives
Do What You Can Do

- Stop the Spread
- Report It
- Spread the Word
- Get Involved
- Go Native

Stop the Spread of Invasives

- Don't accidentally transport on boats, clothing, etc.
- Don't release aquarium plants or fish into a natural body of water
- Don't release pets into the wild
- Don't transport items such as firewood, hay, soil, or sod from one area to Another

Boaters

- Never transport water, animals, or plants from one waterbody to another either intentionally or accidentally
- Before leaving any body of water, examine all your equipment, boats, trailers,

clothing, boots, buckets etc. and remove any visible plants, fish, other animals, mud and dirt

Drain all water from your boat, including the motor, bilge, livewells and bait buckets before leaving a lake

Wash your boat, trailer and other equipment before traveling to a new waterway

If you are leaving a water body that is known to have zebra mussels, leave your boat and trailer out of the water for at least a week or wash it at a commercial car wash using high-pressure, hot (140º F) soapy water to kill microscopic zebra mussel larvae that may be hitching a ride

Learn to Identify & Report Invasive Species

Giant Salvinia Sightings

Report new sightings to TPWD (409-384-9965 or giantsalvinia@tpwd.state.tx.us)

- Take picture and GPS location

It is illegal to knowingly or unknowingly transport plant

Transporting plant is class C misdemeanor punishable by fine of up to $500 per violation

If you see a violation report it to (800-792-4263)

Keep a Lookout for New Pests

Texas Invasives

- http://www.texasinvasives.org/

Learn about species with potential to invade Texas

Report sightings on website

Emerald ash borer

Spread in wood, it kills ash trees

First symptoms include a dying-back from top of the tree, splitting bark, and suckers from base of tree

Surveillance traps used to detect pest before it becomes established

Early detection makes eradication easier

Spread the Word

Tell your family and friends about invasive species

Raise awareness and identify solutions to invasive species issues

The More Eyes the Better

Get Involved

Join a Citizen Scientists group

Join a local invasive eradication effort

- Volunteer python removal program in Florida began in 2009
- 106 Burmese pythons caught between Jan. – Feb. 2016
- Largest was 15 ft. long
-

Go Native

Native plants are less susceptible to pests & diseases and unlikely to escape and become invasive

They help conserve water, reduce mowing costs, provide habitat for birds, butterflies & other wildlife, protect the soil, and save money on fertilizer & pesticides

APPENDIX D: Laboratory Curriculum

LAB EXERCISE 12
THOSE PESKY EXOTIC PESTS
Authored by Emily Arnold, Chelsea Miller, Kathryn Parsley, and Paula Williamson

Species Terminology

Legal definitions exist for categories of species, and these are covered in Executive Order 13112. The executive order defines native species, exotic species and invasive species.

What is the difference between native species and exotic species?

- Native species
  - A native species is a species that, other than as a result of an introduction, historically occurs/occurred in that particular habitat
- Exotic species
  - Any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that habitat
  - Other terms sometimes used for exotic species include "non-native," "non-indigenous," and "alien"

What is an invasive species?

- An invasive species is defined as **"a species that is non-native (or alien) to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health"**.

How many invasive species occur in the United States?

- According to the 2015 U.S. Geological Survey there are over **6,500 invasive species** established in the U.S.
- About 42% of threatened and endangered species in U.S. are at risk primarily due to invasive species

Each species has the potential to become invasive, but declared invasive species show similar characteristics that aid in their spread and survival. For example, the way invasive populations spread is by introduction to an environment with favorable conditions and a lack of predators. Almost all invasive species have a high reproductive rate, and many invasive plants are capable of reproducing asexually.
There are multiple ways that a species can be introduced to a new environment. The most common method of dispersal today is via shipping cargo. Other ways include the exotic pet/plant trade, migration to more favorable conditions, exotic landscaping, or foot traffic. Many invasive plants are introduced landscaping species that have escaped.
APHIS (Animal & Plant Health Inspection Service) is part of the USDA and is the governmental agency that is responsible for safeguarding agriculture & natural resources from the risks associated with the entry, establishment, or spread of animal and plant pests and noxious weeds.

The type of damage an invasive species causes depends on the type of environment it is invading. Damage can be classified as economic, environmental, a hazard to the public's health, or a combination of the three. It is costly to prevent, monitor and control the spread of invasive species. In fact, invasive species cost the United States **$137 billion** annually.

Examples of Damage Caused by Invasive Species

1. Your lab instructor will discuss specific examples of invasive species and the type of damage they cause. Record these examples along with information regarding how they were introduced and their native range:

   a. Economic harm:

   b. Environmental harm:

   c. Harm to human health:

Common Methods Used to Control Invasive Species

- Invasive Animals:
  - Shooting
  - Poisoning
  - Egg destruction
  - Pesticides
  - Trapping & relocating
  - Biological
- Invasive Plants:
  - Mechanical, such as cutting/digging up
  - Herbicides

– Dredging
– Biological

Invasive Insects

Annually, the US Fish and Wildlife Service spends at least twice as much money on invasive insects than any other invasive type of pest. This is because insects usually pose a direct threat to human health (such as the African killer bees), or our food source. Most invasive insects arrive in the United States concealed in produce shipments from other countries. Because they are so hard to detect, produce (as well as many other types of food) imported by the US undergoes irradiation to kill any living microbes or insects present in the shipment. Food that has been irradiated must bear this label issued by the FDA: (you can read more about this process at http://www.fda.gov/Food/ResourcesForYou/Consumers/ucm261680.htm if you are interested).

Insect Mouthparts

The mouthpart of an insect can tell us a lot about it, like what kind of food it eats, the type of damage it is capable of, and it helps us diagnose insect damage when we see it. Insect mouthparts are named for the function that they serve. The four basic categories of mouthparts are:

1. **Chewing**: present in most larvae as well as many adults; damage appears as bites taken out of a leaf or other plant matter, or burrowed holes into tree trunks; if an infestation is present, it will usually lead to mortality of the plant (in cases of herbivorous insects)
2. **Siphoning**: this mouthpart is characteristic of insects in the order Lepidoptera which is made of up moths and butterflies; a coiled straw-like mouthpart that, when in use, stretches to retrieve nectar from flowers
3. **Piercing and Sucking**: mouthpart modified for piercing the outer layer of the food source and sucking the internal fluids; in plants, damage initially appears as small spots on the leaf surface, then wilting as the vascular pathways are restricted; in mammals damage appears as an irritating bump (ex: mosquito bite)
4. **Sponging**: modified for insects such as the housefly which spit digestive enzymes on their food to convert it to a liquid, then use the sponge-like mouthpart to absorb the liquefied food

2. Fill out the following table on invasive insects found in Texas:

PEST	MOUTHPART	DAMAGE	NATIVE TO	HOST PLANT(S)

Controlling Invasive Insects

There are numerous control methods for insect pests. On an agricultural scale, there are many considerations that must be made before deciding on a single method. Tradeoffs to consider are: cost efficiency, environmental impact, level of infestation, customer perception, type of pest/crop. Some insects are very easy to control, and some can be such a threat that certain counties will do a county-wide spray once a certain population level is detected.

The options for control begin with identifying the insect that is causing damage. In some cases, the insect doesn't necessarily need to be identified in order to explore treatment options. If you are aware of the mouthpart of the insect that may be enough to determine what to use. For example, if the damage appears to be a chewing insect, then a foliar insecticide application will likely suffice. The chewing insect will consume the insecticide when it feeds, and the insecticide will poison and kill the pest. Unfortunately, most pest problems are not solved this easily.

3. Discuss the possible implications of various control methods, and fill out the table below:

METHOD	ADVANTAGES	DISADVANTAGES	COST	EFFECTIVENESS

Invasive Species Resources

Did you know there is an entire website devoted to identifying and reporting invasive species here in Texas? Go to www.texasinvasives.org to learn all about what species of invasive plants and animals live in your area! You can go to the "Invasives 101" tab at the top of the page for general information about invasive species, as well as alerts by eco region. Simply find the region of Texas you are in, and click on it. You will know exactly what species are invasive there! You can also go to the “Take Action” tab to report invasive species! The website does almost all the work for you-simply fill out the form, add pictures if you like, and submit. On the national scope, a working list of invasive plants is available at the USDA PLANTS database.

Invasive Species Case Study

4. Read the case study below and answer the associated questions:
You and your friends are exploring your grandparents’ property in Texas when you come across a large pond. You want to go swimming, but quickly realize the entire pond is covered with a thick layer of floating aquatic plants. They look as if they are densely populated over the entire pond. You think to yourself how dangerous this could be. These plants could clog pipes and deny access to waterfowl, as well as depriving the water beneath it of sunlight for other organisms to thrive and grow.

a. Do you think this plant might be invasive? Why or why not?

b. How would you attempt to discover the identity of the plant and determine whether the plant is considered invasive in this eco region of Texas?

After you have answered question b, ask your lab instructor to confirm the identity of the plant.

c. Next, suggest some ways to control or eradicate the plant.

d. How would you report this species to the appropriate government entity? What are some alternative ways to report it if you don’t have a phone with signal or an internet connection at the time that you find the species?

Documenting Invasive Species for Reports

Good field notes are always kept in a bound notebook and are DETAILED to the point of being replicable. You should write down impressions, questions, and thoughts as they come to you. These notes should be able to be referenced for future investigations, and easily understood. Field notes, by nature, are somewhat personal. They should reflect your thoughts and observations about the plants (or animals) you are observing.

The following things should be included in your field notes:

- Date
- Time
- Location (Including GPS coordinates, survey site and county)
- Elevation
- Climate (Temperature, weather, cloud cover, humidity, wind, etc.)
- Site description (What does the area look like? What is growing there?)
- Survey Methods and Materials (What are you doing here? What tools are you using?)
- Any measurements you take and why you take them

Examples of the Plant Offenders

- Giant Reed (*Arundo donax*): Grass family, grows in moist sandy soil, originally introduced by the U.S. Department of Transportation for erosion control, rooting structure nearly impossible to remove, grows in thick groves, can be over 4 meters tall
- Chinaberry (*Melia azedarach*): Empress Tree family, popular landscaping plant 40 years ago, grows in any mild humid climate, persists even when chopped down, easily spread by birds
- Texas Lilac (*Vitex agnus-castus*): Mint family, popular landscaping shrub known for its hardiness, persistent sprouter that degrades soil and occupies niche of native shrubs
- Japanese Honeysuckle (*Lonicera japonica*): Olive family, more persistent than native honeysuckles, introduce because of ease of propagation, chokes out woody and herbaceous native flora
- Kudzu (*Pueraria montana*): Legume (Bean) family, introduced at the 1876 Centennial Exposition and deliberately planted from 1935 to the mid-1950s by farmers in the south to reduce soil erosion, chokes out all other plants, grows in any fairly warm humid climates with disturbed soils, edible
- Johnsongrass (*Sorghum halapense*): Grass family, introduced to stabilize soil and grazing material for cattle, sucks up water, pushes out native grasses, useless as graze, can be lethal to livestock in drought conditions
- King Ranch Bluestem (*Bothriochloa ischaemum* var. *songarica*): Grass family, developed and introduced by King Ranch as alternative grazing material, swiftly spreads and forces out native Little Bluestem and others, no nutritive value as graze

- Glossy Privet (*Ligustrum lucidum*): Olive family, very popular as hedge plant and privacy tree, escapes cultivation easily in all warm semi-humid climates, outcompetes native tall shrubs
- Heavenly Bamboo (*Nandina domestica*): Barberry family, popular as landscaping shrub, spreads quickly via birds, hogs all the water and starves out other understory shrubs
- Vinca Vine, Periwinkle (*Vinca minor*): Dogbane family, native to Eastern Europe and introduced as part of "traditional English gardening," spreads rapidly through vining and cloning, pushes out native ground cover, resistant to direct foliar herbicides
- Bermudagrass (*Cynodon dactylon*): Grass family, native to southern Africa, extremely drought resistant and sod-forming, most popular xeriscape turfgrass, aggressively spreads through seeds and stolons, nutritionally underwhelming and occupies native grassland niches
- Water Hyacinth (*Eichhornia speciosa*): Arum family, free-floating invader of slow-moving freshwater, population multiplies to occupy any given surface area, deoxygenates water sources, aggressively crowds out native plants
- Hydrilla (*Hydrilla verticillata*): Naiad or Frog's-bit family, aquatic plant introduced by the aquarium trade, has a fast growth rate and reproduces vegetatively from fragmented stems, dense stands raise water pH & temperature and lower dissolved oxygen, clogs waterways & irrigation intake pipes
- Elephant Ear (*Colocasia esculenta*): Arum family, Native to Africa and originally brought to N. America as food crop for slaves, forms dense stands along shore crowding out native vegetation

Invasive Species Scavenger Hunt!!!!

5. Now that you have learned how to take proper field notes, go out and follow the map provided by your Lab Instructor to find 3 invasive species examples here on campus. Be sure to take pictures and record proper field notes as if you were going to report the species (see Documenting Invasive Species for Reports section above). Meet back in the classroom in 50 minutes. In the space provided below, list the common name of each species you find and write your detailed field notes.

Invasive Species 1:

Invasive Species 2:

Invasive Species 3:

REFERENCES

Allendorf, F. W., & Lundquist, L. L. (2003). Introduction: Population biology, evolution, and control of invasive species [Special section]. *Conservation Biology, 17*, 24-30.

Andreu, J., Vila, M., & Hulme, P. E. (2009). An assessment of stakeholder perceptions and management of noxious alien plants in Spain. *Environmental Management*, *43*, 1244.

Bardsley, D., & Edwards-Jones, G. (2006). Stakeholder's perceptions of the impacts of invasive exotic plant species in the Mediterranean region. *Geographical Journal*, *65*, 199-210.

Baumgartner, E., & Zabin, C. J. (2008). A case study of project-based instruction in the ninth grade: a semester-long study of intertidal biodiversity. *Environmental Education Research, 14*, 97-114.

Bertolino, S., & Genovesi, P. (2003). Spread and attempted eradication of the grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red squirrel (*Sciurus vulgaris*) in Eurasia. *Biology Conservation*, *109,* 351-358.

Blaustein, R. J. (2001). Kudzu's invasion into southern United States life and culture. In J. A. McNeely (Ed.), *The Great Reshuffling: Human Dimensions of Invasive Alien Species* (pp. 23-34). Norwich, UK: Page Brothers.

Bowles, D. E. & Bowles, B. D. (2001). A review of the exotic species inhabiting the upper San Marcos River, Texas, U.S.A. Austin, TX: Texas Parks and Wildlife Department.

Bremner, A., & Park, K. (2007). Public attitudes to the management of invasive non-native species in Scotland. *Biology Conservation, 139*, 306-314.

Buhle, E. R., Margolis, M., & Ruesink, J. L. (2005). Bang for buck: cost-effective control of invasive species with different life histories. *Ecological Economics, 52,* 355-366.

Burgiel, S., Foote, G., Orellana, M., & Perrault, A. (2006). Invasive alien species and trade: Integrating prevention measures and international trade rules. Retrieved from http://cleantrade.typepad.com/clean_trade/files/iastraderpt0106.pdf

Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE bulletin, 3*, 7.

Colautti, R. I., & MacIsaac, H. J. (2004). A neutral terminology to define 'invasive' species. *Divers and Distribution, 10,* 135-141.

Crall, A. W., Jordan, R., Holfelder, K., Newman, G. J., Graham, J., & Waller, D. M. (2013). The impacts of invasive species citizen science training program in participant attitudes, behavior, and science literacy. *Public Understanding of Science.* Advance online publication. doi: 10.1177/0963662511434894

Crall, A. W., Newman, G. J., Stohlgren, T. J., Holfelder, K. A., Graham, J., & Waller, D. M. (2011). Assessing citizen science data quality: An invasive species case study. *Conservation Letters, 4,* 433-442.

Davis, A. (2015). Effects of an Educational Intervention on Baccalaureate Nursing Students' Knowledge and Attitude in Providing Breastfeeding Support to Mothers. *International Journal Of Childbirth Education*, *30*, 8-12.

Davis, L. L. (1992). Instrument review: Getting the most from a panel of experts. *Applied Nursing Research, 5*, 194-197.

Devin, S., & Beisel, J. (2007). Biological and ecological characteristics of invasive species: a gammarid study. *Biological Invasions, 9,* 13-24.

DiEnno, C. M., & Hilton, S. C. (2005). High school students' knowledge, attitudes, and levels of enjoyment of an environmental education unit on nonnative plants. *The Journal of Environmental Education*, *37*, 13-25.

Dorcas, M. E., Willson, J. D., Reed, R. N., Snow, R. W., Rochford, M. R., Miller, M. A., ... & Hart, K. M. (2012). Severe mammal declines coincide with proliferation of invasive Burmese pythons in Everglades National Park. *Proceedings of the National Academy of Sciences*, *109*, 2418-2422.

Elton, C. G. (1958). *The Ecology of invasions by plants and animals.* London: Methuen.

Estevez, R. A., Anderson, C. B., Pizarro, C., & Burgman, M. A. (2014). Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology*, *29*, 19-30.

Evans, J. (1970). *About nutria and their control* (No. 86). US Fish and Wildlife Service. Retrieved from https://pubs.er.usgs.gov/publication/rp86

Executive Office of the President. (1999). *Executive order 13112 of February 3, 1999.* Retrieved from https://www.federalregister.gov/documents/1999/02/08/99-3184/invasive-species

Farmer, J., Knapp, D., & Benton, G. M. (2007). An elementary school environmental education field trip: Long-term effects on ecological and environmental knowledge and attitude development. *The Journal of Environmental Education, 38*(3), 33-42.

Forseth, I. N., & Innis, A. F. (2004). Kudzu (*Pueraria montana*): History, physiology, and ecology combine to make a major ecosystem threat. *Critical Reviews in Plant Sciences*, *23*, 401-413.

Foster, J., & Sandberg, L. A. (2004). Friends or foe? Invasive species and public green space in Toronto. *The Geographical Review, 94*, 178-198.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*, 8410-8415.

Freedman, M. P. (1997). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. *Journal Of Research In Science Teaching*, *34*, 343-357.

Gall, M. D., Gall, J. P., & Borg, W. R. (2007). *Educational research : An introduction*. Boston: Pearson/Allyn & Bacon, c2007

Gallo, T., & Waitt, D. (2011). Creating a successful citizen science model to detect and report invasive species. *BioScience, 61*(6), 459-465.

García-Llorente, M., Martín-López, B., González, J. A., Alcorlo, P., & Montes, C. (2008). Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biological Conservation, 141,* 2969-2983.

Griffiths, R., Schloesser, D., Leach, J., & Kovalak, W. (1991). Distribution and dispersal of the zebra mussel (*Dreissena polymorpha*) in the Great Lakes region. *Canadian Journal of Fisheries and Aquatic Sciences, 48*, 1381-1388.

Gurevitch, J. & Padilla, D. K. (2004). Are invasive species a major cause of extinctions? *TRENDS in Ecology and Evolution, 19*, 470-474.

Hauser, C. E., & McCarthy, M. A. (2009). Streamlining search and destroy: Cost-effective surveillance for invasive species management. *Ecology Letters, 12,* 683-692.

Hulme, P. E. (2009). Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology, 46,* 10-18.

Hofstein, A., & Lunetta, V. N. (1982). The Role of the Laboratory in Science Teaching: Neglected Aspects of Research. *Review of Educational Research*, *52*, 201-217.

Invasive Species Specialist Group (2000). *IUCN Guidelines for the prevention of biodiversity loss caused by alien invasive species.* Retrieved from http://www.issg.org/pdf/guidelines_iucn.pdf

Johnson, L. E., & Carlton, J. T. (1996). Post-establishment spread in large-scale invasions: Dispersal mechanisms of the zebra mussel *Dreissena polymorpha*. *Ecology*, *77*, 1686-1690.

Johnson, R. J., & Glahn, J. F. (1994). European starlings. Retrieved from http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1070&context=icwdmhandbook

Johnson, D. W., Johnson, R. T., & Scott, L. (1978). The effects of cooperative and individualized instruction on student attitudes and achievement. *The Journal of Social Psychology, 104*, 207-216.

Jordan, R. C., Gray, S. A., Howe, D. V., Brooks, W. R., Ehrenfeld, J. G. (2011). Knowledge gain and behavioral change in citizen-science programs. *Conservation Biology, 25*, 1148-1154.

Kidron, Y., & Lindsay, J. (2014). The effects of increased learning time on student academic and nonacademic outcomes: Findings from a meta-analytic review. REL 2014-015. *Regional Educational Laboratory Appalachia*.

Kim, C. S., Lubowski, R. N., Lewandrowski, J., & Eiswerth, M. E. (2006). Prevention or control: Optimal government policies for invasive species management. *Agricultural and Resources Economics Review, 35*, 29-40.

Kolar, C. S., & Lodge, D. M. (2001). Progress in invasion biology: Predicting invaders. *TRENDS in Ecology and Evolution, 16*, 199-204.

Larson, D. L., Phillips-Mao, L., Quiram, G., Sharpe, L., Stark, R., Sugita, S., & Weiler, A. (2011). A framework for sustainable invasive species management: Environmental, social, and economic objectives. *Journal of Environmental Management, 92*, 14-22.

Lee, H., Liu, S., & Yeh, T. (2016). “Sharks in Your Hands”—A Case Study on Effects of Teaching Strategies to Change Knowledge and Attitudes Towards Sharks. *Journal Of Biological Education (Routledge), 50*, 345-357.

Low, T. (2001). From ecology to politics: The human side of alien invasions. In J. A. McNeely (Ed.), *The Great Reshuffling: Human Dimensions of Invasive Alien Species* (pp. 23-34). Norwich, UK: Page Brothers.

Lowe, S., Browne, M., Boudjelas, S., & De Poorter, M. (2000). *100 of the world's worst invasive alien species: A selection from the global invasive species database.* Retrieved from http://www.iucngisd.org/gisd/pdf/100English.pdf

Mack, R. N. (2001). Motivations and consequences of the human dispersal of plants. In J. A. McNeely (Ed.), *The Great Reshuffling: Human Dimensions of Invasive Alien Species* (pp. 23-34). Norwich, UK: Page Brothers.

Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. A. (2000). Biotic invasions: causes, epidemiology, global consequences, and control. *Ecological Applications, 10,* 689-710.

Maguire, L. A. (2004). What can decision analysis do for invasive species management? *Risk Analysis, 24*, 859-868.

Marchetti, M. P., Moyle, P. B., & Levine, R. (2004). Invasive species profiling? Exploring the characteristics of non-native fishes across invasion stages in California. *Freshwater Biology, 49,* 646-661.

Marshall, N. A., Friedel, M., van Klinken, R. D., & Grice, A. C. (2011). Considering the social dimension of invasive species: The case of buffel grass. *Environmental Science and Policy, 14,* 327-338.

McGeoch, M. A., Butchart, S. H. M., Spear, D., Marais, E., Kleynhans, E. J., Symes, A., Chanson, J., & Hoffmann, M. (2010). Global indicators of biological invasion: Species numbers, biodiversity impact and policy responses. *Diversity and Distributions, 16,* 95-108.

Mehta, S. V., Haight, R. G., Homans, F. R., Polasky, S., & Venette, R. C. (2007). Optimal detection and control strategies for invasive species management. *Ecological Economics, 61,* 237-245.

Mooney, H. A., & Cleland, E. E. (2001). The evolutionary impact of invasive species. *Proceedings of the National Academy of Sciences, 98,* 5446-5451.

National Invasive Species Council (2008). *2008-2012 National invasive species management plan.* Retrieved from https://www.invasivespeciesinfo.gov/council/mp2008.pdf

National Center for Case Study Teaching in Science (2017). *Teaching Resources.* Retrieved from: http://sciencecases.lib.buffalo.edu/cs/

Newman, G., Crall, A., Laituri, M., Graham, J., Stohlgren, T., Moore, J. C., Kodrich, K., Holfelder, K. A. (2010). Teaching citizen science skills online: Implications for invasive species training programs. *Applied Environmental Education and Communication, 9,* 276-286.

Oxley, F. M., Waliczek ,T. M., & Williamson, P. S. (2016). Stakeholder opinions on invasive species and their management in the San Marcos River. *HortTechnology, 26,* 514-521.

Pimentel, D., Lach, L., Zuniga, R., & Morrison, D. (2000). Environmental and economic costs of nonindigenous species in the United States. *BioScience*, *50*, 53-65.

Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, 52, 273-288.

Prinbeck, G., Lach, D., & Chan, S. (2011). Exploring stakeholders' attitudes and beliefs regarding behaviors that prevent the spread of invasive species. *Environmental Education Research, 17*, 341-352.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of engineering education*, *93*, 223-231.

Pysek, P. & Richardson, D. M. (2010). Invasive species, environmental change and management, and health. *Management of Biological Invasions, 35,* 25-55.

Reaveley, A., Bettink, K. and Valentine, L. (2009). Impacts of introduced species on biodiversity. In B. A. Wilson & L. E Valentine (Eds.), *Biodiversity values and threatening processes of the Gnangara groundwater system*. (pp. 1-51). Western Australia: Department of Environment and Conservation.

Reichard, S. H., & Hamilton, C. W. (1997). Predicting invasions of woody plants introduced into North America. *Conservation Biology*, *11*, 193-203.

Reichard, S. H., & White, P. (2001). Horticulture as a pathway of invasive plant introductions in the United States. *BioScience, 51*, 103-113.

Rejmánek, M., & Richardson, D. M. (1996). What attributes make some plant species more invasive?. *Ecology, 77,* 1655-1661.

Schüttler, E., Rozzi, R., & Jax, K. (2011). Towards a societal discourse on invasive species management: A case study of public perceptions of mink and beavers in Cape Horn. *Journal of National Conservation, 19,* 175-184.

Selge, S., Fischer, A., & van der Wal, R. (2011). Public and professional views on invasive non-native species- A qualitative social scientific investigation. *Biological Conservation.* Retrieved from http://www.sciencedirect.com/science/article/pii/S0006320711003703

Shine, R., & Doody, J. S. (2011). Invasive species control: understanding conflicts between researchers and the general community. *Frontiers in Ecology and the Environment, 9,* 400-406.

Smith, A. L., Bazely, D. R., & Yan, N. D. (2011). Missing the boat on invasive alien species: A review of post-secondary curricula in Canada. *Canadian Journal of Higher Education, 41,* 34-47.

Stanton, J. D., Neider, X. N., Gallegos, I. J., & Clark, N. C. (2015). Differences in metacognitive regulation in introductory biology students: when prompts are not enough. *CBE: Life Sciences Education, 14,* 1-12.

Stokes, K. E., O'Neill, K. P., Montgomery, W. I., Dick, J. T. A., Maggs, C. A. & McDonald, R. A. (2006). The importance of stakeholder engagement in invasive species management: A cross-jurisdictional perspective in Ireland. *Biodiversity and Conservation.* Advance online publication. doi: 10.1007/s10531-005-3137-6

Tanner, K. D. (2010). Order matters: using the 5E model to align teaching with how people learn. *CBE-Life Sciences Education, 9,* 159-164.

Taraban, R., Box, C., Myers, R., Pollard, R., & Bowen, C. W. (2007). Effects of active-learning experiences on achievement, attitudes, and behaviors in high school biology. *Journal of Research in Science Teaching*, *44*, 960-979.

Texas Invasives. (2017). *What are invasive species?* Retrieved from: http://texasinvasives.org/i101/

Texas Parks and Wildlife Department. (2017). *Exotic and invasive species.* Retrieved from: http://tpwd.texas.gov/huntwild/wild/species/exotic/

Treves, A., & Naughton-Treves, L. (2005). Evaluating lethal control in the management of human-wildlife conflict. *CONSERVATION BIOLOGY SERIES-CAMBRIDGE-*, *9*, 86-106.

United States Fish and Wildlife Service. (2017). *What is an invasive species?* Retrieved from: https://www.fws.gov/invasives/

Vanderhoeven, S., Piqueray, J., Halford, M., Nulens, G., Vincke, J., & Mahy, G. (2011). Perception and understanding of invasive alien species issues by nature conservation and horticulture professionals in Belgium. *Environmental Mgt*, *47*, 425-442.

van Kleunen, M., Weber, E., & Fischer, M. (2010). A meta-analysis of trait differences between invasive and non-invasive plant species. *Ecology Letters*, *13,* 235-245.

Veitch, C. R., & Clout, M. N. (2001). Human dimension in the management of invasive species in New Zealand. In J. A. McNeely (Ed.), *The Great Reshuffling: Human Dimensions of Invasive Alien Species* (pp. 23-34). Norwich, UK: Page Brothers.

Verbrugge, L. N., Van den Born, R. J., & Lenders, H. R. (2013). Exploring public perception of non-native species from a visions of nature perspective. *Environmental management*, *52*, 1562-1573.

Waliczek, T., McFarland, A., & Holmes, M. (2016). The Relationship between a Campus Composting Program and Environmental Attitudes, Environmental Locus of Control, Compost Knowledge, and Compost Attitudes of College Students. *HortTech*, *26*, 592-598.

Waliczek, T. M., Williamson, P. S., & Oxley, F. M. (in press). College student knowledge and perceptions of invasive species. *HortTech*.

Wandersee, J. H. & Schussler, E. E. (1999). Preventing Plant Blindness. *The American Biology Teacher*, *61*, 82-86.

Wiles, G. J., Bart, J., Beck, R. E., & Aguon, C. F. (2003). Impacts of the brown tree snake: patterns of decline and species persistence in Guam's avifauna. *Conservation Biology*, *17*, 1350-1360.