INSECT EMERGENCE FROM TEMPORARY AND PERMANENT PONDS: RESPONSE TO DRYING

by

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TABLE OF CONTENTS

LIST OF FIGURES

Introduction:

Pond permanence is thought to be the single most important abiotic factor influencing insect community structure in small ponds (Batzer and Wissinger 1996; Welborn et al. 1996; Chumchal and Drenner 2015). In permanent ponds (ponds that hold water for years at a time) containing fish, fish act as size selective predators, reducing the number of large insect taxa, such as dragonflies (Welborn et al. 1996; Tweedy et al. 2013; Chumchal and Drenner 2015). In temporary ponds (ponds that dry periodically), the absence of fish allows for an increase in abundance of large-bodied, predatory insects, e.g. dragonflies, which replace fish as the top predators in the system (Batzer and Wissinger 1996; Welborn et al. 1996; Chumchal and Drenner 2015).

Although it is well established that insect communities are different in permanent and temporary ponds because of fish predation, little is known about aquatic insect succession and emergence after a temporary pond dries and then refills. The objective of this study was to examine insect emergence in small (<1 ha) permanent ponds that continuously hold water and temporary ponds that were dried and refilled with water. I found that insect succession in temporary ponds was rapid and related to insect body size. In addition, for any given taxa the numbers of emerging insects was controlled by the taxa’s vulnerability to fish predation.

Methods:

Study Site: I conducted the present study in 10 experimental ponds at the Eagle Mountain Fish Hatchery near Fort Worth, Texas, USA. The experimental ponds are whole ecosystems with earthen bottoms that contain complex communities of macrophytes, benthic invertebrates, and herptiles (Tweedy et al. 2013). Ponds range in size from 0.23 to 0.54 ha with an average depth of 0.8 meters (Tweedy et al. 2013). Macrophyte communities were variable between ponds and were composed of several species of emergent and submerged taxa (Tweedy et al. 2013). The ponds are supplied with water from Eagle Mountain Lake (Tweedy et al. 2013).

Experimental Design: In spring 2013, the ponds were filled with water from Eagle Mountain Lake. In June 2013, bluegill (Centrachidae: *Lepomis macrochirus*) were purchased from a commercial hatchery and stocked in the ponds (Tweedy et al. 2013). Visual observation in the summers of 2013 (Tweedy et al. 2013) and 2014 confirmed that the bluegill had spawned in all of the ponds. Bluegill are commonly found in fish communities throughout the United States (Lee 1980). Bluegill visually locate and preferentially consume large prey items (O'Brien 1979; Tweedy et al. 2013). Bluegill feed on benthic invertebrates as well as other prey (Vander Zanden and Vadeboncoeur 2002; Tweedy et al. 2013). On April 1, 2014, five of the 10 ponds were drained and the fish removed. The drained ponds dried for 43 days (April 1 – May 12, 2014) before being refilled with water from Eagle Mountain Lake on May 13, 2014. The five ponds that were drained and refilled represent temporary ponds without fish while the five ponds that were not drained represent permanent ponds with fish.

Experimental Procedure: Emergent insects were collected over a continuous 10-week period from May 16, 2014 to July 28, 2014. I used pyramid-shaped floating emergence traps to sample adult emerging insects (Figure 1) (Tweedy et al. 2013). Each trap sampled a 0.53 m × 0.53 m area (0.28 m^2) (Tweedy et al. 2013). Four traps were deployed in each pond (Tweedy et al. 2013). Each trap was held in place with two 1-cm diameter plastic-coated stakes pushed into the sediment by hand (Tweedy et al. 2013). Traps were staked at random locations near each corner of the pond at an average water depth of 52.1 ± 1.51 cm (average ± standard error (SE)). The traps funneled emerging insects (e.g. Chironominae, Trichoptera, Ephemeroptera, Zygoptera) into a collecting bottle containing 95% ethanol (Tweedy et al. 2013). Collecting bottles were replaced, and traps were moved to new locations every four to 11 days (Tweedy et al. 2013). Anisoptera and some Zygoptera and Ephemeroptera did not move into the sampling bottle and were captured by hand from the lower part of the trap and placed in the sample bottle (Tweedy et al. 2013). One trap during one week was excluded from analysis due to damage.

Figure 1: Pyramid-shaped floating emergence trap used to sample adult emerging insects, secured with 1-cm diameter plastic-coated stakes.

All individual insects collected from a given pond were identified and counted. Ten taxonomic groups of insects were captured in adequate numbers for analyses; Diptera: Chironomidae: Chironominae and Orthocladiinae (primarily herbivorous chironomids), Diptera: Chironomidae: Tanypodinae (predatory chironomids), Diptera: Chaoboridae (phantom midges), Diptera: Culicidae (mosquitoes), Diptera: Ceratopogonidae (biting midges), Trichoptera: Hydroptilidae (micro-caddisflies), Ephemeroptera: Baetidae (mayflies), Odonata: Zygoptera (damselflies) and Odonata: Anisoptera (dragonflies). I collected an average of 4845 ± 1395 (average ± SE) individual insects from each pond.

Size Analysis: Total body length measurements were made for all insect taxa. Composite samples were placed into a 6 X 6 gridded petri dish. Grid cells were randomly selected and photographed using AxioVision® micro-photography software. Any insect occurring within the boundaries of the grid cell were measured (total body length, mm) using ImageJ® image processing and analysis software.

Statistical Analysis: For each taxa, daily emergence (number/day/m^2) and total emergence (number/m^2) during the ten week experiment were determined for permanent and temporary ponds. A 2-sample t-test was used to test for differences in total emergence between treatments ($\alpha = 0.05$). Total emergence calculations for Anisoptera, Zygoptera, and Ephemeroptera from temporary and permanent ponds only include individuals collected after the first dates of emergence from temporary ponds.

Results:

Low numbers of Orthocladiinae emerged from permanent ponds throughout the experiment (Fig. 1A). Large numbers of Orthocladiinae emerged from the temporary ponds on days 11 and 18. Orthocladiinae emergence was low between days 25-59 followed by another peak on days 68-73. At the end of the experiment Orthocladiinae total emergence was 151 ± 115/m^2 and 918 ± 521/m^2 from the permanent and temporary ponds, respectively. There was no significant difference in Orthocladiinae total emergence between permanent and temporary ponds ($p = 0.19$).

Tanypodinae emergence was similar from both permanent and temporary ponds throughout most of the experiment (Fig. 1B). There was a spike in Tanypodinae emergence in the temporary ponds on day 73. Average total Tanypodinae emergence was 929 ± 474/m^2 and 753 ± 517/m^2 for permanent and temporary ponds, respectively. There was no significant difference in Tanypodinae total emergence between permanent and temporary ponds ($p = 0.81$).

Ceratopogonidae emergence was similar from both permanent and temporary ponds throughout the experiment (Fig. 1C). The highest levels of Ceratopogonidae emergence occurred on day 11 and then emergence declined throughout the experiment. Total Ceratopogonidae emergence was 294 ± 100/m^2 and 267 ± 95.3/m^2 for permanent and temporary ponds, respectively. There was no significant difference in Ceratopogonidae total emergence between permanent and temporary ponds ($p = 0.850$).

In the permanent ponds, Hydroptilidae emergence was highest during the first 25 days of the experiment and then declined (Fig. 1D). In the temporary ponds Hydroptilidae emergence was consistently low throughout the experiment. Total Hydroptilidae emergence was 752 ± 380/m^2 and 183 ± 62/m^2 from permanent and temporary ponds, respectively. There was no significant difference ($p = 0.18$) in Hydroptilidae total emergence between the two treatments

There was an initial pulse in Chironominae emergence in both permanent and temporary ponds at the beginning of the experiment followed by a decline in daily emergence (Fig. 1E). Total Chironominae emergence was 1885 ± 753/m^2 and 1773 ± 920/m^2 from permanent and temporary ponds, respectively. No significant difference in Chironominae total emergence was detected between permanent and temporary ponds ($p = 0.93$).

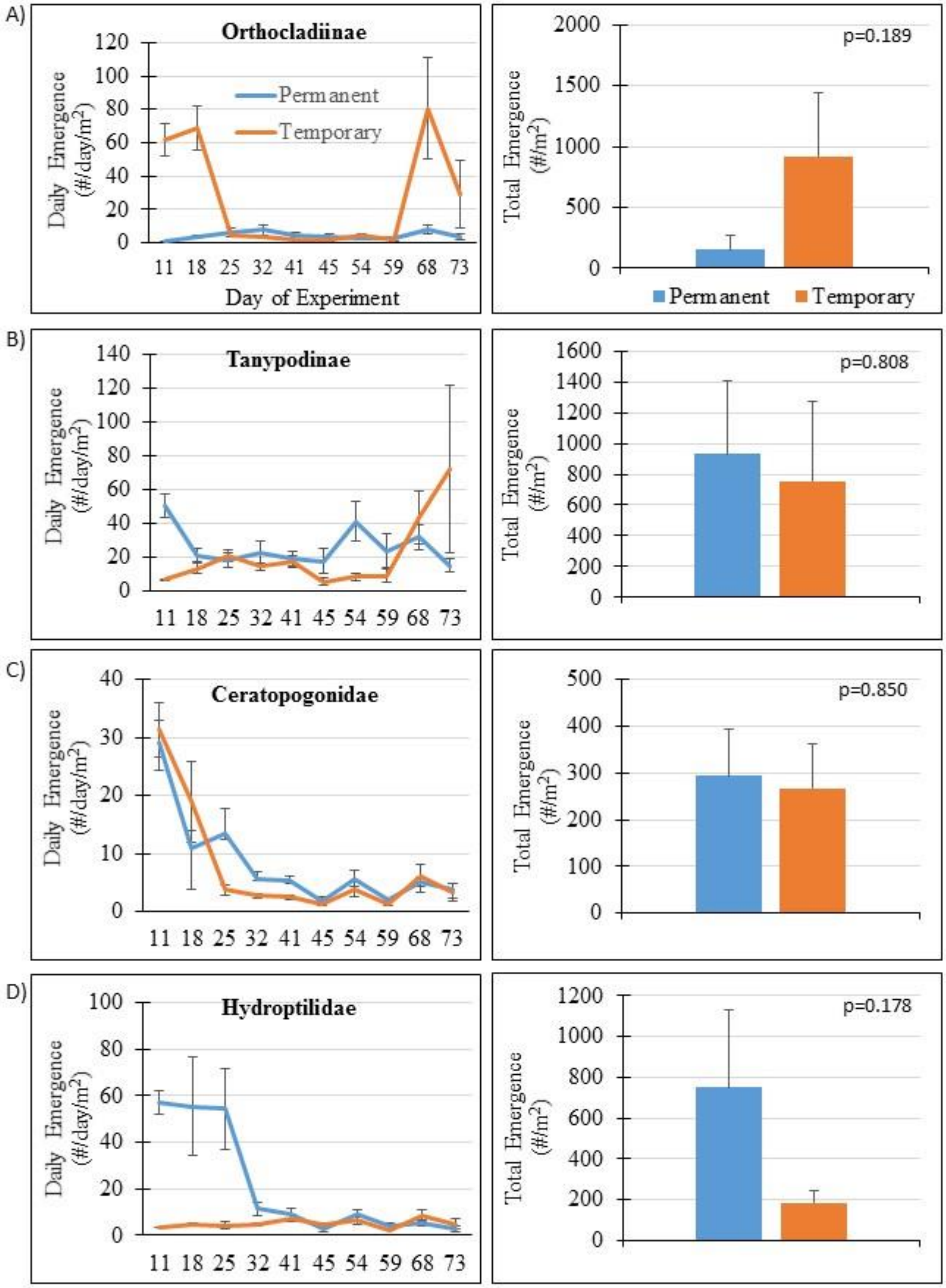
In permanent ponds, Chaoboridae emergence was low throughout the experiment (Fig. 1F). In the temporary ponds, Chaoboridae emergence was elevated from day 11 through day 41 and then declined and became similar to the permanent ponds. Chaoboridae total emergence was 8 ± 4/m^2 and 482 ± 174/m^2 in permanent and temporary ponds, respectively. Chaoboridae total emergence was significantly different in permanent and temporary ponds ($p = 0.03$).

In permanent ponds, Culicidae emergence was low at the start of the experiment and elevated from days 41-73 (Fig 1G). In the temporary ponds Culicidae emergence was low throughout most of the experiment but elevated from days 68-73. Total emergence was 45 ± 26/m^2 and 20 ± 8/m^2 in permanent and temporary ponds, respectively. No significant difference in Culicidae total emergence was detected between permanent and temporary ponds (p = 0.39).

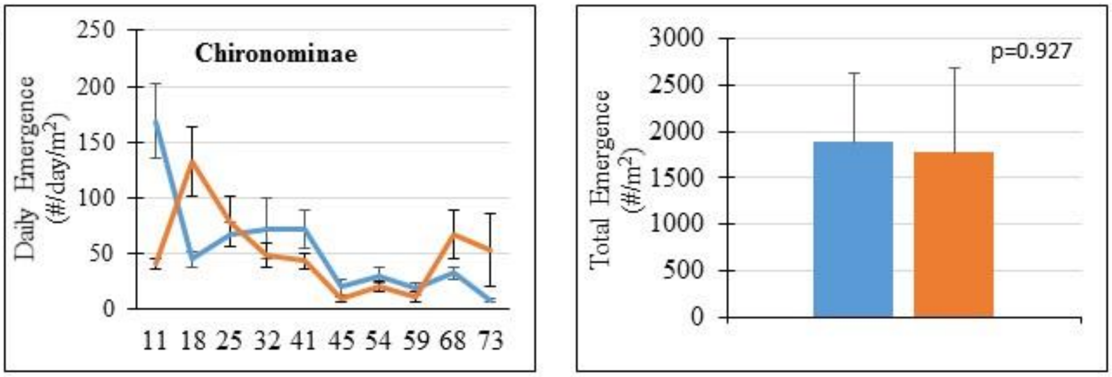
During the experiment very few Ephemeroptera emerged from permanent ponds (Fig 1H). In the temporary ponds, Ephemeroptera emergence was first observed on day 18 and continued throughout the experiment. Total Ephemeroptera emergence was 4 ± 2/m^2 and 86 ± 51/m^2 for permanent and temporary ponds, respectively. No significant difference in Ephemeroptera total emergence was detected between permanent and temporary ponds (p = 0.15).

In permanent ponds, Zygoptera emerged throughout the experiment (Fig. 1I). In temporary ponds, Zygoptera emergence was first observed on day 25 and then fairly constant throughout the experiment. Daily Zygoptera emergence from temporary ponds never exceeded that of permanent ponds. Total emergence was 33 ± 14/m^2 and 20 ± 3/m^2 from permanent and temporary ponds, respectively. No significant difference in Zygoptera total emergence was detected between permanent and temporary ponds (p = 0.38).

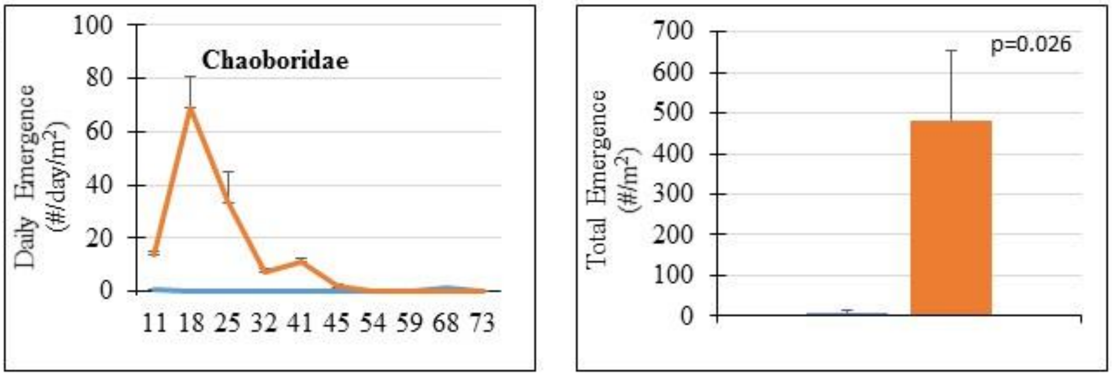
In permanent ponds, relatively low levels of Anisoptera emergence occurred throughout the experiment (Fig. 1J). In temporary ponds, Anisoptera emergence was first observed on day 32 and then remained higher throughout the experiment. Total Anisoptera emergence was 2 ± 0.9 and 9 ± 2/m^2 from permanent and temporary ponds, respectively. Anisoptera total emergence was significantly different in permanent and temporary ponds (p = 0.04).


A)
Orthocladiinae
Daily Emergence (#/day/m^2)
120
100
80
60
40
20
0
Permanent
Temporary
11 18 25 32 41 45 54 59 68 73
Day of Experiment
Total Emergence (#/m^2)
2000
1500
1000
500
0
p=0.189
■ Permanent ■ Temporary
B)
Tanypodinae
Daily Emergence (#/day/m^2)
140
120
100
80
60
40
20
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
1600
1400
1200
1000
800
600
400
200
0
p=0.808
C)
Ceratopogonidae
Daily Emergence (#/day/m^2)
40
30
20
10
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
500
400
300
200
100
0
p=0.850
D)
Hydroptilidae
Daily Emergence (#/day/m^2)
100
80
60
40
20
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
1200
1000
800
600
400
200
0
p=0.178

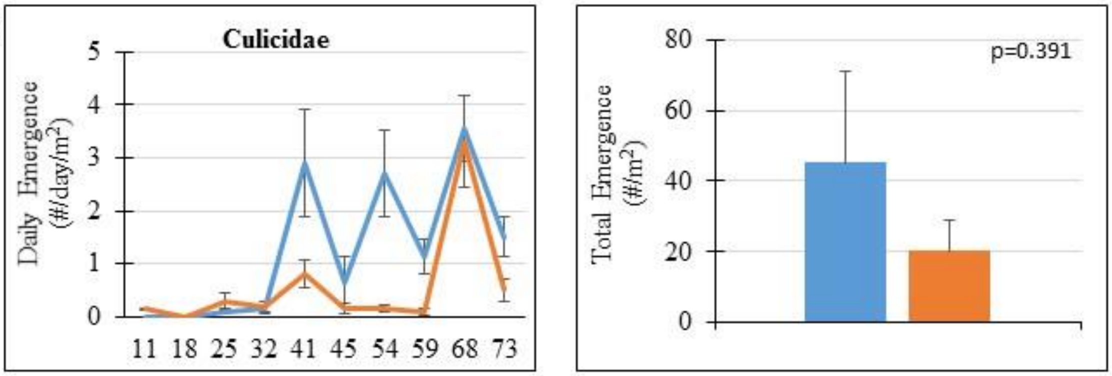
E)


Chironominae
Daily Emergence (#/day/m^2)
250
200
150
100
50
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
3000
2500
2000
1500
1000
500
0
p=0.927

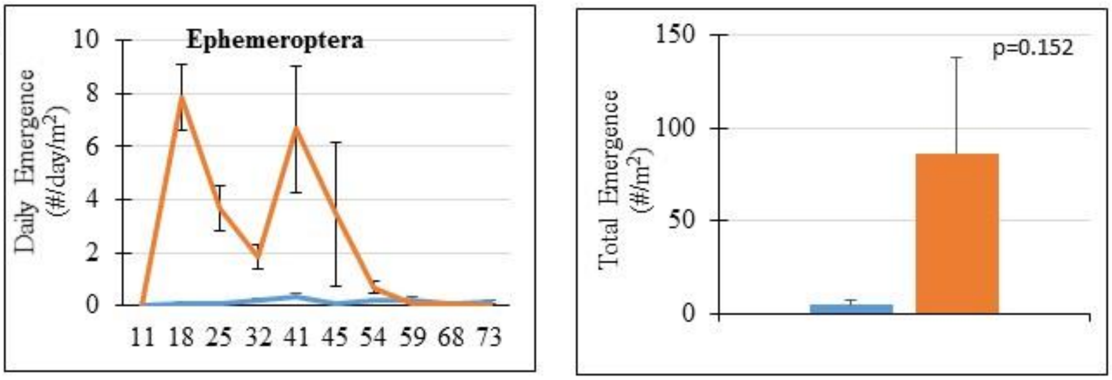
F)


Chaoboridae
Daily Emergence (#/day/m^2)
100
80
60
40
20
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
700
600
500
400
300
200
100
0
p=0.026

G)


Culicidae
Daily Emergence (#/day/m^2)
5
4
3
2
1
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
80
60
40
20
0
p=0.391

H)


Ephemeroptera
Daily Emergence (#/day/m^2)
10
8
6
4
2
0
11 18 25 32 41 45 54 59 68 73
Total Emergence (#/m^2)
150
100
50
0
p=0.152

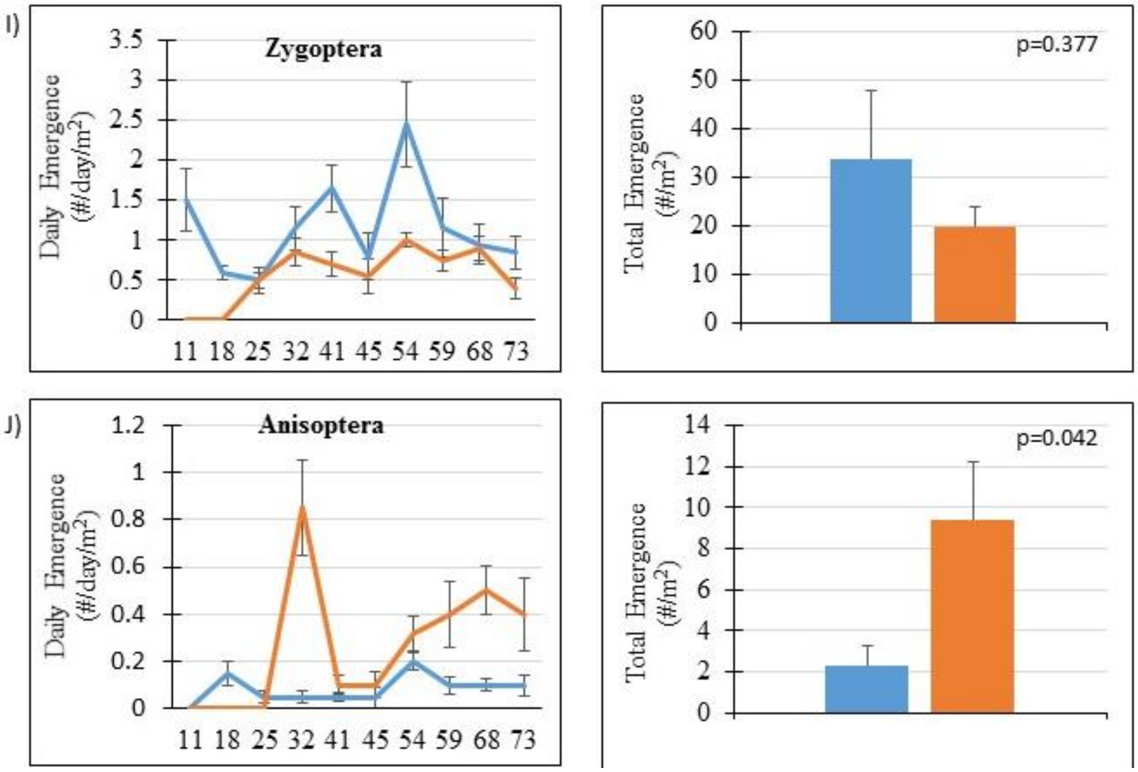


Figure 2: Daily emergence through time (left) and total emergence from permanent ponds with fish (n=5) and temporary ponds without fish (n=5). A) Orthocladiinae, B) Tanypodinae, C) Ceratopognidae, D) Hydroptilidae, E) Chironominae, F) Chaoboridae, G) Culicidae, H) Ephemeroptera, I) Zygoptera, and J) Anisoptera. P-values were calculated using 2-sample *t*-test, testing for differences in total insect emergent between permanent ponds with fish (n=5) and temporary ponds without fish (n=5).

Insect body size (total length) was strongly correlated with the order of insect emergence from temporary ponds (R^2 = 0.94, Figure 3). Small bodied (< 2 mm total length) Chironominae and Orthocladiinae emergence was first observed on day 11 from the temporary ponds and continued throughout the experiment. Ephemeroptera, an intermediate sized insect (3.99 mm total length), emergence from temporary ponds was first observed on day 18 of the experiment. Zygoptera, the second largest insect taxa (28.1 mm total length), emergence from temporary ponds was first observed on day 25. Anisoptera, the largest insect taxa (45.5 mm total length), emergence from temporary ponds was first observed on day 32 of the experiment.

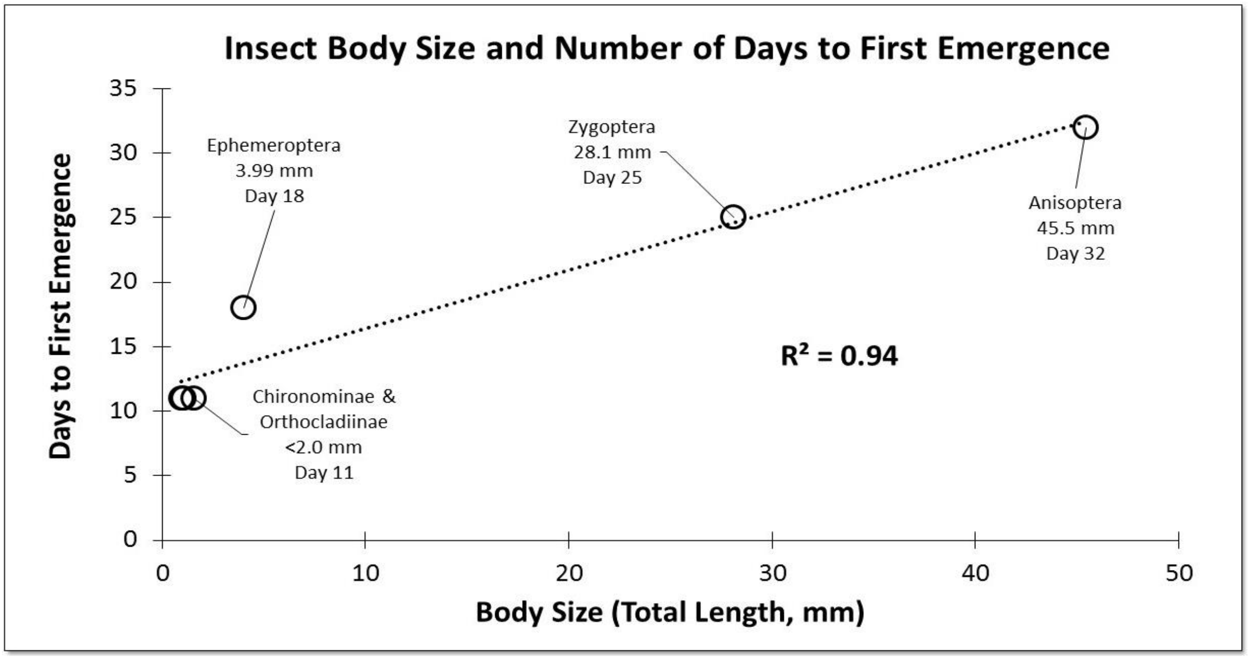


Figure 3: Relationship between insect body size (total length) and day of first emergence. Small taxa (e.g. Chironominae and Orthocladiinae (<2.0 mm total length) emergence were first observed on day 11. Ephemeroptera (3.99 mm total length) emergence was first observed on day 18. Zygoptera (28.1 mm total length) emergence was first observed on day 25. Anisoptera (45.5 total length) emergence was first observed on day 32.

Discussion:

Ponds are one of the most numerous aquatic ecosystems, with 8-9 million in the United States (Smith et al. 2002). The food webs of ponds interact with the surrounding terrestrial environment through emerging aquatic insects that transport carbon and contaminants from ponds to terrestrial consumers (Schindler and Scheuerell 2002; Vander Zanden and Gratton 2011; Tweedy et al. 2013; Speir et al. 2014; Chumchal and Drenner 2015). The species that emerge and the magnitude of their biomass varies with pond type (Tweedy et al. 2013). Permanent ponds that do not dry contain fish that act as size selective predators and reduce the abundance of large-bodied insect taxa (Batzer and Wissinger 1996; Welborn et al. 1996; Tweedy et al. 2013) and thus alter the species composition and the overall biomass of insects emerging from the pond (Tweedy et al. 2013; Chumchal and Drenner 2015). Temporary ponds dry and do not contain fish populations and therefore after they have refilled and undergone succession they have insect communities that have more large species (Batzer and Wissinger 1996) and an overall biomass of emerging insects that is greater than that of permanent ponds (Tweedy et al. 2013, Chumchal and Drenner 2015). The field has never investigated how long it takes after a temporary pond refills for populations of large-bodied taxa to become reestablished and produce a higher biomass of emerging insects than permanent ponds. The key to understanding this are studies of early insect succession in temporary ponds that have been dried and refilled.

The study presented here is one of the first to examine insect succession in temporary ponds after they have been dried and refilled. In this study, I compared the insect communities undergoing succession in temporary ponds to established insect communities in permanent ponds. I found that insect succession in temporary ponds was rapid and the order of emergence was related to insect body size. In addition, for any given taxa the numbers of emerging insects was controlled by the taxa's vulnerability to fish predation. Large-bodied taxa, like Anisoptera, are most vulnerable to fish predation and were least abundant in permanent ponds with fish. Small-bodied taxa, like Chironominae, are least vulnerable to fish predation and their emergence was not significantly different between temporary and permanent ponds. My study suggests that relative to permanent ponds, temporary ponds may have greater insect-mediated carbon and contaminant transport to terrestrial consumers except for a short period (<2 months) while they are undergoing insect community succession following pond refilling.

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VITA

Frank Murchison Greenhill was born August 12, 1981, in Fort Worth, Texas. He is the son of William D. Greenhill and Ann M. Greenhill. Frank Greenhill graduated from Arlington Heights High School, Fort Worth, Texas, in May, 2000. He received his Bachelor of Science with a major in Wildlife and Fisheries Management from Texas Tech University, Lubbock, Texas, 2006.

During his undergraduate study he worked for Texas Tech University, Plant and Soil Sciences, as a greenhouse manager and laboratory technician. After being awarded his Bachelor's degree he gained employment with the United States Forest Service, San Juan National Forest, Columbine Ranger District, as a Biological Science Technician (Wildlife).

Beginning in August 2013, he enrolled in graduate school at Texas Christian University, where he plans on receiving his Master of Science degree in May, 2015. While attending TCU, he was awarded a teaching assistantship and granted an Adkins Fellowship research grant in the summer of 2014.

ABSTRACT

INSECT EMERGENCE FROM TEMPORARY AND PERMANENT PONDS: RESPONSE TO DRYING

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Pond permanence and the presence of predatory fish are the major factors controlling aquatic insect community structure and the emergence of adult insects from aquatic to terrestrial ecosystems. There are two general classes of ponds. Permanent ponds maintain water for years at a time and contain predatory fish. Temporary ponds dry periodically and do not contain fish. Although it's established that insect communities are different in the two pond types due to fish predation, little is known about aquatic insect succession and emergence after a temporary pond dries and then refills. The objective of this study was to examine insect emergence in small (<1 ha) permanent ponds that continuously hold water and temporary ponds that were dried and refilled with water. The study was conducted in five permanent ponds with fish and five temporary ponds without fish at the Eagle Mountain Fish Hatchery, Fort Worth, Texas. During the first 25 days following pond refilling, large and small insects (e.g. Anisoptera and Chironominae, respectively) emerged from the permanent ponds but only small bodied taxa (e.g. Chironominae) emerged from the temporary ponds. Because insects must first oviposit eggs and then develop after pond refilling, emergence of large bodied taxa (Anisoptera) in the temporary ponds was not observed until day 32. Although Anisoptera did not emerge from temporary ponds until later in the experiment, the total numbers of Anisoptera that emerged was greater in the temporary fishless ponds than the permanent ponds with fish. I conclude that insect succession in temporary ponds is rapid and

related to insect body size. In addition, for any given taxa the numbers of emerging insects is controlled by the taxa’s vulnerability to fish predation.