THE EFFECT OF WASTEWATER EFFLUENT AND A FLOOD EVENT ON RESIDENT AMPHIBIAN AND REPTILIAN COMMUNITIES

THESIS

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ABSTRACT

Properly treated wastewater effluent, although usually considered detrimental to the surrounding environment, may actually have beneficial qualities. Information is presented on the effect of wastewater effluent on amphibian and reptilian communities. Data were collected in Mineola, Texas, from May to August 2000 under the IACUC permit 5QGbKa_02. Fourteen days into the collection period, 16 June, a flood occurred that prevented collection for 12 days. The same data that addressed the effect of wastewater effluent on vertebrate communities was used to study the effects of the flood on the same community. The objectives of this study were to determine if there is a significant difference in the herpetofauna communities of the experimental and control areas and between pre-flood and post-flood periods. Data from fifty-three reptiles and 489 amphibians were collected using drift fence arrays, minnow traps, and incidental observation. Three drift fence arrays and nine minnow traps were used in control and experimental areas. The experimental area was located on Dodson Creek downstream from the effluent discharge, while the control area was located upstream from the discharge point source. Plant biomass and water chemistry data were collected at the study site. The Mann-Whitney U test was used to test for the effect of wastewater on herpetofauna communities. The Chi-square test was used to determine differences in composition of pre-flood and post-flood herpetofauna communities. The abundance of amphibians was significantly greater than that of the control area ($U = 665.5$, $U^1 = 2038.5$, $p < 0.0001$). The abundance of reptiles in the control and experimental areas were similar ($U = 1229$,

$U^1 = 1475$, $p = 0.4239$). There was a significant increase in amphibian frequency after the flood event ($X^2 = 7.609$, $p < 0.05$), but no significant difference in reptile frequency before or after a flood event ($X^2 = 1.8148$, $p > 0.05$). Ninety percent of amphibians occurred in the experimental area probably due to the fertilizing effects of the treated effluent and subsequent optimal habitat. Only forty-three percent of the reptiles were found in the experimental area, possibly due to competition pressure of optimal areas. Sixty-nine percent of the amphibians were collected after the flood which may be attributed to the decrease of herbaceous vegetation and lack of home range. Reptiles showed opposite trends from amphibians in that 63 percent were found pre-flood. The discrepancy could be attributed to the possibility that both pre-flood communities were replaced by a smaller community of individuals from upstream.

INTRODUCTION

The effects of wastewater effluent have been documented for some components of the environment, such as vegetative effects, but virtually unstudied in others like vertebrate community structure (Neilsen et al. 1989, Rose et al. 1989, Oladimeji and Wade 1984, Rose 1977). The dominant paradigm recognized by the general public is that expulsion of "pollutants" can only be detrimental to the environment. Some studies, however, have addressed the benefits of properly treated effluent on the quality and biomass of aquatic vegetation, soils and wetlands. DeWalle (1983) found irrigation of mixed-clone hybrid poplar (*Populus* sp.) with wastewater caused a 272% increase in woody biomass in two growing seasons when compared to a control. Fisher (2000) and Clough and DeBusk (1987) described the effectiveness of vegetative systems for reducing biochemical oxygen demand (BOD) levels in wastewater along with other negative chemical influences. Owen and Chiras (1990) stated that the application of treated wastewater improved soil structure and increased its ability to absorb moisture and resist erosion.

Biological monitoring, the use of biota to detect chemical environmental contaminants, provides useful information about the control and regulation of biological contaminants in the environment (Schöne 1989). For accurate biological monitoring, one must select appropriate indicator taxa. Few studies have addressed the value of amphibians and reptiles as appropriate environmental indicators (Hager 1998, Hartwell and Ollivier 1998, Schöne 1989, Stafford et al. 1975). Amphibians and reptiles are excellent environmental indicators for many reasons. Many stream amphibians are highly philopatric and long-lived. Therefore, they may exist in relatively stable populations. Welsh and Ollivier (1998) stated that these attributes make amphibians more reliable indicators of biodiversity than anadromous fish or macroinvertebrates. The skin of amphibians is unique among vertebrate groups because of its use for cutaneous respiration. This makes amphibians susceptible to a high ion exchange, which in turn makes them hypersensitive to environmental conditions (Zug 1993). Reptiles may also serve as environmental indicators. Many reptiles have low metabolic rates and simple enzyme systems that may not detoxify complex chemical compounds ingested by eating contaminated invertebrate prey. This may lead to biological magnification (Lambert 1999).

Floods are stochastic events of nature that disturb and can have detrimental effects on biotic and abiotic components of a community. Such events enhance erosion, displace flora and fauna, and control patterns of resource use by fauna (Sheppe and Osborn 1971). Floods change the physical structure of plant communities by removing trees. As a result, the succession pattern for future communities is altered, which affects cover for the fauna (Friedman et al. 1996).

Two hundred nineteen species of amphibians and reptiles naturally occur in Texas. Records for amphibians and reptiles in Texas reveal that 49 species occur in 61% of the 254 counties, while only 50 species are limited to 1.5% of the counties (Dixon 2000). Seventy-one species, approximately $^{1}/_{3}$ of the total for the state, occur in Wood County, an area of apparent high biodiversity for amphibians and reptiles. Until 1998 with the introduction of Texas Parks and Wildlife regulations concerning non-game species, the general public disregarded the Texas herpetofauna as an important wildlife resource. With the introduction of this legislation, the ecological importance of these taxa has been acknowledged.

The initial objective of this study was to determine whether the discharge of wastewater affected the diversity of amphibian and reptilian communities. However, the occurrence of a flood during the study provided an opportunity to address short-term effects of flooding on amphibian and reptilian communities.

Study Area

The study occurred at the City of Mineola Wastewater Treatment Plant, a Class B, Type-Two facility (Texas Administrative Code 2001). The facility is located approximately 1 km southeast of the city limits on County Road (CR) 2724 (Fig. 2). The 7216.56-ha wastewater treatment center is composed of seven tracts.

In sewage processing, effluents are flocculated by six aerators before being expelled to the first of two settling pools. When the effluent leaves the treatment plant, it enters a series of effluent only streamlets before reaching the Dodson Creek interface, the first substantial stream with flowing water. The areas near Dodson Creek contain extensive riparian areas.

Dodson Creek, on CR 2724, flows perpendicular to the treatment center on adjacent land owned by the city. The habitat is composed of an immature hardwood bottomland of river birch (*Betula nigra*) and oak (*Quercus* sp.) trees with a grassland floodplain interspersed with stands of persimmon (*Diospyros virginiana*). Domestic livestock has historically grazed the flood plain portion of the tract, while the hardwood stands remained undisturbed.

METHODS

Experimental Design and Sampling

Sampling for amphibians and reptiles occurred 6 days a week for 53 days from 18 May until 15 August. Sampling was conducted on Dodson Creek within 1.5 km of the creek-effluent dump interface. Control and treatment sites were located 0.75 km upstream and 0.75 km downstream, respectively, from the effluent interface on Dodson Creek. Drift fence arrays, minnow traps and incidental searching were used to sample the resident herpetofauna community.

Six drift fence arrays were constructed with three in the experimental and control areas, respectively. Each array consisted of 3, ten-meter sections of flashing radiating from a central pitfall trap at 120° intervals (Fig. 1). A pitfall trap was located at the ends of each wing. The 30.46-cm tall flashing was reinforced every 2 m with wooden stakes. Arrays 1, 2, and 3 were in the area affected by the effluent discharge (experimental area) and arrays 4, 5, and 6 occurred along a section of Dodson Creek with no effluent discharge (control area).

Minnow traps were used to catch aquatic snakes (Rabe 1979). Traps were set in water along the edge of Dodson Creek with the top half out of water. Because of the water depth, some traps were suspended from vegetation half way into the water

Incidental searching was another technique used to catch and verify the presence of amphibians and reptiles. Several species that were not caught in minnow traps or drift fence arrays were collected by this technique. I recorded animals as occurring in the control or experimental area (Hager 1998).

Areas near each drift fence array were randomly sampled for plant biomass on 19 August using quadrat methodology. Plant biomass was sampled at three locations at each array. The collection sites near arrays were determined randomly by selecting random numbers between 10 and 20. The distance was then measured from the center bucket of an array to Dodson Creek. Once the initial transect was determined another transect was set perpendicular to the original. This transect was 30 m long and contacted the end of the original transect at the 15 m mark. One-quarter m^2 quadrats were used to sample the plant biomass at random distances within each 10 m distance (Skartvedt 2000). The sampling design accounted for contours of the creek. I hand-clipped the vegetation within each quadrat. The plant matter gathered at each site was dried to a constant weight in a forced-air dryer in the Southwest Texas State University herbarium and weighed.

The Texas Natural Resource Conservation Commission (TNRCC) requires Class B, Type Two treatment plants, such as the one at Mineola, to test for five water chemistry factors in their effluent discharge: suspended solids, pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), and ammonias. The staff of the water treatment plant collected water samples at three points (Fig. 2): the effluent discharge point from the treatment center (Site A), the interface of the effluent with Dodson Creek (Site B) and 0.75 km upstream from the effluent interface with Dodson Creek at CR 2724 (Site C). Tests for the five water chemistry factors were by standard methods (Environmental Protection Agency 2001).

Reptiles and amphibians collected during the study were collected under protocol approved by the Southwest Texas State University IACUC Committee under permit number 5QgbKa-02. Each animal was identified to species and marked to prevent recount. Marking of turtles included notching the seventh right marginal. I clipped the third scale above the cloaca in marking snakes. I clipped the first toe on the left hind foot to mark amphibians and lizards (Carlstrom 1946).

I used data collected for the wastewater study to determine flood effects. Data collected 14 days before the flood, regardless of collection area, were compared to collections 14 days after the flood, once again disregarding collection area.

Statistical Analysis

The one-tailed, two-sample *t* test was used in the analysis of biomass production of effluent and non-effluent plant biomass. The hypothesis of this test was H_o: $\mu_1 < \mu_2$ and H_A: $\mu_1 \geq \mu_2$ with μ_1 representing vegetation from the control and μ_2 representing vegetation from the experimental area (Zar 1999). The test statistic was calculated by the following equation ($P < 0.05$):

$$t = \frac{\overline{X}_1 - \overline{X}_2}{S_{\overline{X}_1 - \overline{X}_2}}$$

Differences in species composition of the experimental and control sites were tested by the Mann-Whitney U test after an *f* test revealed that non-parametric statistics should be used. The hypothesis was H_o: $\mu_1 < \mu_2$ and H_A: $\mu_1 \geq \mu_2$ with μ_1 representing the control area (Zar 1999). The test statistic was calculated by the following equations ($P < 0.05$) where n_1 and n_2 are the number of observations in samples one and two respectively and R_1 is the sum of ranks of the observations in sample one:

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

$$U^l = n_1 n_2 - U$$

A goodness of fit analysis using the Chi-square test tested for pre-flood and post-flood impacts on the herpetofauna after an *f* test revealed that non-parametric statistics should be used. The hypothesis tested was H_o: $n_1 < n_2$ and H_A: $n_1 \geq n2$ with n_1 representing the control area and n_2 representing the experimental area (Zar 1999). The test statistic was calculated by the following equation ($P < 0.05$) where *fo* is the observed value and *fe* is the expected value.

$$X^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

RESULTS

Water Chemistry

All five chemical factors in the wastewater effluent had high levels at Site A (Table 1). Water from Site B showed a decrease in all five chemical factors compared to Site A. Water from Site C had slightly higher pH, DO, and BOD in comparison to Site B. Solids in the water were lowest at Site C. Although all chemical factors were reduced from Site A to Site B, the results suggested that water quality was the same or about the same for four of the chemical tests except for solids.

Vegetative Biomass

The mean plant biomass was greatest at array 2 and least in array 5 (Table 2). The large standard error indicated a less than uniform dispersion of plant biomass in array 2. This may be due to the collection of plant biomass in the post-flood period. The mean plant biomass for drift fence arrays 1to 3 was 49.44 g, while the mean for arrays 4 to 6 was 24.55 g. The amount of biomass in the experimental area was greater than the control ($t = 2.30475$, $p = 0.0417$).

Herpetofauna Communities in the Experimental and Control Areas

Amphibians

The species of amphibians recorded during the 53 days of collections were southern leopard frog (*Rana utricularia*), bronze frog (*R. clamitans clamitans*), eastern narrowmouth toad (*Gastrophryne carolinensis*), Woodhouse's toad (*Bufo woodhousii woodhousii*), green treefrog (*Hyla cinerea*), and northern cricket frog (*Acris crepitans crepitans*).

All six species inhabited the experimental area (Appendix A). Three species were encountered in the control area (Appendix B). Total number of amphibians recorded in the experimental area over the 53-day collection period was 295. The mean catch per day was 5.673 (S.E. = 1.027) (Fig. 3). The number of individuals recorded in the control area was 34. The mean catch per day was 0.6539 (S.E. = 0.232) (Fig. 3). There was a significant difference in the abundance of amphibians in the control and experimental areas ($U = 665.5$, $U^1 = 2038.5$, $p < 0.0001$).

Reptiles

During the 53-day collection period, 13 species of reptiles were collected: western cottonmouth (*Agkistrodon piscivorus leucostoma*), southern copperhead (*A. contortrix contortrix*), diamondback water snake (*Nerodia rhombifer rhombifer*), yellowbelly water snake (*N. erythrogaster flavigaster*), broad-banded water snake (*N. fasciata confluens*), glossy crayfish snake (*Regina regida*), speckled kingsnake (*Lampropeltis getula holbrooki*), five-lined skink (*Eumeces fasciatus*), ground skink (*Scincella lateralis*), smooth softshell turtle (*Apalone mutica*), snapping turtle (*Chelydra serpentina*), eastern box turtle (*Terrepene carolina carolina*), and red-eared slider (*Trachemys scripta elegans*).

Eight of the 13 species were found in the experimental area (Appendix C). These included three snakes, two species of skinks, and three species of turtles. *Eumeces fasciata,, A. pisciverous, N. rhombifer,* and *S. lateralis* were the only species recorded more than once. Ten of the 13 species occurred in the control area (Appendix D). These included six species of snakes, two species of skinks, and two species of turtles. *A. pisciverous, A. contortrix, L. getula, E. fasciata, S. laterallis,* and *T. carolina* were recorded more than once.

Total number of reptiles collected in the experimental area was 21. The mean catch per day was 0.4038 (S.E. = 0.149) (Fig. 4). The sum of individuals recorded in the control area was 24. The mean catch per day was 0.4615 (S.E. = 0.111) (Fig. 4). The abundance of reptiles in the control and experimental areas were similar ($U = 1229$, $U^1 = 1475$, $p = 0.4239$).

Herpetofauna Communities Before and After a Flood Event

This study was conducted during a time of moisture extremes. Ten days into the study, 8 June, it rained for seven days. During this period, 35.56 cm of rain fell and raised the water levels of nearby lakes Tawakoni and Fork. The study site was located in the floodplain of both lakes. As the rain ended on 15 June, floodwaters from Lake Fork arrived. Three days later floodwaters from Lake Tawakoni arrived. Floodwaters from these lakes inundated the study site with 1.6 m of water for 11 days. When the water level receded, there were four drift fence arrays with missing buckets, which were replaced. Once the rain ceased on 15 June there was no precipitation for the remainder of the study.

Amphibians

Sixty-three amphibians were recorded pre-flood during the first 14 days (30 May -14 June) of the study and 98 during the 14 days post-flood (29 June -14 July) (Fig. 5). Data for the 14 days prior to and after the-flood were recorded and compared by frequency of observance (Fig. 6). *Rana utricularia* was the most abundant before and after the disturbance with sporadic sightings of *R. clamitans* and

Bufo woodhousii. Gastrophryne carolinenesis was present six times post-flood but not present pre-flood. No individuals captured before the flood were recaptured during the 14-day post-flood collection. There was a significant difference in amphibian frequency before or after the flood event ($X^2 = 7.609$, $p < 0.05$).

Reptiles

Seventeen reptiles were collected during the first 14 days (30 May -14 June) of collection. Ten reptiles were recorded during the 14 days immediately following reclamation of study site (29 June -14 July) (Fig. 7). Data from the 14 days prior to and after the flood were recorded and compared by frequency of observance (Fig. 8). Three species (*Lampropeltis getula, Chelydra serpentina*, and *Apalone mu*tica) were catalogued in a field notebook only once pre-flood. Three species (*Agkistrodon contortrix, Regina regida*, and *Nerodia erytherogastor*) were encountered only once post-flood. There was no significant difference in reptile frequency before or after the flood event ($X^2 = 1.8148$, $p > 0.05$).

DISCUSSION

While conducting this study, two collection techniques proved successful in the sampling of amphibians and reptiles. Minnow traps yielded only two water snakes. Drift fence arrays and incidental searching proved better collection methods for most taxa collected. All drift fence arrays were set in close proximity to Dodson Creek, and hence, were in areas of almost full canopy cover. Incidental searching was the only technique by which *Hyla cinerea,* and all but one *Acris crepitans* were recorded. Most *Agkistrodon pisciverous* were also collected by this technique, but a few were caught in array buckets eating anurans. All turtles were caught by incidental searching.

By the end of the study, the sewage facility in Mineola had been scheduled for upgrading to a tertiary facility. A tertiary facility is twice as expensive to build and four times as expensive to operate (Smith 2000). Based on data in this study, the wastewater effluent did not appear to be an ecological detriment to the surrounding environment, and there did not seem to be an ecological reason for upgrading the facility. My data indicated that the treated wastewater effluent was beneficial to the amphibian and floral communities. This study was conducted at one particular type of sewage treatment center. For a comprehensive understanding of this subject, all types of sewage treatment centers should be studied.

Herpetofauna Communities in the Control and Experimental Areas

Amphibians

Ninety percent of all individual amphibians were observed in the experimental area. This site had greater plant biomass probably due to the fertilizing affect of the application of the wastewater effluent. Although the wastewater effluent met TNRCC standards as it left the facility, it did have relatively high level of the five pollutants when compared to the control. The passage of the water though a series of small wetlands decreased the high levels of chemicals other than solids in the water. Other studies have detailed the increase in water quality by decreasing levels of BOD, DO, pH, solids and ammonias in wetlands (Hiley 1995, Kuenzler 1987, Finlayson et al. 1986). The application of treated wastewater effluent to an area has been shown to increase vegetative biomass and algae populations (Neilsen et al. 1989, DeWalle 1983). This increase in plant biomass in turn increases the suitability of habitat for animals by increasing habitat, food resources, and available cover. Zug (1993) stated that the distributions of amphibians and reptiles involve habitat selection as defined by the availability of resources required for the survival of individuals of a particular species, for example, moisture and temperature regimes within a species' physiological tolerances, availability of food for both growth and reproduction, and shelter for protection from predators and weather. The large number of amphibians collected in the experimental area reflects the beneficial quality of the treated wastewater effluent on the Dodson Creek riparian area. Site quality is reinforced by the amount of plant biomass.

Reptiles

Although both food and cover appeared in abundance in the experimental area, the abundance of reptiles was about the same for the two sites with 53% in the control site and 47% in the experimental site. Most ecological concepts suggest that reptiles should be more abundant in the wastewater effluent area where there was more food and cover, but this was not the case. Perhaps, there was enough food and cover in both areas to sustain reptiles, however, the experimental area was relatively small for the amount of resources it offers. This small area per resource available may possibly cause territory conflicts. If this is the case, dominant reptiles will occupy the optimal sites leaving the less subordinate individuals to occupy the sub-optimal sites, the control area. With no significant difference between abundance of reptiles in the control and experimental areas, it appears that the application of treated wastewater effluent has no obvious effects on the reptilian community.

The Effect of a Flood Event on Amphibian and Reptile Communities

Flood effects on any type of community are relatively difficult to study because of unpredictability. Although the study area was in the floodplain of the Sabine River, the area had not been fully submerged as it was during the study for approximately 36 years. Fourteen days into the study recaptures were more common. Flooding occurred on day 15. As the floodwaters receded and collections began again, no previously marked amphibians or reptiles were caught. The entire resident community was displaced and new individuals moved into the study sites from the surrounding area or upstream. Flood intensity described by Blair (1939) and Grinnell (1939) was comparable to flood intensity of the current study in that the previous herpetofauna community was eliminated. However, new individuals quickly inhabited the study site after the recession of the floodwaters (Stickel 1948).

Amphibians

Thirty-one percent of the individual amphibians were collected and recorded before the flood, while 69% were recorded after the flood. The literature for such an event is limited. One study detailed a pattern of use by mammals in a floodplain (Sheppe 1971). The current study, however, did not have a gradual rise in water level with the extended precipitation. The tract was quickly inundated by the headwater from the release of water from lakes Fork and Tawakoni. The amphibians had no time to react. Floods remove vegetation and hence less cover was available for the remaining fauna (Keeley 1979). There was less vegetation and litter after the flood and it may have made it easier to see and collect amphibians. Amphibians in the study area were not as apparent before the disturbance. Once the flood arrived, it removed the resident amphibians and these were later replaced with new individuals. The assumption of a community replacement was based on no recaptures of individuals collected during the first 14 days of the study and all individuals captured after the flood had no marks of a previous capture.

Reptiles

Sixty-three percent of individual reptiles were collected before the flood while only 37% were collected after. Keeley (1979) stated that a flood causes a decrease in the amount of vegetation and litter biomass. The decrease in herbaceous vegetation and litter caused a decrease in cover for the current community. Reptiles are not as dependent on water as amphibians and may have found areas with more cover, disregarding the distance to water. This is supported by the fact that there were only two of six terrestrial species (*A. contortrix* and *R. regida*) were more common post-flood. They were only recorded once post-flood and not recorded pre-flood. With the rapid influx of floodwaters, individuals imported by the flood from upstream might have replaced the resident community. This is reinforced by the fact that no recaptures from the first day of reclamation and collection occurred until at least two weeks afterward the flood.

Management Implications

The City of Mineola Wastewater Treatment Plant discharged wastewater effluent that ultimately benefited the affected environment. Data indicate a beneficial impact on herpetofauna downstream as compared to the upstream control. Although the wastewater effluent is chemically tested when it leaves the plant it undergoes further treatment between the plant and the interface with Dodson Creek. The Clean Water Act states that a permit is needed to discharge a pollutant from a point source. A point source is defined by the Clean Water Act as any discernable, confined and discreet conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or floating craft from which pollutants are or may be discharged. Chemical testing at the City of Mineola Wastewater Treatment Plant occurs where the wastewater effluent leaves the man-made part of the treatment center, but the wastewater effluent enters an effluent only ditch or channel and receives further treatment before reaching the interface. I believe that chemical testing at the end of the discharge area (interface site) would yield more precise data of environmental quality of the discharge.

Flood event are random stochastic events of nature. As a manager, you usually cannot prepare for such events. The Sabine River complex has evolved under a series of floods over the centuries. The habitat in this study has evolved under flooding pressure, and therefore should not be altered to lessen the effects of the stochastic event. The fact that the area was quickly repopulated by amphibians and reptiles following the flood event is a testament of the adaptability of stream adapted species to buffer the effect of stochastic events.

LITERATURE CITED

Blair, W.F. 1939. Some observed effects of stream-valley flooding on mammalian populations in eastern Oklahoma. Journal of Mammology 20:304-306.

Brown, W.S., and W.S. Parker. 1976. A ventral scale clipping system for permanently marking snakes (Reptilia, Serpentes). Journal of Herpetology. 10: 247-249.

Carlstrom, D., and C. Edelstram. 1946. Methods of marking reptiles for identification after recapture. Nature 158: 748-749.

Clough, K.S., and T.A. DeBusk. 1987. Aquatic plants for water treatment and resource recovery. Magnolia Publishing, Oklahoma City, Oklahoma.

DeWalle, D.R. 1983. Conjunctive use of soil warming and municipal wastewater irrigation to enhance woody biomass production. Energy in Agriculture 2:37-50.

Dixon, J.R. 2000. Amphibians and reptiles of Texas. Texas A&M University Press. College Station, Texas.

Environmental Protection Agency. 2001. Report 600/4-79-020. Method 0150.1, 0360.1, 0405.l, 0170.1, 1689. Environmental Protection Agency, Washington, D.C.

Finlayson, M., P. Cullen, D. Mitchell, and A. Chick. 1986. An assessment of a natural wetland receiving sewage effluent. Australian Journal of Ecology 11:33-47.

Fisher, P. J. 2000. Alternate waste treatment systems. Elsevier Applied Science. London, England.

Friedman, J.M., W.R. Ostercamp, and W.M. Lewis Jr., 1996. Channel narrowing and vegetation development following a great plains flood. Ecology 77:2167-2181.

Grinnell, J. 1939. Effects of a wet year on mammalian populations. Journal of Mammology 20:62-64.

Hager, H.A. 1998. Area-sensitivity of reptiles and amphibians: are there indicator species for habitat fragmentation? Ecoscience 5:139-147.

Hartwell, H.W., and L.M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: a case study from California's redwoods. Ecological Applications 8:1118-1132.

Hiley, P.D. 1995. The reality of sewage treatment using wetlands. Water Science Technology 32:329-338.

Keeley, Jon E. 1979. Population differentiation along a flood frequency gradient: physiological adaptations to flooding in *Nyssa sylvatica*. Ecological Monographs 49:89-108.

Kuenzler, E.J. 1987. Impacts of sewage effluent on tree survival, water quality and nutrient removal in coastal plain swamps. Water Resources Research Institute of the University of North Carolina, Chapel Hill, North Carolina.

Lambert, M.R.K. 1999. Lizards as bioindicators. Biologist 46:12-16.

Neilsen, G.H., D.S. Stevenson, J.J. Fitzpatrick, and C.H. Brownlee. 1989. Yield and plant nutrient content of vegetables trickle-irrigated with municipal wastewater. HortScience 24:249-252.

Oladimji, A.A., and J.W. Wade. 1984. Effects of effluents from a sewage treatment plant on the aquatic organisms. Water, Air, and Soil Pollution 23:309-316.

Owen, O.S., and D.D. Chiras. 1990. Natural resource conservation: an ecological approach. Macmillan Publishing, New York, New York.

Rabe, M.L. 1979. Impact of wastewater discharge upon a northern Michigan wetland community. Dissertation, Michigan State University, East Lansing, Michigan.

Rose, F.L. 1977. Tissue lesions of tiger salamanders (*Ambystoma tigrinum*): relationship to sewage effluents. Annals of the New York Academy of Sciences 298:270-279.

Rose, F.L., D.R. Long, , D.B. Pence, and D.D. Waid. 1989. Gastric oxyuriasis and its consequences in yellow mud turtles (*Kinosternon flavescens*) associated with sewage effluent. Herpetopathologica 1:53-64.

Schöne, L.M. 1989. Comparison of two freshwater turtle species as monitors of environmental contamination. Dissertation, The University of Tennessee, Knoxville, Tennessee.

Sheppe, Walter. and T. Osborne. 1971. Patterns of use of a floodplain by Zambian mammals. Ecological Monographs 41:179-205.

Skartvedt, P.H. 2000. Woody riparian vegetation patterns in the Upper Mimbres Watershed, Southwestern New Mexico. The Southwestern Naturalist 45:6-14.

Smith, Z.A. 2000. The environmental policy paradox. Prentice Hall, Upper Saddle River, New Jersey.

Stafford, D.P., F.W. Plapp, and R.R. Fleet. 1975. Snakes as indicators of environmental contamination: Relation of detoxifying enzymes and pesticide residues to species occurrence in three aquatic ecosystems. Archives of Environmental Contamination and Toxicology 5:15-27.

Stickel, L.F. 1948. Observations of the effect of flood on animals. Ecology 505–507.

Texas Administrative Code. 2001. Title 30. Part 1. Chapter 325. Subchapter B. Rule 325.106. Austin, Texas.

Welsh, H.H., and L.M. Ollivier. 1998. Stream amphibians as indicators of ecosystem stress: a case study from the California redwoods. Ecological Applications. 8:1118-1132.

Zar, J.H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, New Jersey.

Zug, G.R. 1993. Herpetology: an introductory biology of amphibians and reptiles. Academic Press, San Diego, California.

TABLES

Table 1. Water chemistry analysis for solids, pH, DO, BOD, and ammonias at three collection sites at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Factors	Site A	Site B	Site C
Solids	41.0	31.5	9.0
PH	8.0	6.7	6.8
DO (mg/L)	5.4	3.9	4.3
BOD (mg/L)	18.1	3.8	4.3
Ammonias (mg/L)	1.1	0	0

Table 2. Mean, standard error and range of values for plant biomass of Dodson Creek drift fence arrays at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Array	n	$\overline{X}$ Biomass (g/ ¼ m^2)	SE	Min - Max (g/ ¼ m^2)
1	3	38.33	5.61	30 – 49
2	3	59.00	31.90	15 – 121
3	3	51.00	2.08	47 – 54
4	3	30.00	9.07	19 – 48
5	3	17.33	8.84	0 – 29
6	3	26.33	8.88	16 – 44

FIGURES

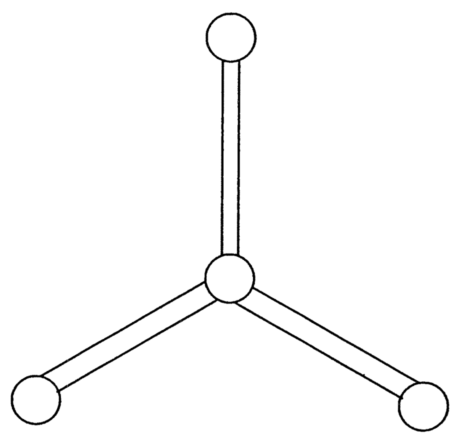

Figure 1. Configuration of an individual drift fence array located at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

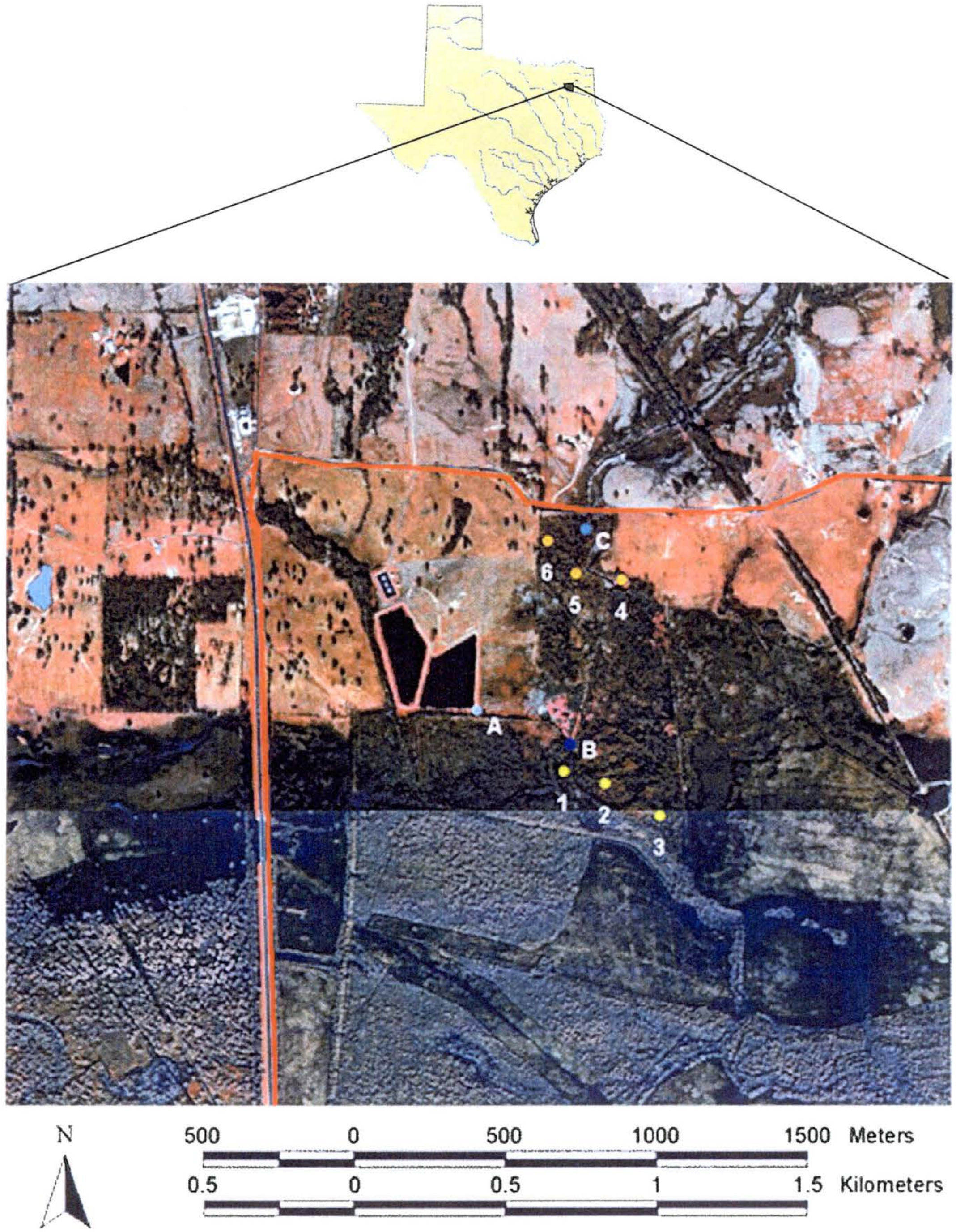

Figure 2. Image of the City of Mineola Wastewater Treatment Plant and study sites on or near Dodson Creek in Wood County, Texas, 2000. Drift fence arrays in the experimental area are indicated by 1, 2, and 3 and on the control by 4, 5, and 6. Water samples were collected at points A, B, and C.

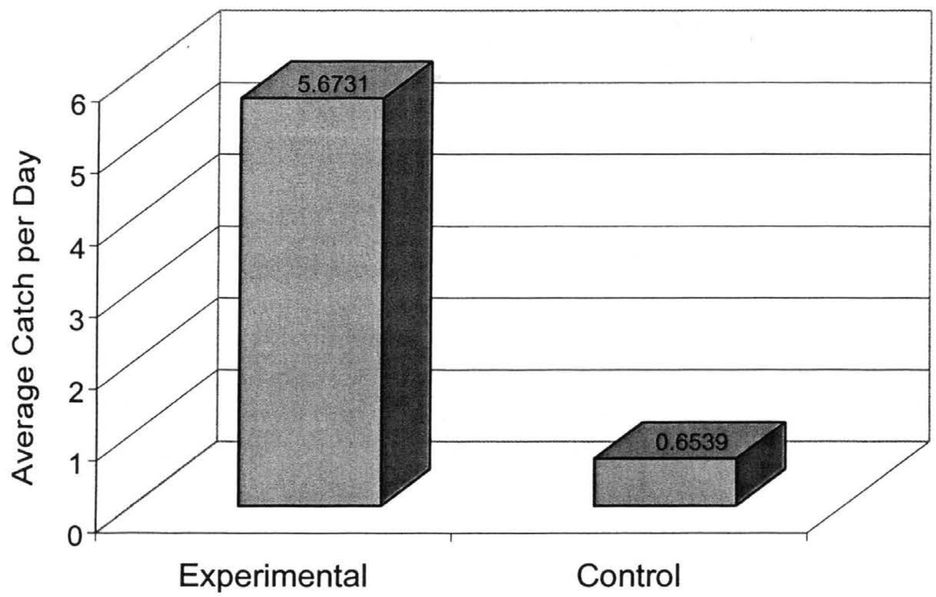

Figure 3. Comparison of the average number of amphibians collected per day in experimental and control areas at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

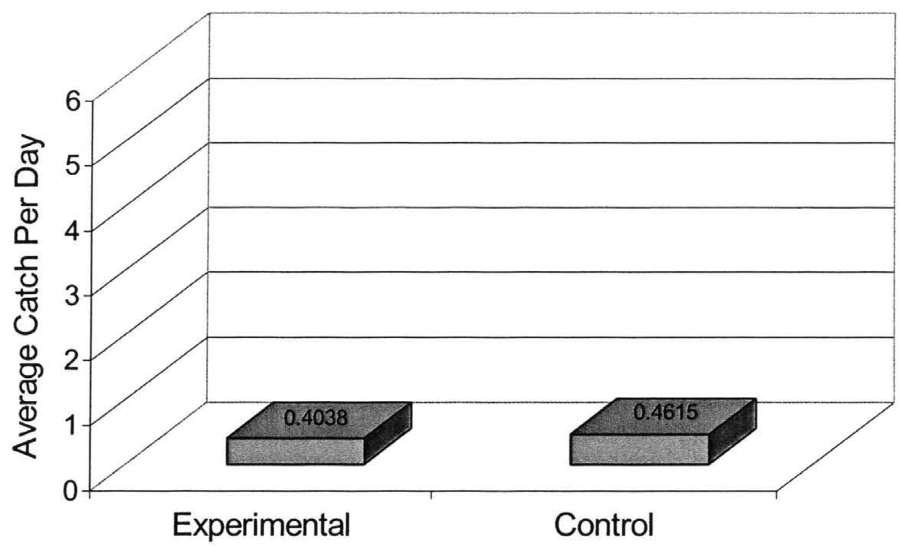

Figure 4. Comparison of the average number of reptiles collected per day in experimental and control areas at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

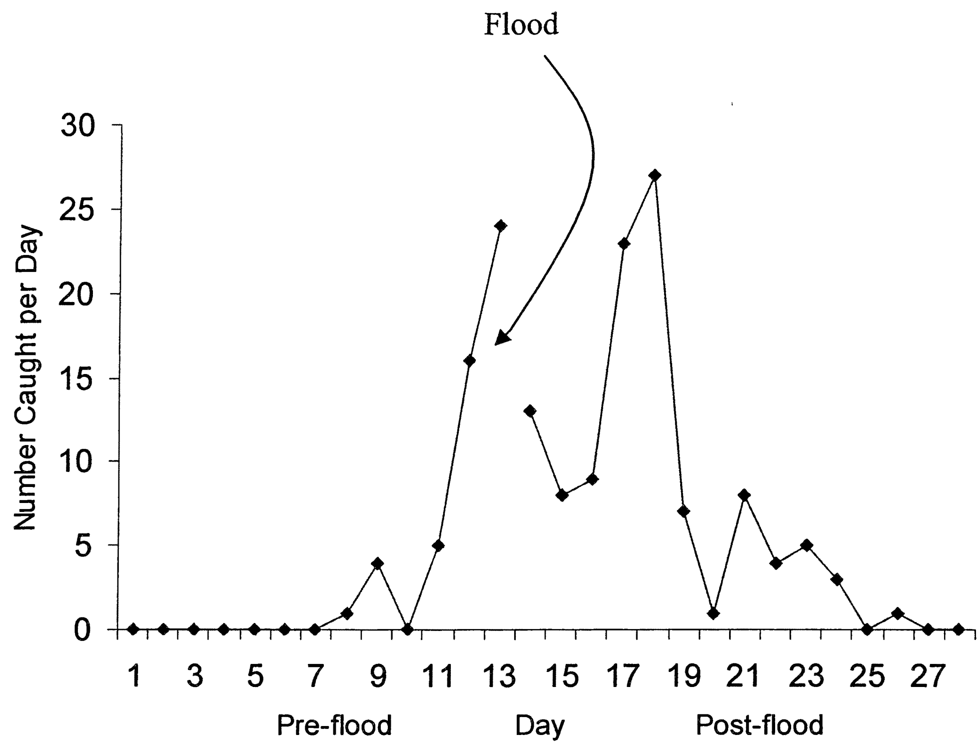

Figure 5. Number of amphibians collected per day during the 14 days pre-flood (30 May –14 June) and the 14 days post-flood (29 June – 14 July) at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

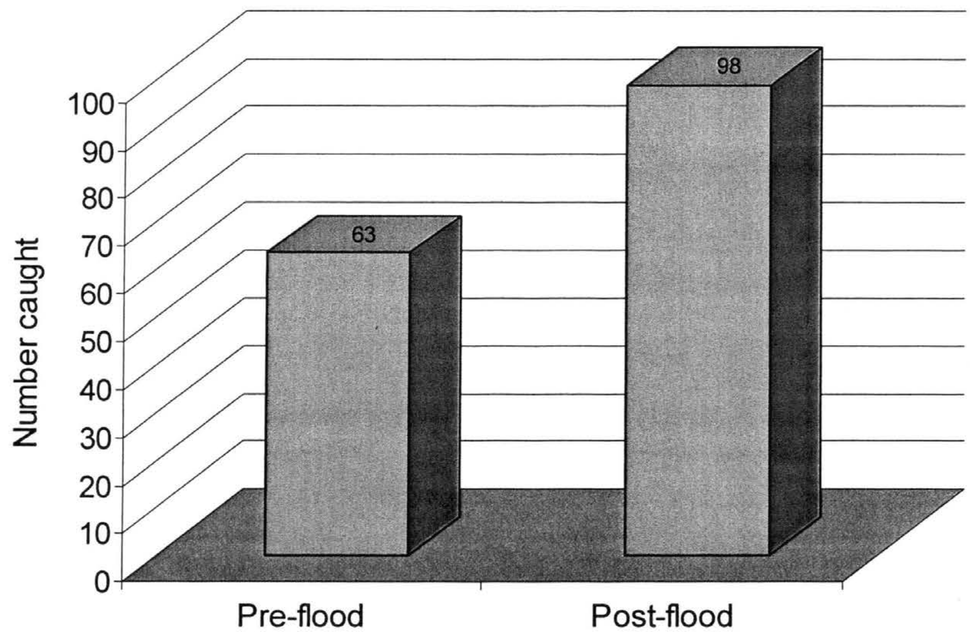

Figure 6. Abundance of amphibians collected 14 days pre-flood and 14 days post-flood at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

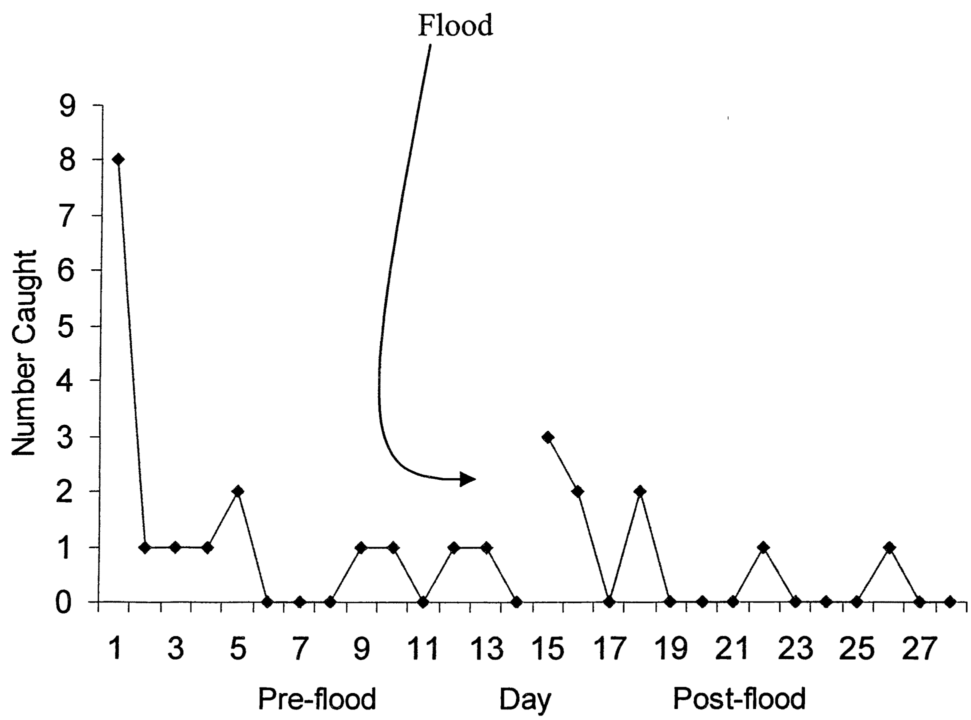

Figure 7. Number of reptiles collected per day during the 14 days pre-flood (May 30 – June 14) and the 14 days post-flood (June 29 – July 14) at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

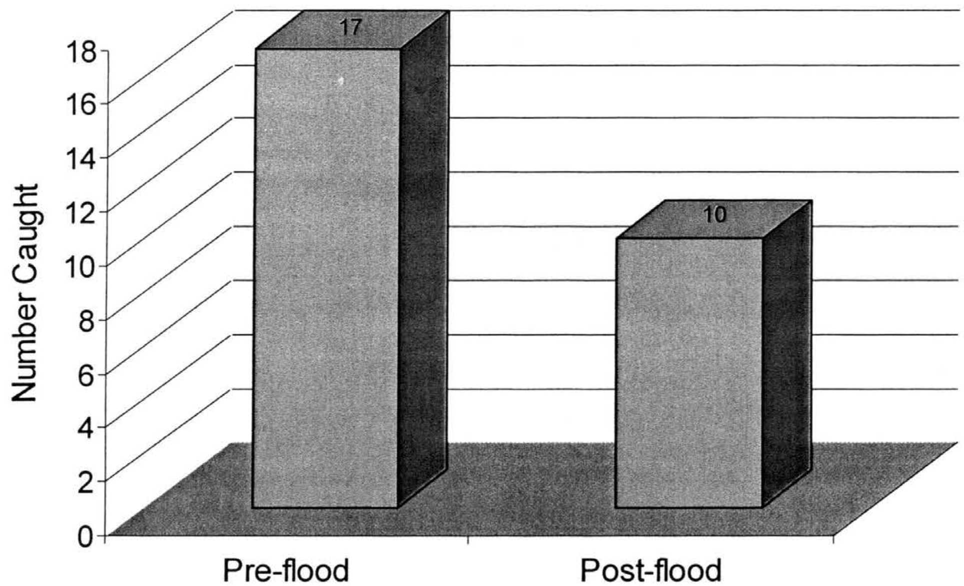

Figure 8. Number of reptiles collected 14 days pre-flood and 14 days post-flood at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

APPENDICES

APPENDIX A. Amphibian species collected per day in the experimental area at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Date	*Rana utricularia*	*Rana clamitans*	*Gastrophryne carolinensis*	*Bufo woodhousii*	*Hyla cinerea*	*Acris crepitans*
30 May	0	0	0	0	0	0
31	0	0	0	0	0	0
1 Jun	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	1	0	0	0	0	0
8	2	0	0	0	0	0
9	0	0	0	0	0	0
10	5	0	0	0	0	0
12	6	0	0	0	0	0
13	18	0	0	1	0	0
14	8	2	0	0	0	0
29	4	0	1	0	0	0
30	6	0	1	1	0	0
1 Jul	19	2	1	1	0	0
3	25	0	0	0	0	1
4	7	0	0	0	0	0
5	1	0	0	0	0	0
6	5	0	0	3	0	0
7	4	0	0	0	0	0
8	5	0	0	0	0	0
10	1	0	0	2	0	0
11	0	0	0	0	0	0
12	0	0	1	0	0	0
13	0	0	0	0	0	0
14	0	0	0	0	0	0
15	0	0	1	0	0	0
17	1	0	0	0	0	0
18	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	1	0	0	0	0	0
27	0	0	0	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
31	0	0	0	0	0	0
1 Aug	7	0	0	0	0	0
2	3	0	0	0	0	0
3	5	0	0	0	2	0
4	9	0	0	0	3	0
5	3	0	0	0	0	0
7	12	0	0	0	4	0
8	0	0	0	0	2	0
9	3	0	0	0	17	0
10	2	0	0	0	9	0
11	0	0	0	0	7	0
12	0	0	0	0	4	13
14	0	0	0	0	2	9
15	0	0	0	0	2	12
16	0	0	0	0	9	19

APPENDIX B. Amphibian species collected per day in the control area at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Date	*Rana utricularia*	*Rana clamitans*	*Gastrophryne carolinensis*
30 May	0	0	0
31	0	0	0
1 Jun	0	0	0
2	0	0	0
3	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	2	0	0
9	0	0	0
10	0	0	0
12	10	0	0
13	2	3	0
14	2	1	0
29	0	3	0
30	0	1	0
1 Jul	0	0	0
3	1	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
10	0	0	0
11	0	0	0
12	0	1	0
13	0	0	1
14	0	0	0
15	0	1	2
17	0	0	0
18	0	1	0
24	0	0	0
25	0	0	0
26	0	0	0
27	0	0	0
28	0	0	0
29	0	0	0
31	0	0	0
1 Aug	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
7	0	0	0
8	1	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0

APPENDIX C. Reptile species collected per day in the experimental area at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Date	*Agkistrodon piscivorous*	*Nerodia rombifer*	*Eumeces fasciata*	*Regina regida*	*Scincella laterallis*	*Apalone mutica*	*Terrepene carolina*	*Trachemys scripta*
30 May	0	0	3	0	2	1	1	0
31	0	0	0	0	0	0	0	0
1 Jun	0	0	0	0	0	0	0	1
2	0	1	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	1	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
30	0	0	0	1	0	0	0	0
1 Jul	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0
27	0	0	1	0	0	0	0	0
28	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0
31	1	0	0	0	0	0	0	0
1 Aug	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0
8	0	1	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	1	0	1	0	0	0	0	0
11	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0
15	0	0	1	0	0	0	0	0
16	0	0	0	0	0	0	0	0

APPENDIX D. Reptile species collected per day in the experimental area at the City of Mineola Wastewater Treatment Plant, Wood County, Texas, 2000.

Date	*Agkistrodon pisciverous*	*Nerodia rombifer*	*Nerodia erytherogastor*	*Nerodia fasciata*	*Eumeces fasciata*	*Agkistrodon contortrix*	*Scincella laterallis*	*Lampropeltis getulla*	*Chelydra serpentina*	*Terrepene carolina*
30 May	0	0	0	0	1	0	0	0	0	0
31	0	0	0	0	0	0	1	0	0	0
1 Jun	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	1	0	1	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	1	0	0	0
9	0	0	0	0	1	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	1	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	1	1	0	0	0
30	0	0	1	0	0	0	0	0	0	0
1 Jul	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	1	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	1	0	0
17	0	0	0	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
24	1	0	0	0	0	0	0	0	0	0
25	0	0	0	1	0	1	1	0	0	1
26	0	0	0	0	0	0	0	0	0	0

APPENDIX D Cont.

Date	Agkistrodon pisciverous	Nerodia rombifer	Nerodia erytherogastor	Nerodia fasciata	Eumeces fasciata	Agkistrodon contortrix	Scincella laterallis	Lampropeltis getulla	Chelydra serpentina	Terrepene carolina
27-Jul	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0
1-Aug	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	1	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	1	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	1	0	0	0	0	0	0	0	0

VITA

Roy Blake Dean was born in Tyler, Texas on November 14, 1975, the son of Roy Wayne Dean and Cathy Jo Walker. After completing his work at Mineola High School, Mineola, Texas, in 1994, he entered Tyler Junior College in Tyler, Texas. He received the degree of Bachelor of Science from Texas A&M University, College Station, Texas, in May 1999. The following summer he worked for Texas Parks and Wildlife, as a Natural Resource Specialist Intern and entered the Graduate School of Southwest Texas State University, Biology Department, San Marcos, Texas, in August 1999. While at Southwest Texas State University he was a graduate Instructional Assistant for six different laboratory classes including Ecology, Genetics, Organismal Biology, Functional Biology, Modern Biology II, and General Science. He is now employed as an Environmental Scientist for TGE Resources, Houston, Texas.

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