Young of year largemouth bass (Micropterus salmoides) relative abundance and diet: role of habitat type, spatial context, and size

by

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Abstract

Habitat is a central focus of ecological research and fisheries management. For example, a Web of Science search returned over 88,000 peer-reviewed studies that examined fish habitat, the National Fish Habitat Partnership has invested millions of dollars to "foster fish habitat conservation," and "essential fish habitat" is a central tenet of marine fisheries policy. The overarching goal of my thesis was to examine the spatial context of fish habitat research in order to improve the effectiveness of fisheries management. To achieve this goal, I quantified approaches to fish habitat used in the peer reviewed literature. Then I tested if approaches to assessing habitat provided different ecological answers to key questions using 1,200 young of year largemouth bass (*Micropterus salmoides*) collected in Hillsdale Lake, Kansas, in 2014-2015.

Within, the fisheries habitat literature, several gaps exist. First, although vegetation was a major focus of young of year largemouth bass habitat research, few studies quantitatively compared young of year largemouth abundance and diet across vegetated and non-vegetated habitats. Second, relatively little of the fisheries habitat literature on young of year largemouth bass explicitly tested habitat type, a common approach used in management and restoration. Third, peer reviewed papers on young of year largemouth bass physical habitat used multiple approaches to studying habitat (local characteristics, habitat type, lakewide characteristics), then often ignored spatial variation completely in interpreting empirical results.

Field sampling provided information on several of these gaps. First, young of year largemouth bass were more abundant in vegetation and beach habitats than in rock, wood, or offshore habitats. Young of year largemouth bass utilized beach habitats as often as vegetated habitats. Diets were similar across vegetated and beach habitat types. Second, size of young of

year largemouth bass increased through time but size and habitat were not related. My data showed that the size range seen for first year largemouth bass in the first summer in Hillsdale Lake did not alter their distribution or diet.

From my research, I make the following recommendations. 1.) Concurrently examine local characteristics, habitat type, and lakewide characteristics with the same data set. 2.) Include insights about different approaches in the discussion of all future fisheries habitat studies. 3.) Continue to test multiple approaches to test fisheries response to habitat. In summary, using different approaches to study young of year largemouth bass habitat use could improve our scientific understanding and aid in restoration and management of reservoir and lake fisheries.

Table of Contents

List of Figures

List of Tables

Introduction

Habitat can be conceptualized, defined, and measured in many ways. The choice of how to measure habitat can affect the outcome of research and management in fisheries ecology (Dibble et al. 1996). For example, when studying young of year largemouth bass feeding efficiency, Olson et al. (2003) studied feeding in two different habitat types whereas Ferrari et al. (2014) studied the effects of stem density. Each of these approaches provides valuable information but neither approach tells the whole story. If the outcome of research is influenced by how habitat is conceptualized, defined, and measured, then fisheries biologists and managers must account for these potentially confounding effects when planning sampling and implementing management plans.

Aquatic landscapes are heterogeneous and therefore we can expect ecological dynamics to vary spatially. What I define as the spatial context of habitat (i.e., different metrics, scales, and conceptualizations of habitat), is often ignored in fisheries research and management. Considering multiple approaches when planning habitat research and management could improve our understanding of how largemouth bass interact with their environment at this life stage.

The purpose of my thesis is to compare two responses (relative abundance and diet) of young of year largemouth bass to several different approaches to studying habitat. In my thesis, I ask the overarching question of *whether different conceptualizations of habitat, hereafter spatial context of habitat, provide different information about distribution and diets of young of year largemouth bass?* I will answer this overarching question using the following organization (Fig. O.1). In Chapter 1, I examine the response of young of year largemouth bass to categorical habitat types. Habitat type is a useful approach to classifying habitats, integrates a number of important habitat features (Hawkins et al. 1993), and is useful for management and restoration. In Chapter 2, I will analyze a single, standardized dataset using multiple spatial contexts to ask if different approaches provide different answers to the same ecological questions. In the appendices, I include additional data about size, stocking treatment, and other areas of interest. If different approaches to habitat research and management provide different answers to the same fisheries questions, then the spatial context of habitat should be consciously considered, standardized, and integrated in other young of year largemouth bass habitat research.

This thesis is part of a larger Kansas Department of Wildlife, Parks, and Tourism (KDWPT) project. The purpose/scope/activity of the larger agency largemouth bass project is substantial. In my research, I address a small piece of the larger project. Specifically, I only examine numbers, location-habitat diets, and size during the first summer. Below I highlight the main findings of this research and identify where specific data is located within the thesis. First, wild fish were more abundant than early spawned largemouth bass but all group(wild and hatchery) performed well (Appendix A, Figs. A.4, A.5). Second, both wild and early spawned largemouth bass used vegetated and beach habitats in the same way (Appendix A, Figs. A.6, A.7). Third, early spawned largemouth bass fish were larger than wild largemouth bass. They started larger and remained larger throughout the summer (Chapter 1 & Appendix A, Figs. A.3, A.4). Fourth, benthic invertebrates were commonly eaten in the early summer. Fish prey were eaten in increasing amounts as the summer progresses. Terrestrial invertebrates are eaten throughout the summer. In summary, fish prey is somewhat important, but other diet items are important too (Chapter 1, Appendix B). Fifth, no difference existed in diet by habitat (Chapter 1, Appendix B) or stocking treatment (Appendix A). Sixth, no differences were detected for diet composition of different sized young-of year largemouth bass (Appendix A). Finally, KDWPT's hatchery and stocking programs were very effective. Whether any hatchery young of year largemouth bass survive to creel/trophy size will need to be assessed by KDWPT as these young fish survive through the years.

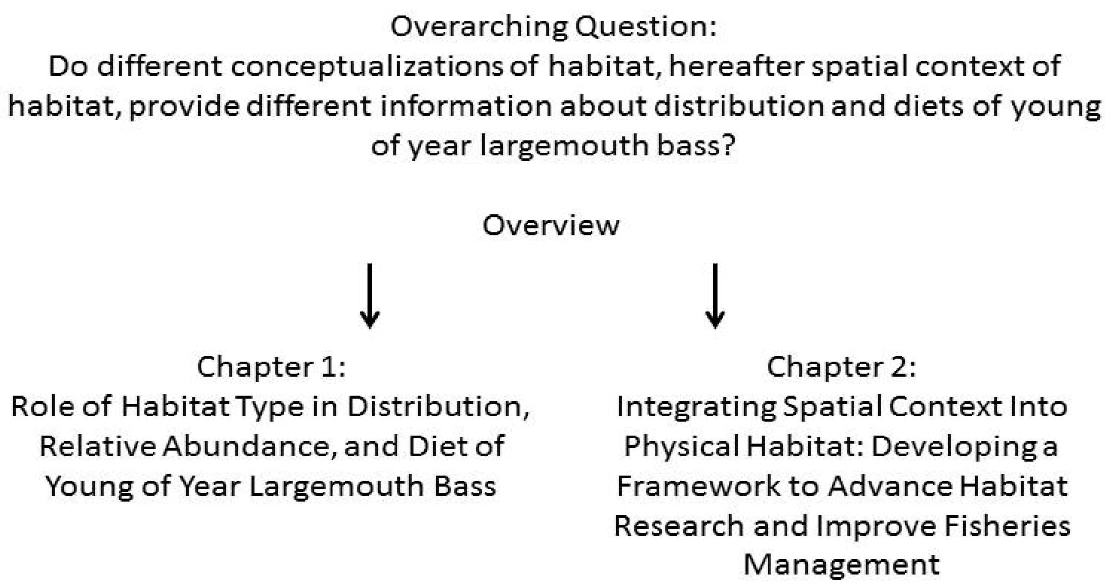

Figure 0.1: Conceptual framework for the thesis.

Chapter 1 - Role of Habitat Type in Distribution, Relative Abundance, and Diet of Young of Year Largemouth Bass

Introduction

***What is the purpose, novelty, and generality of this research*?** Habitat is an important component of fish ecology and sportfish management. Here, I focus on the effect of habitat type on young of year largemouth bass (*Micropterus salmoides*) abundance and diet because habitat type plays a major role in sampling, stock assessment, stocking, restoration, and other fisheries science and management activities (Fisher et al. 2012). Much research has examined adult largemouth bass habitat use. Researchers and managers have assumed that young of year and adult largemouth bass use habitat similarly (Olson et al. 2003). Specifically, researchers and managers have assumed that young of year largemouth bass preferentially use vegetated habitats (DeBoom & Wahl 2013). Here I examine these assumptions by quantitatively reviewing the literature to quantify gaps in what is known about young of year largemouth bass habitat type. Then I compare relative abundance and diet in multiple habitat types. The resulting insights have generality for largemouth bass populations and can benefit researchers and managers who seek to understand patterns of habitat use by young sportfish across a range of systems.

How important is habitat in fisheries? Habitat, the physical, chemical, and biological features of the environment that an organism needs to sustain life (McMahon et al. 1996), is a fundamental concept in aquatic ecology, fisheries biology, and fisheries management. More than 516,649 papers were published on “habitat” between 1980 and 2016 across all taxa. Although many informative and influential papers were written prior to 1980, for logistic reasons, I limited my search to the last 35 years. Over 88,000 of these papers specifically focused on fish habitat (keyword: habitat, fish and habitat, Web of Science, September, 2016). Habitat is also important in fisheries management. A Web of Science search combining the search terms “habitat” and “fisheries management” returned 14,475 peer-reviewed papers from 1980-2016. Furthermore, a number of management initiatives such as the National Fish Habitat Partnership (National Fish Habitat Action Plan 2012) and NOAA’s Essential Fish Habitat program (Yoklavich et al. 2010) use habitat to manage fisheries. Habitat research focuses on a variety of variables including water chemistry (i.e. temperature, pH, dissolved oxygen), water velocity, and physical habitat (depth, substrate, structure or cover such as vegetation or woody debris). Here, I examine physical habitat because most habitat improvement and restoration work that is conducted to improve fish populations focuses on physical habitat. Physical habitat serves many functions for fish and can affect fish physiological processes (Millidine et al. 2006), provide protection from predators (Strakosh et al. 2009), and influence prey communities (Dibble et al. 1996).

What is known about young of year largemouth bass habitat? Over 7,087 peer reviewed papers have been published on largemouth bass (keyword: largemouth bass or *Micropterus salmoides*; Web of Science literature search; September 2016). Of these 957 (13.5%) examined largemouth bass habitat during any life stage (Fig. 1.1A). Of the 7,087 largemouth bass papers, 399 focused on the young of year life stage regardless of topic (Fig. 1.1A). After removing studies that focused directly on other taxa and only considered young of year largemouth bass peripherally as predators or competitors, only 20 papers (2.1% of all largemouth bass habitat papers; 5% of all young of year largemouth bass research papers) examined both physical habitat use and young of year largemouth bass (Fig. 1.1A). Of these 20 papers, 18 focused on young of year largemouth bass physical habitat (Fig. 1.1B; Table 1.1) and of these 15 of 18 were field studies (Fig. 1-1C, Table 1.1). In summary, in spite of the great interest in habitat and young of year largemouth bass, relatively little literature quantifies young of year largemouth bass physical habitat associations in the field (Table 1.1).

Is habitat type (or category) a useful approach in fisheries ecology and management? Classifying habitat categorically based on the dominant physical feature (e.g., vegetation, beach, rock, wood) is a useful approach to conceptualizing, quantifying, and managing habitat effects in fisheries. Submerged vegetation is thought to be an important feature of habitats where all life stages of largemouth bass thrive (Paukert & Willis 2004). Coarse woody habitat has also been shown to be important for adult largemouth bass (Ahrenstorff et al. 2009). Some aspect of vegetation is common in most young of year largemouth bass physical habitat research (Table 1.1; 14/18 papers). For young of year largemouth bass habitat type research, Strakosh et al. (2009) found that water willow (*Justicia americana*) increased habitat complexity and allowed for higher densities of young of year largemouth bass in three Kansas reservoirs. An advantage of using type or classification to characterize fish habitat is that this approach integrates a number of important habitat features such as depth, flow, and substrate (Hawkins et al. 1993). For example, classifying a habitat as “littoral vegetation” tells the biologist that the habitat contains macrophytes and is located in shallow water near the shoreline. Although using habitat type is a useful approach, of all the field based physical habitat literature on young of year largemouth bass, only three (16.7%; 3 of 18) studies quantitatively tested responses to habitat type (Fig. 1.1D, context in Table 1.1, 1.3).

What predictions does the peer reviewed literature make about how habitat type affects abundance and diet? Of the 18 young of the year largemouth bass physical habitat studies, six examined relative abundance (catch per unit effort, hereafter CPUE) only, five examined diet only, and three examined both relative abundance (CPUE) and diet (Table 1.1). Of these 18 studies, vegetation was a variable (coverage, type, or stems) in 14 (77.7%) studies. In these studies, young of year largemouth bass were abundant in vegetated habitats (Miranda & Pugh 1997, Tate et al. 2003, Ratcliffe et al. 2009, Strakosh et al. 2009) or more abundant in habitats with greater amounts of vegetation (Tate et al. 2003). However, only two of these studies (Ratcliffe et al, 2009, Strakosh et al. 2009) compared relative abundance between vegetated and other non-vegetated habitats. Diet of young of year largemouth bass can also be affected by habitat (Bettoli et al. 1992, Miranda & Pugh 1997, Valley & Bremigan 2002), but both studies that compared diet composition of young of year largemouth bass across vegetated and non-vegetated habitats found no difference in diet (Olson et al. 2003, Strakosh et al. 2009). In summary, gaps in the literature exist relative to our understanding of how young of year largemouth bass (abundance and diet) utilize different habitat types, especially vegetated vs non-vegetated habitats. Reservoirs are generally vegetation limited due to lack of propagules and water level fluctuations (Smart et al. 1995). Therefore understanding how young of year largemouth bass utilize vegetated, unvegetated and other habitats can be important for managing sportfish populations in reservoirs.

Specific research questions addressed here. This chapter seeks to address the above gaps in the literature and to assess the relative importance of habitat type, especially vegetated and unvegetated habitats, on young of year largemouth bass relative abundance and diet. Here I ask six specific questions about young of year largemouth bass in Hillsdale Lake, KS during 2014-2015. First, does habitat type (vegetated, beach, rock, wood, offshore), sample event (i.e., time during the first summer) and the interaction among habitat type and sample event affect young of year largemouth bass relative abundance. Second, do the same variables (habitat, sample event, the interaction among habitat and sample event) affect diet composition as measured by percent empty stomachs, number, and weight of four major prey categories eaten. Relative to these first two questions, based on the literature, I predict that young of year largemouth bass will be most abundant (higher CPUE) in vegetated habitats but will have similar diets across habitats. Third, do prey type and number differ across habitat types? Based on the existing literature, I predict that invertebrate prey will be more abundant in vegetated habitats (Tolonen et al. 2003). Fourth, is habitat use of young of year largemouth bass related to body size? The justification behind the stocking manipulation was that larger fish would eat more fish prey so I predict that habitat use and diet could be different for stocking treatments and larger fish.

Methods

Study System. Hillsdale Lake is a flood control reservoir located in eastern Kansas approximately 30 miles south of the Kansas City metropolitan area (Fig.1.2). The reservoir has a surface area of 4,580 acres and a mean depth of five meters. Hillsdale Lake is classified as eutrophic by the Kansas Department of Health and Environment (KDHE 2016). The reservoir supports extensive recreation opportunities and features park areas managed by the Kansas Department of Wildlife, Parks, and Tourism (KDWPT) and US Army Corps of Engineers (USACE). American water willow (*Justicia americana*) has been established in the reservoir in an effort to provide habitat for sportfish, especially largemouth bass (Strakosh 2009). Similar to other Great Plains reservoirs, Hillsdale Lake has areas of standing timber but few aquatic macrophytes, other than planted water willow. There are 27 species of fish in the reservoir including largemouth bass, white and black crappie (*Pomoxis* spp.), channel catfish (*Ictalurus punctatus*), and flathead catfish (*Pylodictus olivares*).

Stocking Manipulation. Kansas Department of Wildlife, Parks, and Tourism (KDWPT) began stocking early-spawn young of year largemouth bass in Hillsdale Lake during 2013 in an effort to improve angling opportunities of quality sized largemouth bass within the reservoir and stocking of early spawned largemouth bass continued through 2014-2015. Early spawn young of year largemouth bass were raised in hatcheries and stocked at two sizes; 35 mm during May (phase one) and 65 mm during June (phase two). This stocking manipulation resulted in three potential groups of young of year largemouth bass in the reservoir (wild, phase 1, phase 2) that were genetically marked so that their origin could be determined by KDWPT through fin clip analysis.

***Habitat Classification*.** Habitat was classified into five types: vegetation, beach, rock, wood, or offshore. Habitats were classified using a decision tree based on dominant habitat feature (Fig. 1.3). The first division was based on whether the habitat was located in the littoral (< 3 m deep) or non-littoral zone (> 3 m deep). To classify littoral habitats, I first determined the presence/absence of vegetation. Then non-vegetated patches were divided by the presence (rock habitat) or absence (beach habitat) of rip-rap. Non-littoral habitats (> 3 m deep) were classified based on the presence (wood habitat) or absence (offshore) of standing timber (Fig. 1-3). Four (2014) and five vegetation (2015) locations were sampled (Fig. 1.4A-B). Five beach locations were sampled during both sample years (Fig.1.4A-B). One rock location was sampled during both sample years (Fig.1.4). Seven (2014) and 10 (2015) offshore locations were sampled (Fig. 1.4A.B). Six (2014) and seven (2015) wood locations were sampled (Fig. 1.4A.B). I did not randomize sample locations because, based on a survey of shoreline that had depths suitable for seining, I seined > 80% of all available wadeable habitat.

Gear Selection. Freshwater fish can be captured with different sampling gears. I conducted a gear comparison to evaluate the most effective method for sampling young of year largemouth bass in Hillsdale Lake, KS. I chose a variety of gears that have been used to sample largemouth bass and other littoral fish in the literature (seine net, backpack electrofisher, minnow traps, and trap nets). Specifically, I compared catches in two vegetated locations during two sample events during 2014. Vegetated habitats in Hillsdale Lake were very sparse (< 10 stems/m^2) and did not appear to interfere with the effective seining of vegetated habitats. I sampled ~900 m^2 with both seine and backpack electrofisher. I walked a serpentine pattern with the backpack electrofisher across the entire sample area. Seine nets were hauled in a semi-circle pattern on the shoreline. Ten minnow traps were fished overnight on three occasions and no young of year largemouth bass were captured in any trap. Hoop nets (mesh: 15 mm, N = 3) were fished overnight across three occasions and also failed to capture any young of year largemouth bass. Seining caught more young of year largemouth bass in vegetated habitats that other gear (seining = 154, electrofishing = 17). Because I was focused on comparing relative abundance of largemouth bass across habitats, a standardized sampling method (seine) across all sample locations that provided a comparable catch per unit effort was ideal for my study question.

Fish Collection and Processing. Based on the results of the above gear test, I collected young of year largemouth bass every two weeks from June 4 to September 30 during 2014 and from June 9 to September 25 during 2015. I used a 15 m x 2 m bag seine net (mesh = 9 mm) towed in a semi-circle starting at a central location at the shoreline of each site. A seine haul at a location constituted a sample and was repeated for every sample event. After capture, all fish < 120 mm were euthanized by an overdose of Aqui-S and immediately placed on ice. Young of year largemouth bass were measured (total length, TL). Euthanized fish were brought back to

Kansas State University for further laboratory analysis. Relative abundance or CPUE was calculated as number of young of year largemouth bass / 100 m^2.

In the laboratory, young of year largemouth bass were dissected and alimentary canals were removed for diet analysis (Bettoli et al. 1992). Stomach contents were immediately fixed in 70% ethanol. Diet items eaten were identified to order, and then counted, measured, and weighed before classification into one of five categories; benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified (Chipps & Garvey 2006, Table 1.2). Terrestrial invertebrates were differentiated from benthic invertebrates by the presence/absence of adult morphological features such as wings or legs. Subsequent analyses are based on the four categories of identified prey. Diet composition was analyzed by both number and weight of diet items. These two metrics provide different ways to view the data (Chipps & Garvey 2006) and I chose to use both metrics to fully understand the data.

***Prey Sampling*.** Prey samples were collected monthly in sample locations across habitats to examine differences in availability. Zooplankton were collected with a 20-cm diameter, 125 µm mesh, zooplankton net towed horizontally for 4.6 meters at 0.5 – 1 meter depth within 15 meters of shore. Zooplankton densities were calculated as individuals/sample. Samples were concentrated and diluted to 25 mL and a 1 mL aliquot was analyzed. Organisms were identified to order and counted using a dissecting microscope (Kelso et al. 2013). Benthic invertebrates were collected using a 0.5 meter substrate sweep of a 30 cm X 25 cm tall D-frame net (Strakosh 2006). Benthic invertebrate densities were calculated as individuals / 0.5 m sweep sample. Fine sediment was washed away from organisms using a 125 micron sieve. Organisms were identified to order and counted using a dissecting microscope. Potential prey fish were collected concurrently with young of year largemouth bass in all habitat types, identified to species, and measured. Non largemouth bass that were smaller than 50% of the mean young of year largemouth bass total length were considered potential fish prey.

Young of Year Largemouth Bass Size. Differences in body size across sample events were calculated for each stocking treatment (wild, phase 1, phase 2). Total length of each young of year largemouth bass was measured to the nearest mm in the field. Mean total length of each stocking treatment was calculated for every sample event in order to detect changes in body size as young of year largemouth bass grew throughout the season. Mean body size was also calculated for each habitat type and for each stocking treatment.

Data Set Used, Data Analysis, and Data Presentation

Final Dataset. I created the final dataset used in my analysis by making five changes to the raw data. First, for all data collected, young of year largemouth bass in consecutive 2-week sample events were combined to create monthly summaries that minimized missing sample events (due to high or low water or other conditions that prevented sampling a location). Monthly CPUEs were combined as a sum of adjacent samples. Monthly diet analyses were combined as the mean of adjacent samples. Second, rock habitat was removed from my analyses because I only had one location with this habitat. The rock data were ecologically intriguing but too variable for inclusion in a reliable statistical analysis. Third, for relative abundance, I examined the data both for all four habitats sampled (vegetated, beach, wood, offshore) and for the two habitats in which we had multiple samples that caught largemouth bass (vegetation, beach). In all habitats, a comparable area was sampled. Fourth, for diet data, I used a sample mean in the statistical analysis. Specifically, for all individual young of year largemouth bass in each sample location for each monthly sample event, I took the mean number or mean weight of the four main groups of diet items consumed by all young of year largemouth bass in that sample. This sample specific mean eliminated zeros from the analysis. Fifth, in the statistical analysis (described below), fish with empty stomachs were removed from the analysis, even though a comparison of sample means with and without empty stomachs revealed few differences in mean data for the sample.

Statistical Analyses. For CPUE, diet, prey, and size, I used a repeated measures analysis of variance (AVOVA), with habitat as a fixed factor, sample event as the repeated measure and the interaction between habitat type and sample event (von Ende 2001, Cadotte 2006, Munes et al. 2015). This analysis was chosen because habitat type was the primary focus of my research and the existing literature suggests that repeated sampling through time at or near the same sites may influence the results as well as the independence of the data (Hurlbert 1984). Repeated measures ANOVA is a well-established statistical method for addressing the ecological problem that occurs when sampling the same type of data through time (von Ende 2001). This method of statistical analysis has been evaluated in the statistical and ecological literature (Cody & Smith 1997, von Ende 2001). For all my data, I first show mean plots of the habitat main effect (all data by habitat). Then I show mean plots for the sample event main effect (all data by sample event) Finally, I show mean plots of the habitat by sample event interaction (each habitat by each sample event). Throughout the figures and text, I link these three set of plots to the related repeated measures ANOVA table. In many cases, one or more of these three effects are not significant ($p \leq 0.05$), but I continue to show the three sets of mean plots and ANOVA tables because the separate and combined effect of habitat and data are an important part of my research design. In interpreting the repeated measures ANOVA table, I always examined the interaction first, then I only interpreted the main effects if this interaction was not significant. For a main effect or significant interaction in which I had more than two categories, I located the source of the significant difference using Tukey multiple comparisons. I used the Greenhouse-Geisser adjusted *p*-value (Bathke et al. 2012).

I tested all assumptions of the statistical analyses. The assumption that the residuals of each repeated measures ANOVA were normally distributed was tested using QQ plots of the residuals. Response data were transformed and retested as needed. The CPUE response variable was square root transformed to meet these assumptions. Diet or prey data did not require transformation. Years were compared qualitatively.

Data Presentation. For readability, I do not present all data I collected and analyzed here. For example, I analyzed data for two years (2014, 2015). I also analyzed CPUE in two and four habitats. For diet, I analyzed total and taxa-specific numbers and weights for four types of diet taxa. For prey abundance, I analyzed taxa-specific numbers for three groups of prey in four habitats. For body size, I analyzed mean total length across three habitats. For each of the above responses, I plotted mean main and interaction effects that corresponded to the repeated measures ANOVA as described above. This vast amount of information is impossible to summarize concisely in a single readable chapter. My solution to this information management challenge is to show the 2014 data for CPUE and diet (both number and weight) in detail in this chapter, summarize the results of 2015 in this chapter, then present the detailed 2015 plots in the appendix. Thesis and appendix results showed similar trends.

Results

General. Across all habitats and sample events, 949 young of year largemouth bass were collected during 2014 and 251 young of year largemouth bass were collected during 2015 in

Hillsdale Lake. In total, my sampling collected a total of 1200 fish across both years (Table 1.3). Size distribution ranged from 22 mm to 120 mm during 2014 and from 31 mm to 120 mm during 2015 (Table 1.3).

Q1: Relative Abundance (CPUE) - 2014

How did CPUE differ across habitat, sample event, and habitat by sample event? In 2014, habitat-specific mean CPUEs ranged from 2.23 young of year largemouth / 100 m^2 for vegetated samples, 2.68 young of year largemouth / 100 m^2 for beach samples, and 0 young of year largemouth / 100 m^2 for woody and off shore habitats (*Habitat main effect*; Fig. 1.5).

Mean CPUEs ranged from 0.074 young of year largemouth bass / 100 m^2 during sample event 4 to 3.78 young of year largemouth bass/100 m^2 during sample event 1 (*Sample event main effect*; Fig. 1.6). Mean trends for habitat by sample event reflected habitat and time main effects (*Habitat by sample event interaction*; Fig. 1.7).

Statistically, in 2014, young of year largemouth bass were not evenly distributed across all habitat types. The habitat main effect (p<0.001, Fig. 1.5; Table 1.4) and sample event main effect (p= 0.0411; Fig. 1.6; Table 1.4) were both significant when all four habitat types were considered, but the habitat by sample event interaction (NS, Fig. 1.7; Table 1.4) was not significant. Young of year largemouth bass were more abundant in the two littoral habitat types (vegetation, beach) than in the two limnetic habitat types (offshore and wood) (Fig. 1.5). During sample events 1 and 3, young of year largemouth bass were significantly more abundant than during sample event 4 (Tukey MC: p = 0.0011).

When only the two littoral habitat types at which I caught fish were examined (vegetation, beach), neither habitat (*Habitat main effect*; NS, Fig. 1.5, Table 1.5), nor sample event (*Sample event main effect*; NS; Fig. 1.6 Table 1.5), nor the habitat by sample event interaction (NS, Figure 1.7; Table 1.5) were significant. Together, these results demonstrated that young of year largemouth bass used multiple h (littoral vegetated and unvegetated beach), but not all (non-littoral offshore, wood) habitats.

Q2 - Diet- 2014

How do empty stomachs vary across habitats, sample events, and habitats by sample events? During 2014, 46.1% of young of year largemouth bass had empty stomachs (Table 1.6). Vegetated samples had the lowest proportion of empty stomachs in 2014 (38.4%, Table 1.6). Proportion of empty stomachs in beach habitats were 52.2% during 2014 (Table 1.6). Statistically, during 2014, the proportion of young of year largemouth bass with empty stomachs was not affected by the habitat main effect (NS, Table 1.7), the sample event main effect (NS, Table 1.7), nor the habitat by sample event interaction (NS, Table 1.7).

Numbers Eaten

By number, what diet type was eaten most often by number? Did diet type by number differ by habitat, sample event, and habitat by sample event for 2014? In 2014, mean number of prey consumed overall was 6.80 in vegetated habitats and 8.71 in beach habitats (Fig. 1.8). Sample event specific number of prey consumed overall ranged from 1.61 during sample event 3 to 14.43 during sample event 1 (*Sample event main effect*; 1.9). Mean trends for habitat by sample event reflected habitat and sample event main effects (Fig. 1.10). Statistically during 2014, total number of diet items eaten was not affected by habitat type or time. The habitat main effect (NS; Fig. 1.8; Table 1.8), sample event main effect (NS; Fig. 1.9; Table 1.8), and habitat by sample event interaction (NS; Fig. 1.10: Table 1.8) were not significant.

In 2014, mean number of prey consumed in vegetated habitats was 6.18 benthic invertebrates (*Habitat main effect*; Fig. 1.11A), 0.56 zooplankton (Fig. 1.11B), 1.49 terrestrial invertebrates (Fig. 1.11C), and 0.28 fish (Fig. 1.11D). The mean number of prey consumed in the beach habitat was 3.04 benthic invertebrates (*Habitat main effect*; Fig. 1.11A), 0.03 zooplankton (Fig. 1.11B), 3.27 terrestrial invertebrates (Fig. 1.11C), and 0.47 fish in beach samples (Fig. 1.11D).

Sample event specific number of prey consumed ranged from 0.11 during sample event 3 to 11.57 during sample event 1 for benthic invertebrates (*Sample event main effect*; Fig. 1.12A), 0.00 during sample event 4 to 1.04 during sample event 1 for zooplankton (Fig. 1.12B), 0.81 during sample event 3 to 4.60 during sample event 4 for terrestrial invertebrates (Fig. 1.12C), and 0.11 during sample event 1 to 0.61 during sample event 3 for fish (Fig. 1.12D). Mean trends for habitat by sample event reflected habitat and time main effects for benthic invertebrates (*Habitat by sample event interaction*; Fig. 1.13), zooplankton (Fig. 1.14), terrestrial invertebrates (Fig. 1.15), and fish prey (Fig. 1.16).

Statistically, during 2014, young of year largemouth bass diet composition by number was not affected by habitat type, sample time, or the habitat by time interaction for benthic invertebrates (Table 1.9), zooplankton (Table 1.10), terrestrial invertebrates (Table 1.11) and fish prey (Table 1.12). Thus, based on number of diet items eaten, young of year largemouth bass fed equally well in all habitats.

Weight Eaten

What diet type was eaten most often by <u>weight</u>? Did diet type differ by habitat, sample event, and habitat by sample event for <u>2014</u>? In 2014, mean weight of prey consumed overall was 0.072 g in vegetated habitats and 0.076 g in beach habitats (Fig. 1.17). Sample event specific total weight of prey eaten ranged from 0.033 g during sample event 1 to 0.114 g during sample event 3 (*Sample event main effect*; Fig. 1.18). Mean trends for total weight of prey eaten by habitat and sample event reflected habitat and sample event main effects (Fig. 1.19). Statistically during 2014, total weight eaten was not affected by habitat type. The habitat main effect (NS; Fig. 1.17; Table 1.13), sample event main effect (NS; Fig. 1.18; Table 1.13); and habitat by sample event interaction (NS; Fig. 1.19: Table 1.13) were not significant.

During 2014, habitat-specific mean weight of prey consumed in the vegetated habitat ranged from 0.004 g benthic invertebrates (*Habitat main effect*; Fig. 1.20A), <0.00015 g zooplankton (Fig. 1.20B), 0.024 g terrestrial invertebrates (Fig. 1.20C), and 0.282 g fish (Fig. 1.20D). In the beach habitat, habitat-specific mean weight of prey consumed ranged from 0.010 g benthic invertebrates (Fig. 1.20A), <0.00005 g zooplankton (Fig. 1.20B), 0.013 g terrestrial invertebrates (Fig. 1.20C), and 0.049 g fish in beach samples (Fig. 1.20D).

Sample event specific weight of prey consumed ranged from 0.002 g during sample event 3 to 0.016 g during sample event 1 for benthic invertebrates (*Sample event main effect*; Fig. 1.21A), 0.00 g during sample event 4 to <0.001 g during sample event 1 for zooplankton (Fig. 1.21B), 0.012 g during sample event 1 to 0.032 g during sample event 2 for terrestrial invertebrates (Fig. 1.21C), and 0.027 g during sample event 1 to 0.261 g during sample event 3 for fish (Fig. 1.21D). Mean trends for habitat by sample event reflected habitat and time main effects (*Habitat by sample event interaction*) for benthic invertebrates (Fig. 1.22), zooplankton (Fig. 1.23), terrestrial invertebrates (Fig. 1.24), and fish prey (Fig. 1.25).

Statistically, during 2014, weight of benthic invertebrates eaten by young of year largemouth bass was not affected by habitat type. However, benthic invertebrates, by weight, in young of year largemouth bass diets changed with sample event (G-G adjusted p=0.0399; Table

1.14) in that fewer benthic invertebrates were eaten later in the summer (Fig. 1.21A). Neither the habitat main effect (NS), the sample event main effect, nor the habitat by sample event interaction (NS) were significant for zooplankton (Table 1.15), terrestrial invertebrates (Table 1.16), or fish prey (Table 1.17). Thus, based on weight of food items eaten, young of year largemouth bass fed equally well in all habitats throughout their first summer although some temporal changed occurred.

Q3 – Prey - 2014

Did prey vary across habitat and sample month during 2014? During 2014, habitat-specific mean abundance of benthic invertebrates was 8.9 individuals/sample in vegetation habitats, 2.1 individuals/sample in beach habitats, 2.9 individuals/sample in rock habitats, and 0.7 individuals/sample in offshore habitats (Fig. 1.26). Sample event mean abundance of benthic invertebrates ranged from 1.5/sample during August to 9.1/sample during June (Fig. 1.27). Habitat-specific density of zooplankton was 54.0/mL in vegetation habitats, 40.0/mL in beach habitats, 13.2/mL in rock habitats, and 24.6/mL in offshore habitats (Fig. 1.28). Sample event mean density ranged from 19.3/mL during July to 99.3/mL during June (Fig. 1.29). Habitat-specific CPUE of prey fish was 14.2 fish / 100 m^2 in vegetated habitats, 21.8 fish / 100 m^2 in beach habitats, 13.0 fish / 100 m^2 in rock habitats, and 3.3 fish / 100 m^2 in offshore habitats (Fig. 1.30). Sample event mean CPUE of prey fish ranged from 10.4 fish / 100 m^2 during September to 22.5 fish / 100 m^2 during June (Fig. 1.31). Statistically, during 2014, the habitat main effect, sample event main effect, and habitat by sample event interaction were not significant for benthic invertebrates (Table 1.18), zooplankton (Table 1.19), or fish prey (Table 1.20).

Q5 - Stocking Treatment and Size - 2014

Did young of year <u>size</u> (mean total length) vary across habitat or sample event during 2014? Sample event specific mean total length of wild fish ranged from 61.7 mm during sample event 1 to 89.9 mm during sample event 4 (Fig. 1.32). Mean total length of phase 1 fish ranged from 61.3 mm during sample event 1 to 143 mm during sample event 4 (Fig. 1.32). Mean total length of phase 2 fish ranged from 74.5 mm during sample event 1 to 123.8 mm during sample event 4 (Fig. 1.32). Statistically during 2014, there was no significant difference in body size across habitat types (*habitat main effect*, NS, Fig. 1.32, Table 1.21).

Sample event specific mean total length of wild fish ranged from 61.7 mm during sample event 1 to 89.9 mm during sample event 4 (Fig. 1.33). Mean total length of phase 1 fish ranged from 61.3 mm during sample event 1 to 143 mm during sample event 4 (Fig. 1.33). Mean total length of phase 2 fish ranged from 74.5 mm during sample event 1 to 123.8 mm during sample event 4 (Fig. 1.33). Statistically during 2014, mean total length of young of year largemouth bass was significantly larger in sample event 3 than sample events 1 or 2 (*sample event main effect*, G-G adjusted $p = 0.0053$, Fig. 1.33, Table 1.21).

Year

How did results vary across years? My results in 2014 and 2015 were very similar. During both sample years, young of year largemouth bass were more abundant in littoral habitats than non-littoral habitats. CPUE was lowest in the later (fall) samples in both years although some differences occurred in the specific temporal patterns across years (Appendix A). Habitat and sample date main effect differences occurred in both years. In 2015 only, the interaction was significant when all four habitat types were considered ($p = 0.0077$; Appendix A). In regard to diet composition, there were no significant differences in prey consumed by number in either year across habitats or sample events. Mean weight of benthic invertebrates consumed were affected by sample event during 2014 but not in 2015.

Discussion

Take home message 1 - Gaps exist in the literature. Relatively few tests of the effect of non-vegetated habitats on young of year largemouth bass have been published in the peer reviewed literature in spite of the popularity of largemouth bass in research and management. Largemouth bass are a well-studied fish species and much of the published habitat literature on the adult life stage of this species has focused on associations with vegetated habitats (e.g., Ahrenstorff et al. 2009, Conrad et al. 2016). The lack of research on young of the year largemouth bass habitat use and the untested assumption that juvenile and adult largemouth bass use habitat the same has led to a focus on vegetation. Because unvegetated habitats are rarely examined (but see Ratcliffe et al. 2009 & Strakosh et al. 2009), additional research into how young of year largemouth bass use unvegetated habitats in other lakes and reservoirs is needed.

Take home message 2 – Young of year largemouth bass used multiple littoral habitats. I found young of year largemouth bass CPUE to be equal in vegetation and beach habitats even though the literature predicts that more young of year largemouth bass would use vegetated habitats. Although CPUE varied across sampling years, in our system, vegetated and beach habitats had similar CPUE of young of year largemouth bass during both years. In addition, fish caught in both of these littoral habitats had similar amounts and types of food in their stomachs. It is possible that conditions in Hillsdale Lake are unique and that beach habitats in this system are more profitable than in other systems. However, young of year largemouth bass use of unvegetated habitats bears additional scrutiny in other lakes and reservoirs.

Take home message 3 - Diets do not differ across habitat. Habitat type had few effects on young of year largemouth bass diet composition by number and weight in Hillsdale Lake. Habitat can influence diet composition of fish through foraging efficiency (Savino & Stein 1982) and altered prey communities (Smart et al. 1995, Dibble et al. 1996). However, in other studies, young of year largemouth bass diet composition also are similar across habitat types (Olson et al. 2003, Strakosh et al. 2009). My findings support these findings that young of year largemouth bass diet composition is not significantly affected by habitat type (Olson et al. 2003, Strakosh et al. 2009).

Take home message 4 - Prey were highly variable, but equally distributed across habitats as reflected in young of year largemouth bass diets. No differences in prey abundance were detected for benthic invertebrates, zooplankton, or fish during either sample year. Although differences in community composition of many aquatic organisms have been shown to be affected by habitat (i.e. Dibble et al. 1996), prey were equally distributed across all habitats in Hillsdale Lake. The lack of difference in prey communities across habitats could explain why young of year largemouth bass diets were similar across habitat types. Young of year largemouth bass inhabiting any habitat type had similar prey availability and the lack of diet differences suggests that young of year largemouth bass also had similar foraging efficiency across all habitat types. Habitat complexity in my sample locations was far below the thresholds needed to inhibit young of year largemouth bass foraging success in laboratory settings (Alexander et al. 2015). In general, equal distribution of prey across habitats matched young of year largemouth bass diets.

Take home message 5 - Size increased through time but size and habitat were not related. Young of year largemouth bass body size generally increased throughout the season as expected but there was no difference in mean total length across habitat types. During the first year of life young of year largemouth bass grow rapidly and larger fish are thought to have greater over-winter survival during their first winter (Ludsin & DeVries 1997). Early spawn hatchery fish were larger than wild fish initially and remained larger through the summer and fall. Generally, young of year largemouth bass mean total length increased with sample event for wild and hatchery fish. The lack of differences in diet composition and prey availability across habitats likely suggests similar feeding behavior. Thus, it is not surprising that no differences in body size were detected across habitats.

Sampling Caveats. No sampling method is 100% efficient, efficiency varies, and therefore all field studies have some limitations and my study is no different. Seine nets can be inhibited by the stems of aquatic vegetation in some systems, however in Hillsdale Lake the stem densities were low (all sample locations <10 stems/m^2). I conducted a gear comparison to determine if seining was an effective method in vegetated habitats in Hillsdale Lake and seining captured more young of year largemouth bass than any other tested gear (Appendix C). Based on the conclusions of the gear comparison I am confident in the effectiveness of seining in Hillsdale Lake. In offshore and wood habitats, water was too deep to seine and boat electrofishing was used. No other possible gears were available. Although I acknowledge that there could be some gear bias associated with electrofishing deep water, in all of my sampling, an identically sized area was sampled.

Other insights about untested assumptions. Non-significant trends are often viewed as uninformative. However, because the literature clearly predicts higher young of year largemouth bass abundance in vegetation, my finding of no significant difference in relative abundance between vegetation and beach has utility for fisheries biology and management. Specifically, my results that showed similar numbers of young of year largemouth bass in the beach and vegetation suggested that researchers and managers may want to reevaluate unvegetated habitats for first summer habitat use. As a corollary, a related but second untested assumption is that differences in diet and consumption make the vegetated habitat more profitable for young of year largemouth bass. Similar to other studies (Olson et al. 2003, Strakosh et al. 2009) young of year largemouth bass have similar diet composition in multiple habitats across a variety of times. Hence, the beach is not a desert, but an equally profitable habitat in Hillsdale Lake. Third, researchers and managers have assumed that body size has an advantage for largemouth bass (of all ages). The stocking manipulation that occurred in Hillsdale Lake provided an unprecedented opportunity (N=1200 young of year fish of a range of sizes sampled over two years) to compare abundance and diet of a large number of young of year largemouth bass through the summer. My data show that the size range seen for first year largemouth bass in the first summer does not alter relative abundance, habitat use, or diet. Of course, size may be an advantage through the first winter and in subsequent years.

Summary

Conventional wisdom suggests that young of year largemouth bass utilize vegetated habitats more often than other habitat types. However in Hillsdale Lake, young of year largemouth bass CPUE was similar across all littoral habitat types. Beach habitats provided similar prey resources to vegetated habitats and the diets of young of year largemouth bass suggest these fish are utilizing these prey resources in the same way across both habitats. This suggests that beach habitats need not be less profitable than vegetated habitats. Consequently, comparing multiple habitat types within and across ecosystems can provide a better understanding of young of year largemouth bass habitat use and improve our management of this important species.

Management Implications

This research could be used to improve targeted habitat restoration and stocking programs. If young of year largemouth bass are able to eat enough prey items in beach habitats then this suggests that the amount of suitable habitat in many Midwestern reservoirs may be greater than currently thought. Also, habitat restoration to improve survival of largemouth bass during this important life stage could include modifications to beach habitats in addition to adding vegetation. Further research to understand what factors of non-vegetated habitats are important to young of year largemouth bass is needed. Differential vulnerability to predator across vegetated and unvegetated habitats still requires examination for a full evaluation of beach and vegetated habitats. Fish stocking is done at multiple sites can improve survival of stocked fish by stocking fish into habitats where they have the best chance for success. Based on my results, fish stocked into beach habitats may do well. My results show that young of year largemouth bass in beach habitats consume prey in similar amounts as fish in other habitats.

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Table 1.1. Summary of literature on young of year largemouth bass habitat use.

Paper Number	Author	Year	Species	Life Stage	Context (Micro, Type, Macro)	Field or Lab	Fish Response	Type of Habitat	Habitat Variable Studied
1	Strakosh et al.	2009	LMB	YOY	Type	Field	CPUE, Diet	Physical	Veg/No Veg
2	Ratcliffe et al.	2009	LMB	YOY	Type	Field	CPUE	Physical	Veg/No Veg
3	Olson et al.	2003	LMB	YOY	Type	Lab	Diet	Physical	Veg/Cobble
4	Bettoli et al.	1992	LMB	YOY	Micro	Field	Diet	Physical	Coverage
5	Hoyer & Canfield	1996	LMB	YOY	Micro	Field	CPUE	Physical	Coverage
6	Irwin et al.	1997	LMB	YOY	Micro	Field	CPUE	Physical	Slope, Substrate
7	Miranda & Pugh	1997	LMB	YOY	Micro	Field	CPUE, Diet	Physical	Coverage
8	Irwin & Noble	2000	LMB	YOY	Micro	Field	CPUE	Physical	Coverage, Slope
9	Tate et al.	2003	LMB	YOY	Micro	Field	CPUE	Physical	Coverage
10	Havens et al.	2005	LMB	YOY	Micro	Field	CPUE	Physical	Coverage
11	Sammons & Maceina	2006	LMB	YOY	Micro	Field	Diet	Physical	Coverage
12	Middaugh et al.	2013	LMB	YOY	Micro	Field	CPUE, Diet	Physical	Coverage
13	Nagid et al.	2015	LMB	YOY	Micro	Field	CPUE	Physical	Coverage
14	Valley & Bremigan	2002	LMB	YOY	Micro	Lab	Diet	Physical	Stem Density
15	Alexander et al.	2015	LMB	YOY	Micro	Lab	Diet	Physical	Stem Density
16	Phillips et al.	1997	LMB	YOY	Macro	Field	CPUE	Physical	Cove
17	Braun & Walser	2011	LMB	YOY	Macro	Field	Diet	Physical	Above/Below Dam
18	Daugherty et al.	2014	LMB	YOY	Macro	Field	CPUE	Physical	Reservoir Region

Table 1.2: Classification of prey orders (species for fish) into groups.

Prey Group

Benthic Invertebrates	Zooplankton	Terrestrial Invertebrates	Fish (species)
Amphipoda	Calanoida	Acari	Emerald Shiner
Decapoda	Cladocera	Aranea	Gizzard Shad
Diptera (larvae)	Cyclopoida	Coleoptera	Green Sunfish
Odonata (larvae)		Diptera (adult)	Largemouth Bass
		Hemiptera	Red Shiner
		Hymenoptera	
		Megadrilacea	
		Odonata (adult)	

Table 1.3: Number, minimum length, and maximum length of young of year largemouth bass collected from Hillsdale Lake 2014-2015.

Sample Year	YOY Largemouth Bass Captured	Minimum TL (mm)	Maximum TL (mm)
2014	949	22	120
2015	251	31	120
Total	1200	22	120

Table 1.4. Repeated measures analysis of variance for young of year largemouth bass **CPUE** in 2014 for **four habitat types (vegetation, beach, wood, offshore).** Data have been square root transformed. Data correspond to main habitat effect plot (Figure 1.5), main sample event effect plot (Figure 1.6) and habitat by sample event plot (Figure 1.7).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**21**	**0.4478**				
Habitat	3	0.3983	0.1328	48.25	**<0.0001**	
Error	18	0.0495	0.0028			
Within subjects	**66**	**0.0780**				
Time	3	0.0264	0.0088	3.88	**0.0139**	**0.0411**
Time * Habitat	9	0.0288	0.0032	1.41	0.2077	0.2524
Error(Time)	54	0.0228	0.0004			
Total	**87**	**0.5258**				

Table 1.5. Repeated measures analysis of variance for young of year largemouth bass **CPUE** in 2014 for **two habitat types (vegetation, beach)**. . Data have been square root transformed. Data correspond to main habitat effect plot (Figure 1.5), main sample event effect plot (Figure 1.6) and habitat by sample event plot (Figure 1.7).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0499**				
Habitat	1	0.0004	0.0004	0.06	0.8213	
Error	7	0.0495	0.0071			
Within subjects	**27**	**0.1687**				
Time	3	0.0446	0.0149	2.55	0.0835	0.1298
Time * Habitat	3	0.0015	0.0005	0.08	0.9676	0.8796
Error(Time)	21	0.1226	0.0058			
Total	**35**	**0.2186**				

Table 1.6: Proportions of young of year largemouth bass with **empty stomachs** during 2014.

Year	Habitat	% Empty Stomachs
2014	Vegetation	38.4
2014	Beach	52.2
2014	**Total**	**46.1**

Table 1.7. Repeated measures analysis of variance for young of year largemouth bass **proportion of empty stomachs** in 2014 for **two habitat types (veg, beach).** . Data have been arcsine transformed. Data correspond to Table 1.6.

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**1.5154**				
Habitat	1	0.1702	0.1702	0.89	0.3780	
Error	7	1.3452	0.1922			
Within subjects	**27**	**3.6854**				
Time	3	0.0931	0.0310	0.21	0.8913	0.8683
Time * Habitat	3	0.4226	0.1409	0.93	0.4421	0.4135
Error(Time)	21	3.1696	0.1509			
Total	**35**	**5.2008**				

Table 1.8. Analysis of repeated measures for young of year largemouth bass **total diet composition by number** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.8), main time effect plot (Figure 1.9) and habitat x time effect plot (Figure 1.10).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**8**	**1312.5027**				
Habitat	1	26.0543	26.0543	0.14	0.7177	
Error	7	1286.4484	183.7783			
Within subjects	**27**	**4544.2886**				
Time	3	744.3492	248.1164	1.83	0.1727	0.2106
Time * Habitat	3	951.9370	317.3123	2.34	0.1026	0.1539
Error(Time)	21	2848.0024	135.6192			
Total	**35**	**5856.7913**				

Table 1.9. Repeated measures analysis of variance for young of year largemouth bass **benthic invertebrate consumption by number** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.11A), main sample event effect plot (Figure 1.12A) and habitat by sample event plot (Figure 1.13).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**1455.7295**				
Habitat	1	87.6004	87.6004	0.45	0.5246	
Error	7	1368.1291	195.4470			
Within subjects	**27**	**3745.9335**				
Time	3	688.8372	229.6124	1.97	0.1494	0.1950
Time * Habitat	3	609.3680	203.1227	1.74	0.1890	0.2242
Error(Time)	21	2447.7282	116.5585			
Total	**35**	**5201.6630**				

Table 1.10. Repeated measures analysis of variance for young of year largemouth bass **zooplankton consumption by number** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.11B), main sample event effect plot (Figure 1.12B) and habitat by sample event plot (Figure 1.14).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**8**	**11.5623**				
Habitat	1	2.5348	2.5348	1.97	0.2037	
Error	7	9.0275	1.2896			
Within subjects	**27**	**44.4194**				
Time	3	6.5970	2.1990	1.51	0.2419	0.2596
Time * Habitat	3	7.1743	2.3914	1.64	0.2107	0.2413
Error(Time)	21	30.6481	1.4594			
Total	**35**	**55.9816**				

Table 1.11. Repeated measures analysis of variance for young of year largemouth bass **terrestrial invertebrate consumption by number** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.11C), main sample event effect plot (Figure 1.12C) and habitat by sample event plot (Figure 1.15).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**80.3791**				
Habitat	1	27.9948	27.9948	3.74	0.0943	
Error	7	52.3843	7.4835			
Within subjects	**27**	**399.4829**				
Time	3	69.5834	23.1945	1.64	0.2111	0.2386
Time * Habitat	3	32.2844	10.7615	0.76	0.5294	0.5294
Error(Time)	21	297.6151	14.1721			
Total	**35**	**479.8620**				

Table 1.12. Repeated measures analysis of variance for young of year largemouth bass **fish consumption by number** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.11D), main sample event effect plot (Figure 1.12D) and habitat by sample event plot (Figure 1.16).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**8**	**3.8614**				
Habitat	1	0.3094	0.3094	0.61	0.4604	
Error	7	3.5520	0.5074			
Within subjects	**27**	**9.3451**				
Time	3	1.3259	0.4420	1.33	0.2902	0.2924
Time * Habitat	3	1.0596	0.3532	1.07	0.3848	0.3527
Error(Time)	21	6.9596	0.3314			
Total	**35**	**13.2065**				

Table 1.13. Analysis of repeated measures for young of year largemouth bass **total prey consumption by weight** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.17), main time effect plot (Figure 1.18) and habitat x time effect plot (Figure 1.19).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0627**				
Habitat	1	0.0001	0.0001	0.01	0.9276	
Error	7	0.0627	0.0090			
Within subjects	**27**	**0.1844**				
Time	3	0.0398	0.0133	2.07	0.1344	0.1766
Time * Habitat	3	0.0101	0.0034	0.52	0.6704	0.5624
Error(Time)	21	0.1345	0.0064			
Total	**35**	**0.2472**				

Table 1.14. Repeated measures analysis of variance for young of year largemouth bass **benthic invertebrate consumption by weight** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.20A), main sample event effect plot (Figure1.21A) and habitat by sample event plot (Figure 1.22).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0022**				
Habitat	1	0.0003	0.0003	0.98	0.3556	
Error	7	0.0020	0.0003			
Within subjects	**27**	**0.0032**				
Time	3	0.0012	0.0004	4.82	**0.0104**	**0.0399**
Time * Habitat	3	0.0002	0.0001	0.98	0.4211	0.3829
Error(Time)	21	0.0018	0.0001			
Total	**35**	**0.0055**				

Table 1.15. Repeated measures analysis of variance for young of year largemouth bass **zooplankton consumption by weight** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.20B), main sample event effect plot (Figure 1.21B) and habitat by sample event plot (Figure 1.23).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**8**	**5.6876E-07**				
Habitat	1	1.55E-07	1.55E-07	2.62	0.1492	
Error	7	4.14E-07	5.91E-08			
Within subjects	**27**	**2.6484E-06**				
Time	3	2.93E-07	9.76E-08	1.06	0.3859	0.3525
Time * Habitat	3	4.26E-07	1.42E-07	1.55	0.2318	0.2539
Error(Time)	21	1.93E-06	9.19E-08			
Total	**35**	**3.2172E-06**				

Table 1.16. Repeated measures analysis of variance for young of year largemouth bass **terrestrial invertebrate consumption by weight** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.20C), main sample event effect plot (Figure 1.21C) and habitat by sample event plot (Figure 1.24).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0098**				
Habitat	1	0.0009	0.0009	0.74	0.4177	
Error	7	0.0088	0.0013			
Within subjects	**27**	**0.0401**				
Time	3	0.0028	0.0009	0.55	0.6517	0.5186
Time * Habitat	3	0.0024	0.0008	0.48	0.6992	0.5519
Error(Time)	21	0.0350	0.0017			
Total	**35**	**0.0499**				

Table 1.17. Repeated measures analysis of variance for young of year largemouth bass **fish consumption by weight** with empty stomachs excluded in 2014 for **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 1.20D), main sample event effect plot (Figure 1.21D) and habitat by sample event plot (Figure 1.25).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0464**				
Habitat	1	0.0000	0.0000	0	0.9478	
Error	7	0.0464	0.0066			
Within subjects	**27**	**0.2040**				
Time	3	0.0477	0.0159	2.19	0.1194	0.1558
Time * Habitat	3	0.0037	0.0012	0.017	0.9159	0.8238
Error(Time)	21	0.1526	0.0073			
Total	**35**	**0.2504**				

Table 1.18. Repeated measures analysis of variance for **benthic prey abundance** in 2014 for **four habitat types (vegetation, beach, rock, offshore).** Data correspond to main habitat effect plot (Figure 1.26) and main sample event effect plot (Figure 1.27).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**5**	**79.2816**				
Habitat	3	39.6674	3.2225	0.67	0.6461	
Error	2	39.6143	19.8073			
Within subjects	**18**	**82.4062**				
Time	3	16.0373	5.3458	0.49	0.7034	0.5593
Time * Habitat	9	0.5847	8.9539	0.82	0.6235	0.5918
Error(Time)	6	65.7842	10.9640			
Total	**23**	**161.6878**				

Table 1.19. Repeated measures analysis of variance for **zooplankton abundance** in 2014. for **four habitat types (vegetation, beach, rock , offshore).** Data correspond to main habitat effect plot (Figure 1.28) and main sample event effect plot (Figure 1.29).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**5**	**10624.56**				
Habitat	3	5604.351	1868.117	0.74	0.6169	
Error	2	5020.211	2510.106			
Within subjects	**18**	**35724.33**				
Time	3	5335.06	1778.353	0.53	0.6793	0.5446
Time * Habitat	9	10180.03	1131.115	0.34	0.931	0.8078
Error(Time)	6	20209.24	3368.171			
Total	**23**	**46348.89**				

Table 1.20. Repeated measures analysis of variance for **fish prey abundance** in 2014 for **four habitat types (vegetation, beach, rock, offshore).** Data correspond to main habitat effect plot (Figure 1.30) and main sample event effect plot (Figure 1.31).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**5**	**6649.34**				
Habitat	3	5692.186	1897.395	3.96	0.2080	
Error	2	957.1542	478.5771			
Within subjects	**18**	**2935.355**				
Time	3	45.02525	15.00842	0.05	0.9849	0.9181
Time * Habitat	9	997.3464	110.8163	0.35	0.9229	0.8447
Error(Time)	6	1892.983	315.4972			
Total	**23**	**9584.694**				

Table 1.21. Analysis of repeated measures for young of year largemouth bass **body size** in 2014. **For two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 32) and main time effect plot (Figure 33).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**5**	**3188.6507**				
Habitat	1	45.7737	45.7737	0.06	0.8211	
Error	4	3142.8771	785.7193			
Within subjects	**12**	**4196.7147**				
Time	2	3457.6689	1728.8344	21.46	**0.0006**	**0.0053**
Time * Habitat	2	94.4491	47.2245	0.59	0.5787	0.5122
Error(Time)	8	644.5967	80.5746			
Total	**17**	**7385.3654**				

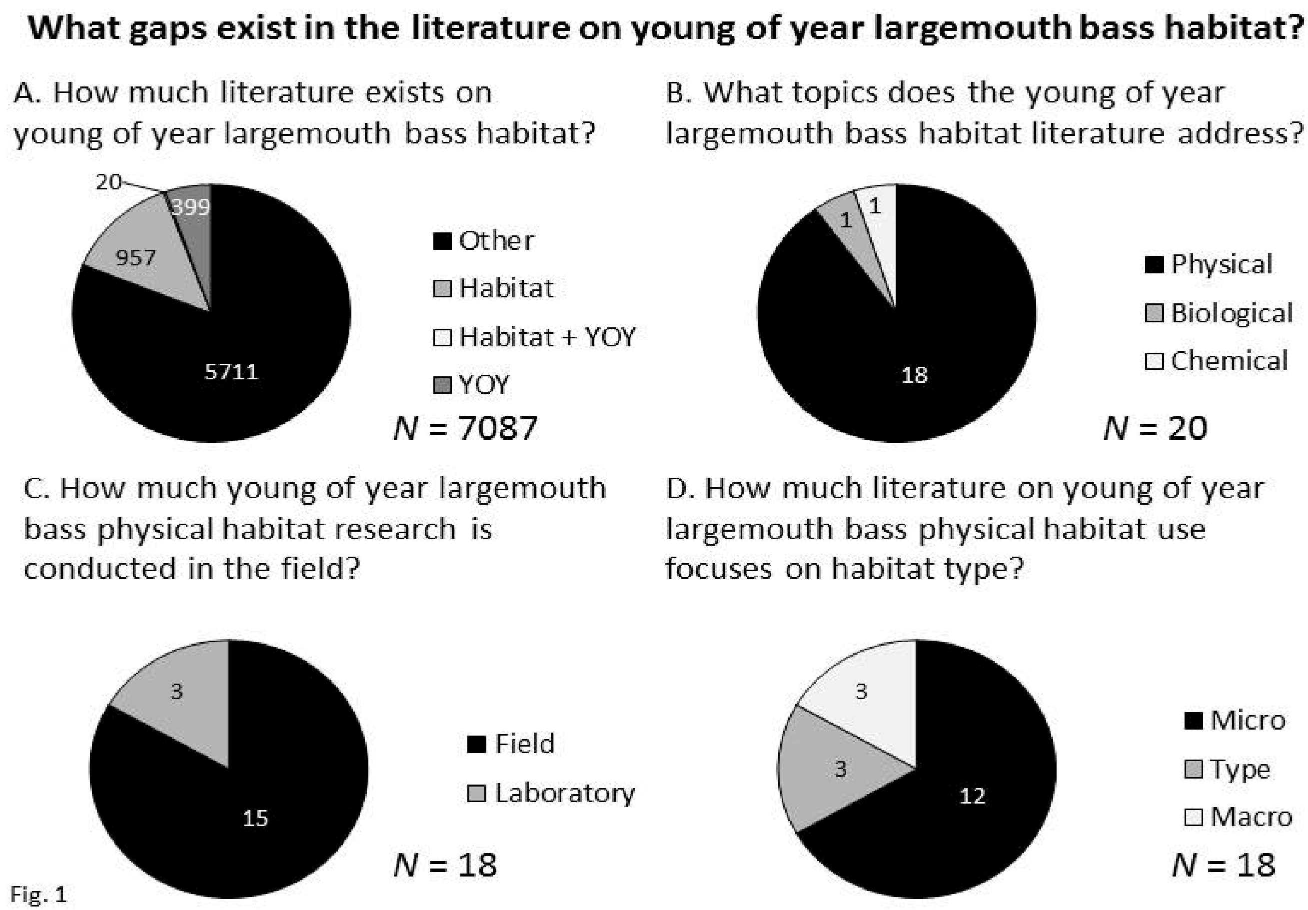

Figure 1.1: Proportions of largemouth bass literature

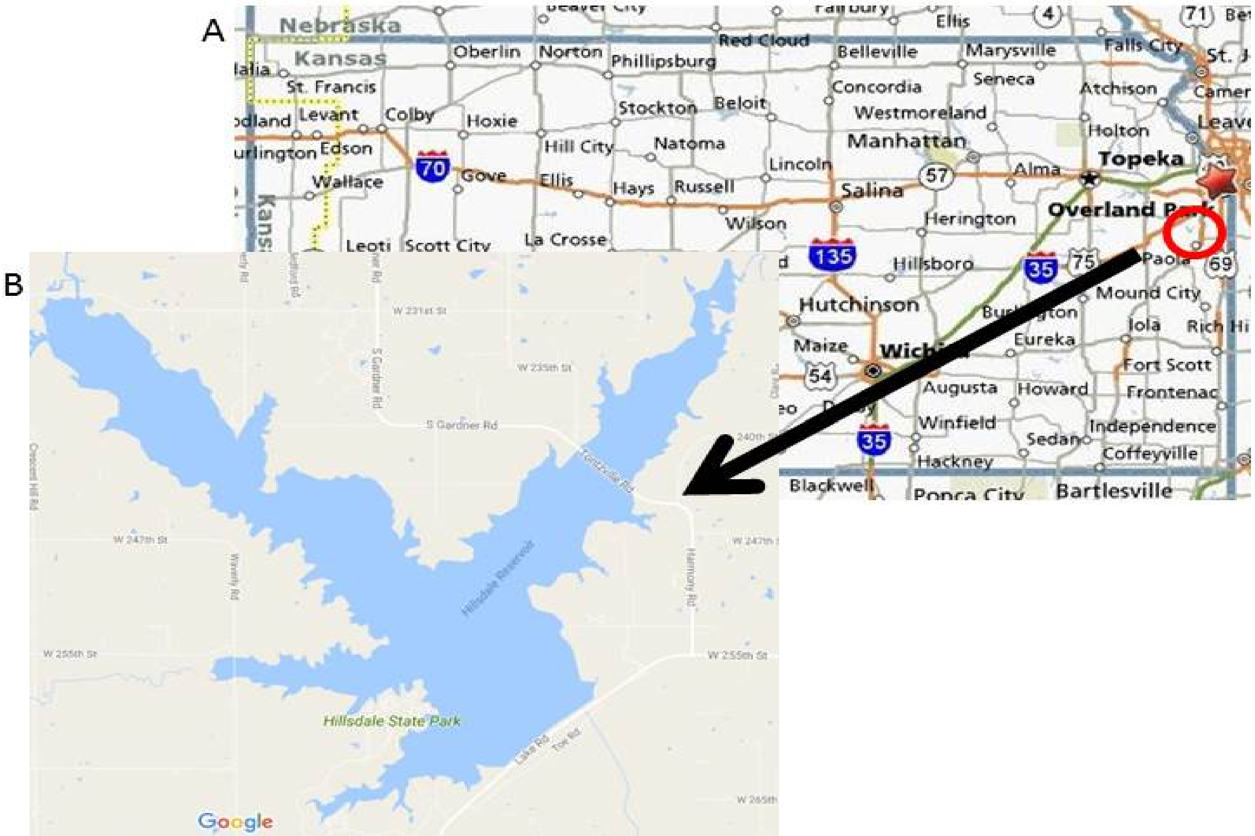

Figure 1.2: Map of Hillsdale Lake, KS A- State of Kansas, B – Hillsdale Lake.

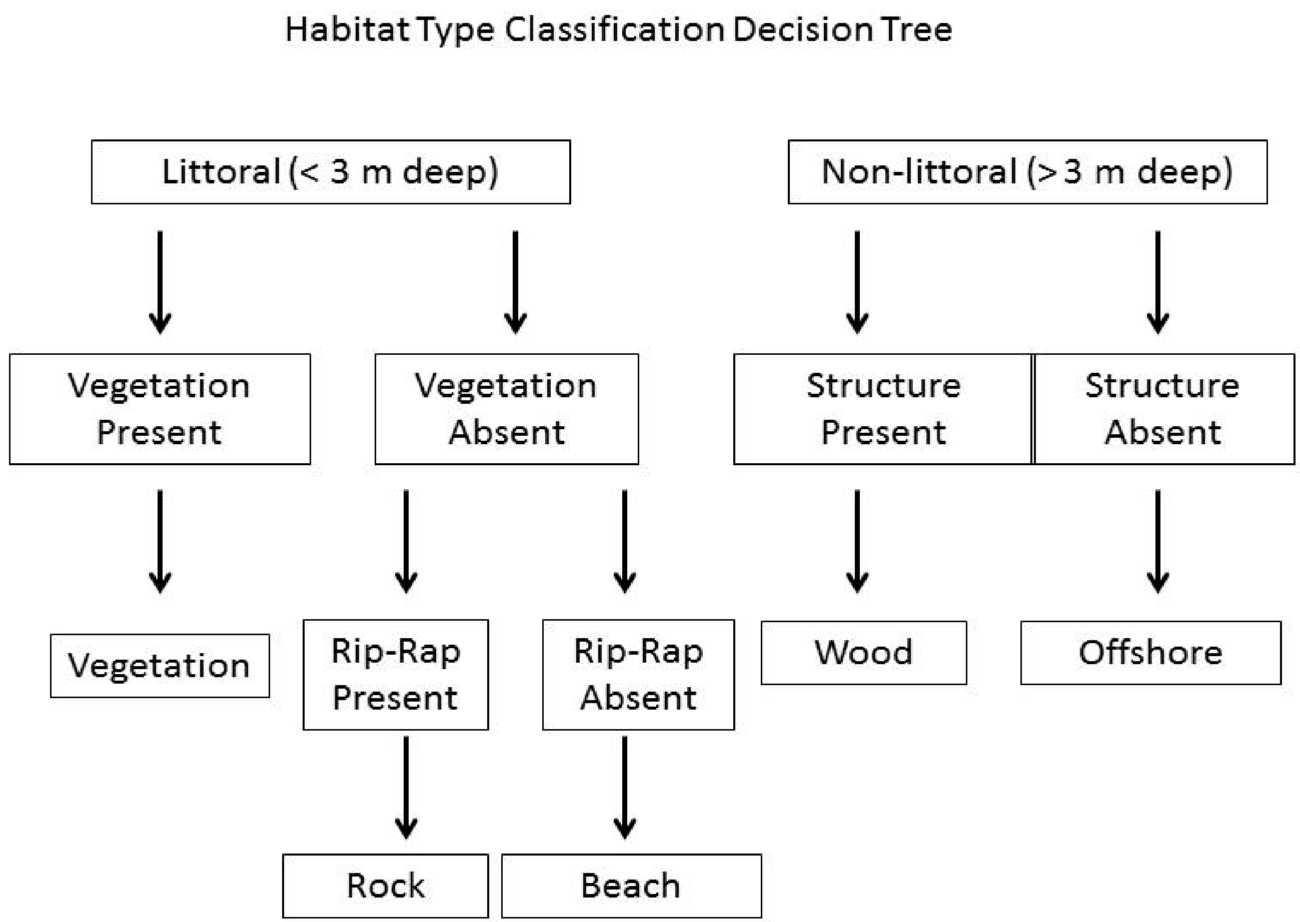

Figure 1.3: Decision tree for classifying habitats in Hillsdale Lake, KS.

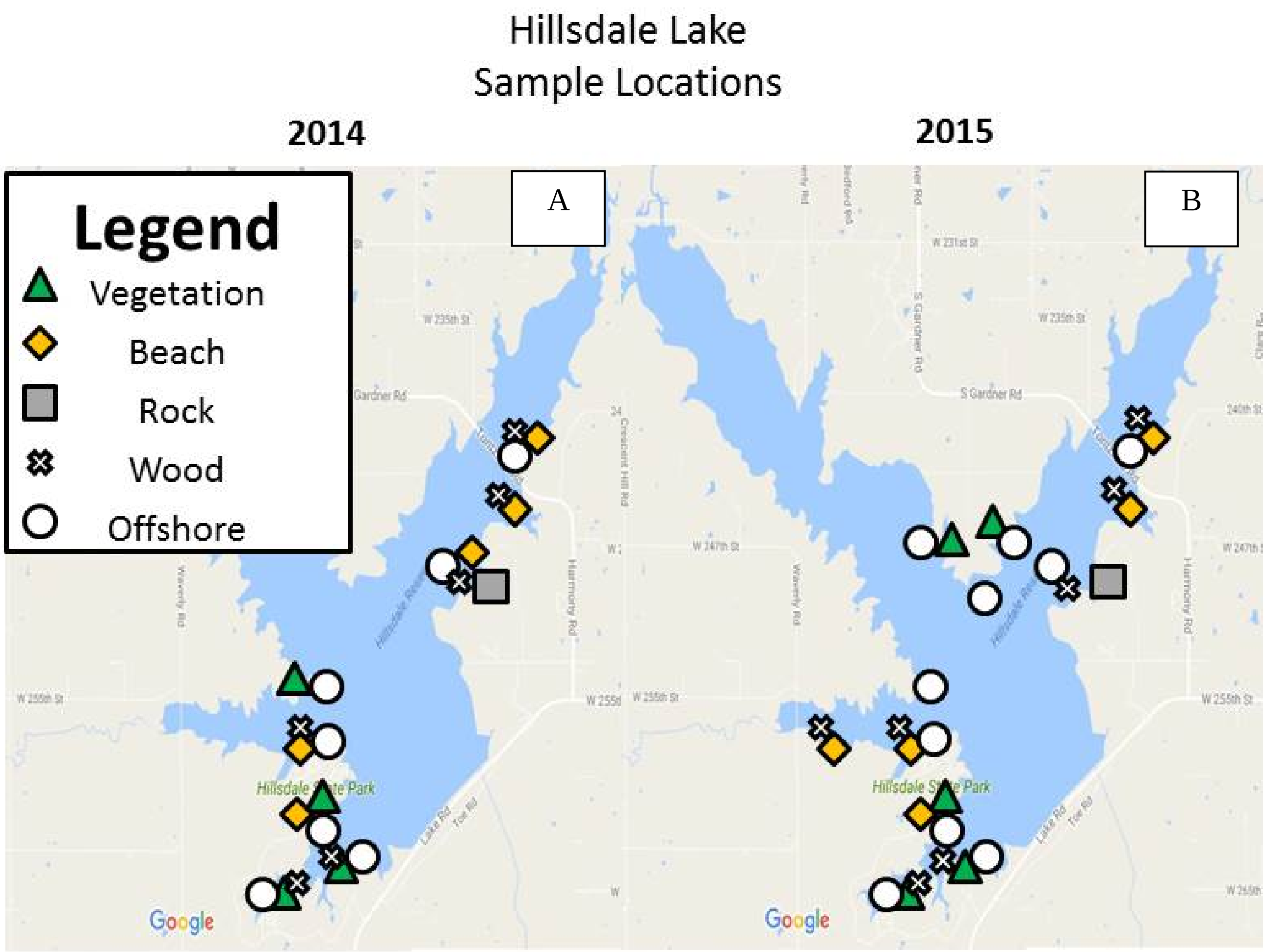

Figure 1.4: Sample locations within Hillsdale Lake, KS during 2014 and 2015.

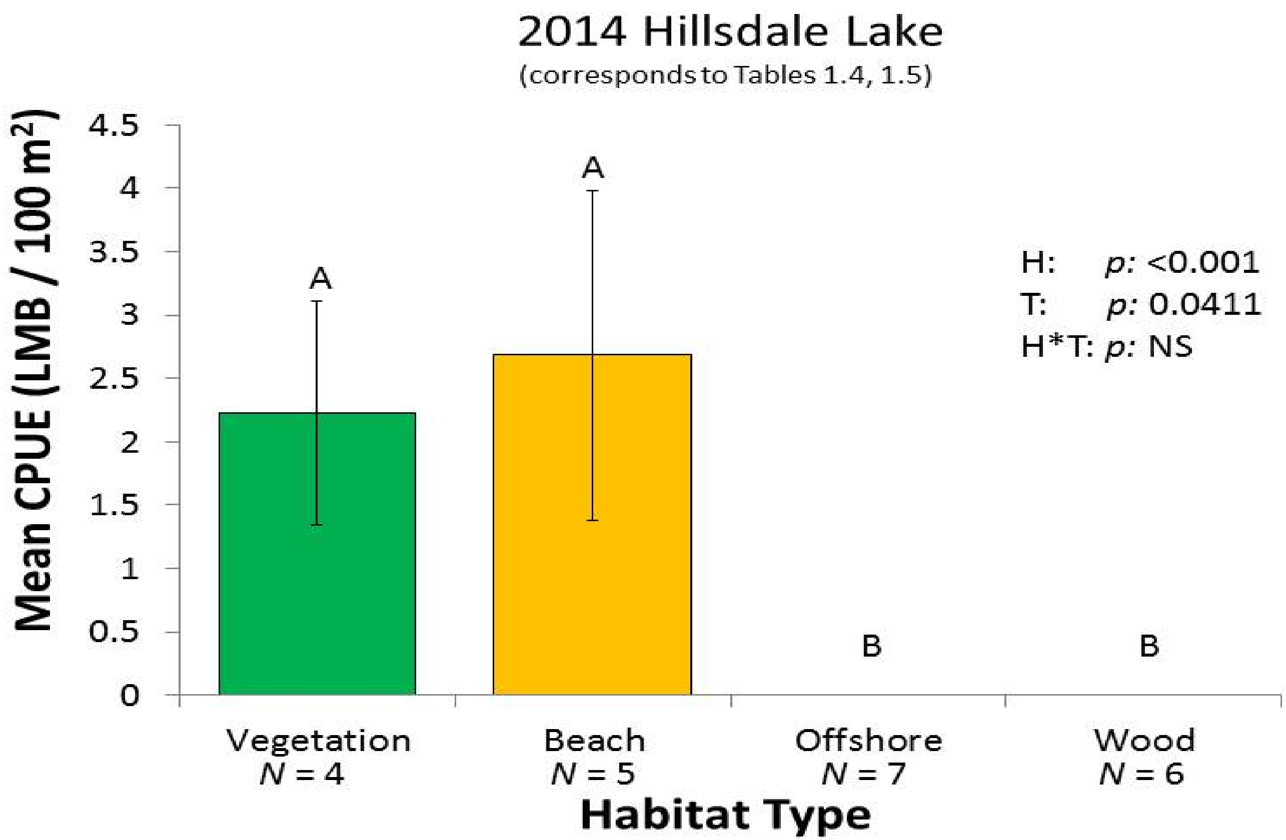

Figure 1.5: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for four habitat types (vegetation, beach, offshore, wood) in Hillsdale Lake, KS during 2014.Data are mean and standard error.

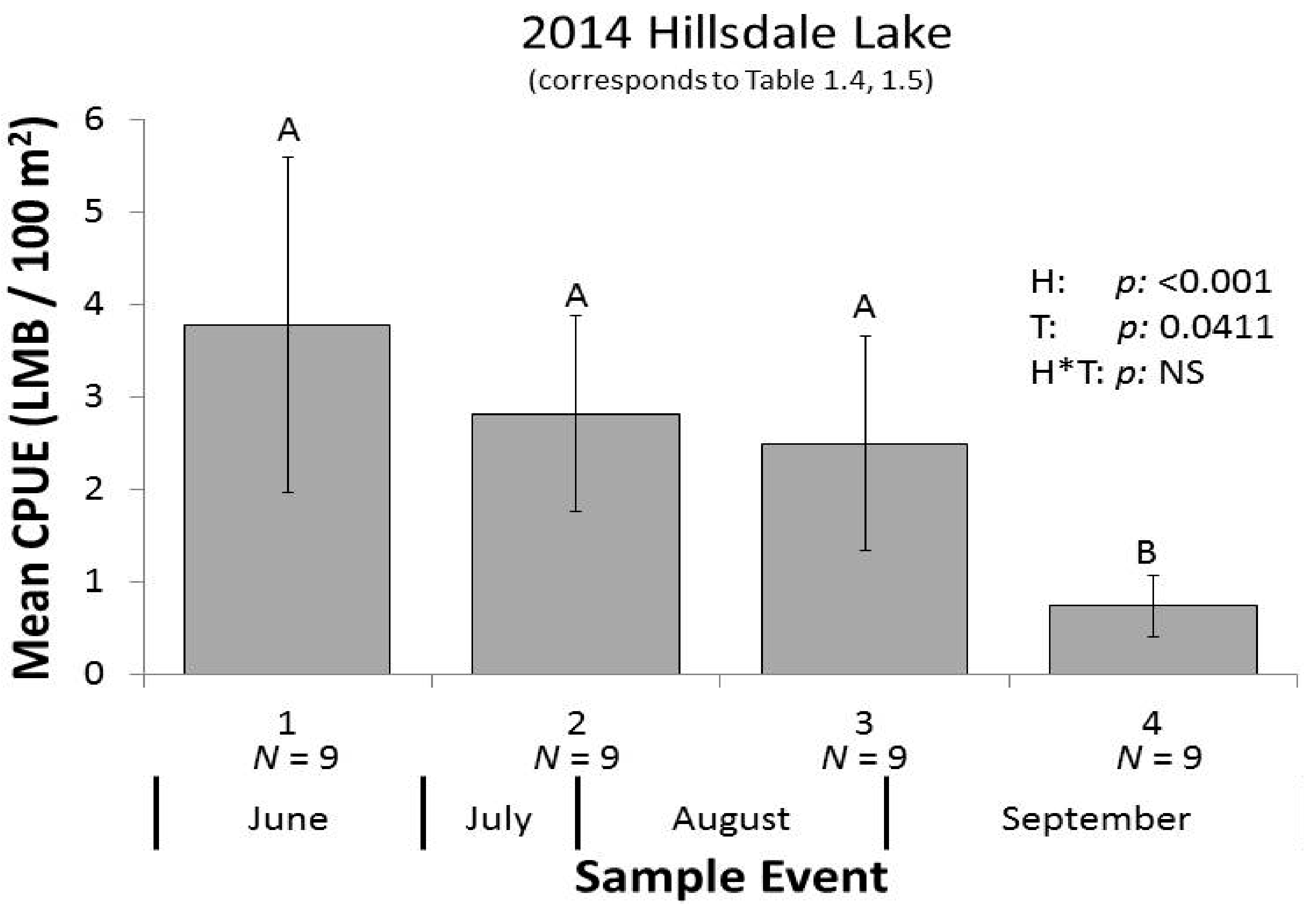

Figure 1.6: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for four sample events in Hillsdale Lake, KS during 2014.Data are mean and standard error.

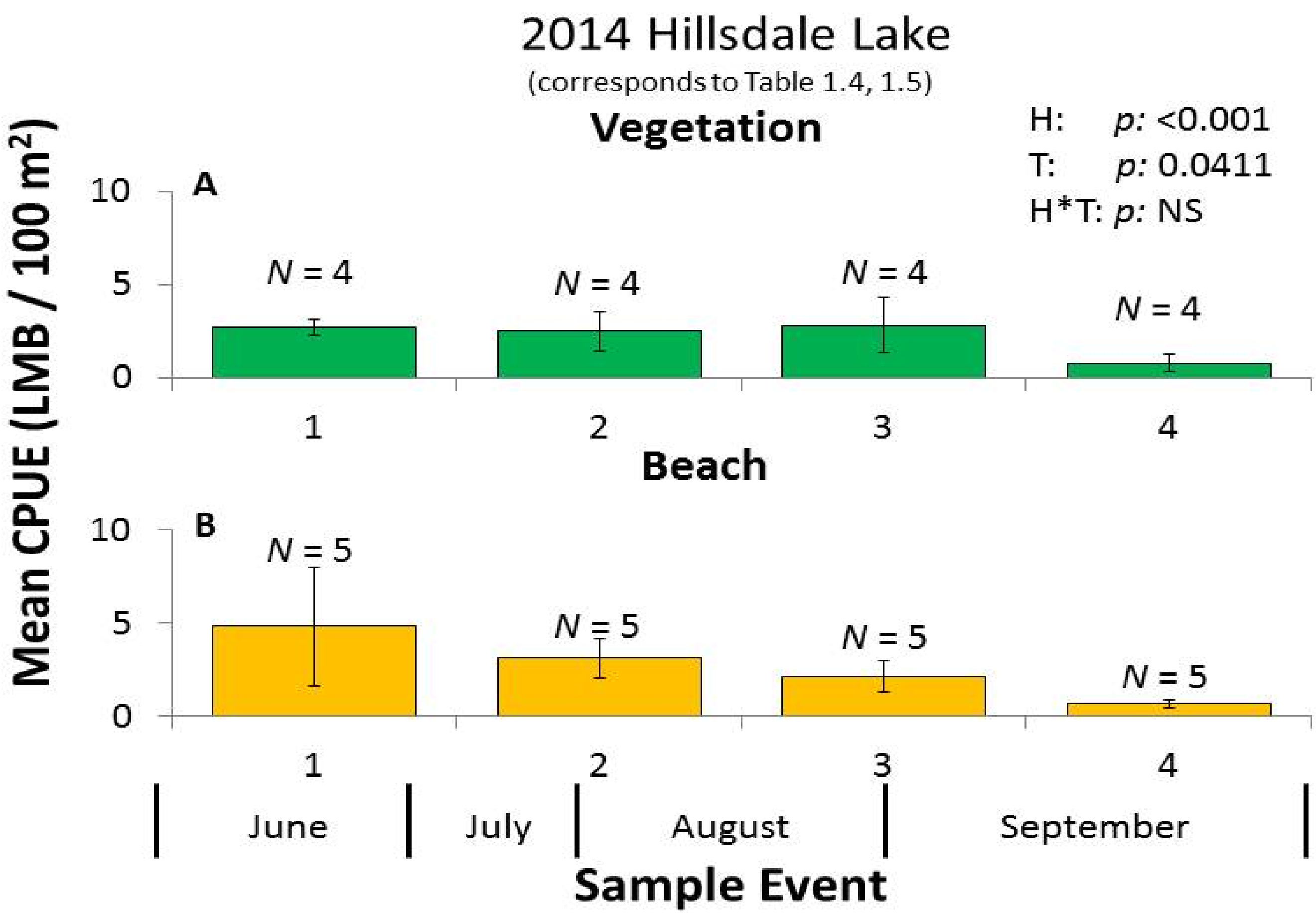

Figure 1.7: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two habitat types (vegetation, beach) across four sample events in Hillsdale Lake, KS during 2014.Data are mean and standard error.

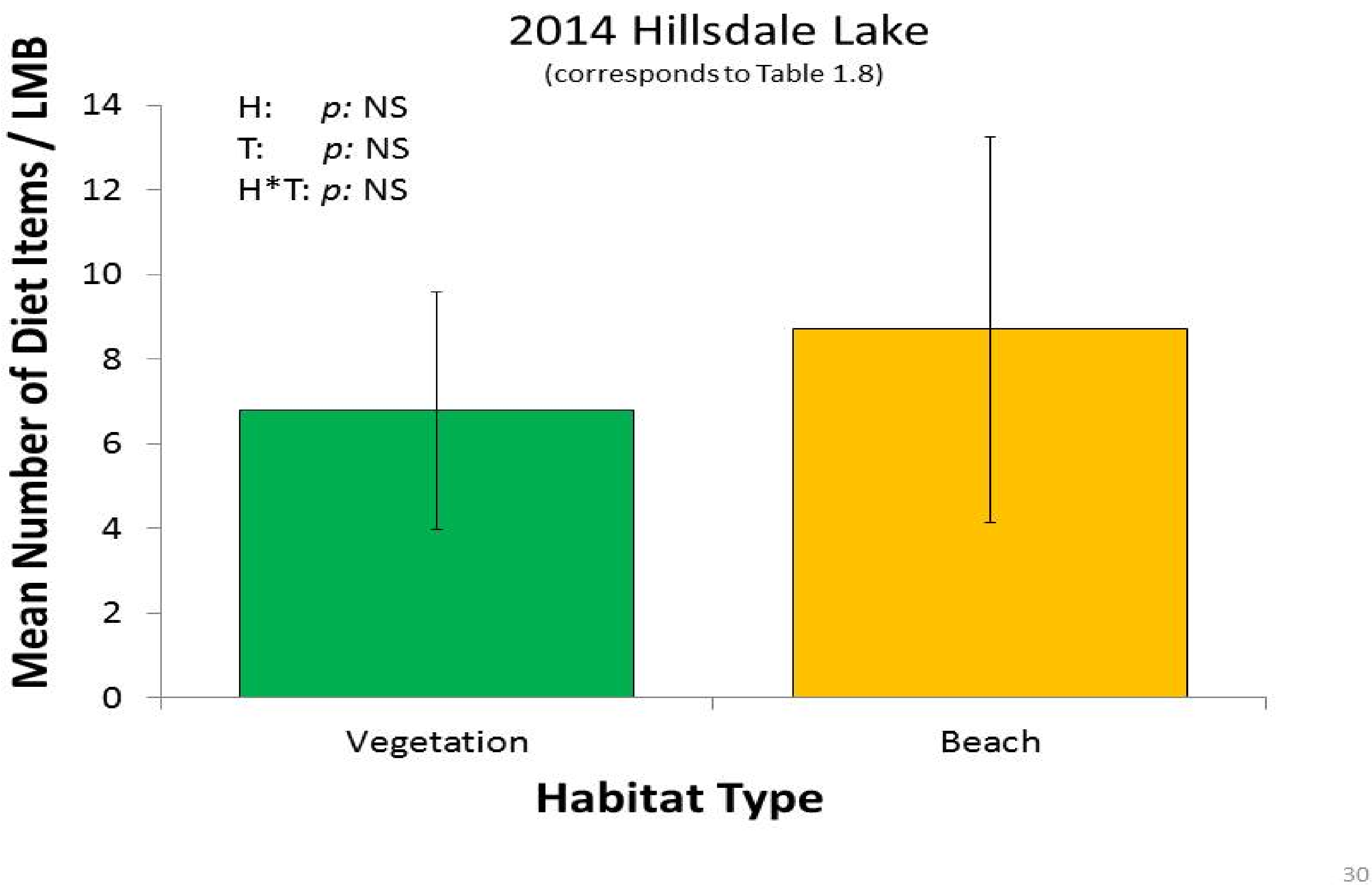

Figure 1.8: Mean total number of diet items eaten by young of year largemouth bass for two habitat types (vegetation, beach) during 2014. Data are mean and standard error.

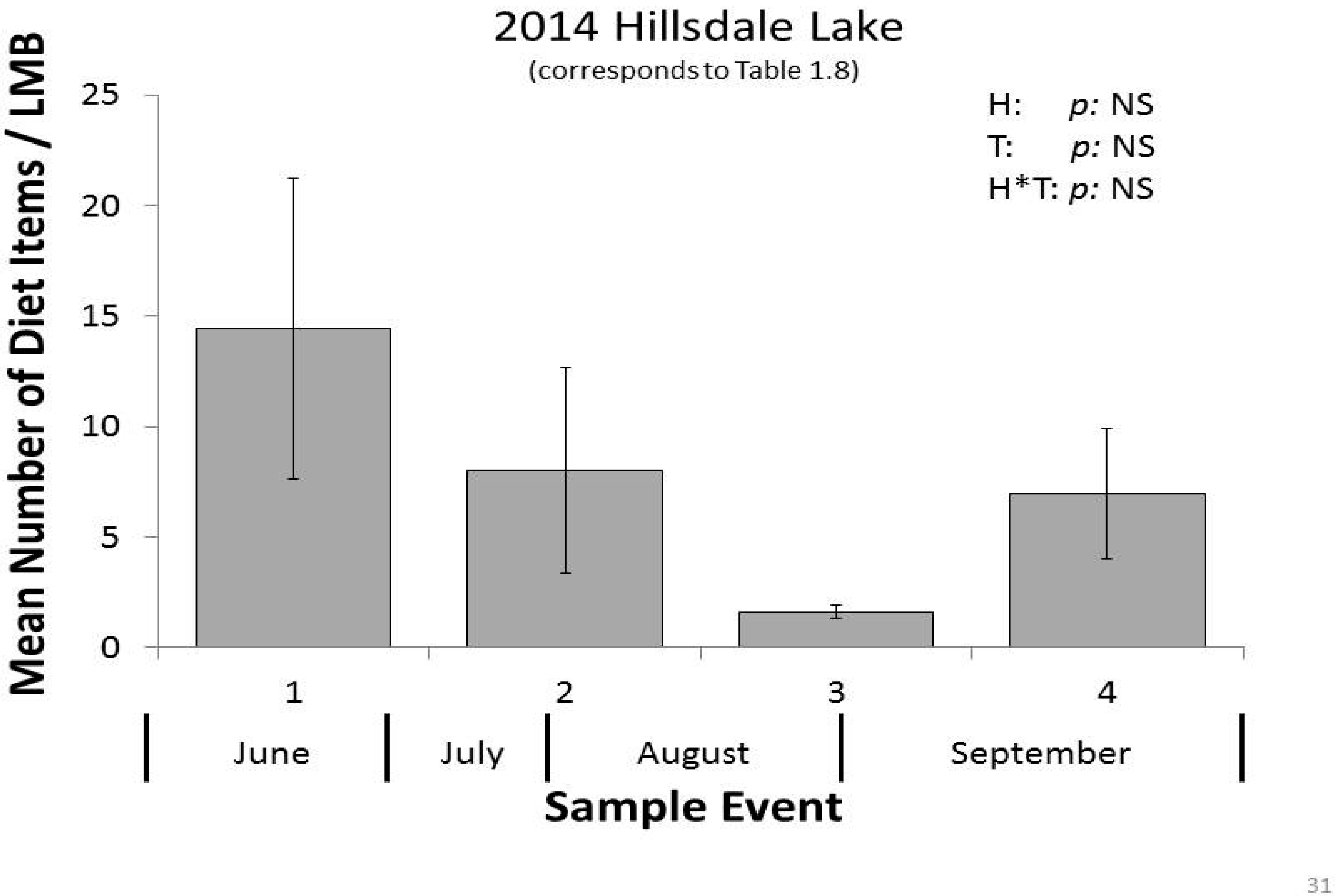

Figure 1.9: Mean total number of diet items eaten by young of year largemouth bass for four sample events during 2014.Data are mean and standard error.

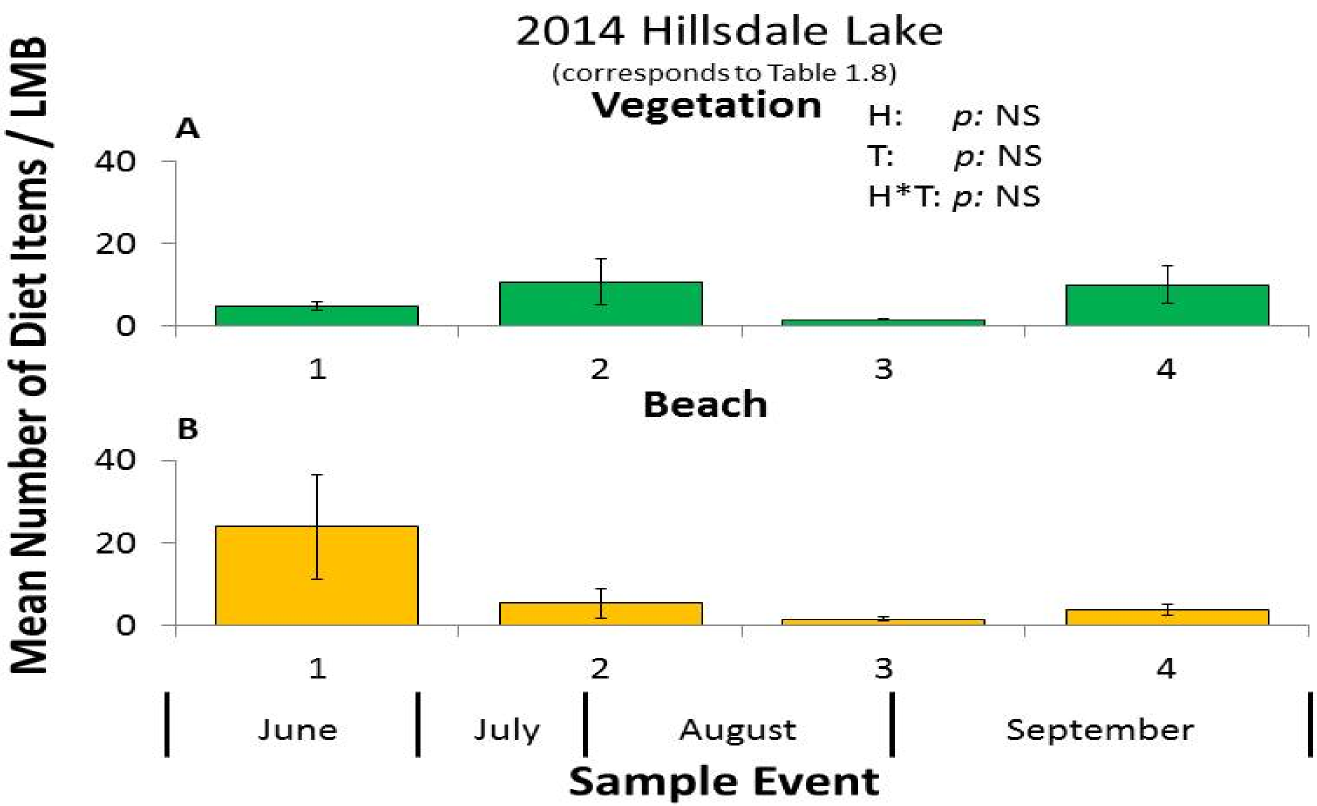

Figure 1.10: Mean total number of diet items eaten by young of year largemouth bass for two habitat types (vegetation, beach) for four sample events during 2014.Data are mean and standard error,

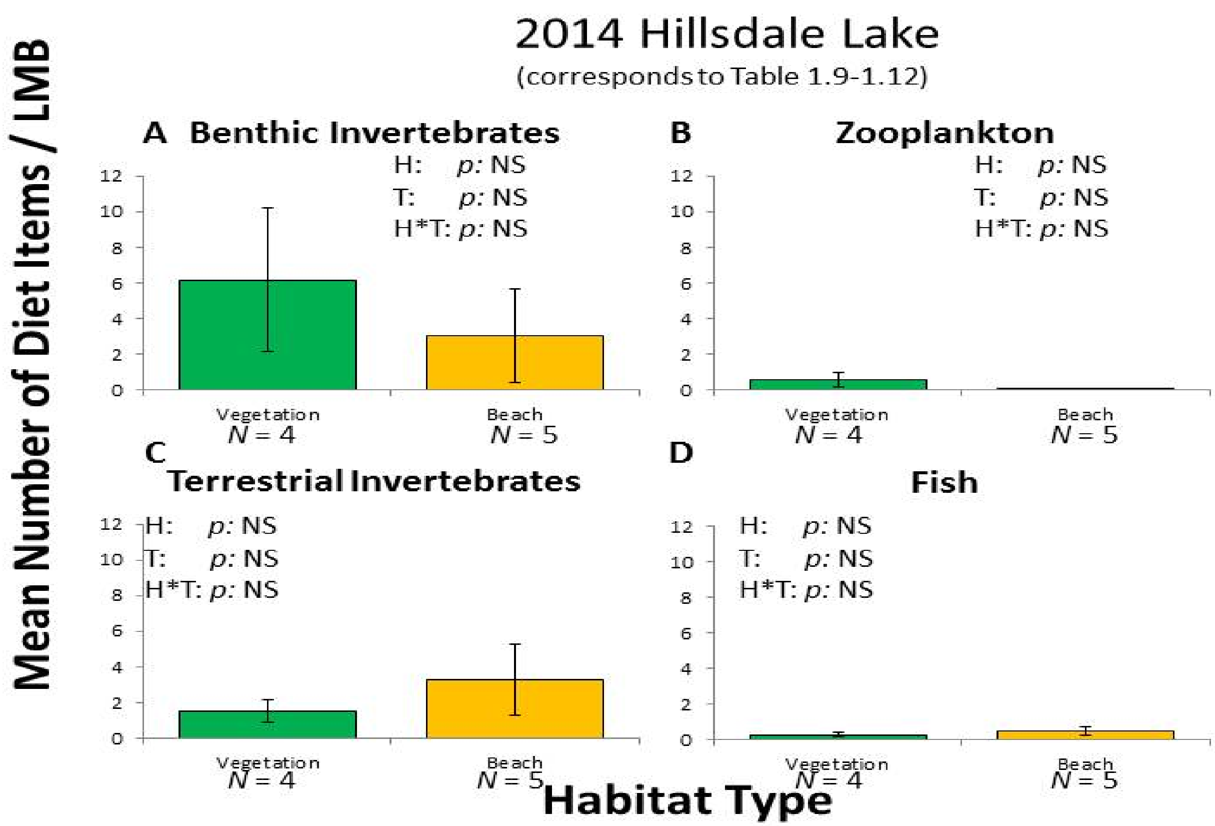

Figure 1.11: Mean number of diet items eaten by young of year largemouth bass across two habitat types (vegetation and beach) in Hillsdale Lake during 2014 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

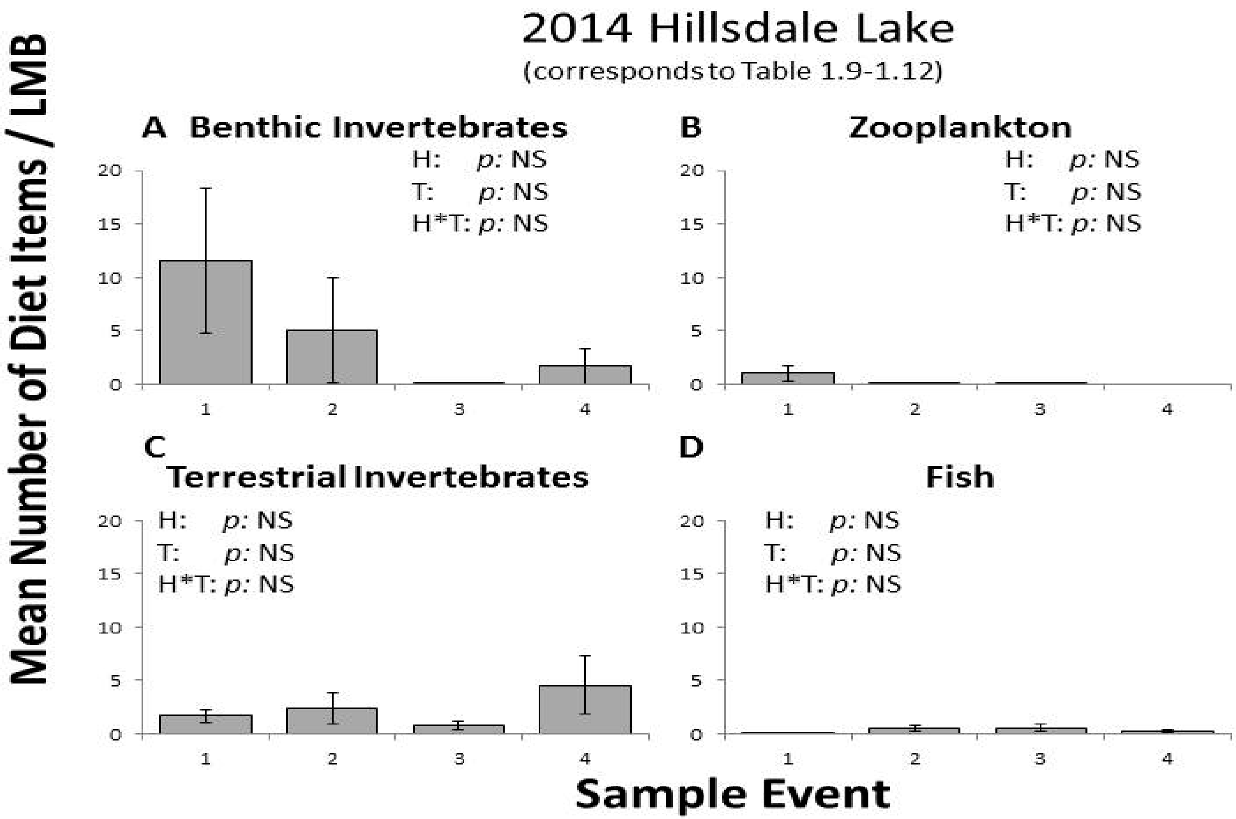

Figure 1.12: Mean number of diet items eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2014 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

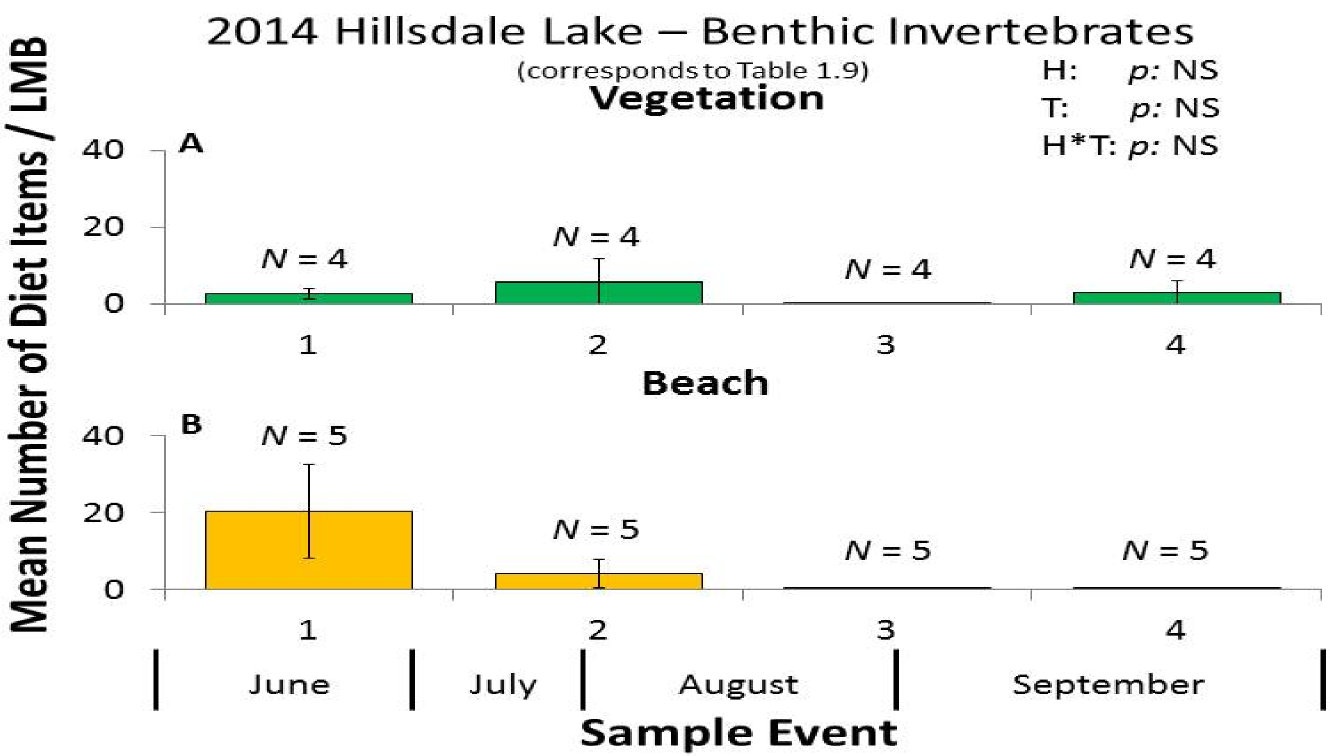

Figure 1.13: Mean number of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

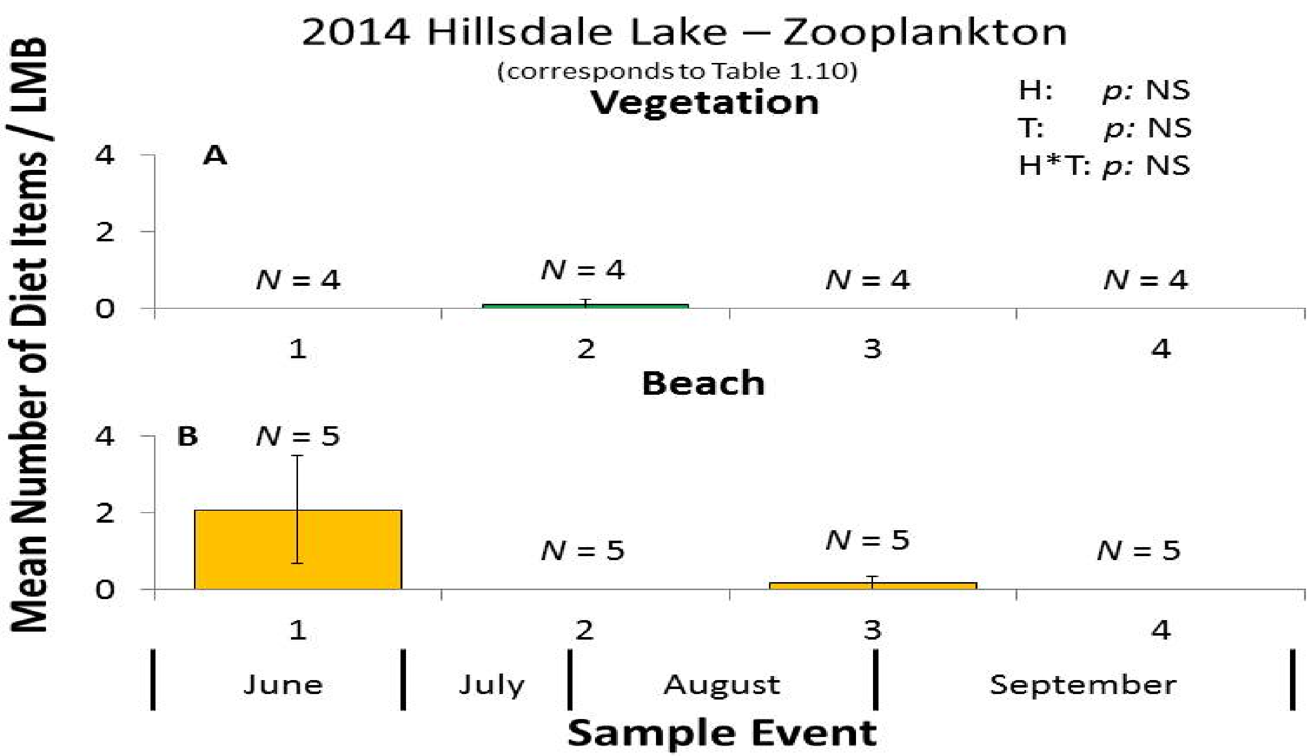

Figure 1.14: Mean number of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

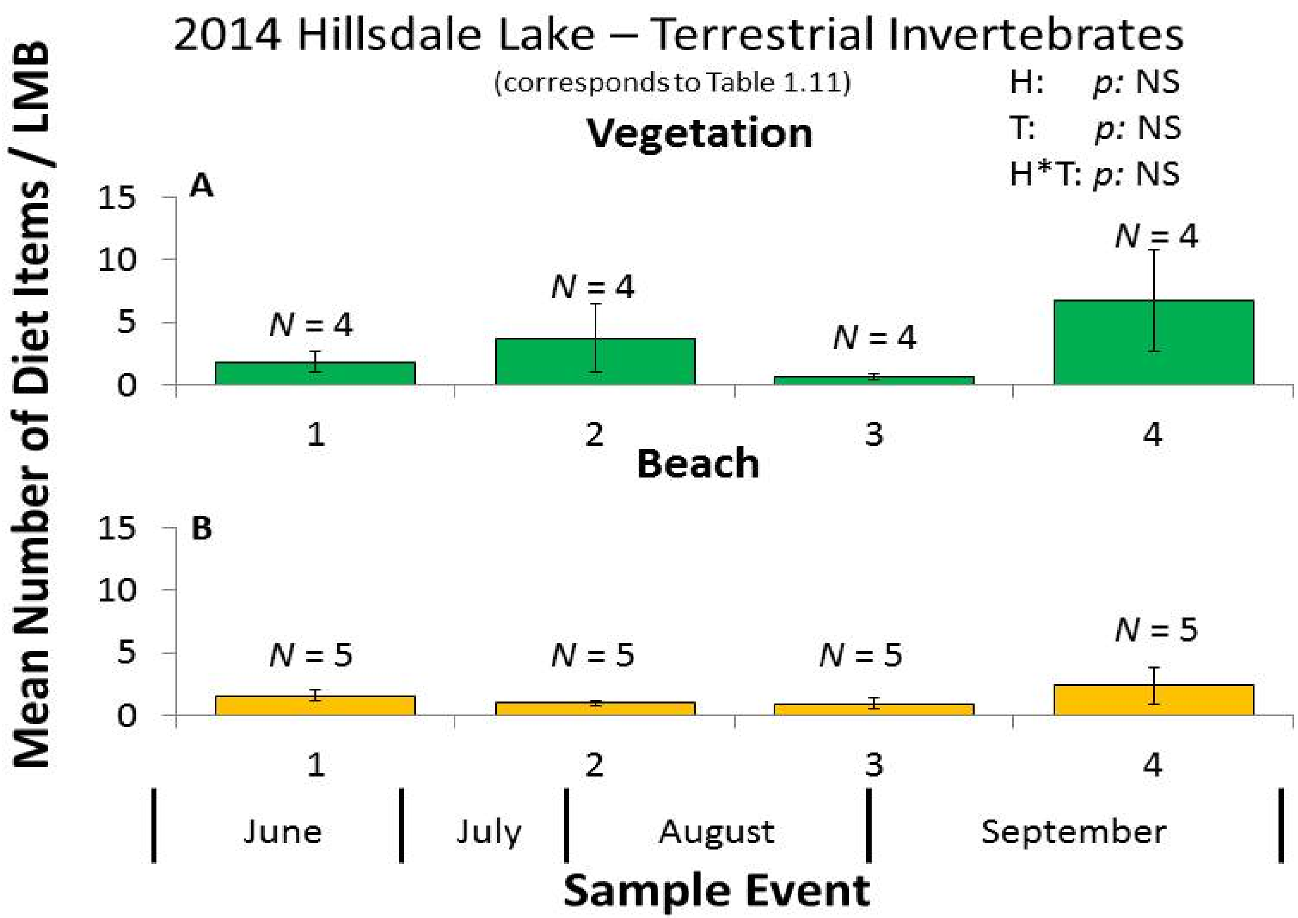

Figure 1.15: Mean number of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

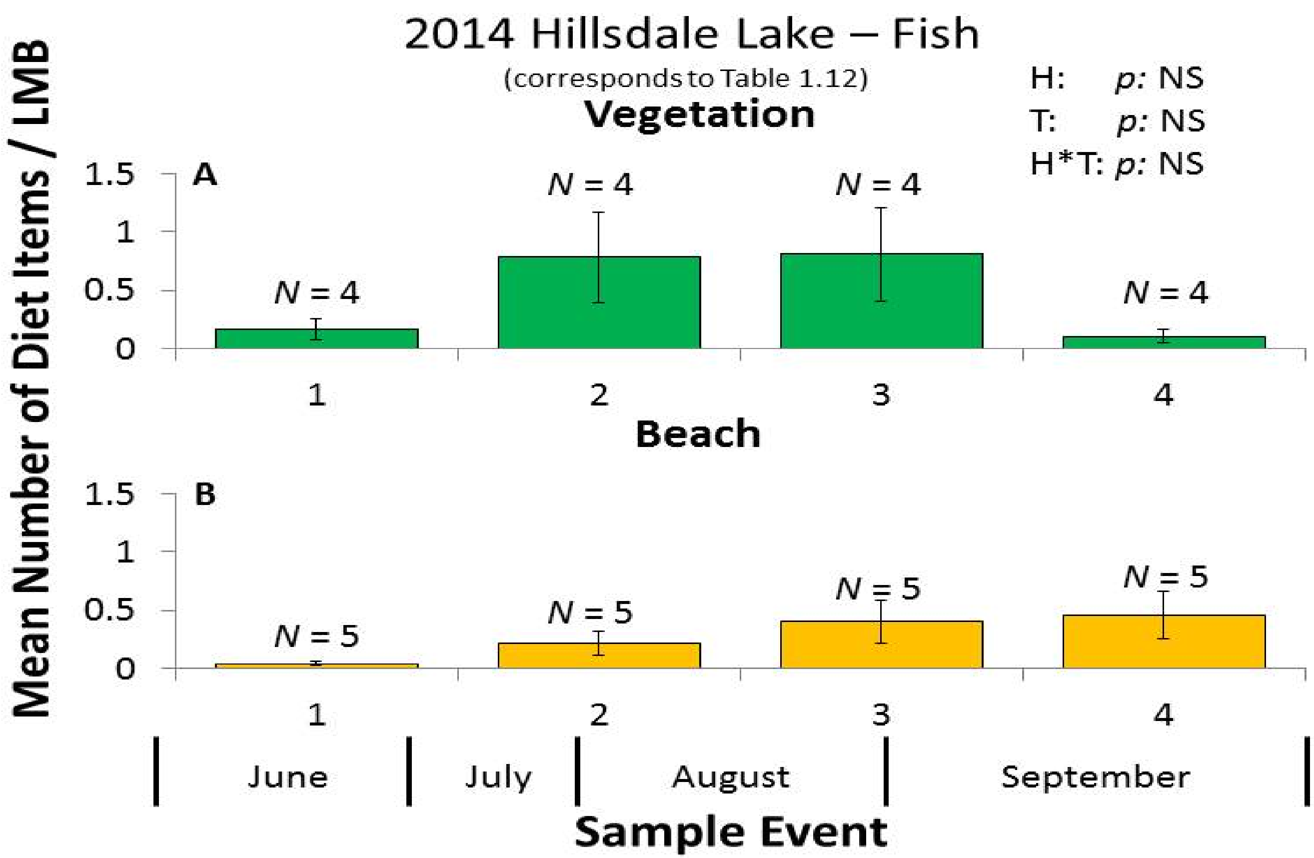

Figure 1.16: Mean number of fish prey eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

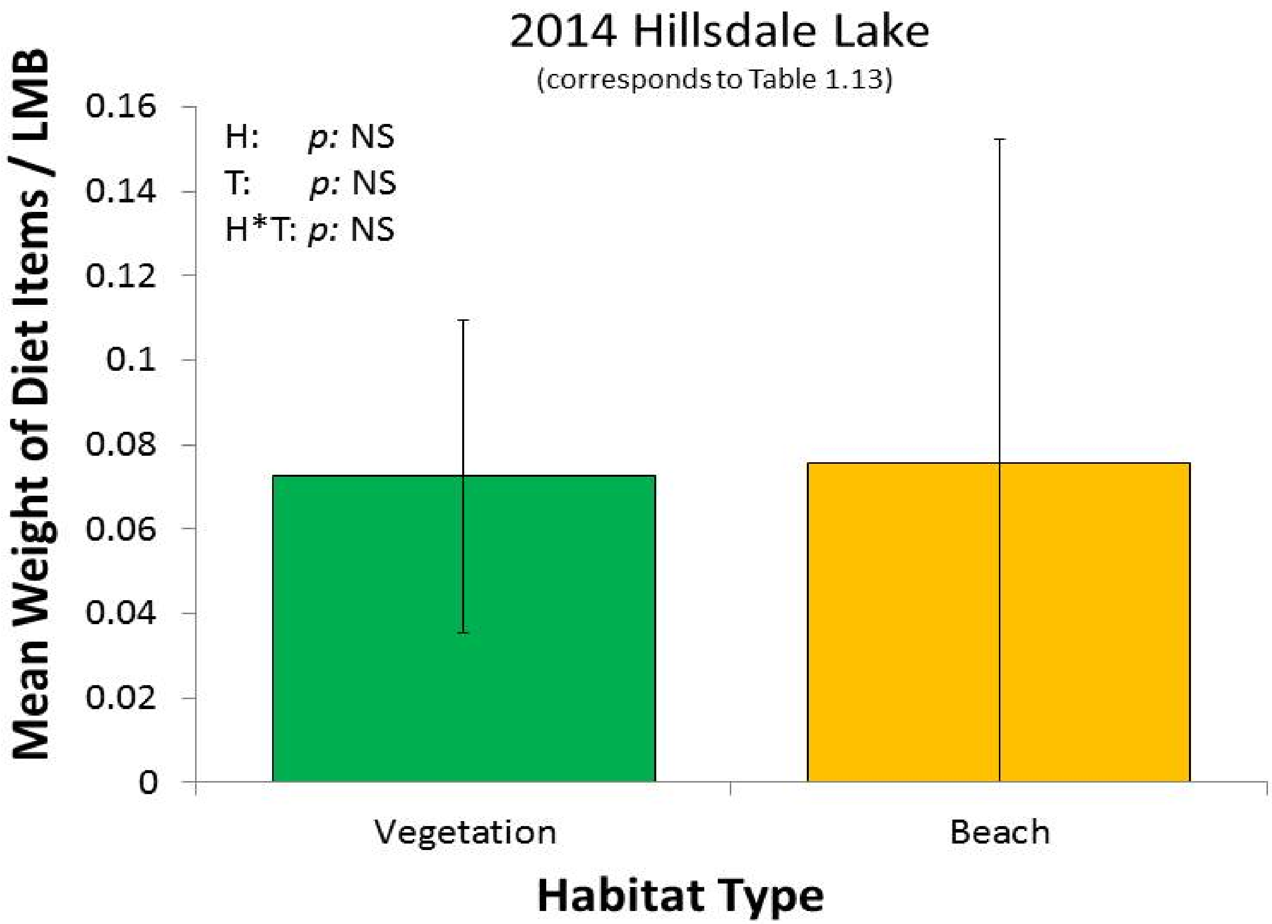

Figure 1.17: Mean total weight of diet items eaten by young of year largemouth bass for two habitat types (vegetation, beach) during 2014. Data are mean and standard error.

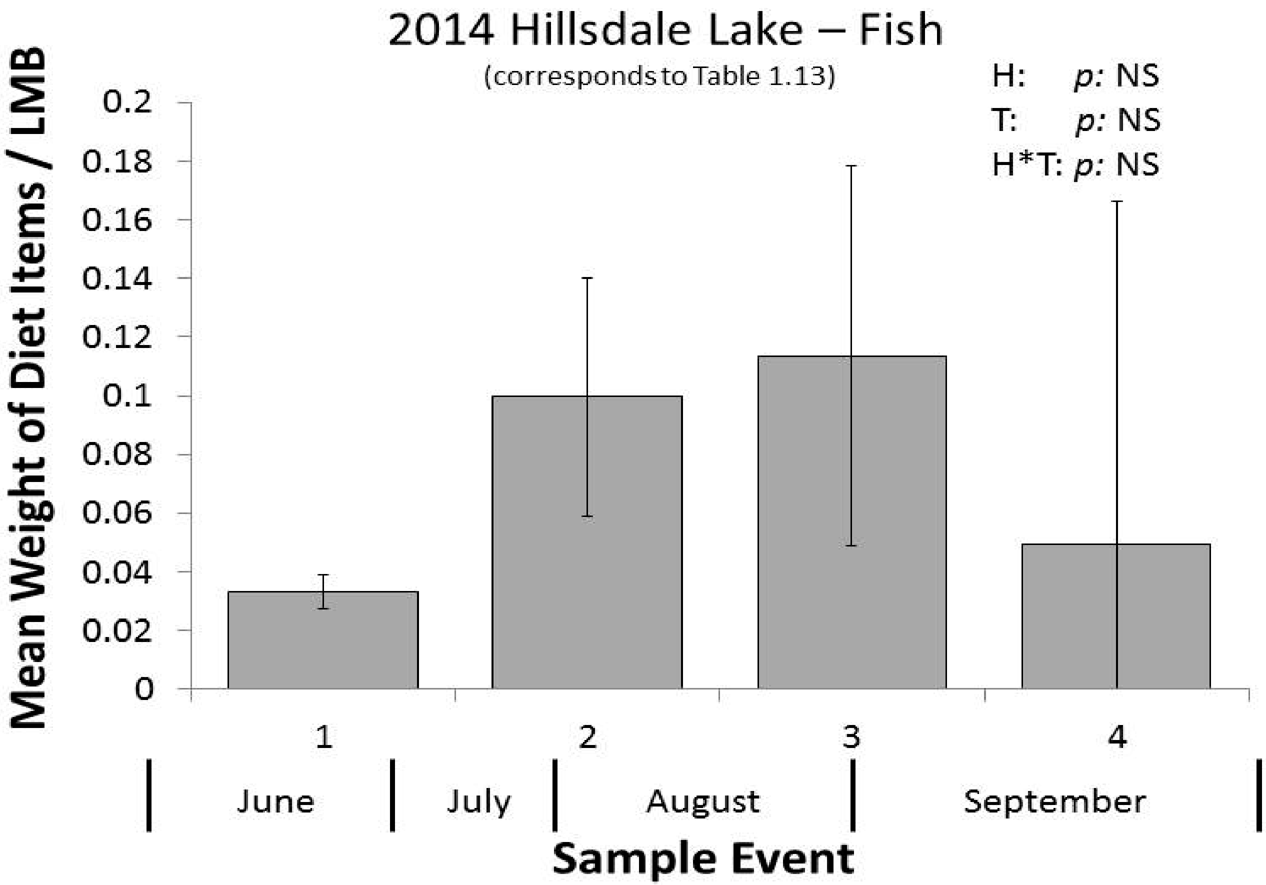

Figure 1.18: Mean total weight of diet items eaten by young of year largemouth bass for four sample events during 2014. Data are mean and standard error.

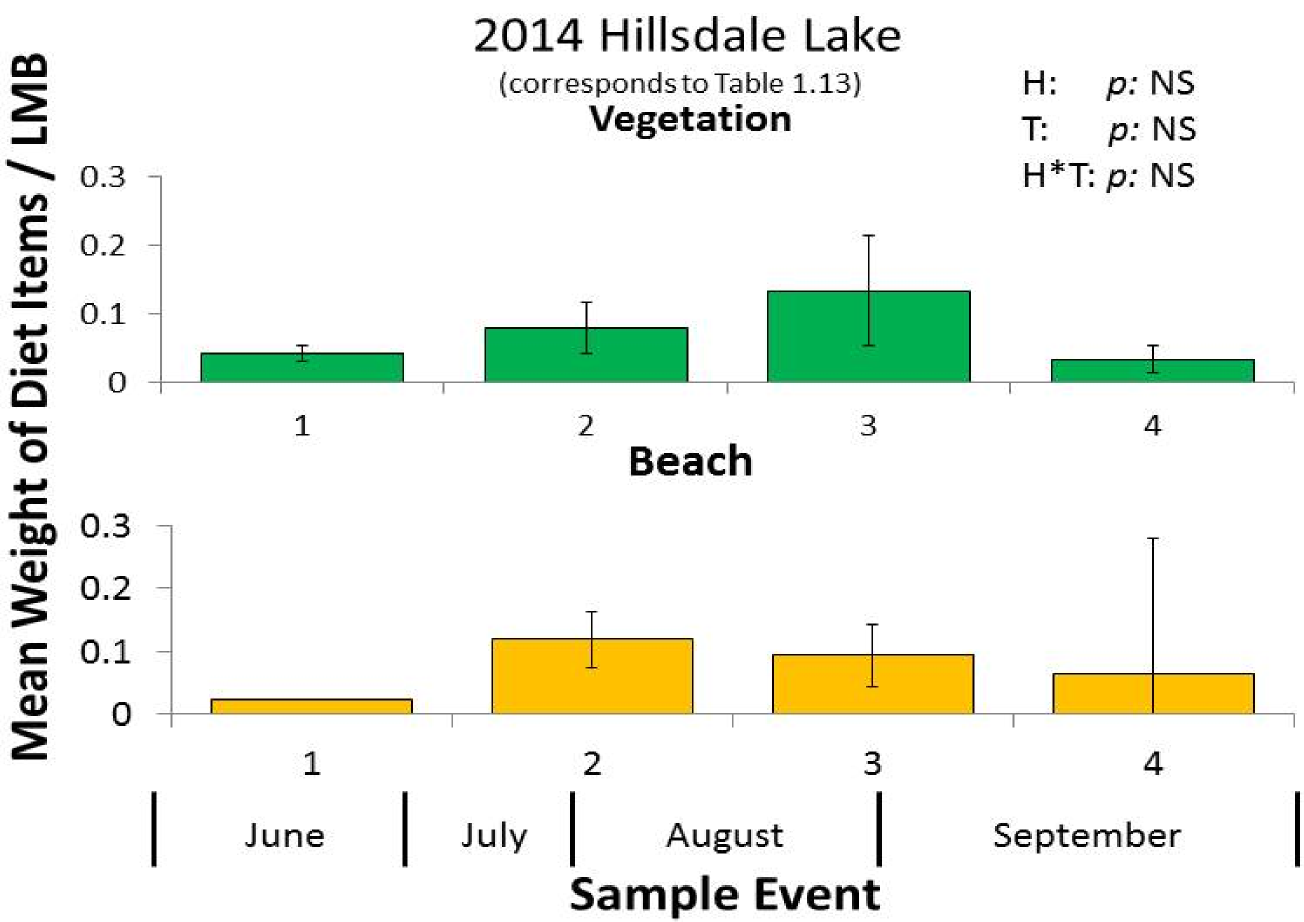

Figure 1.19: Mean total weight of diet items eaten by young of year largemouth bass across two habitat types (vegetation, beach) for four sample events during 2014. Data are mean and standard error.

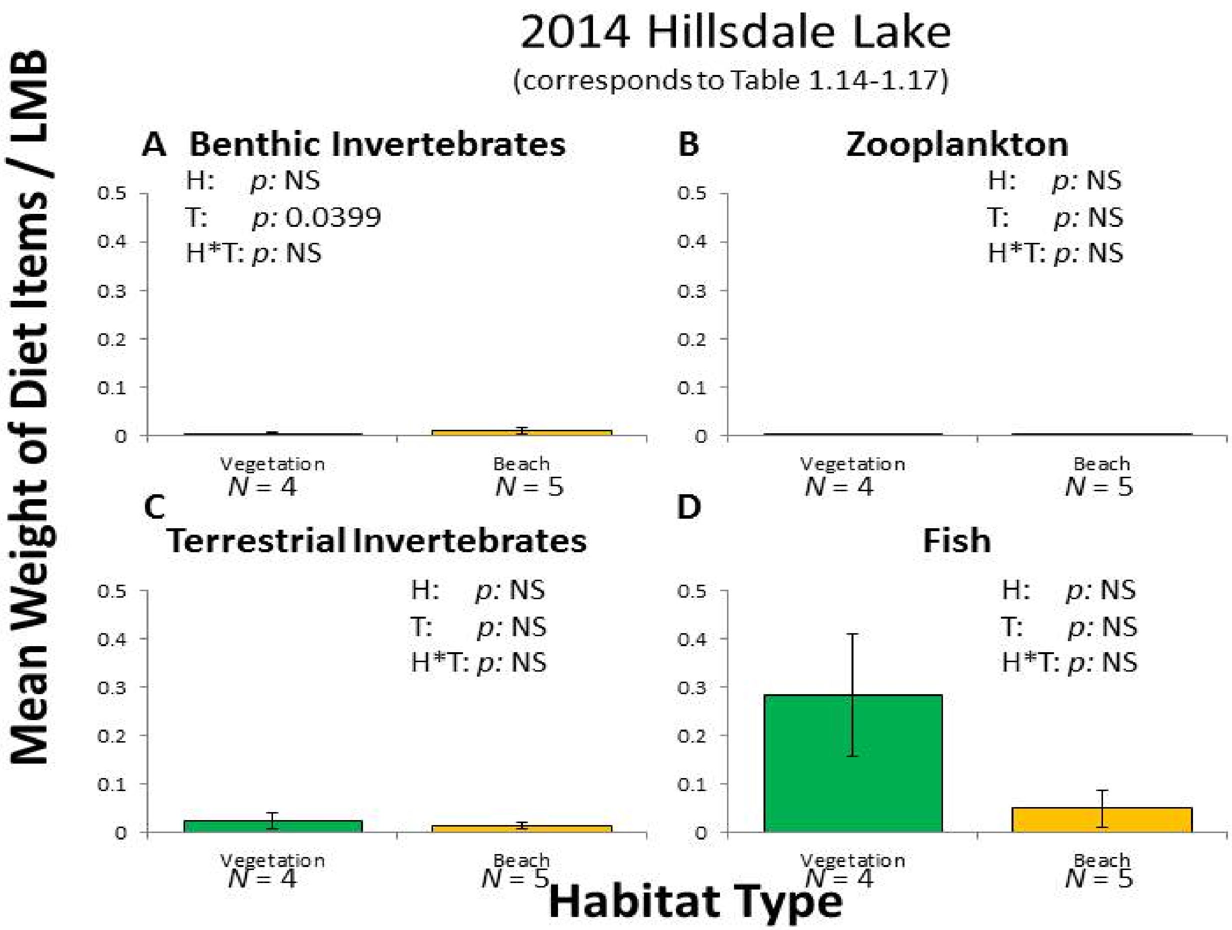

Figure 1.20: Mean weight of diet items eaten by young of year largemouth bass across two habitat types (vegetation and beach) in Hillsdale Lake during 2014 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

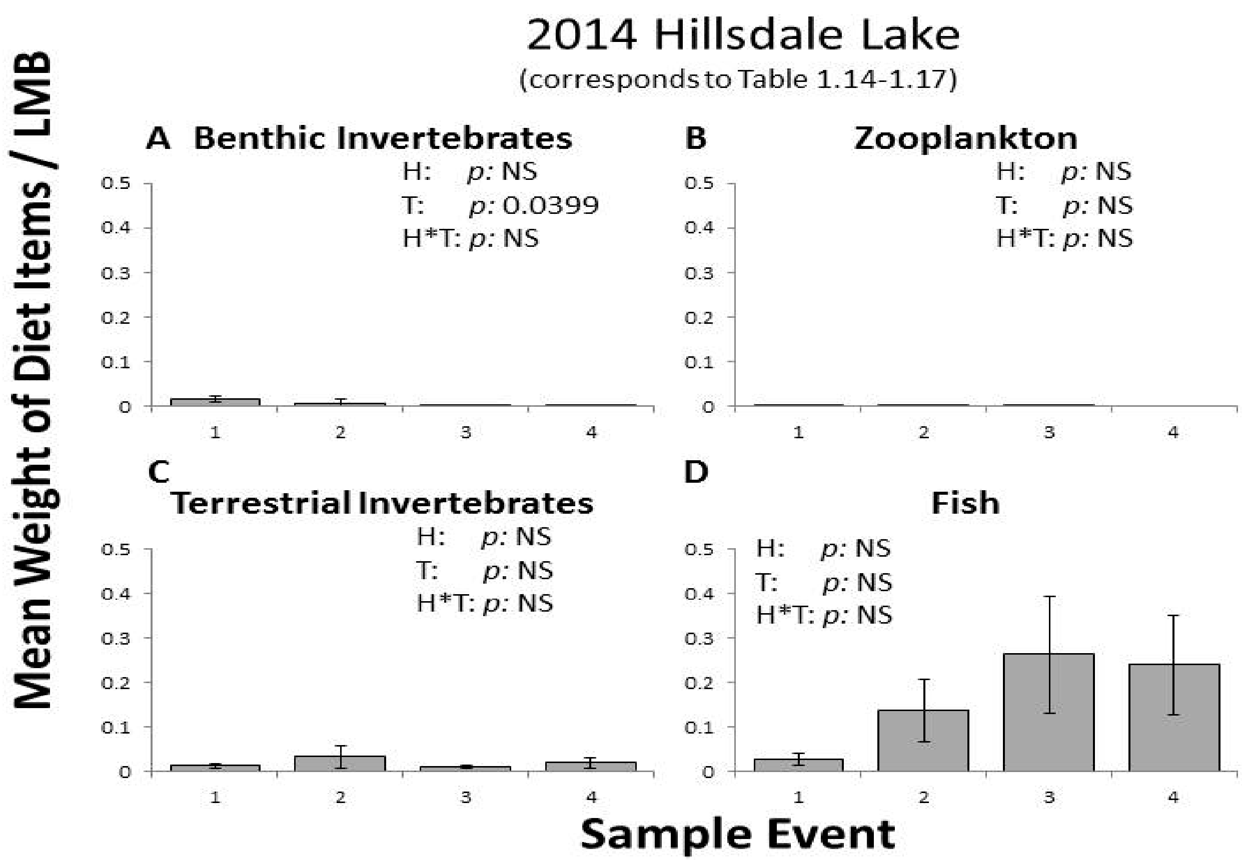

Figure 1.21: Mean weight of diet items eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2014 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

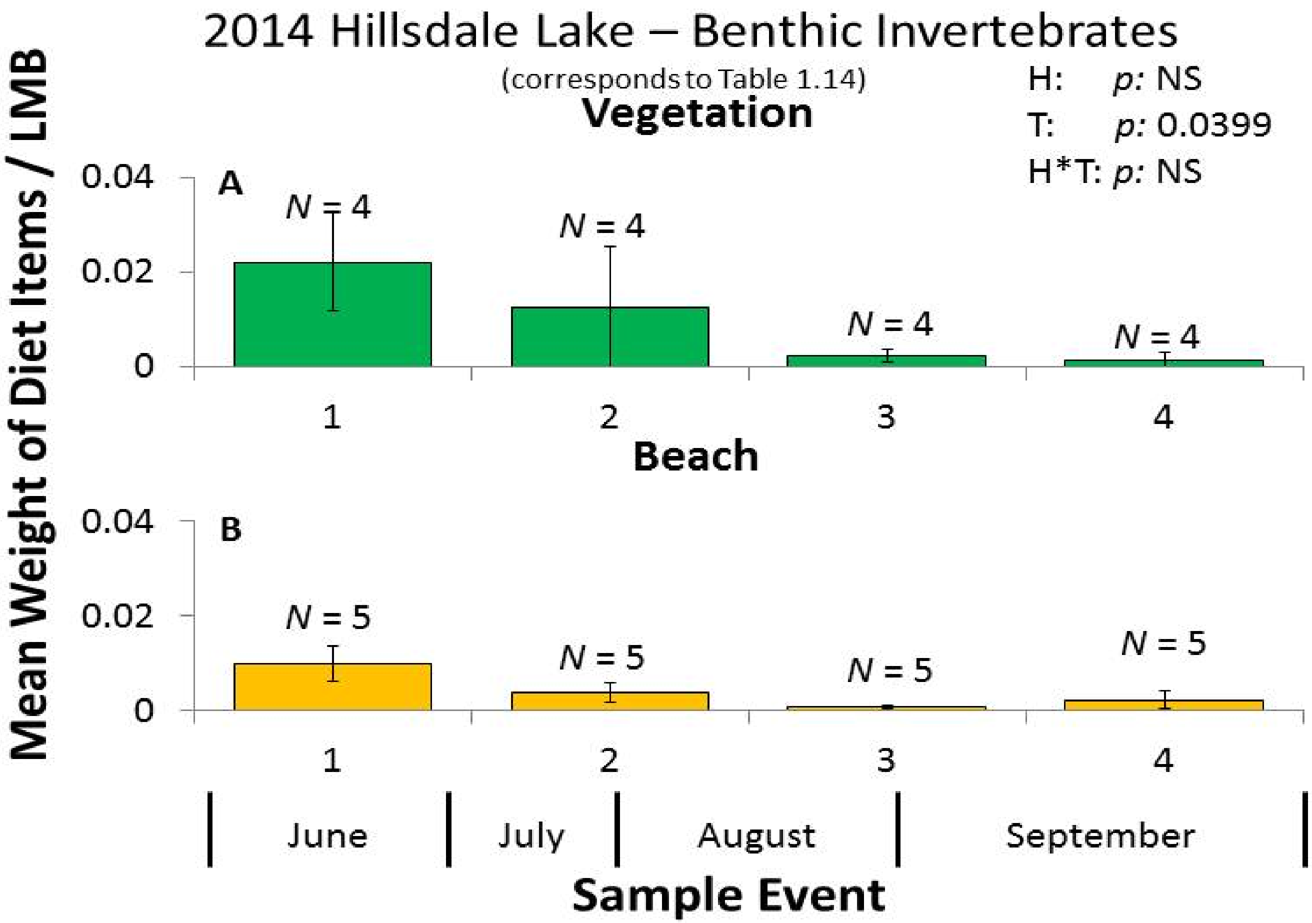

Figure 1.22: Mean weight of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

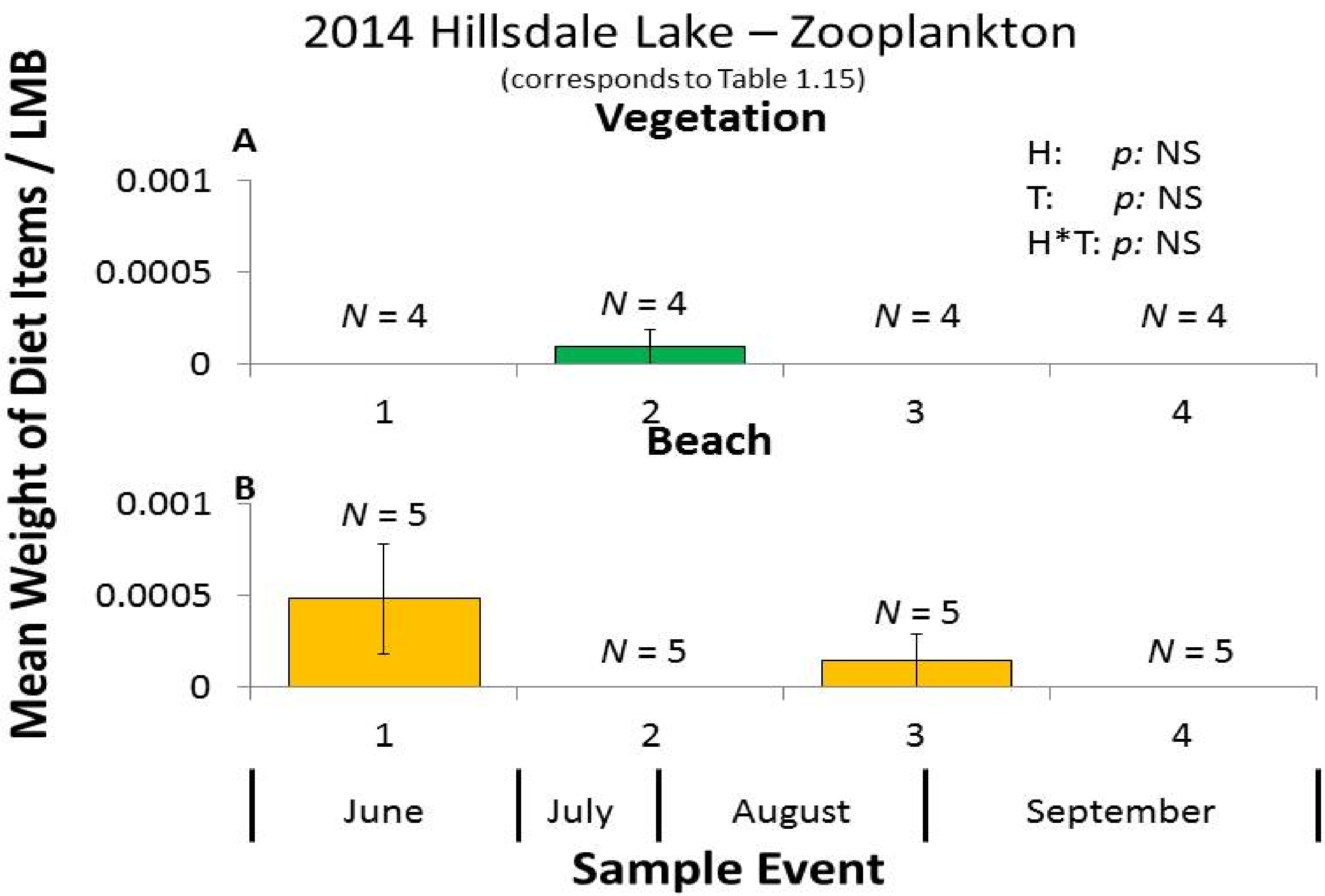

Figure 1.23: Mean weight of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

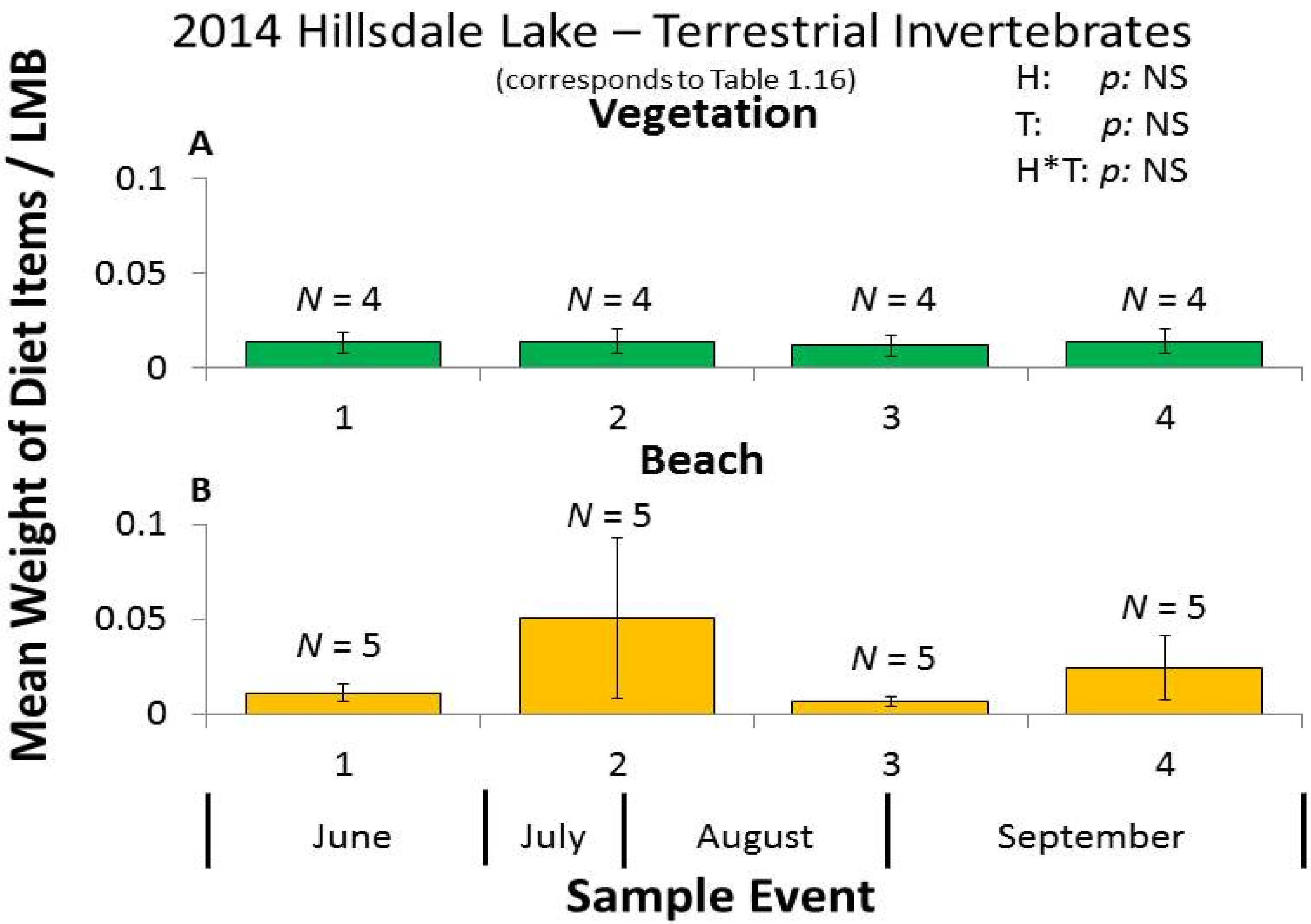

Figure 1.24: Mean weight of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

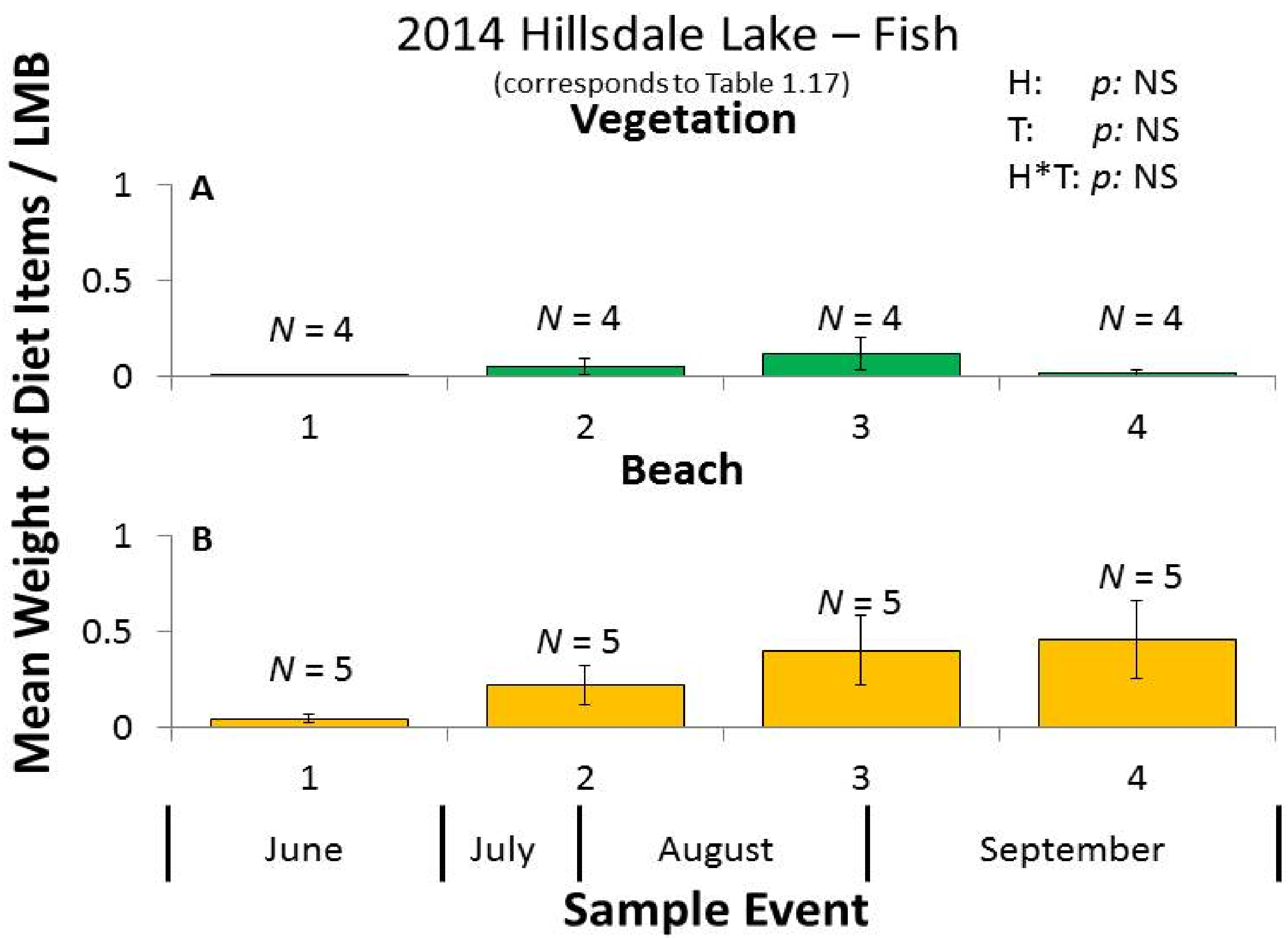

Figure 1.25: Mean weight of fish prey eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

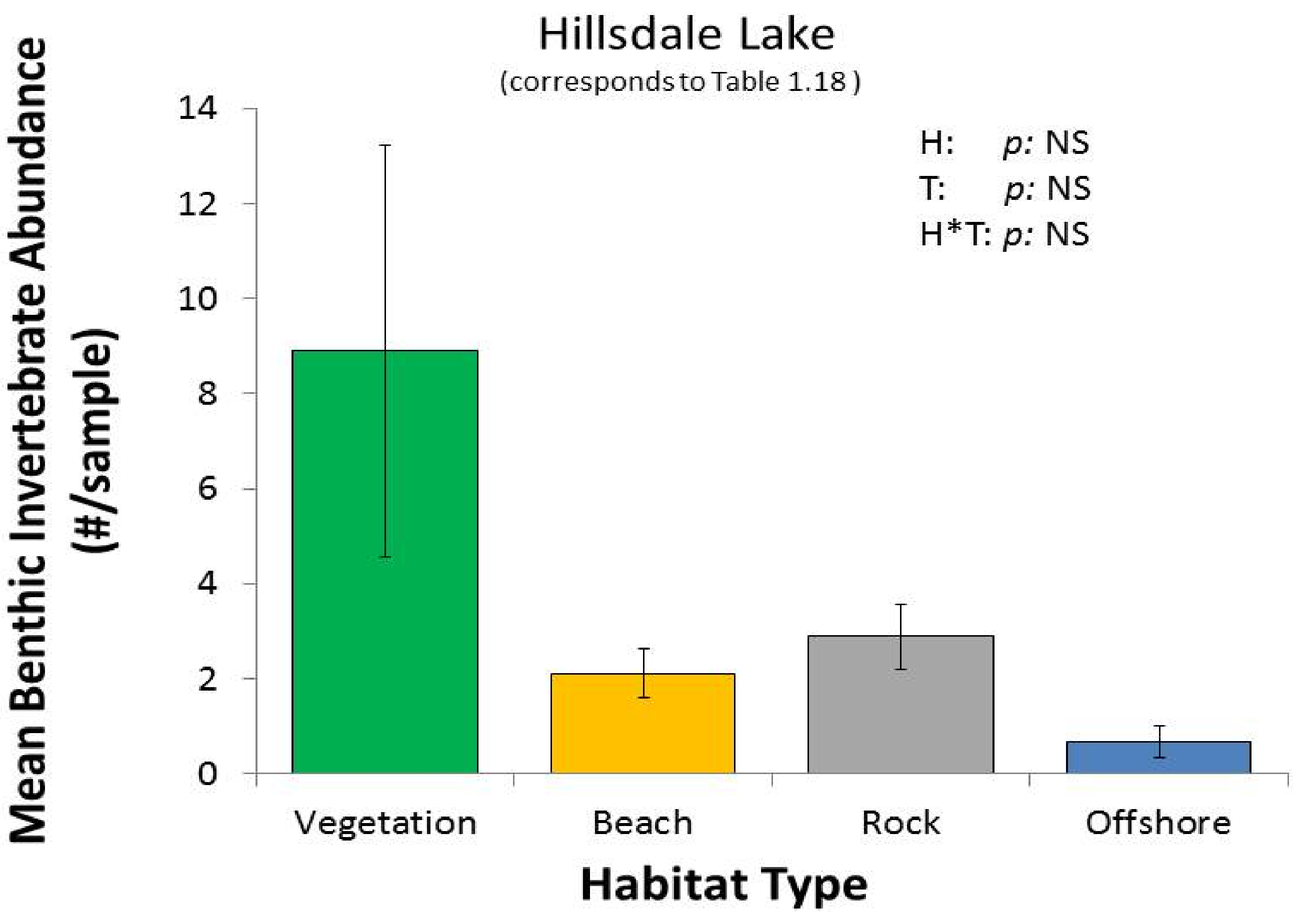

Figure 1.26: Mean benthic invertebrate abundance (number/sample) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

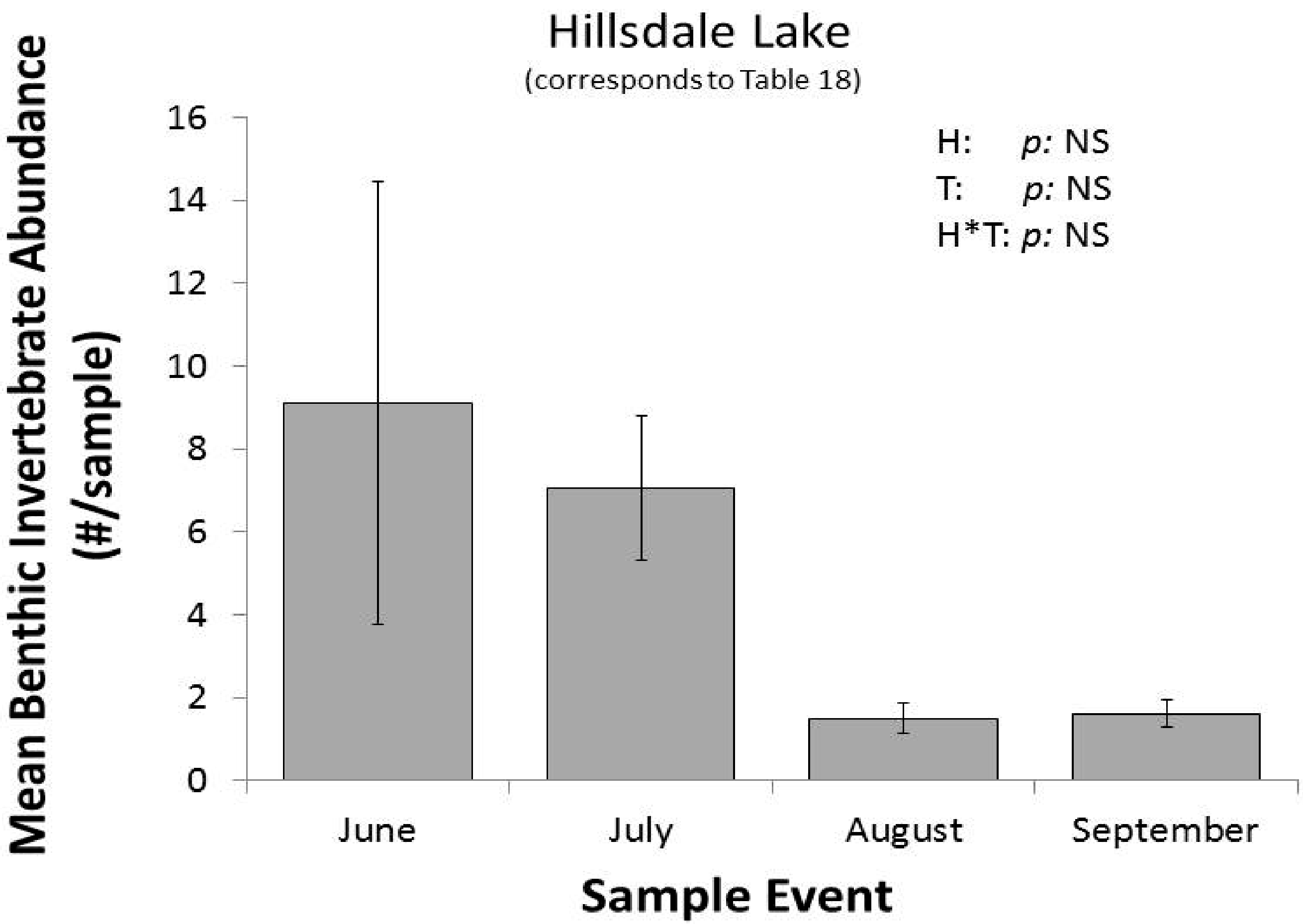

Figure 1.27: Mean benthic invertebrate abundance (number/sample) across four sample months in Hillsdale Lake, KS during 2014. Data are mean and standard error.

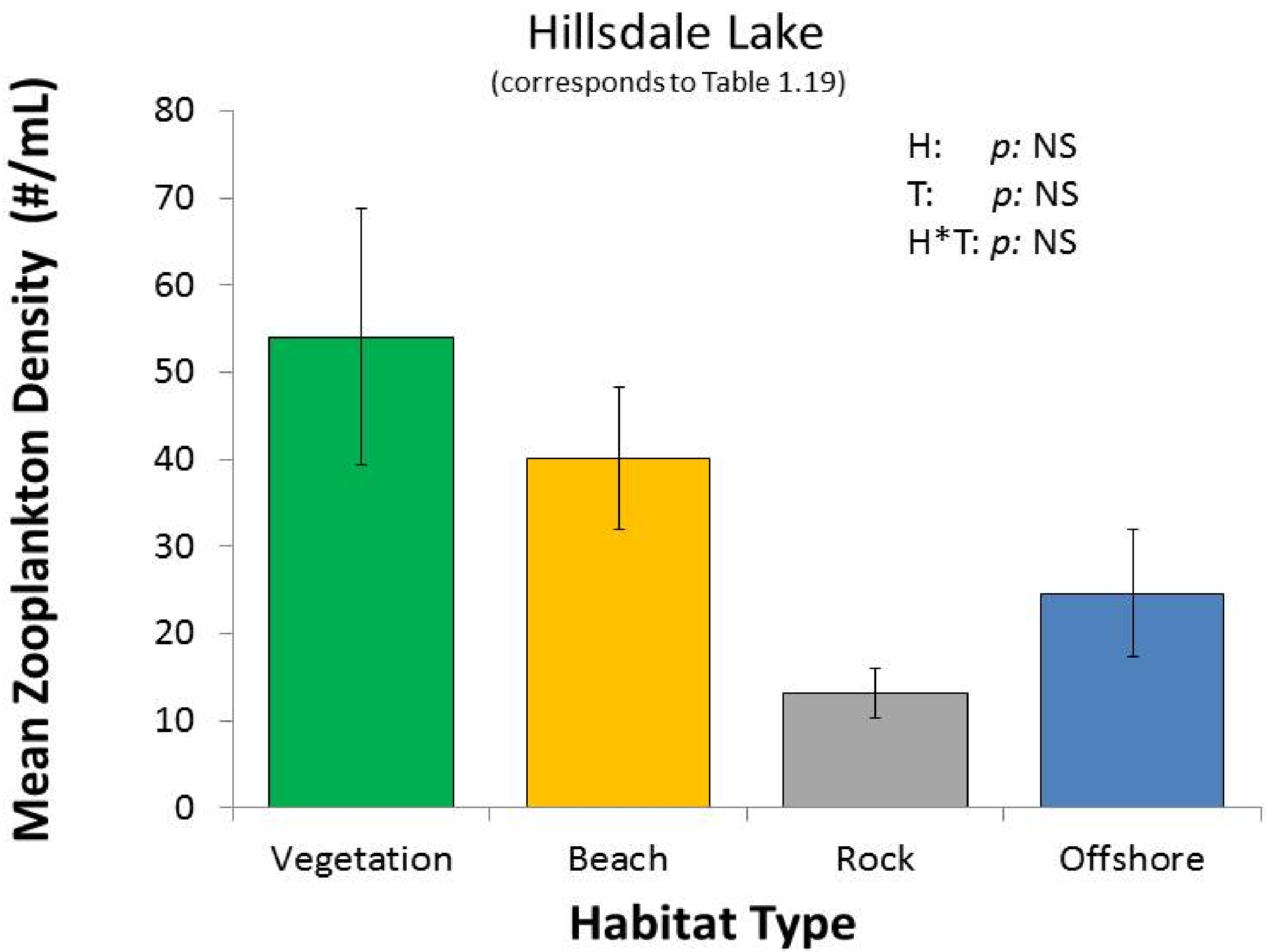

Figure 1.28: Mean zooplankton density (number/mL) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

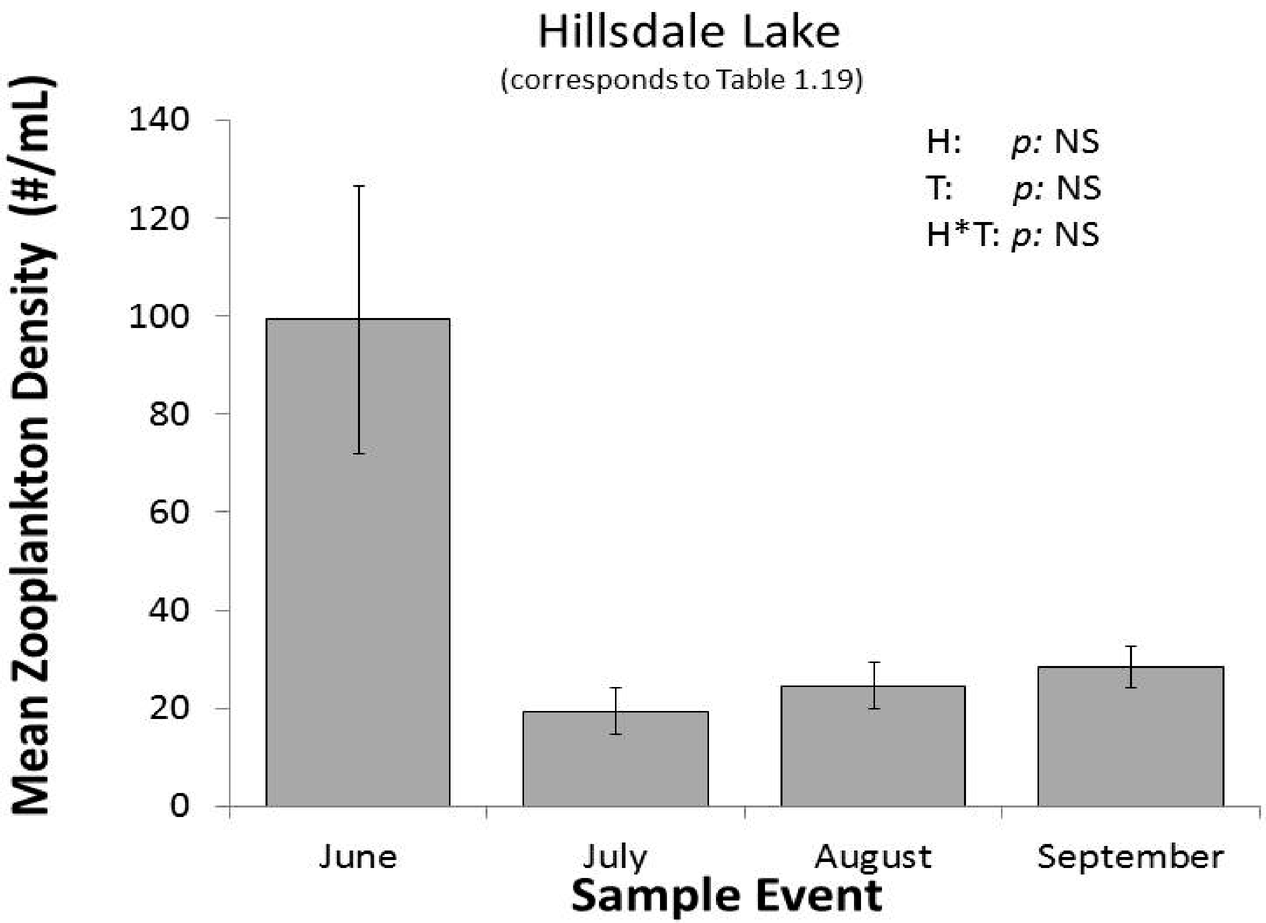

Figure 1.29: Mean zooplankton density (number/mL) across four sample months in Hillsdale Lake, KS during 2014. Data are mean and standard error.

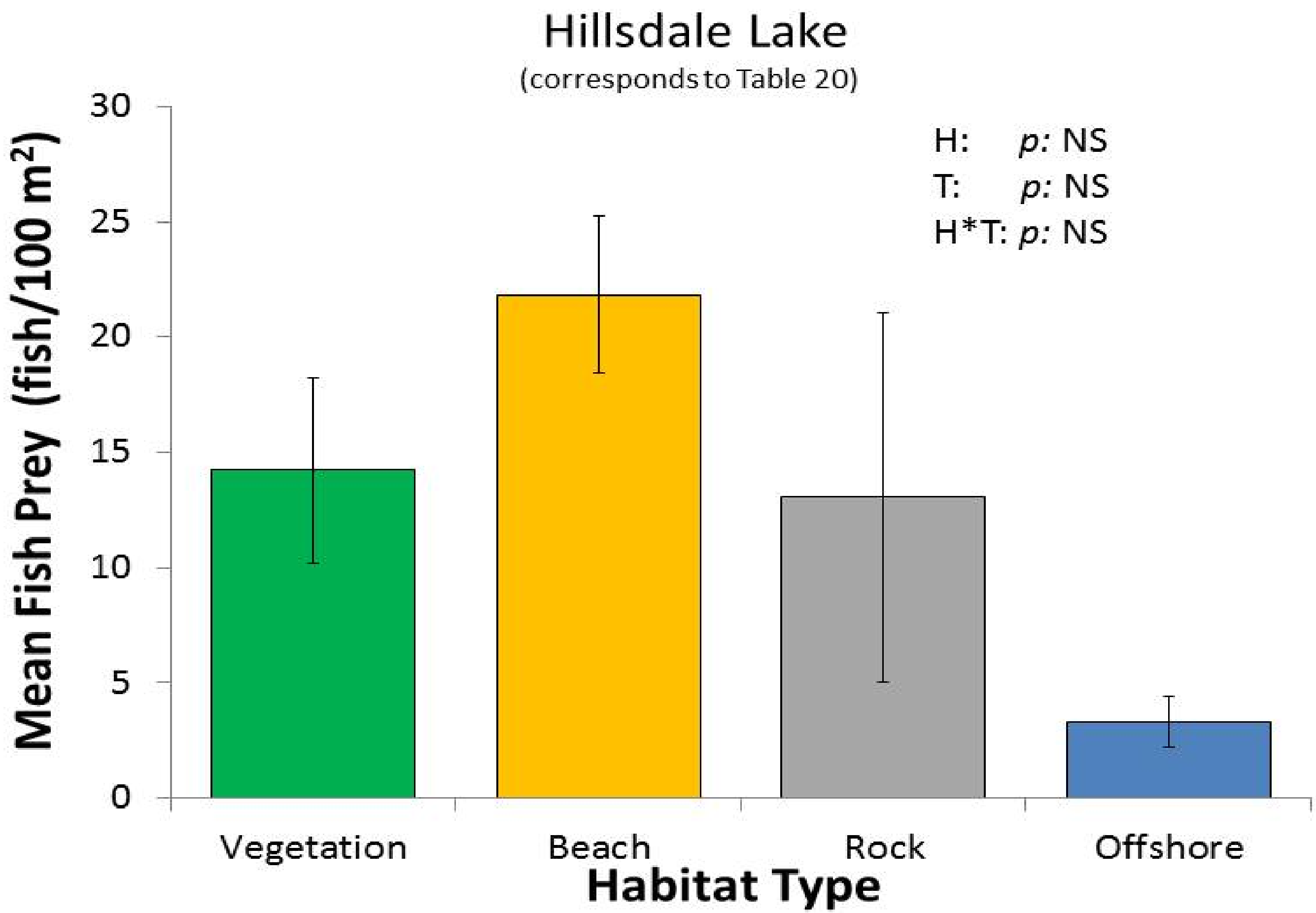

Figure 1.30: Mean prey fish density (number/ 100 m^2) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

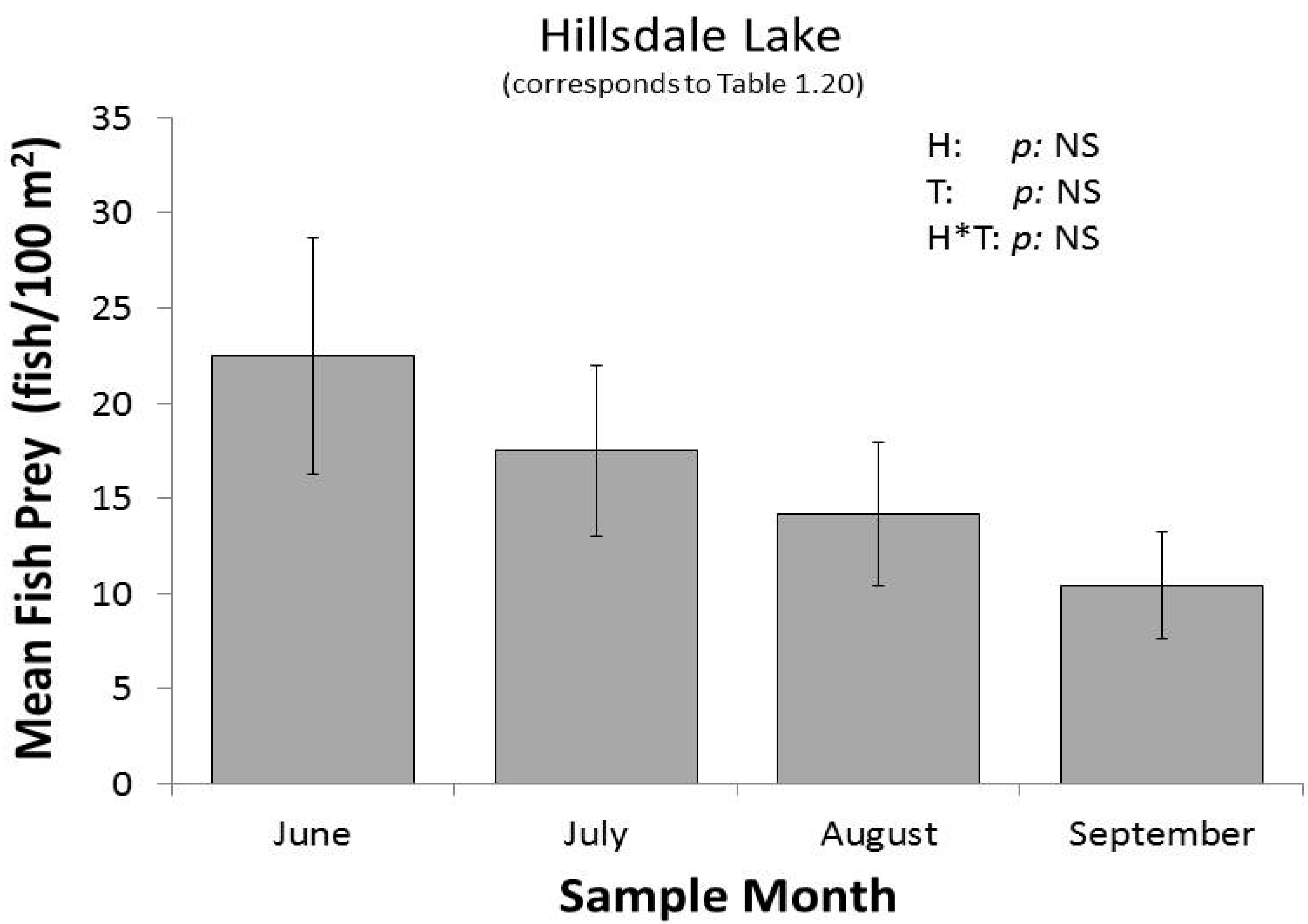

Figure 1.31: Mean prey fish density (number/ 100 m^2) across four sample months during Hillsdale Lake, KS during 2014. Data are mean and standard error.

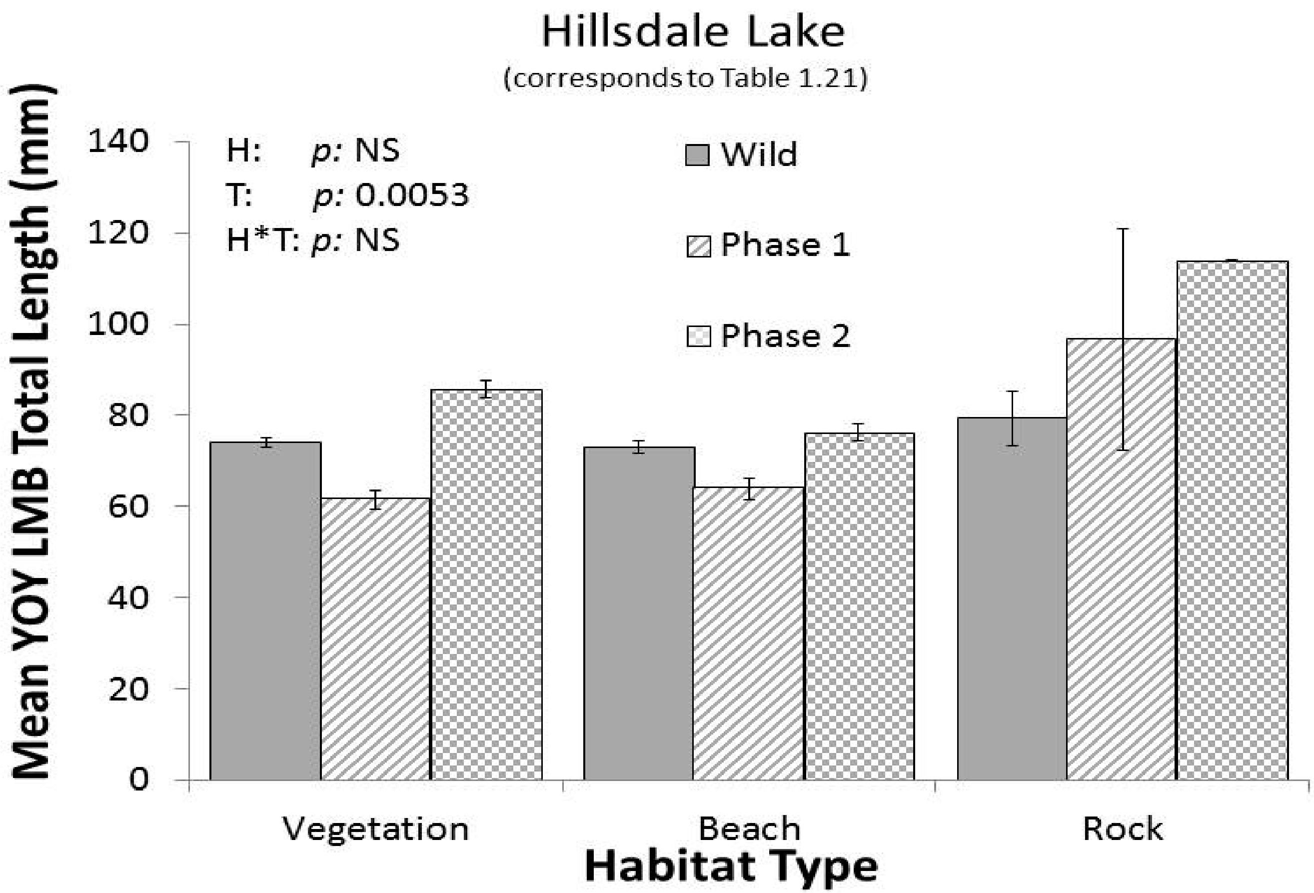

Figure 1.32: Mean total length (mm) of three stocking treatments (wild, phase 1, phase 2) of young of year largemouth bass across three habitat types in Hillsdale Lake, KS during 2014. Data are mean and standard error.

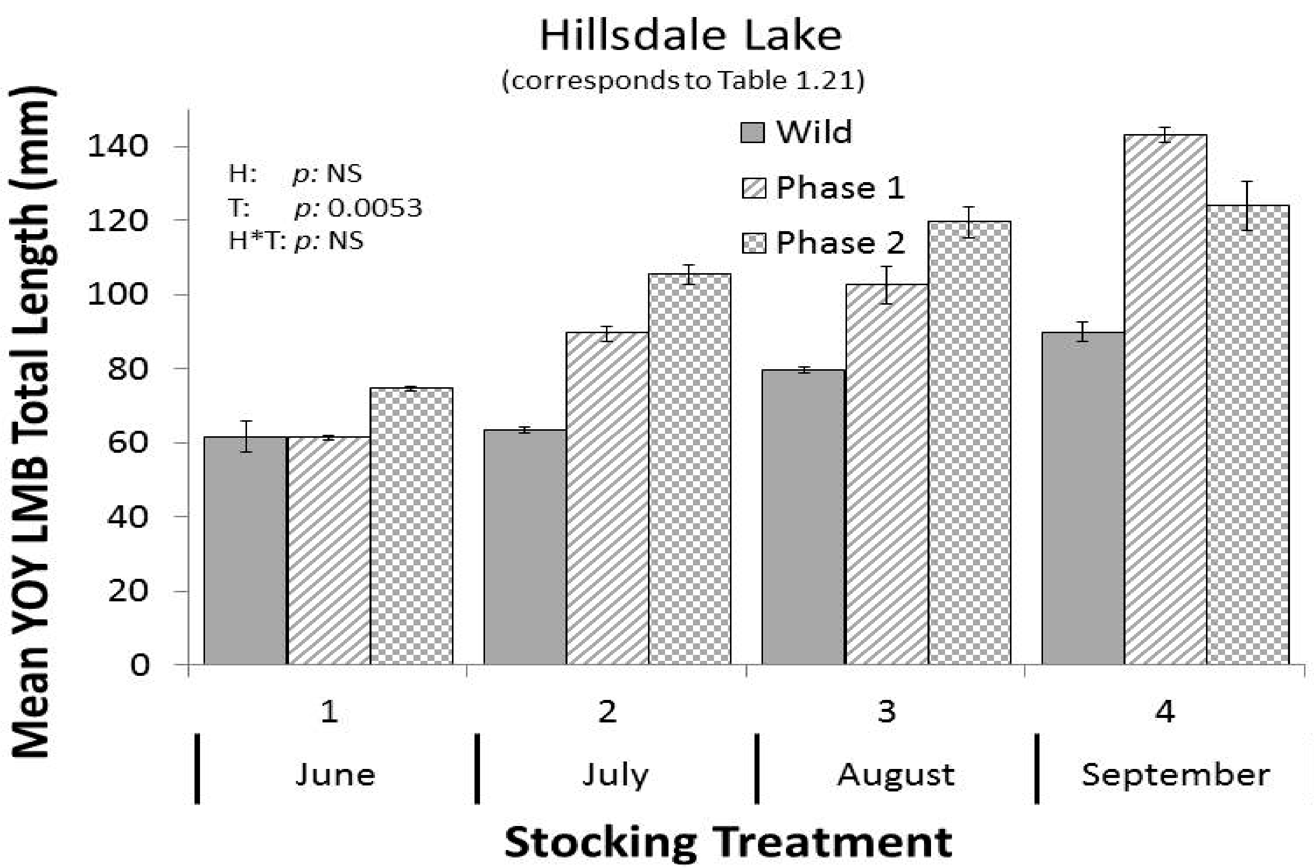

Figure 1.33: Mean total length of three stocking treatments (wild, phase 1, phase 2) of young of year largemouth bass across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

Chapter 2 - Integrating Spatial Context into Physical Habitat: Developing a Framework to Advance Habitat Research and Improve Fisheries Management

Introduction

How important is habitat in fisheries research and management? Habitat is a central focus of fisheries research and the object of substantial fisheries management investment (Bain and Stevenson 1999; Fisher et al. 2012; Arlinghaus et al 2016). Fish habitat has been variably defined as (a) the physical, chemical, and biological features of the environment that an organism needs to sustain life (McMahon et al. 1996), (b) “the places where individuals, populations, or assemblages can find the physical and chemical features needed for life” (Hubert and Bergerson 1999), and (c) “a set of places where a fish, a fish population, or a fish assemblage finds suitable environmental features to survive and reproduce (Orth and White, 1993, Fisher et al. 2012). Relative to research, over 88,000 peer-reviewed studies have been published on fish habitat (Web of Science keywords: fish and habitat, September, 2016). In fisheries management, the National Fish Habitat Partnership invested > $3,000,000,000 in 2012 “to protect, restore and enhance the nation's fish and aquatic communities through partnerships that foster fish habitat conservation…” (National Fish Habitat Action Plan 2012*)*. For policy, identifying and conserving “essential fish habitat”, defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity," is a central tenet of the Sustainable Fisheries Act of 1996 (Rosenburg et al. 2000), the primary legislation used to implement marine fisheries policy.

How is habitat synthesized and conceptualized in fisheries research and management? Diverse approaches exist to studying fisheries habitat goals and efforts. Some fish habitat approaches include regional settings, drainage basins, water body identification, reach surveys and classification, lakewide characteristics identification, as well as quantification of substrate, cover, refuges, bank and shoreline condition, vegetation, barriers, stream flow, temperature, morphology, and water transparency (Bain and Stevenson 1999). Other fish habitat approaches focus on classification of aquatic systems, sampling design, mapping, water quality, width and depth, water velocity, discharge, topography, substrate, wood, vegetation, shoreline structure (Fisher et al. 2012). Yet another approach is to view habitat primarily within a management action context (Arlinghaus et al 2016). Clearly, no single, generally-agreed upon way exists to study fish habitat.

The way in which a researcher conceptualizes habitat has a profound impact on the development of the ideas that shape the study. Approaching a fisheries problem from a fundamentally different habitat perspective could affect the outcome of the research. For example, categorizing habitats by type could miss important local characteristics of individual habitat locations that are driving observed differences. Using different approaches often leads to measuring different habitat variables. However the problem with divergent approaches to habitat can be more complex than just using different habitat measurements. Different approaches alter how researchers think about habitat. For example, conceptualizing habitat as a gradient is fundamentally different than conceptualizing a mosaic of discrete habitat patches (Forman 1995). Consciously or unconsciously using different approaches to fish habitat relationships could lead to conflicting conclusions about the same natural phenomenon. If approaching and conceptualizing habitat problems differently leads to contrasting conclusions for fisheries management, then a standard framework is needed to decide which approach is appropriate under what circumstances. The first steps in this clarification are to identify what approaches to fish habitat assessment have been taken and to assess if these approaches provide different answers to the same fisheries questions. My purpose in this chapter is to take these first steps.

How does physical habitat affect young of year largemouth bass? Largemouth bass is one of the most popular sportfish in the United States (Philipp & Ridgeway 2002). Habitat, especially physical habitat, can influence survival of these young fish during the vulnerable young of year or first year life stage. Physical structure (depth, substrate, cover) is a common component of fish habitat research (Millidine et al. 2006, Ahrenstorff et al. 2009). Physical structure can affect physiological costs of metabolic maintenance (Millidine et al. 2006), provide protection from predators (Olson et al. 2003), and affect feeding success (Ferrari et al. 2014). Researchers have assumed that young of year largemouth bass physical habitat use is similar to that of adults (Olson et al. 2003), but this assumption is rarely tested. Young of year largemouth bass are small and vulnerable to predation and starvation during the first year of life (Ludsin & DeVries 1997, Parkos & Wahl 2010). Consequently, aspects of physical habitat such as aquatic macrophytes can provide refuge from predators and augment prey communities (Dibble et al. 1996). However, less is known about how these fish utilize other unvegetated habitats during this young of year life stage (Strakosh et al. 2009).

Does spatial context of physical habitat research matter? The diverse ways that habitat is defined, synthesized, measured, and conceptualized, as described above, is extensive and inclusive, but can also be ambiguous and counterproductive. *In this chapter, my overarching goal is to provide an integrative approach to spatial context to advance fish habitat research and improve the effectiveness of fisheries management.* Specifically, I (1) review approaches to physical habitat research for young of year largemouth bass in the literature, (2) identify a framework for examining spatial context, then (3) compare the insights from multiple approaches using empirical field data on young of year largemouth bass relative abundance (CPUE) and diet to ask if different spatial approaches provide different answers to the same ecological and fisheries questions.

Literature Review

What habitat research has been undertaken on young of year largemouth bass? In order to identify how fisheries biologists conceptualize habitat, I conducted a Web of Science literature search using the search terms "largemouth bass" or "*Micropterus salmoides*" to represent the fish species, the terms "young of year" or "age 0" to represent the life stage, and "microhabitat", "habitat", or "macrohabitat" to identify habitat focused research.. Eighteen research studies tested the response of young of year largemouth bass to various physical habitat metrics (Table 2.1). Below I summarize these papers in two ways to establish a framework to integrate spatial context.

How does largemouth bass research vary by local characteristics, habitat type, and lakewide characteristics approaches? In fisheries research, habitat can be categorized into local characteristics, habitat type, and macrohabitat (McMahon et al. 1996; Fisher et al. 2012). Local characteristics are defined as the small scale variation within habitats. Habitat type is the categorical classification of habitat based on the dominant physical feature. Lakewide characteristics refer to across habitat features. Twelve of the 18 studies identified above (67%) focused on local characteristics (Table 2.1). In 11/12 of these local characteristics papers (92%), the focus was some aspect of vegetation. Ten of the 12 local characteristics papers (83%) were undertaken in the field. Of the variables examined in the 12 local characteristics papers, nine (75%) examined percent coverage of vegetation, two (17%) tested stem density, and two (17%) looked at bottom topography and slope. Of these 12 local characteristics studies, six (50%) examined catch per unit effort only, four examined diet only (33%) and two (17%) examined both diet and catch per unit effort. Of the 18 physical habitat studies on young of year largemouth bass, three (17%) examined habitat type. Of these, one was undertaken in the laboratory and two were undertaken in the field. The focus of two field studies (66%, 2 of 3) was vegetation vs no vegetation, one lab study (33%) compared two different type of habitats (vegetated vs cobble substrate), and no field studies systematically quantified differences in two different types of non-vegetated habitats. Of the research that examined habitat type, one study examined diet only and two studies examined both diet and catch per unit effort. Of the 18 studies that quantified the effect of physical habitat on young of year largemouth bass, three (17%) field studies took a lakewide characteristics approach and looked at whole system effects of region, dams, and coves. Of these, one study examined diet and two studies examined catch per unit effort. Other than the focus on vegetation, no consensus exists on the way local characteristics, habitat type, and lakewide characteristics approaches are used to examine the effect of physical habitat on young of the year largemouth bass.

Why did fisheries researchers examine spatial patterns? I also classified these papers based on the way researchers dealt with spatial variation (or why they looked at spatial variation) to assess if these differences in approach transcended methodology and scale. Almost half of the studies (44%, 8 of 18) ignored the spatial context and studied sample locations as independent replicates (“ignored space”, Table 2.2). Specifically, these researchers treated different sample locations as replicates to guide sampling and did not subsequently address spatial patterns in their results. Seven papers (39%) examined the spatial pattern further (Table 2.2). Specifically, as the authors sampled and analyzed the data, they acknowledged that some aspect of spatial arrangement might influence their results and stratified or otherwise adjusted their sampling to account for spatial differences. Outside of this sampling and analysis adjustment, these papers “acknowledged, but did not test” spatial patterns. Three “spatially implicit” studies (17%, 3 of 18) tested spatial relationships such as the role of region or cove (Table 2.2). No studies took a “spatially explicit” approach that used GPS coordinates to test spatial relationships.

These overall trends are reflected in local characteristics, habitat type, and lakewide characteristics studies. Spatial context was ignored in six of the 12 local characteristics studies (50%), in five other local characteristics studies (42%), researchers acknowledged spatial variation, stratified sampling to account for large scale spatial variation, and then ignored spatial variation. In one local characteristics study (8%), researchers implicitly examined spatial patterns (Table 2.1, 2.2). Spatial context was ignored in two of the three habitat type studies (66%), but one habitat type study (33%) acknowledged and stratified sampling and analysis. In the three lakewide characteristics studies, one (33%) acknowledged spatial variation, and two others (66%) implicitly tested spatial relationships. This diversity in the treatment of spatial variation indicates that the lack of consensus in how physical habitat is measured for young of year largemouth bass is not just methodological or scale-dependent, but also represents different ways of conceptualizing the habitat problem for fisheries and fish management. The way in which a biologist approaches habitat, either as a replicate of a particular habitat or as a part of an interconnected system, will influence other choices in the study design such as where to sample. If the choice of how to measure habitat influences the outcome, then an agreement on how to standardize habitat measurement could improve management of largemouth bass populations.

What Framework Can Be Used For Standardization? These differences in conceptualization may have major consequences for the effectiveness of fish habitat research. Because of the diversity of approaches currently in the literature, a comparison of the local characteristics, habitat type, and lakewide characteristics approaches is needed. Here, I undertake this empirical comparison for a standardized young of year largemouth bass data set from Hillsdale Lake, KS. I collected data on three local characteristics variables (percent vegetation, stem density, slope), five habitat types (vegetation, beach, rock, offshore, wood), two lakewide characteristics responses (region and cove) for three fish responses (relative abundance or catch per unit effort, diet by numbers, diet by weight) in two years (2014 and 2015). For brevity, however, I only present a subset of these data (Table 2.3) as trends were generally similar. Specifically, I compare the relationship between percent vegetation, vegetated/beach habitat types, and reservoir region to catch per unit effort and diet by weight for 2014.

Based on the existing literature, I predict that young of year largemouth bass will be most abundant at sample locations with intermediate percent vegetation coverage and in vegetated habitat types. Predictions for reservoir region are unclear from the literature. I also predict that habitat will not have any effect on diet composition of young of year largemouth bass for any habitat approach. Furthermore, I predict that testing different approaches to studying habitat will provide different answers to the same ecological questions. If the last prediction is true, fisheries biologists and managers need to make a conscious plan about when to use each approach, how to integrate approaches, and how to describe that decision in their research and management summaries.

Methods

Study System, Stocking Manipulation, Sampling Events, Habitat Measurement and Classification. These methodological details are identical to those provided in Chapter 1.

Within-Habitat Measurements. After habitats were categorized by type, I measured variables in all vegetated habitats to quantify the local characteristics spatial context. For this, I measured a 3 m x 3 m grid at every location that encompassed the entire sampled shoreline and extended 15 m away from the shoreline. I took measurements of vegetation presence/absence, vegetation stem density, and depth in each grid square. These measurements were averaged across the entire sample location to calculate mean percent vegetation coverage and stem density. During 2014, I measured local characteristics variables in four vegetated samples, and, during 2015, I measured local characteristics variables in five vegetated samples (Fig. 2.1, Table 2.3). In relation to percent vegetation coverage, vegetated locations were classified as low, medium, or high based on percent vegetation coverage. Low coverage locations had < 30% areal coverage, medium coverage locations had 30%-60% areal coverage, and high coverage locations had > 60% areal coverage. During 2014, there were two low coverage and two medium coverage locations and during 2015, there was one low coverage location, three medium coverage locations and one high coverage location (Table 2.3).

Whole Lake Habitat Measurements. Finally, habitat was classified in relation to lakewide characteristics spatial context. Hillsdale Lake is V-shaped with two arms meeting to form the lacustrine section of the reservoir. All sample locations upstream of this confluence were considered "upper" and sample locations downstream of this confluence were classified as "lower" (Fig. 2.1). During 2014, six locations were located in the lower reservoir and three locations were located in the upper reservoir (Table 2.3). During 2015, six locations were in the lower reservoir and four locations were in the upper reservoir (Table 2.3) In relation to cove position, sample locations inside of concave shorelines were considered “inside” and sample locations on convex shorelines were considered “outside”. During 2014, three locations were inside of coves and six locations were outside of coves, and, during 2015, four locations were inside of coves and six locations were outside of coves (Table 2.3).

***Fish Collection, Fish Processing, and Data Analysis*.** These methodological details are identical to those provided in Chapter 1.

Results

Relative Abundance (CPUE) - 2014

Local characteristics - Percent Vegetation Coverage. During 2014, mean CPUEs were 1.19 young of year largemouth bass / 100 m^2 in low vegetation coverage locations and 3.26 young of year largemouth bass/100 m^2 in medium vegetation coverage locations (*Habitat main effect*; Fig. 2.2). Mean CPUEs for sample date ranged from 0.81 young of year largemouth bass / 100 m^2 during sample event 4 to 2.85 young of year largemouth bass / 100 m^2 during sample event 3 (*Sample date main effect*; Fig. 2.3). Mean trends for habitat by sample date reflected habitat and time main effects (*Habitat by sample date interaction*; Fig. 2.4). Statistically, neither the percent vegetation coverage habitat main effect (NS; Fig. 2.2; Table 2.4), the sample event date main effect (NS; Fig. 2.2; Table 2.4), nor the interaction between percent vegetation coverage and time (NS; Fig. 2.2; Table 2.4) were significant.

Habitat Type (Same as Chapter 2 but Included Here for Continuity). In 2014, habitat-specific mean CPUEs ranged from 2.23 young of year largemouth / 100 m^2 for vegetated samples, 2.68 young of year largemouth / 100 m^2 for beach samples, and 0 young of year largemouth / 100 m^2 for woody and offshore habitats (*Habitat main effect*; Fig. 2.5). Sample date specific mean CPUEs ranged from 0.074 young of year largemouth bass / 100 m^2 during sample event 4 to 3.78 young of year largemouth bass / 100 m^2 during sample event 1 (*Sample date main effect*; Fig. 2.6). Mean trends for habitat by sample date reflected habitat and time main effects (*Habitat by sample date interaction*; Fig. 2.7).

Statistically, in 2014, young of year largemouth bass were not evenly distributed across all habitat types. Specifically, the habitat main effect (Fig. 2.5; Table 2.5), and sample event main effect (Fig. 2.6; Table 2.5) were both significant when all four habitat types were considered although the habitat by time interaction was not (Fig. 2.7, Table 2.5). Young of year largemouth bass were more abundant in the littoral habitat types (vegetation, beach) than in the two non-littoral habitat types (offshore and wood). Fewer young of year largemouth bass were caught in the fall sample event than earlier in the summer (Fig. 2.6). No significant differences in CPUE existed when just the two littoral habitat types, vegetation, beach, were examined (*Habitat main effect*; NS, Fig. 2.5, Table 2.6; *Sample date main effect*; NS; Fig. 2.6, Table 2.6).

Lakewide characteristics - Region. During 2014, mean CPUE was 2.27 young of year largemouth bass / 100 m^2 for samples from the lower reservoir and 2.90 young of year largemouth bass / 100 m^2 for samples taken from the upper reservoir (*Habitat main effect*; Fig. 2.8). Sample date specific mean CPUEs ranged from 0.73 young of year largemouth bass / 100 m^2 during sample event 4 to 4.46 young of year largemouth bass / 100 m^2 during sample event 1 (*Sample date main effect*; Fig. 2.9). Mean trends for habitat by sample date reflected habitat and time main effects (*Habitat by sample date interaction*; Fig. 2.10). Statistically, in 2014, young of year largemouth bass relative abundance was not affected by reservoir region, i.e., the habitat main effect (NS, Fig.2.8; Table 2.7), sample date main effect (NS; Fig. 2.9; Table 2.7), and habitat by sample date interaction (NS; Fig. 2.10; Table 2.7) were not significant.

Diet

Diet by Weight, 2014

Empty Stomachs. During 2014, 46.1% of young of year largemouth bass had empty stomachs. Fish were the most common diet item by weight during 2014 (p = 0.00148).

Local characteristics - Percent Vegetation Coverage. During 2014, mean weight of benthic invertebrates consumed was 0.001 g in low vegetation coverage locations and 0.018 g in medium vegetation coverage locations (Fig. 2.11A). Zooplankton was not consumed in low vegetation coverage locations. In medium vegetation coverage locations, mean weight of zooplankton consumed was <0.0001 g (Fig. 2.11B). Mean weight of terrestrial invertebrates consumed was 0.012 g in low vegetation coverage locations and 0.015 in medium vegetation coverage locations (Fig. 2.11C). Mean weight of fish prey consumed was 0.072 g in low vegetation coverage locations and 0.031 g in medium coverage locations (Fig. 2.11D).

Sample date specific weight of prey consumed ranged from 0.002 g during sample event 3 to 0.022 g during sample event 1 for benthic invertebrates (Fig. 2.12A), 0.00 g during sample events 1, 3, and 4 to 0.000096 g during sample event 2 for zooplankton (Fig. 2.12B), 0.012 g during sample event 3 to 0.014 g during sample event 4 for terrestrial invertebrates (Fig. 2.12C), and 0.007 g during sample event 1 to 0.119 g during sample event 3 for fish prey (Fig. 2.12D). Local characteristics by sample date interactions reflected the habitat and time trends described above for benthic invertebrates (Fig. 2.13), zooplankton (Fig. 2.14), terrestrial invertebrates (Fig. 2.15), and fish prey (Fig. 2.16).

Statistically, during 2014, no differences were significant for the local characteristics main effect of percent vegetation coverage, the sample event effect, or the local characteristics by sample event interaction for benthic invertebrates (NS, Figs. 2.11A, 2.12A, 2.13,Table 2.8), zooplankton (NS, Figs. 2.11B, 2.12B, 2.14, Table 2.9), and fish prey (NS, Fig. 2.11D, 2.12D, 2.15; Table 2.11). For terrestrial invertebrate consumption was higher in the medium vegetation coverage (p = 0.0393, Fig. 2.11C, Table 2.10), but no significant sample event or local characteristics by sample event interactions were detected.

Habitat type (Same as Chapter 2 but Included Here for Continuity). During 2014, habitat-specific mean weight of prey consumed ranged from 0.004 g benthic invertebrates, <0.00015 g zooplankton, 0.024 g terrestrial invertebrates, and 0.282 g fish in vegetated samples, and 0.010 g benthic invertebrates, <0.00005 g zooplankton, 0.013 g terrestrial invertebrates, and 0.049 g fish in beach samples (*Habitat main effect*; Fig. 2.17). Sample date specific weight of prey consumed ranged from 0.002 g during sample event 3 to 0.016 g during sample event 1 for benthic invertebrates (Fig. 2.18A), 0.00 g during sample event 4 to <0.001 g during sample event 1 for zooplankton (Fig. 2.18B), 0.012 g during sample event 1 to 0.032 g during sample event 2 for terrestrial invertebrates (Fig. 2.18C), and 0.027 g during sample event 1 to 0.261 g during sample event 3 for fish prey (Fig. 2.18D). Mean trends for habitat by sample date reflected habitat and time main effects (*Habitat by sample date interaction*; Figs. 2.19-2.22). Statistically, during 2014, young of year largemouth bass diet composition by weight for benthic invertebrates was not affected by habitat type, but more benthic invertebrates were eaten early in the summer (Fig. 2.19A; Table 2.12). For zooplankton, terrestrial invertebrates, and fish prey, neither habitat type, sample event, nor the habitat by time interaction were significant (Tables 2.13 - 2.15).

Lakewide characteristics – Region. During 2014, mean weight of benthic invertebrates consumed ranged from 0.008 g in the lower reservoir to 0.005 g in the upper reservoir (Fig. 2.23A). Mean weight of zooplankton consumed was <0.001 g in both reservoir regions (Fig. 2.23B). Mean weight of terrestrial invertebrates consumed ranged from 0.021 g in the lower reservoir to 0.015 g in the upper reservoir (Fig. 2.23C). Mean weight of fish prey consumed ranged from 0.050 g in the lower reservoir to 0.045 g in the upper reservoir (Fig. 2.23D).

Sample date specific weight of prey consumed ranged from 0.002 g during sample event 3 to 0.016 g during sample event 1 for benthic invertebrates (Fig. 2.24A), 0.00 g during sample event 4 to <0.001 g during sample event 1 for zooplankton (Fig. 2.24B), 0.012 g during sample event 1 to 0.032 g during sample event 2 for terrestrial invertebrates (Fig. 2.24C), and 0.027 g during sample event 1 to 0.261 g during sample event 3 for fish (Fig. 2.24D). Lakewide characteristics by sample date interactions reflected the habitat and time trends described above for benthic invertebrates (Fig. 2.25), zooplankton (Fig. 2.26), terrestrial invertebrates (Fig. 2.27), and fish prey (Fig. 2.28).

Statistically, during 2014, young of year largemouth bass diets were not different across reservoir regions. Specifically, the habitat main effect, sample date main effect, and habitat by sample date interaction were not significant for benthic invertebrates (NS, Fig. 2.25, Table 2.16), for zooplankton (NS, Fig. 2.26, Table 2.17), for terrestrial invertebrates (NS, Fig. 2.27, Table 2.18), and for fish prey (NS, Fig. 2.28, Table 2.19).

Does testing different spatial contexts of habitat provide different answers to the same ecological questions? The spatial context affected the results of relative abundance and diet for young of year largemouth bass. During 2014, young of year largemouth bass relative abundance was related to habitat type but not local characteristics or lakewide characteristics. During 2014, diet composition by weight was related to percent vegetation coverage for terrestrial invertebrates, to time for benthic invertebrates by habitat type, but not lakewide characteristics. Different responses of young of year largemouth bass to different spatial contexts of habitat suggest that how habitat is conceptualized and approached matters.

Discussion

Take-Home Message 1 –Variation in spatial context weakens habitat insights from the literature. Habitat is an important focus of fisheries research and management and consumes many research hours/dollars as well as agency manpower/budgets. In spite of the importance of fish habitat in general, the popularity of largemouth bass as a sportfish, and the acknowledgement that population trends can be set in the first year of life, surprisingly little research exists on how young of year largemouth bass use physical habitat. Furthermore, the limited young of year largemouth bass habitat research that has been undertaken uses a diversity of approaches (local characteristics, habitat type, lakewide characteristics) that deals with spatial patterns in a variety of ways (ignores, acknowledges then ignores, spatially implicit tests). Different perspectives can provide useful insights if they are undertaken in a coordinated, synthetic fashion. However, much young of year, largemouth bass research is undertaken in a vacuum relative to other habitat and spatial approaches. This lack of coordination in habitat research has created gaps in our knowledge, e.g., do largemouth bass use only vegetated habitats or have researchers and managers found largemouth bass more often in vegetation because that is the only habitat they have sampled? I define spatial context (a) by whether local characteristics, habitat type, or lakewide characteristics is measured and (b) how researchers deal with the effect of spatial variation.

Take-Home Message 2 - Local characteristics can be important for young of year largemouth bass. The local characteristics variable, percent vegetation coverage, influenced young of year largemouth diet composition. Specifically, in Hillsdale Lake during 2014, young of year largemouth bass consumed greater weights of terrestrial invertebrates in locations with medium vegetation coverage. Literature suggests that consumption by young of year largemouth bass increases as percent vegetation coverage decreases and this is consistent with my findings. Furthermore, an intermediate level of vegetation coverage between 15% to 66% that maximizes prey abundance and foraging efficiency can be the most profitable habitats for young of year largemouth bass (Bettoli et al. 1992, Miranda & Pugh 1997, Sammons & Maceina 2006, Middaugh et al. 2013) and percent vegetation coverage is within this optimal range for all sample locations.

Take Home Message 3 - Habitat type can influence young of year largemouth bass abundance and distribution. Classifying habitat by type is a common approach to studying habitat but few studies on young of year largemouth bass have categorized habitat this way. In Hillsdale Lake, KS, young of year largemouth bass used multiple habitats but not every available habitat. I never caught young of year largemouth bass in offshore or wood habitats and numbers of young of year largemouth bass were highly variable in rock habitat. However, numbers of young of year largemouth bass were consistently similar and high in vegetated and beach habitats. Although young of year largemouth bass have been thought to select vegetated habitats, the body of literature studying habitat type is limited. Based on this extant literature, I expected young of year largemouth bass to be more abundant in vegetated habitats than other habitat types, but I found no statistical difference in young of year largemouth bass relative abundance across vegetated and beach habitats. Elsewhere, young of year largemouth bass were more abundant in vegetation when compared to non-vegetated habitats (Ratcliffe et al. 2009, Strakosh et al. 2009).Young of year largemouth bass are more vulnerable to predation outside of vegetation (Olson et al. 2003) and predator avoidance could be driving the aggregation of young of year largemouth bass in vegetated habitats.

None of the two studies that examined habitat type found any differences in diet across vegetated and non-vegetated habitats (Olson et al. 2003, Strakosh et al. 2009). Hillsdale Lake may differ from other systems naturally or because of the stocking manipulation. Alternatively, young of year largemouth bass may use non vegetated littoral habitats, but researchers have simply not sampled in these habitats in the past. Because diets were similar across habitats, beach habitat may provide profitable habitat for young growing fish, especially in the absence of a large predator population. Young of year largemouth bass consumption can increase in less complex habitats (Sammons and Maceina 2006) and this could be influencing the selection of beach habitats in areas where shallow water provides sufficient refuge from predators for the young of year largemouth bass. My results demonstrate the need to look at non-vegetated habitats using standard methods.

Take Home Message 4 – Quantifying lakewide characteristics effects requires more investigation. Lakewide characteristics effects on young of year largemouth bass are relatively unstudied. All three of the lakewide characteristics studies I reviewed examined lakewide characteristics differently and each study tested different variables. Young of year largemouth bass were more abundant near artificial structures in the lower region of Striker Reservoir, TX but were larger on average in the upper region of the reservoir (Daugherty et al. 2014). Abundance of young of year largemouth bass across coves varied significantly (Phillips et al. 1997). Young of year largemouth bass were also more abundant downstream of dams than upstream in the lower Boise River, ID, but no lakewide characteristics effect was attributed to diet composition (Braun & Walser 2011). I did not find any lakewide characteristics effects on young of year largemouth bass relative abundance and diet. Nevertheless, the lack of research testing the effect of lakewide characteristics variables could be detrimental to our understanding of young of year largemouth bass habitat use.

Take Home Message 5 - Comparing approaches provides new insights and identifies gaps. I gained new insights by comparing my results across approaches. For example, local characteristics are the most common habitat approach and may contribute greatly to our understanding of foraging behavior. However, the intensive focus on the complexity of vegetation may not be the most broadly informative approach if young of year largemouth bass use an array of non-vegetated habitats. In fact, this emphasis on local characteristics may be misleading fisheries biologists about within and across lake trends of young of year largemouth bass. This possible disconnect was only identified by comparing local characteristics and habitat type using a standard data set. Habitat type is rarely examined but is probably the most useful approach for management and restoration because it incorporates multiple habitat factors into the classification system. To evaluate type effectively, multiple habitats need to be sampled in the same way, then compared, an approach that has rarely been adopted prior to my study. Lakewide characteristics is the focus on much reservoir management (i.e., for water quality) and for large scale restoration (e.g., Fish Habitat Initiatives). An additional approach which is an obvious next step for lake fisheries research and management is landscape ecology. Landscape ecology is the study of how landscape patterns influence ecological processes (With 2015). Using landscape ecology methods that test how multiple habitats interact with each other, future research and management can combine tests of local characteristics, habitat type and lakewide characteristics to understand the role of specific component and the spatial arrangement among those components.

Take Home Message 6 – Incorporating spatial context into young of year largemouth bass research could improve our scientific understanding and aid in restoration and management of reservoir and lake fisheries. Future research could be improved by incorporating spatial context into sampling designs, population monitoring, and habitat restoration programs. Accurately assessing sportfish population sizes is an important aspect of fisheries management and spatial context can affect these assessments by concentrating fish in areas of structural complexity, especially in structure limited systems. Restoration projects are often large scale, both monetarily and operationally, and effectively targeting these efforts is crucial to their success (Summerfelt 1999). Based on the results from Hillsdale Lake, KS, I make the following three recommendations. First, concurrently examine local characteristics, habitat type, and lakewide characteristics with the same data set to continue to build the synthetic framework I have initiated here. Second, I also suggest consideration of multiple approaches when planning future fisheries habitat studies. Third, incorporate multiple approaches to studying habitat to test fisheries response to landscape patterns.

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Table 2.1: Young of year largemouth bass spatial context of habitat literature since 1980.

Paper Number	Author	Year	Species	Life Stage	Type of Habitat	Field or Lab	Spatial Context	Habitat Variable	Fish Response	Approach
1	Tate et al.	2003	LMB	YOY	Physical	Field	Micro	Coverage	CPUE	Ignored
2	Bettoli et al.	1992	LMB	YOY	Physical	Field	Micro	Coverage	Diet	Ignored
3	Middaugh et al.	2013	LMB	YOY	Physical	Field	Micro	Coverage	CPUE, Diet	Ignored
4	Irwin & Noble	2000	LMB	YOY	Physical	Field	Micro	Coverage, Slope	CPUE	Ignored
5	Valley & Bremigan	2002	LMB	YOY	Physical	Lab	Micro	Stem Density	Diet	Ignored
6	Alexander et al.	2015	LMB	YOY	Physical	Lab	Micro	Stem Density	Diet	Ignored
7	Hoyer & Canfield	1996	LMB	YOY	Physical	Field	Micro	Coverage	CPUE	Acknowledged
8	Nagid et al.	2015	LMB	YOY	Physical	Field	Micro	Coverage	CPUE	Acknowledged
9	Sammons & Maceina	2006	LMB	YOY	Physical	Field	Micro	Coverage	Diet	Acknowledged
10	Miranda & Pugh	1997	LMB	YOY	Physical	Field	Micro	Coverage	CPUE, Diet	Acknowledged
11	Havens et al.	2005	LMB	YOY	Physical	Field	Micro	Coverage	CPUE	Spatially Implicit
12	Irwin et al.	1997	LMB	YOY	Physical	Field	Micro	Slope, Substrate	CPUE	Acknowledged
13	Ratcliffe et al.	2009	LMB	YOY	Physical	Field	Type	Veg/No Veg	CPUE, Diet	Ignored
14	Strakosh et al.	2009	LMB	YOY	Physical	Field	Type	Veg/No Veg	CPUE, Diet	Acknowledged
15	Olson et al.	2003	LMB	YOY	Physical	Lab	Type	Veg/Cobble	Diet	Ignored
16	Daugherty et al.	2014	LMB	YOY	Physical	Field	Macro	Reservoir Region	CPUE	Spatially Implicit
17	Phillips et al.	1997	LMB	YOY	Physical	Field	Macro	Cove	CPUE	Spatially Implicit
18	Braun & Walser	2011	LMB	YOY	Physical	Field	Macro	Dams	Diet	Acknowledged

Table 2.2: Young of year largemouth bass physical habitat literature classified by approach to spatial context.

	Approach to Spatial Context				
Spatial Context	Ignored Space	Acknowledged, stratified	Spatially Implicit	Spatially Explicit	Totals
Microhabitat	6	5	1	0	12
Habitat Type	2	1	0	0	3
Macrohabitat	0	1	2	0	3
Totals	8	7	3	0	18

Table 2.3: Number of sample locations categorized by different spatial contexts in Hillsdale Lake, KS during sample years 2014-2015.

	Vegetation Coverage			**Habitat Type**		**Reservoir Region**		**Cove Position**	
	Low	Medium	High	Vegetation	Beach	Lower	Upper	Inside	Outside
2014	2	2	0	4	5	6	3	3	6
2015	1	3	1	5	5	6	4	4	6

Table 2.4. Analysis of repeated measures for young of year largemouth bass **CPUE** in 2014. For two **vegetation coverage categories** (low, medium). Data correspond to main habitat effect plot (Figure 2.2), main time effect plot (Figure 2.3) and habitat x time effect plot (Figure 2.4).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**3**	**0.0327**				
Habitat	1	0.0245	0.0245	5.93	0.1353	
Error	2	0.0083	0.0041			
Within subjects	**12**	**0.0405**				
Time	3	0.0166	0.0055	2.24	0.1843	0.2603
Time * Habitat	3	0.0090	0.0030	1.21	0.3831	0.3874
Error(Time)	6	0.0148	0.0025			
Total	**15**	**0.0732**				

Table 2.5. Analysis of repeated measures for young of year largemouth bass **CPUE** in 2014. Data has been square root transformed. For **four habitat types (vegetation, beach, wood, offshore).** Data correspond to main habitat effect plot (Figure 2.5), main time effect plot (Figure 2.6) and habitat x time effect plot (Figure 2.7).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**21**	**0.4478**				
Habitat	3	0.3983	0.1328	48.25	**<0.0001**	
Error	18	0.0495	0.0028			
Within subjects	**66**	**0.0780**				
Time	3	0.0264	0.0088	3.88	**0.0139**	**0.0411**
Time * Habitat	9	0.0288	0.0032	1.41	0.2077	0.2524
Error(Time)	54	0.0228	0.0004			
Total	**87**	**0.5258**				

Table 2.6. Analysis of repeated measures for young of year largemouth bass **CPUE** in 2014. Data has been square root transformed. **For two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 2.5), main time effect plot (Figure 2.6) and habitat x time effect plot (Figure 2.7).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0499**				
Habitat	1	0.0004	0.0004	0.06	0.8213	
Error	7	0.0495	0.0071			
Within subjects	**27**	**0.1687**				
Time	3	0.0446	0.0149	2.55	0.0835	0.1298
Time * Habitat	3	0.0015	0.0005	0.08	0.9676	0.8796
Error(Time)	21	0.1226	0.0058			
Total	**35**	**0.2186**				

Table 2.7. Analysis of repeated measures for young of year largemouth bass **CPUE** in 2014. For **two reservoir region categories (lower, upper).** Data correspond to main habitat effect plot (Figure 2.8), main time effect plot (Figure 2.9) and habitat x time effect plot (Figure 2.10).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0499**				
Habitat	1	0.0000	0.0000	0.00	0.9660	
Error	7	0.0499	0.0071			
Within subjects	**27**	**0.1675**				
Time	3	0.0434	0.0145	2.49	0.0885	0.1339
Time * Habitat	3	0.0021	0.0007	0.12	0.9482	0.8473
Error(Time)	21	0.1220	0.0058			
Total	**35**	**0.2174**				

Table 2.8. Analysis of repeated measures for young of year largemouth bass **benthic invertebrate consumption** by weight with empty stomachs excluded in 2014. For **two vegetation coverage categories (low, medium).** Data correspond to main habitat effect plot (Figure 2.11A), main time effect plot (Figure 2.12A) and habitat x time effect plot (Figure 2.13).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**3**	**0.0018**				
Habitat	1	0.0010	0.0010	2.51	0.2537	
Error	2	0.0008	0.0004			
Within subjects	**12**	**0.0026**				
Time	3	0.0011	0.0004	3.25	0.1021	0.2117
Time * Habitat	3	0.0008	0.0003	2.20	0.1885	0.275
Error(Time)	6	0.0007	0.0001			
Total	**15**	**0.0044**				

Table 2.9. Analysis of repeated measures for young of year largemouth bass **zooplankton consumption by weight** with empty stomachs excluded in 2014. For **two vegetation coverage categories (low, medium).** Data correspond to main habitat effect plot (Figure 2.11B), main time effect plot (Figure 2.12B) and habitat x time effect plot (Figure 2.14).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**3**	**2.77367E-08**				
Habitat	1	9.25E-09	9.25E-09	1.00	0.4226	
Error	2	1.85E-08	9.25E-09			
Within subjects	**12**	**1.10947E-07**				
Time	3	2.77E-08	9.25E-09	1.00	0.4547	0.4226
Time * Habitat	3	2.77E-08	9.25E-09	1.00	0.4547	0.4226
Error(Time)	6	5.55E-08	9.25E-09			
Total	**15**	**1.38683E-07**				

Table 2.10. Analysis of repeated measures for young of year largemouth bass **terrestrial invertebrate consumption by weight** with empty stomachs excluded in 2014. **For two vegetation coverage categories (low, medium).** Data correspond to main habitat effect plot (Figure 2.11C), main time effect plot (Figure 2.12C) and habitat x time effect plot (Figure 2.15).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**3**	**0.0001**				
Habitat	1	0.0000	0.0000	23.97	**0.0393**	
Error	2	0.0000	0.0000			
Within subjects	**12**	**0.0016**				
Time	3	0.0000	0.0000	0.02	0.9968	0.9627
Time * Habitat	3	0.0001	0.0000	0.18	0.9078	0.7924
Error(Time)	6	0.0015	0.0002			
Total	**15**	**0.0017**				

Table 2.11. Analysis of repeated measures for young of year largemouth bass **fish consumption by weight** with empty stomachs excluded in 2014. For two **vegetation coverage categories (low, medium).** Data correspond to main habitat effect plot (Figure 2.11D), main time effect plot (Figure 2.12D) and habitat x time effect plot (Figure 2.16).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**3**	**0.0322**				
Habitat	1	0.0076	0.0076	0.62	0.5129	
Error	2	0.0246	0.0123			
Within subjects	**12**	**0.0947**				
Time	3	0.0246	0.0082	1.02	0.4474	0.4208
Time * Habitat	3	0.0218	0.0073	0.9	0.4935	0.4455
Error(Time)	6	0.0483	0.0081			
Total	**15**	**0.1269**				

Table 2.12. Analysis of repeated measures for young of year largemouth bass **benthic invertebrate consumption** by weight with empty stomachs excluded in 2014. For **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 2.17A), main time effect plot (Figure 2.18A) and habitat x time effect plot (Figure 2.19).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0022**				
Habitat	1	0.0003	0.0003	0.98	0.3556	
Error	7	0.0020	0.0003			
Within subjects	**27**	**0.0032**				
Time	3	0.0012	0.0004	4.82	**0.0104**	**0.0399**
Time * Habitat	3	0.0002	0.0001	0.98	0.4211	0.3829
Error(Time)	21	0.0018	0.0001			
Total	**35**	**0.0055**				

Table 2.13. Analysis of repeated measures for young of year largemouth bass **zooplankton consumption by weight** with empty stomachs excluded in 2014. **For two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 2.17B), main time effect plot (Figure 2.19B) and habitat x time effect plot (Figure 2.20).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**5.6876E-07**				
Habitat	1	1.55E-07	1.55E-07	2.62	0.1492	
Error	7	4.14E-07	5.91E-08			
Within subjects	**27**	**2.6484E-06**				
Time	3	2.93E-07	9.76E-08	1.06	0.3859	0.3525
Time * Habitat	3	4.26E-07	1.42E-07	1.55	0.2318	0.2539
Error(Time)	21	1.93E-06	9.19E-08			
Total	**35**	**3.2172E-06**				

Table 2.14. Analysis of repeated measures for young of year largemouth bass **terrestrial invertebrate consumption by weight** with empty stomachs excluded in 2014. For **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 2.17C), main time effect plot (Figure 2.18C) and habitat x time effect plot (Figure 2.21).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0098**				
Habitat	1	0.0009	0.0009	0.74	0.4177	
Error	7	0.0088	0.0013			
Within subjects	**27**	**0.0401**				
Time	3	0.0028	0.0009	0.55	0.6517	0.5186
Time * Habitat	3	0.0024	0.0008	0.48	0.6992	0.5519
Error(Time)	21	0.0350	0.0017			
Total	**35**	**0.0499**				

Table 2.15. Analysis of repeated measures for young of year largemouth bass **fish consumption by weight** with empty stomachs excluded in 2014. For **two habitat types (vegetation, beach).** Data correspond to main habitat effect plot (Figure 2.17D), main time effect plot (Figure 2.18D) and habitat x time effect plot (Figure 2.22).

Source	**df**	**SS**	**MS**	**F**	**p-value**	**Adjusted G-G p-value**
Between subjects	**8**	**0.0464**				
Habitat	1	0.0000	0.0000	0	0.9478	
Error	7	0.0464	0.0066			
Within subjects	**27**	**0.2040**				
Time	3	0.0477	0.0159	2.19	0.1194	0.1558
Time * Habitat	3	0.0037	0.0012	0.017	0.9159	0.8238
Error(Time)	21	0.1526	0.0073			
Total	**35**	**0.2504**				

Table 2.16. Analysis of repeated measures for young of year largemouth bass **benthic invertebrate consumption by weight** with empty stomachs excluded in 2014. For **two reservoir region categories (lower, upper).** Data correspond to main habitat effect plot (Figure 2.23A), main time effect plot (Figure 2.24A) and habitat x time effect plot (Figure 2.25).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0022**				
Habitat	1	0.0000	0.0000	0.09	0.7736	
Error	7	0.0022	0.0003			
Within subjects	**27**	**0.0030**				
Time	3	0.0010	0.0003	3.43	0.0357	0.0818
Time * Habitat	3	0.0000	0.0000	0.00	0.9997	0.9879
Error(Time)	21	0.0020	0.0001			
Total	**35**	**0.0052**				

Table 2.17. Analysis of repeated measures for young of year largemouth bass **zooplankton consumption by weight** with empty stomachs excluded in 2014. For **two reservoir region categories (lower, upper).** Data correspond to main habitat effect plot (Figure 2.23B), main time effect plot (Figure 2.24B) and habitat x time effect plot (Figure 2.26).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**5.68758E-07**				
Habitat	1	1.14E-07	1.14E-07	1.75	0.2276	
Error	7	4.55E-07	6.50E-08			
Within subjects	**27**	**2.84619E-06**				
Time	3	4.91E-07	1.64E-07	1.59	0.2223	0.2478
Time * Habitat	3	1.91E-07	6.38E-08	0.62	0.61005	0.4902
Error(Time)	21	2.16E-06	1.03E-07			
Total	**35**	**3.41495E-06**				

Table 2.18. Analysis of repeated measures for young of year largemouth bass **terrestrial invertebrate consumption by weight** with empty stomachs excluded in 2014. For **two reservoir region categories (lower, upper).** Data correspond to main habitat effect plot (Figure 2.23C), main time effect plot (Figure 2.24C) and habitat x time effect plot (Figure 2.27).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0098**				
Habitat	1	0.0003	0.0003	0.19	0.6759	
Error	7	0.0095	0.0014			
Within subjects	**27**	**0.0394**				
Time	3	0.0022	0.0007	0.47	0.7067	0.5535
Time * Habitat	3	0.0045	0.0015	0.98	0.4207	0.3706
Error(Time)	21	0.0328	0.0016			
Total	**35**	**0.0492**				

Table 2.19. Analysis of repeated measures for young of year largemouth bass **fish consumption by weight** with empty stomachs excluded in 2014. For **two reservoir region categories (lower, upper).** Data correspond to main habitat effect plot (Figure 2.23D), main time effect plot (Figure 2.24D) and habitat x time effect plot (Figure 2.28).

Source	df	SS	MS	F	p-value	Adjusted G-G p-value
Between subjects	**8**	**0.0355**				
Habitat	1	0.0009	0.0009	0.17	0.6900	
Error	7	0.0347	0.0050			
Within subjects	**27**	**0.1030**				
Time	3	0.0109	0.0036	0.97	0.4259	0.371
Time * Habitat	3	0.0135	0.0045	1.21	0.3317	0.3154
Error(Time)	21	0.0786	0.0037			
Total	**35**	**0.1386**				

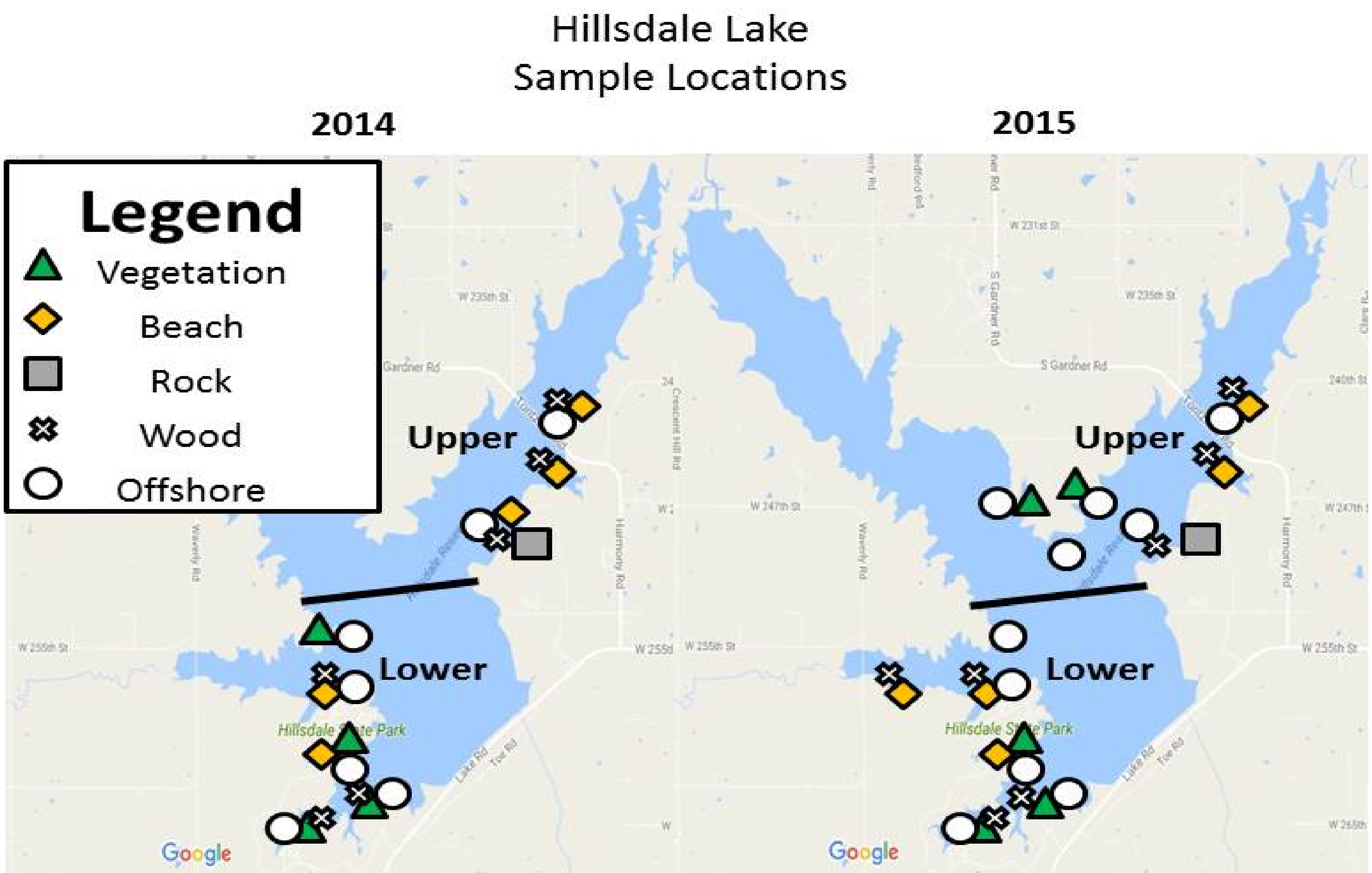

Figure 2.1: Sample Locations within Hillsdale Lake, KS.

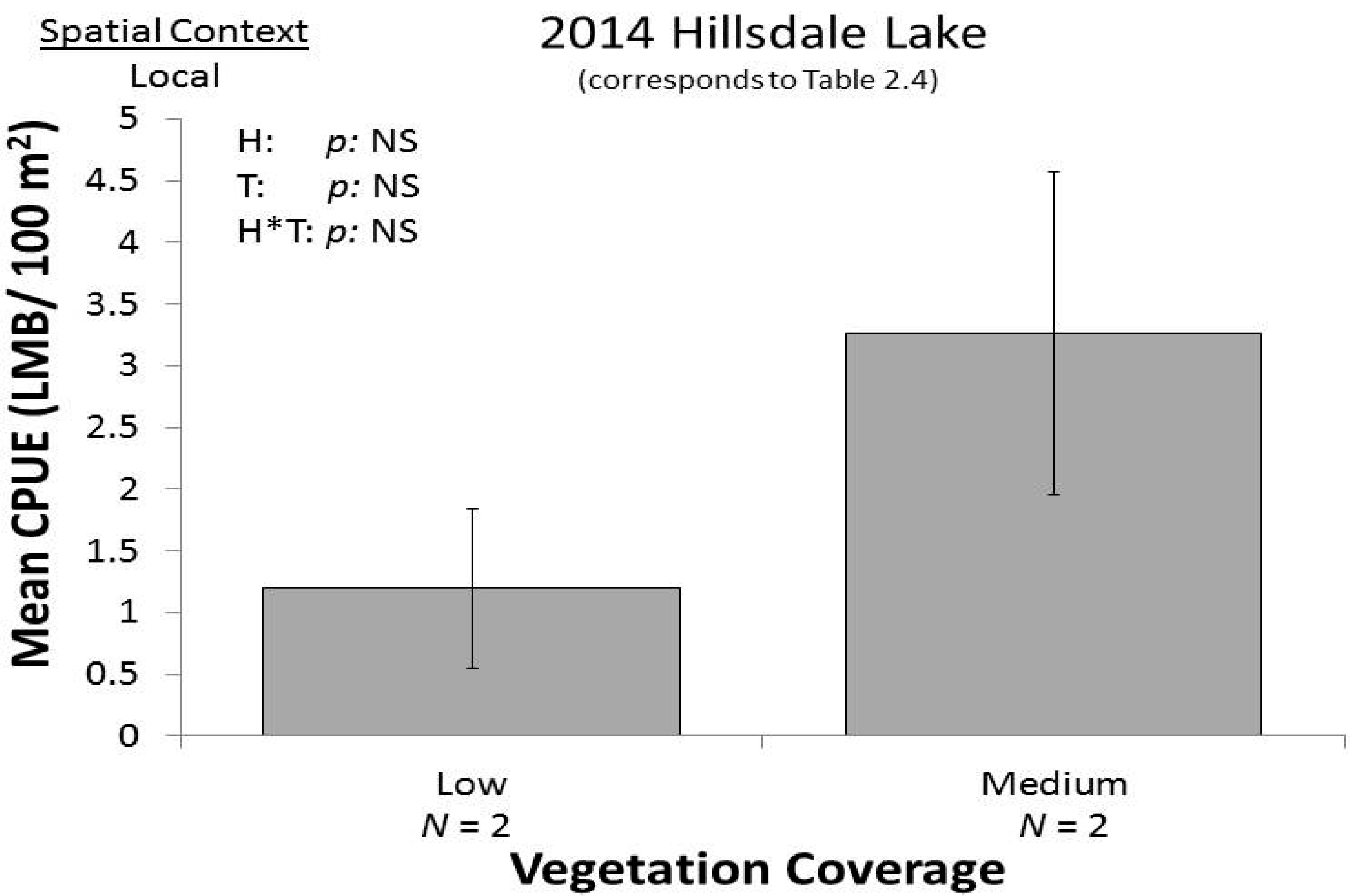

Figure 2.2: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

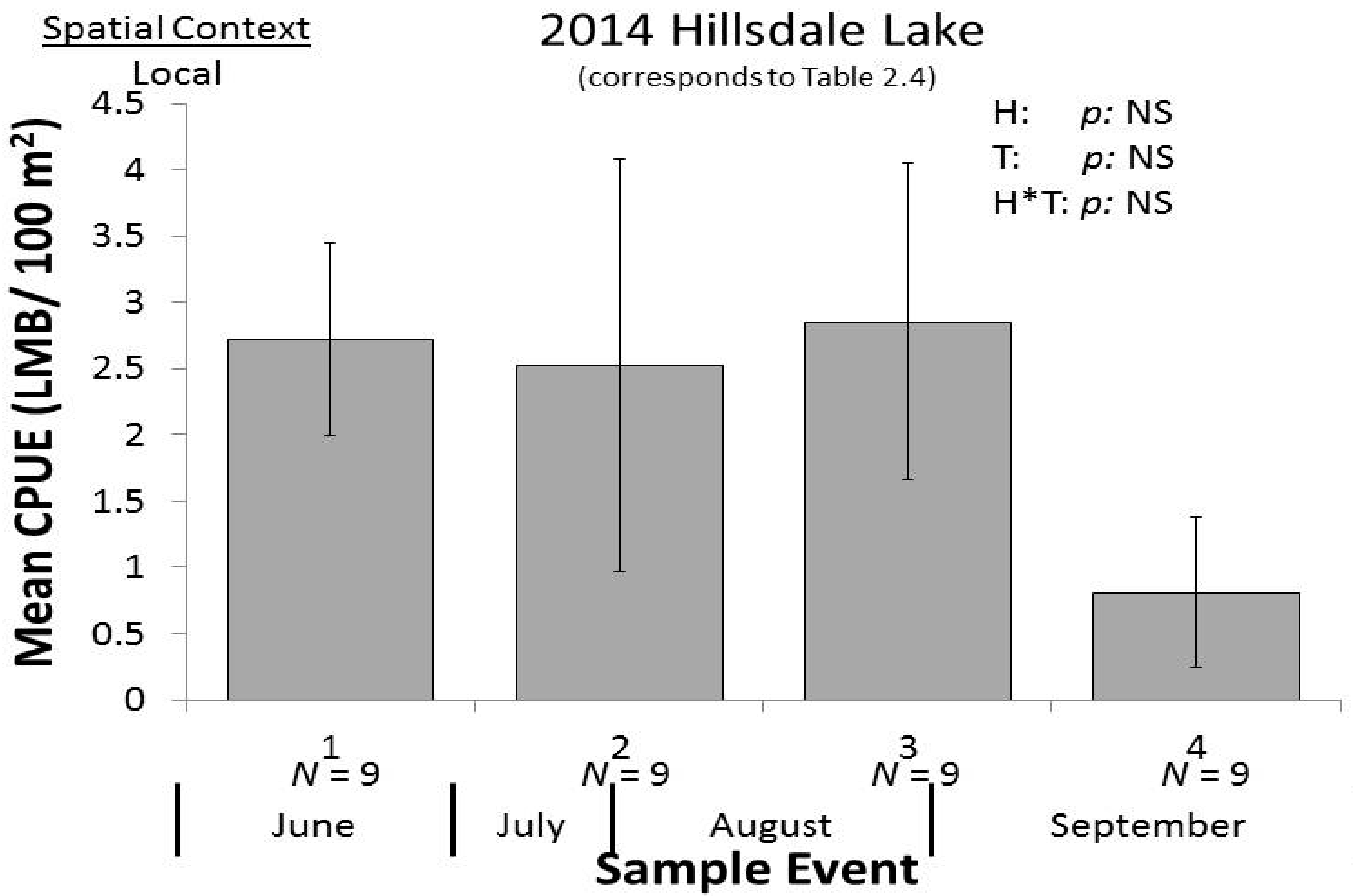

Figure 2.3: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

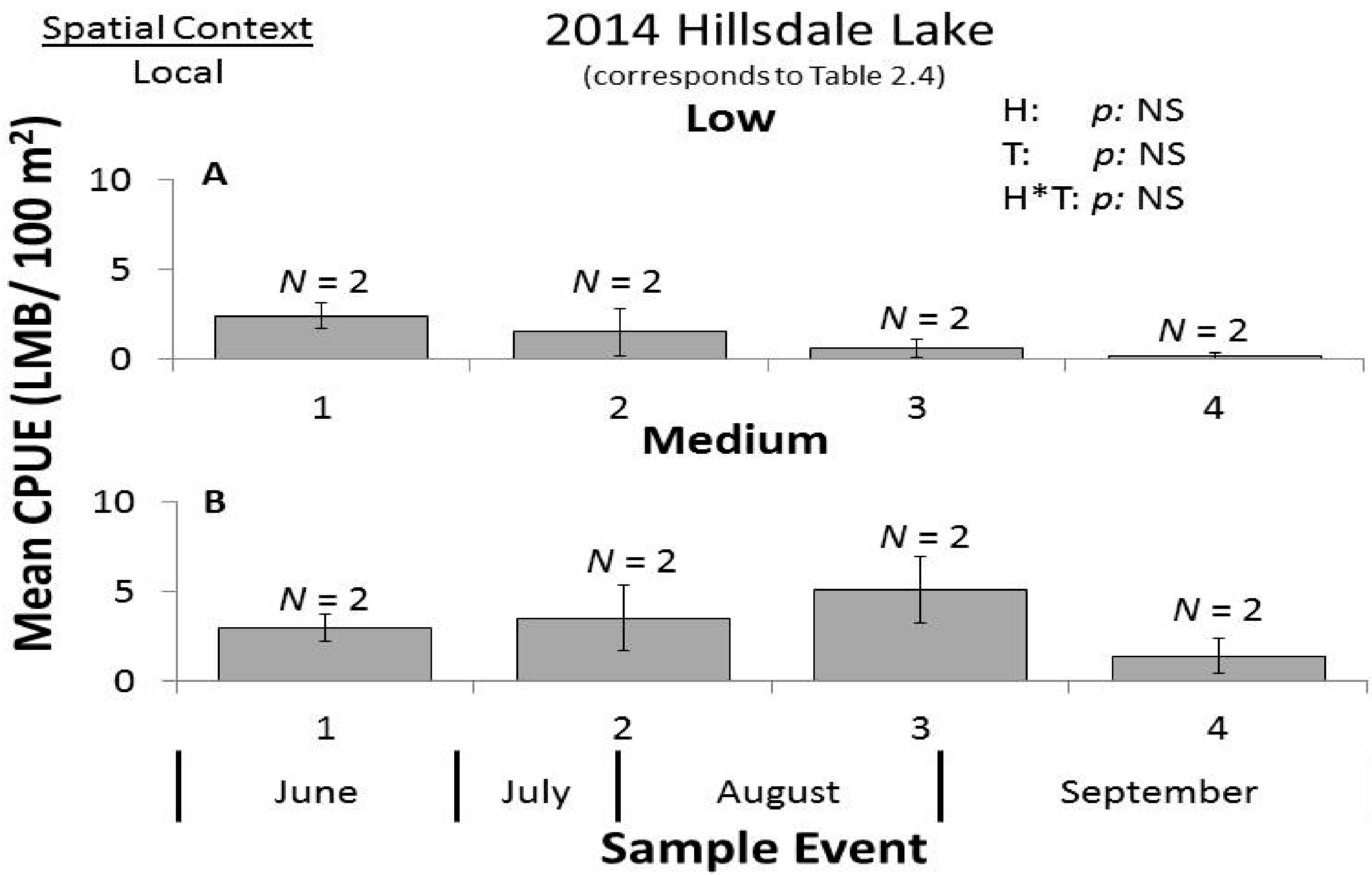

Figure 2.4: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two categories of percent vegetation coverage (low, medium) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

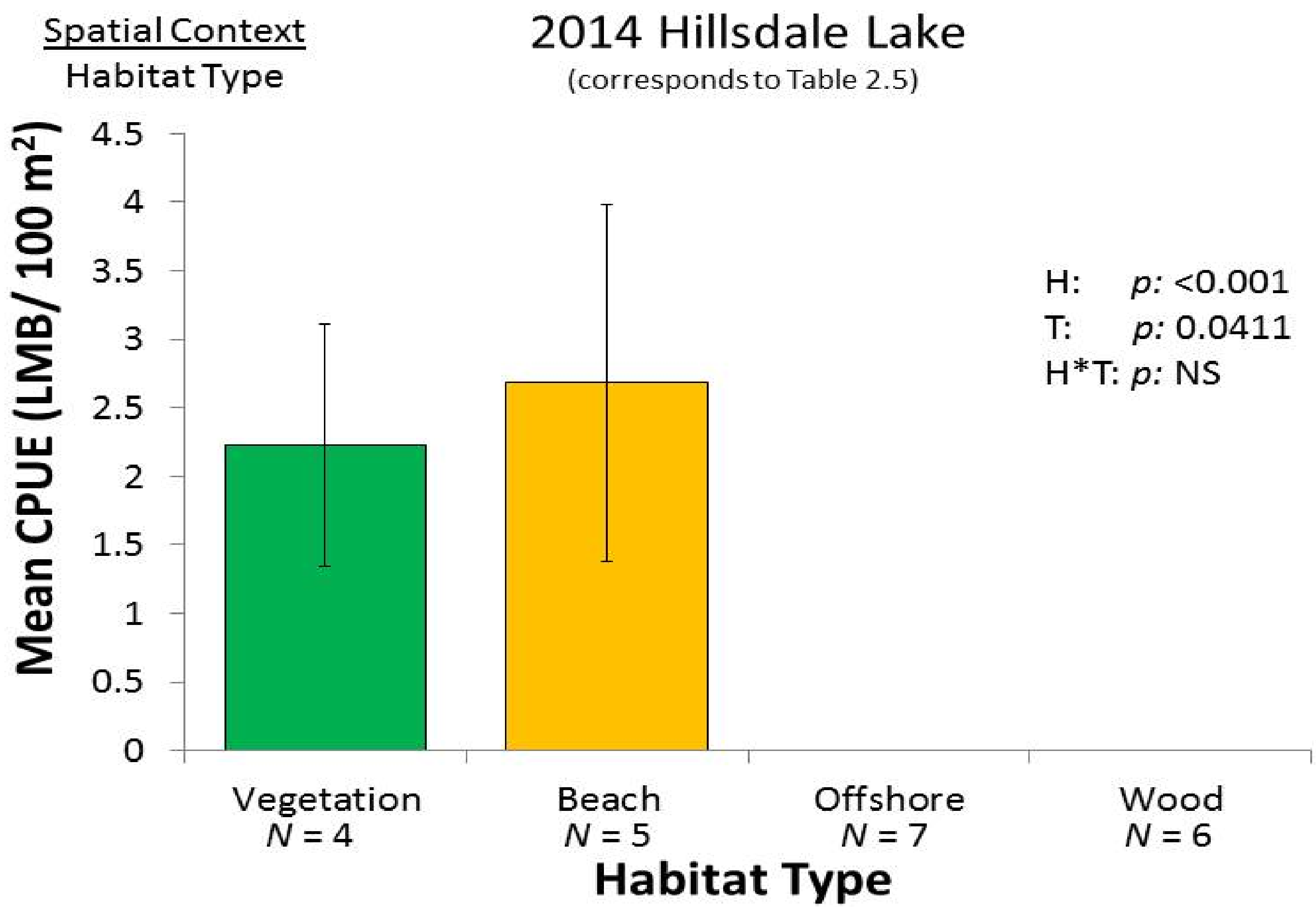

Figure 2.5: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for four habitat types (vegetation, beach, offshore, wood) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

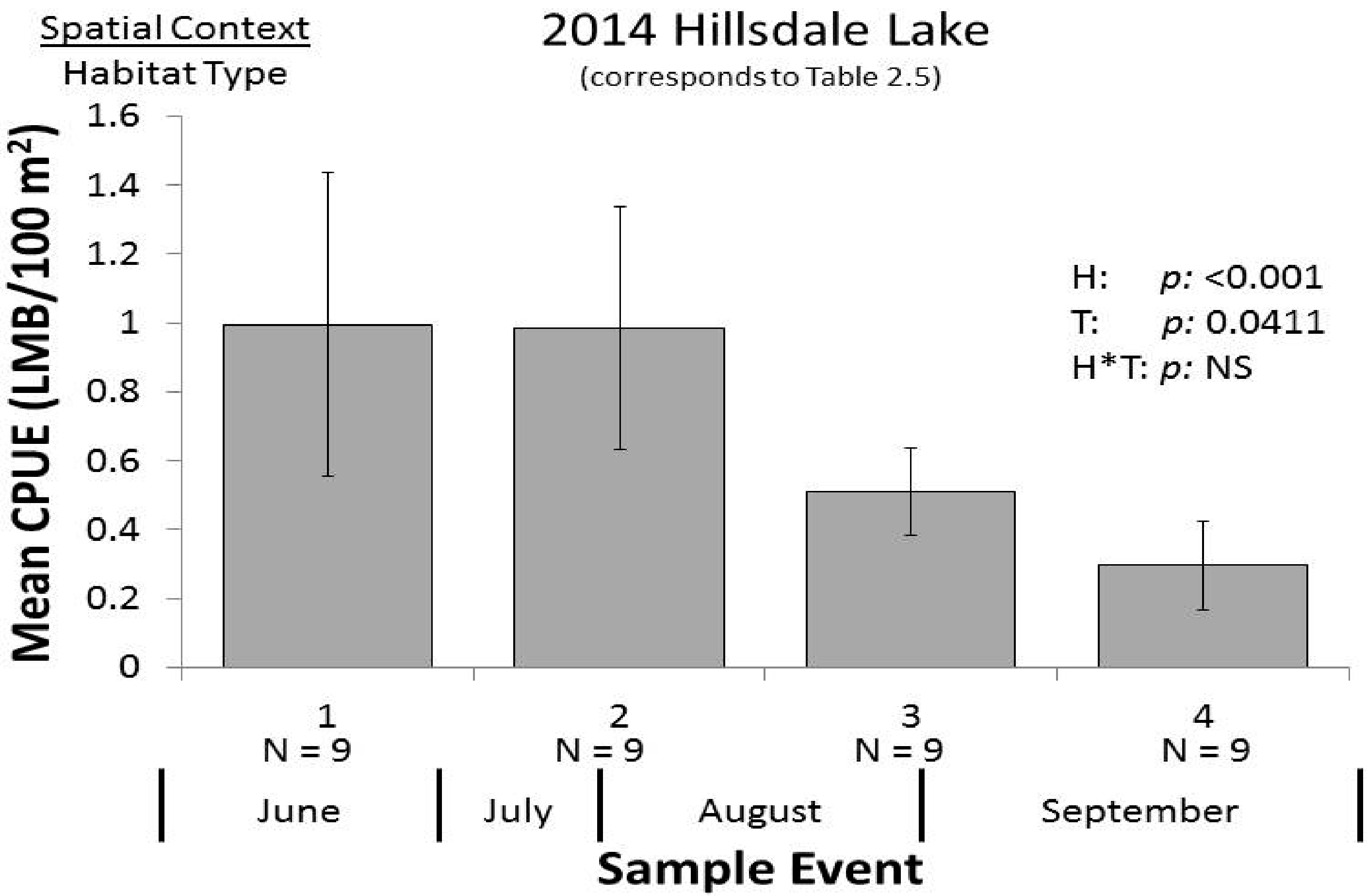

Figure 2.6: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

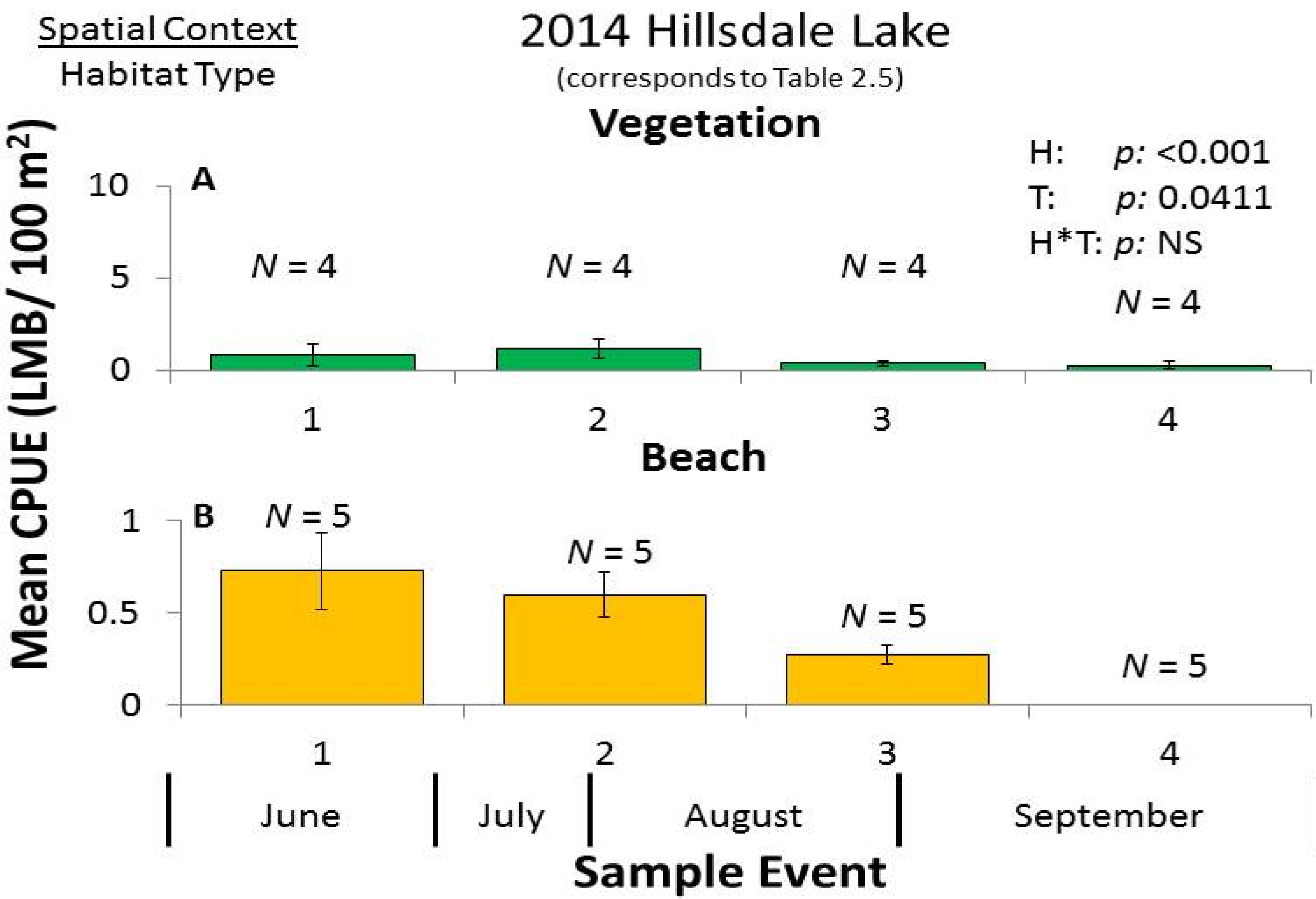

Figure 2.7: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two habitat types (vegetation, beach) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

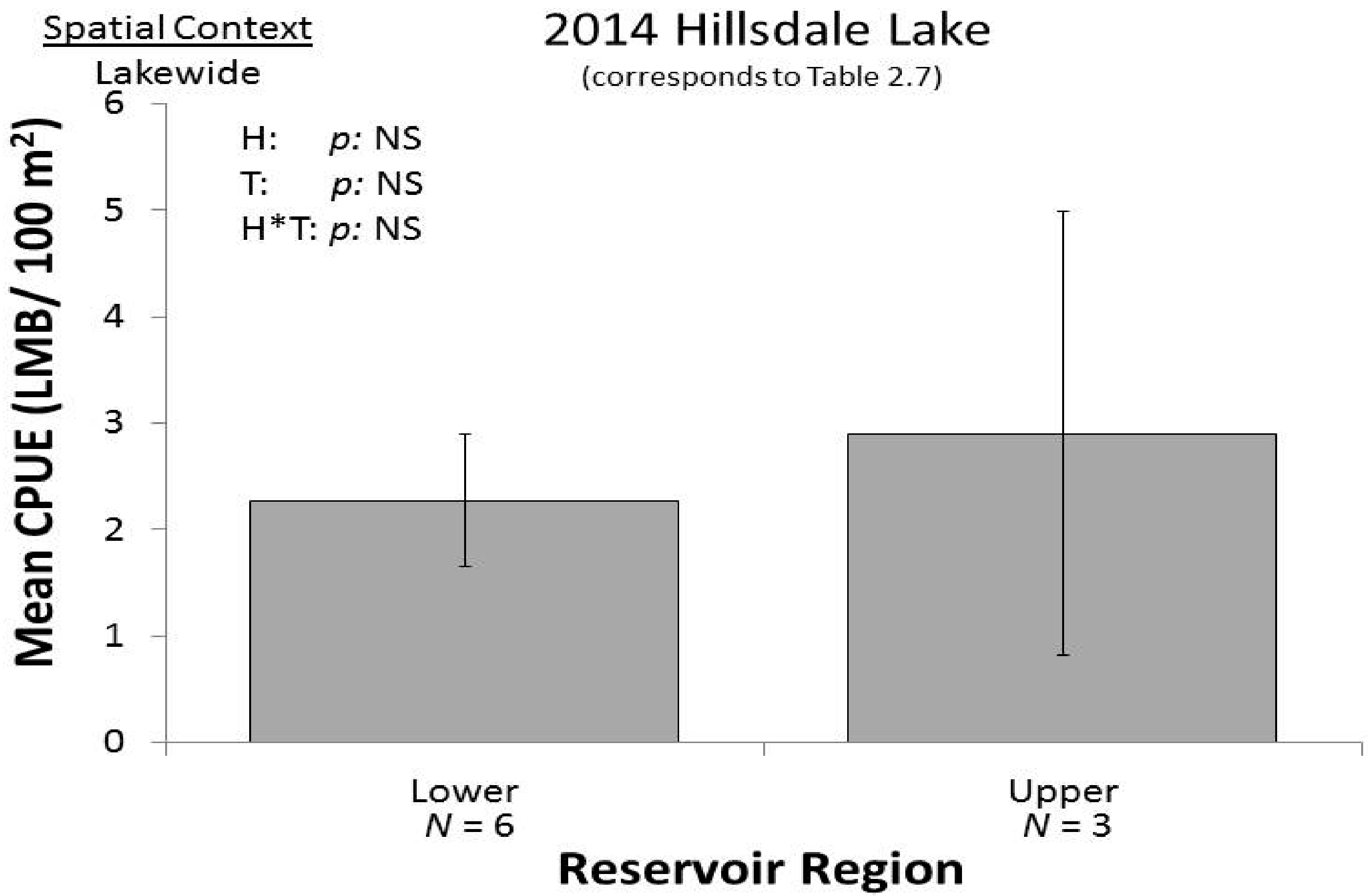

Figure 2.8: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two reservoir regions (lower, upper) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

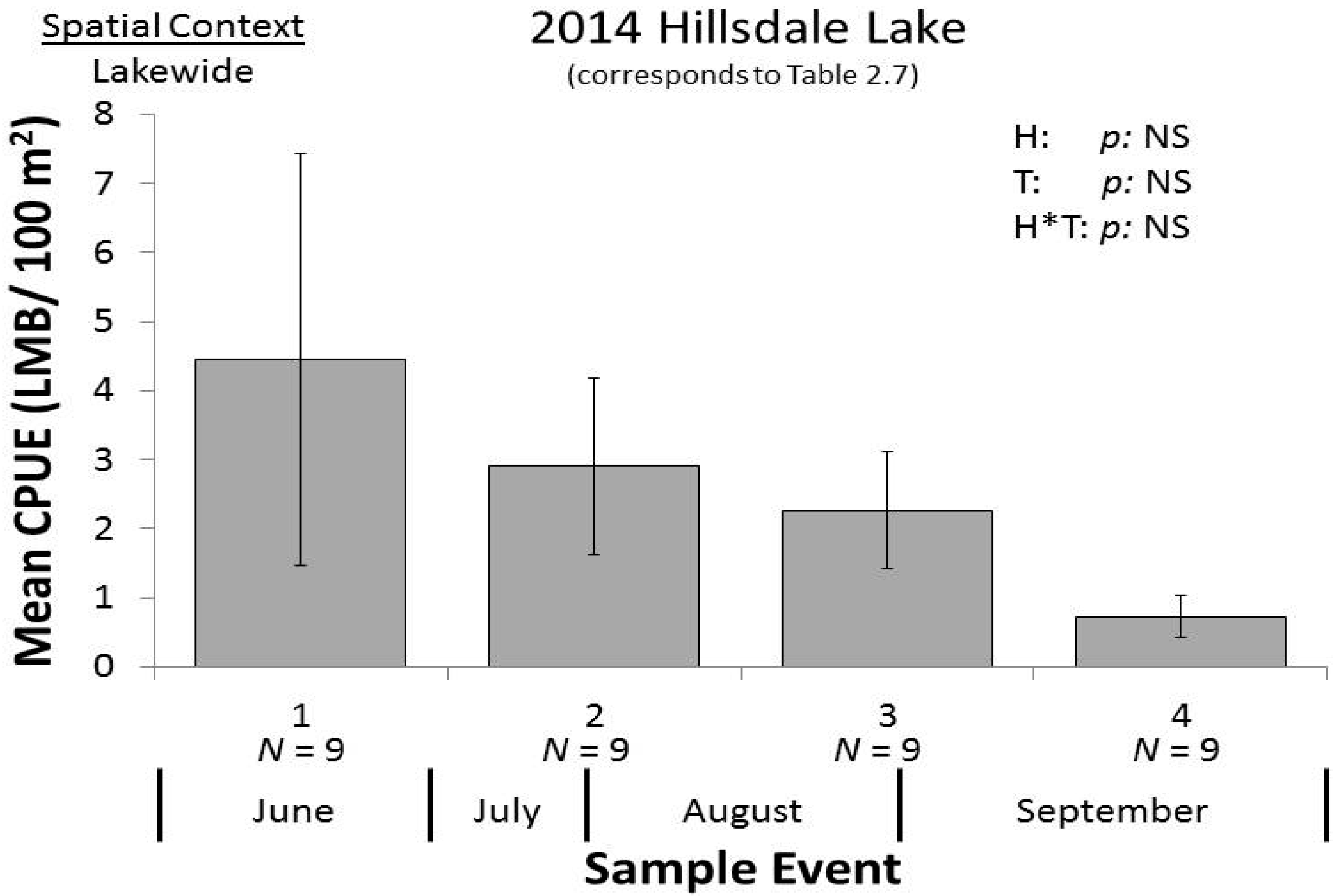

Figure 2.9: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

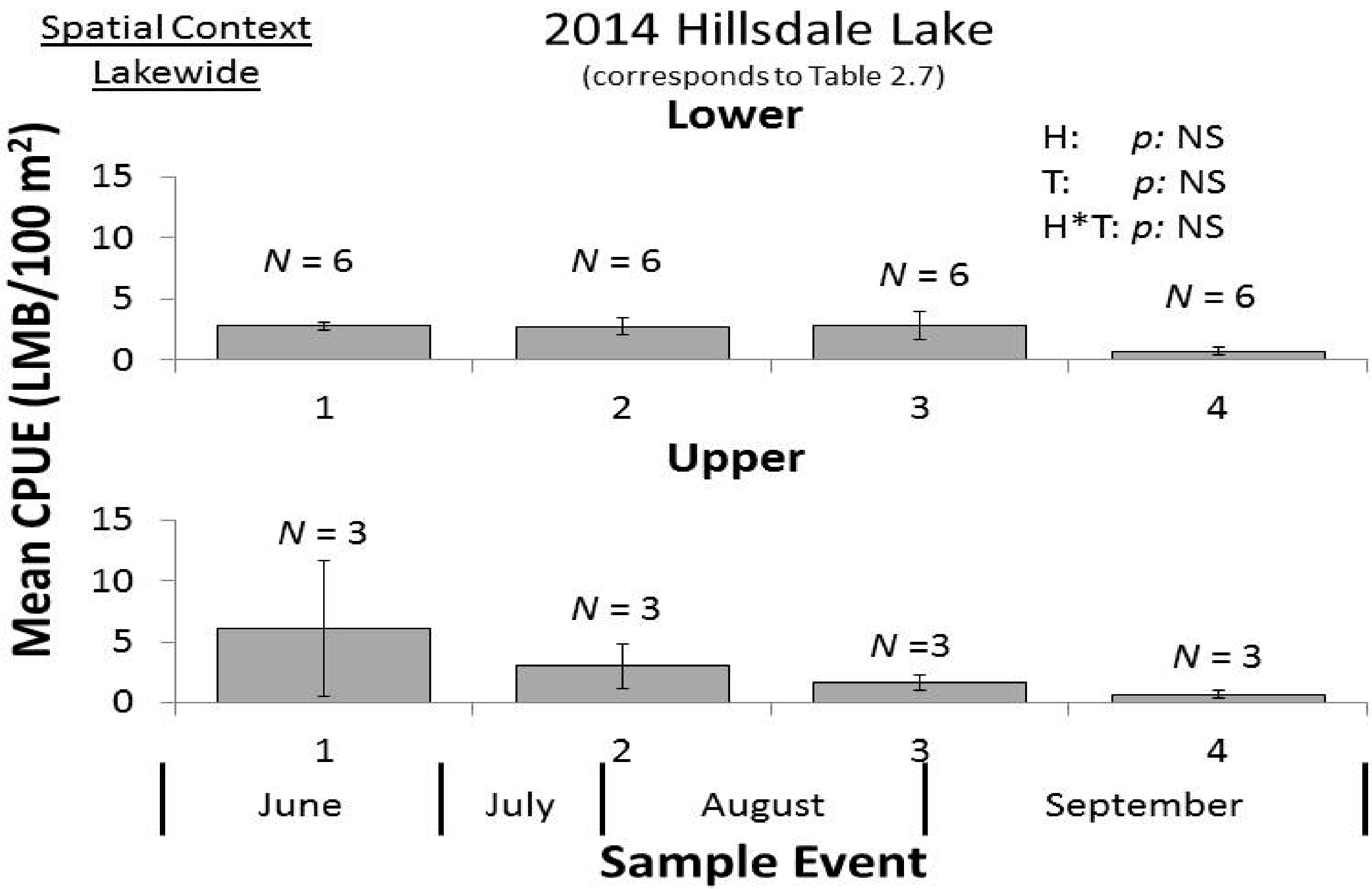

Figure 2.10: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two reservoir regions (lower, upper) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

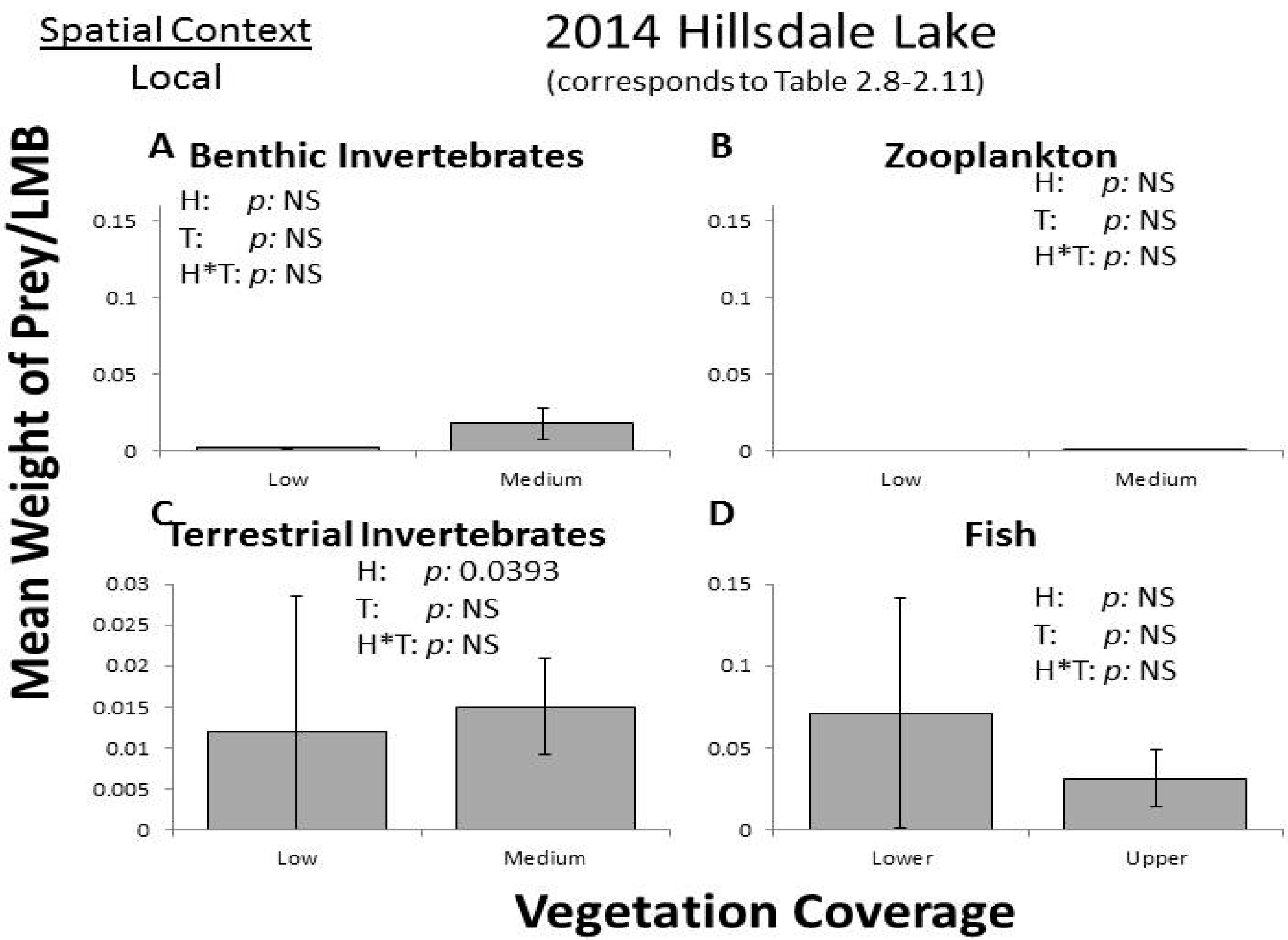

Figure 2.11: Mean weight of prey eaten by young of year largemouth bass for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake during 2014. Data are mean and standard error.

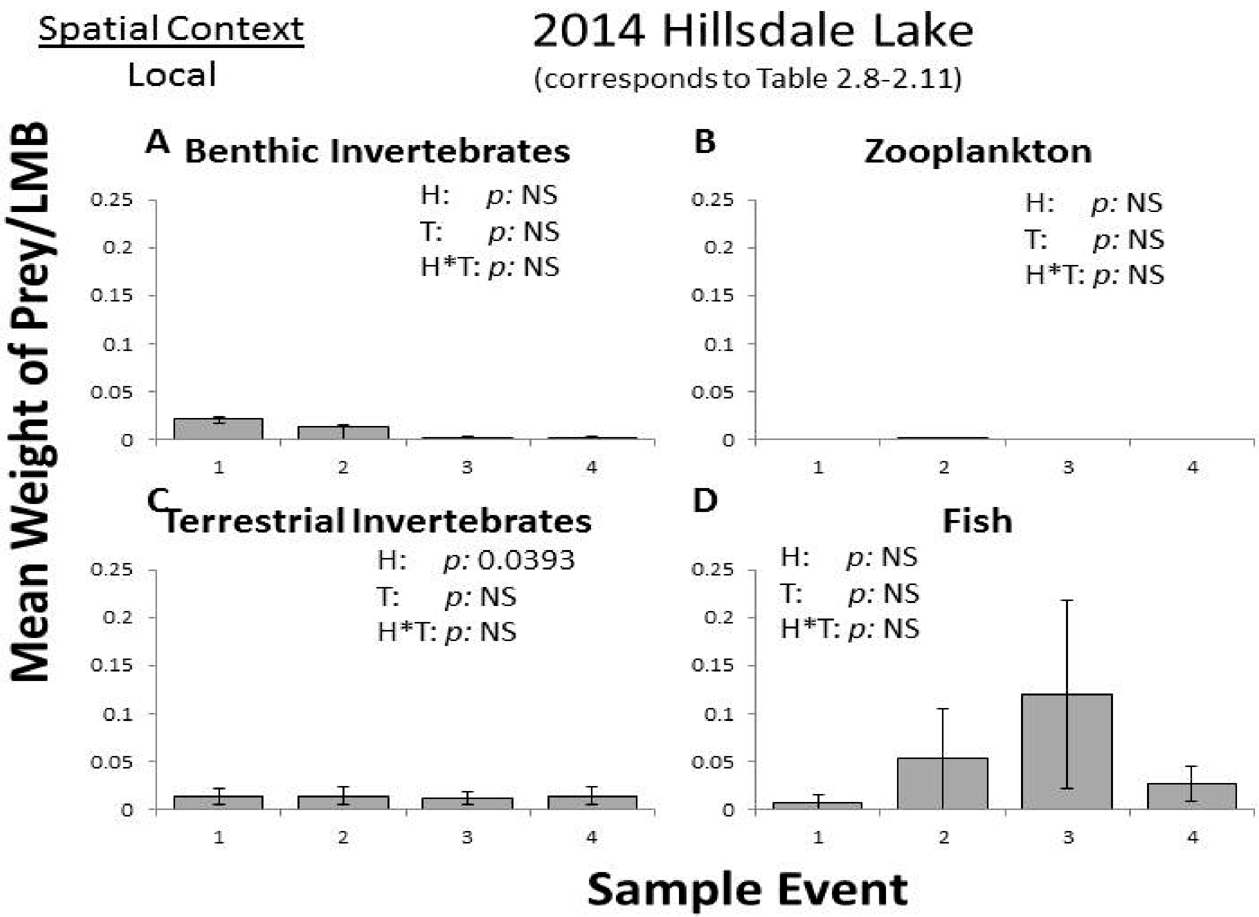

Figure 2.12: Mean weight of prey eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

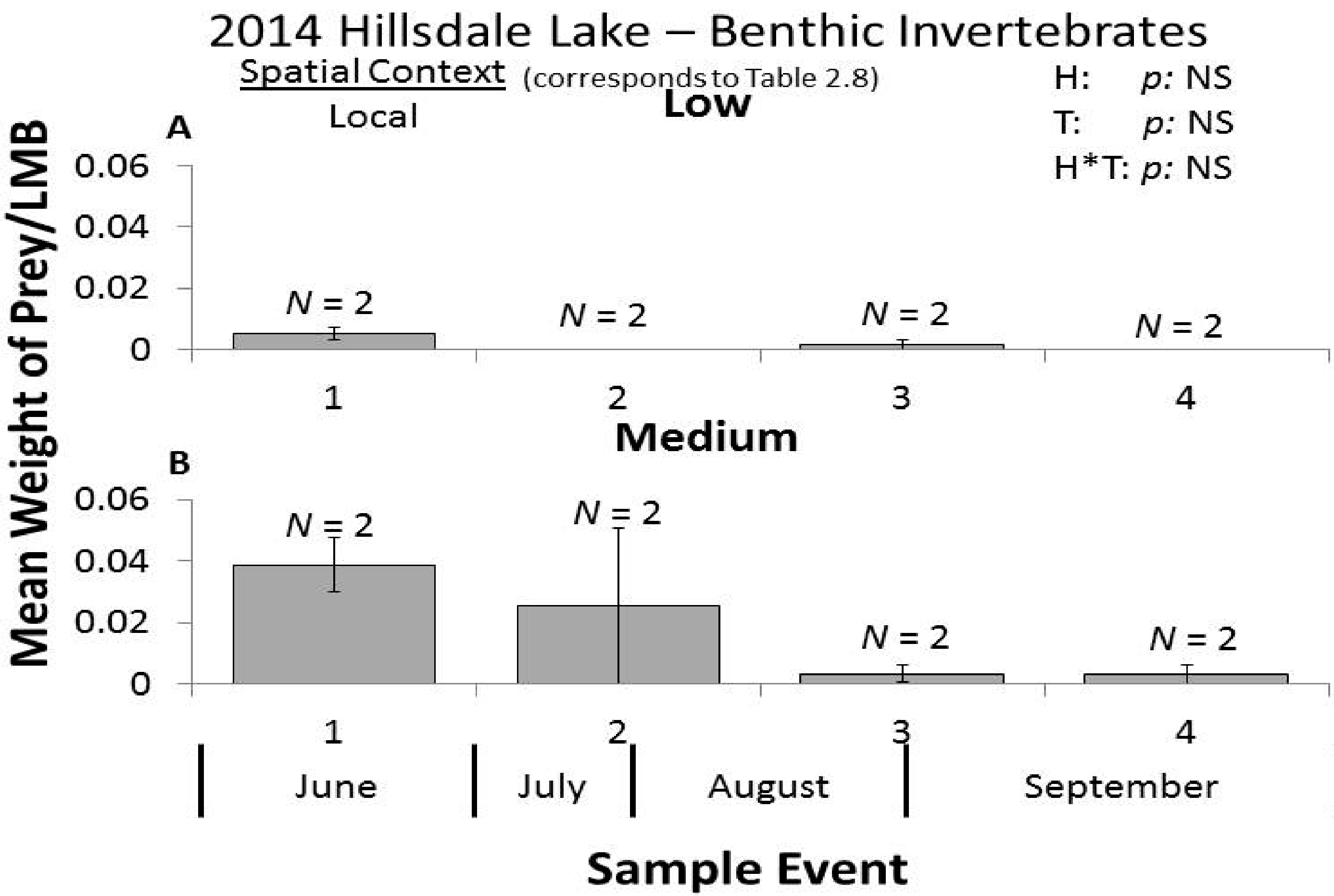

Figure 2.13: Mean weight of benthic invertebrates consumed by young of year largemouth bass for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

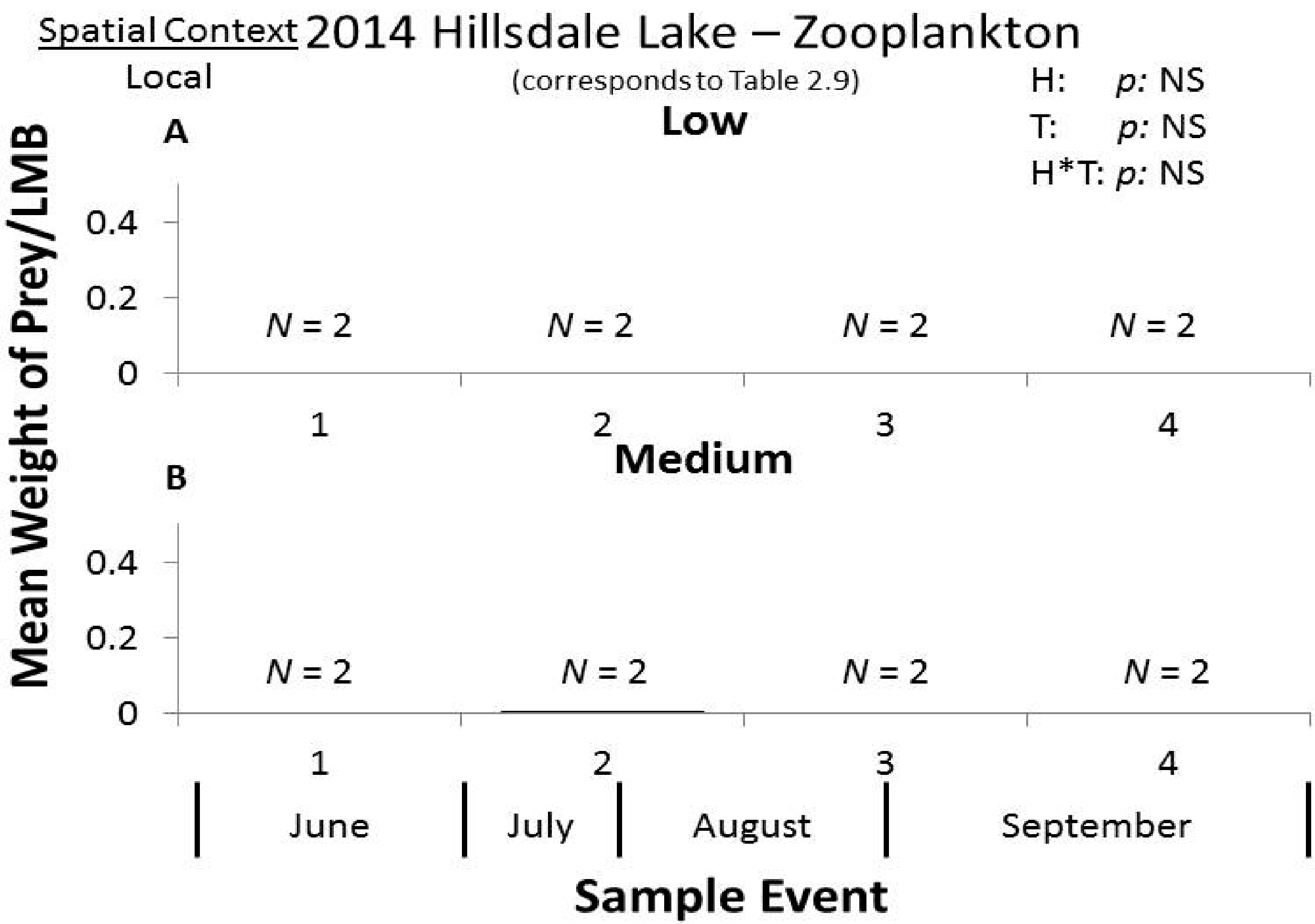

Figure 2.14: Mean weight of zooplankton consumed by young of year largemouth bass for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

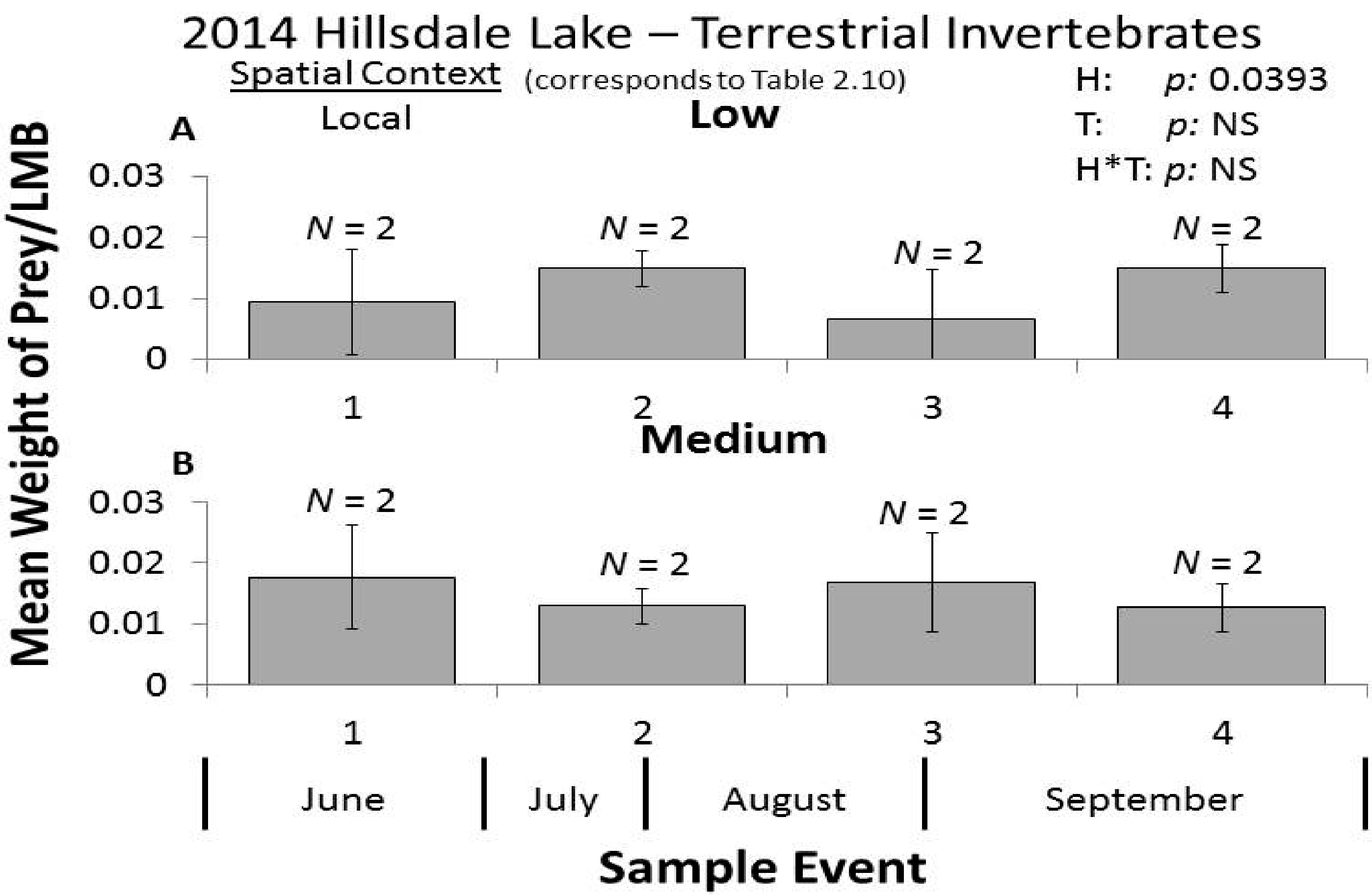

Figure 2.15: Mean weight of terrestrial invertebrates consumed by young of year largemouth bass for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

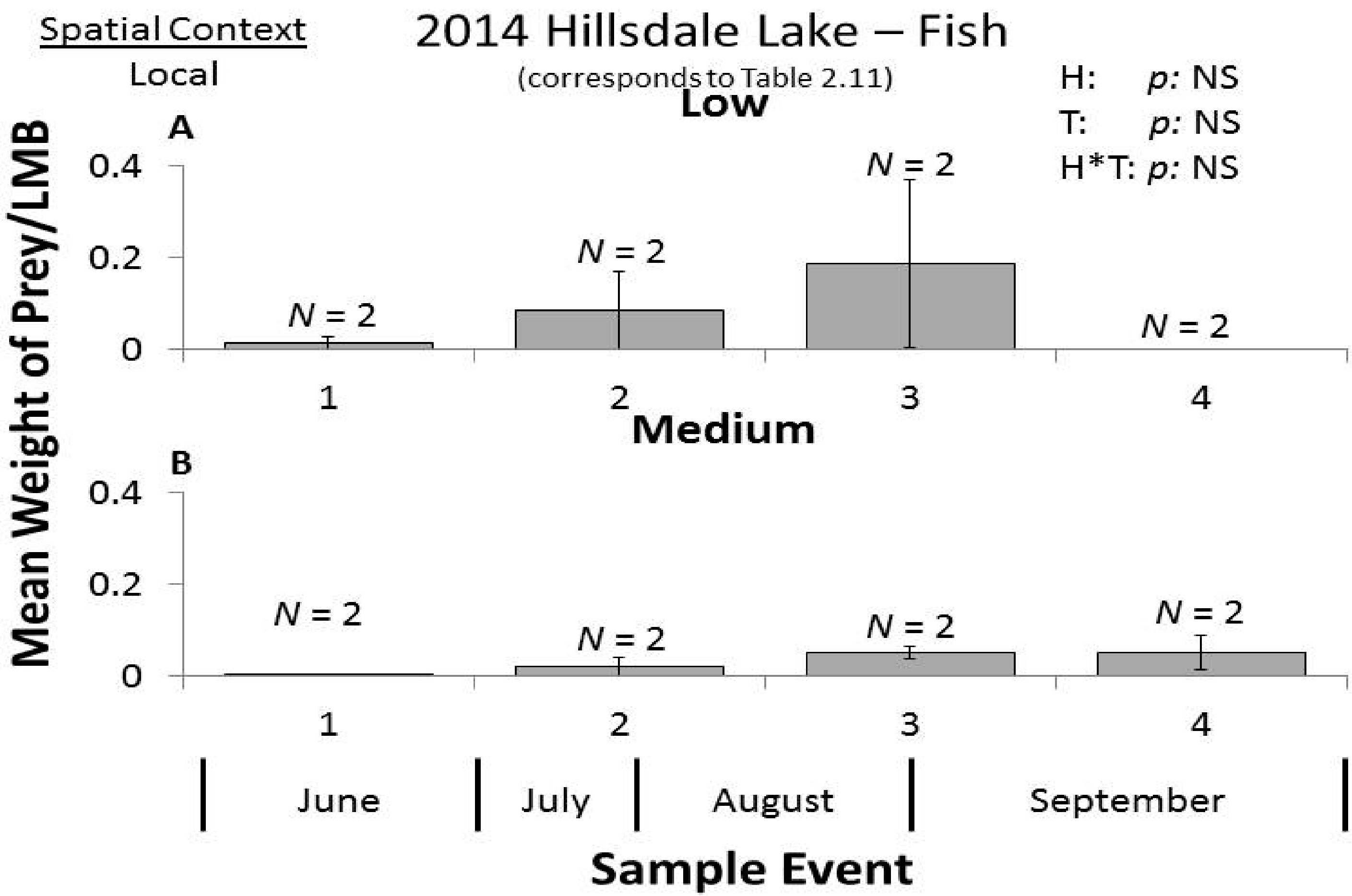

Figure 2.16: Mean weight of fish consumed by young of year largemouth bass for two categories of percent vegetation coverage (low, medium) in Hillsdale Lake, KS during 2014. Data are mean and standard error.

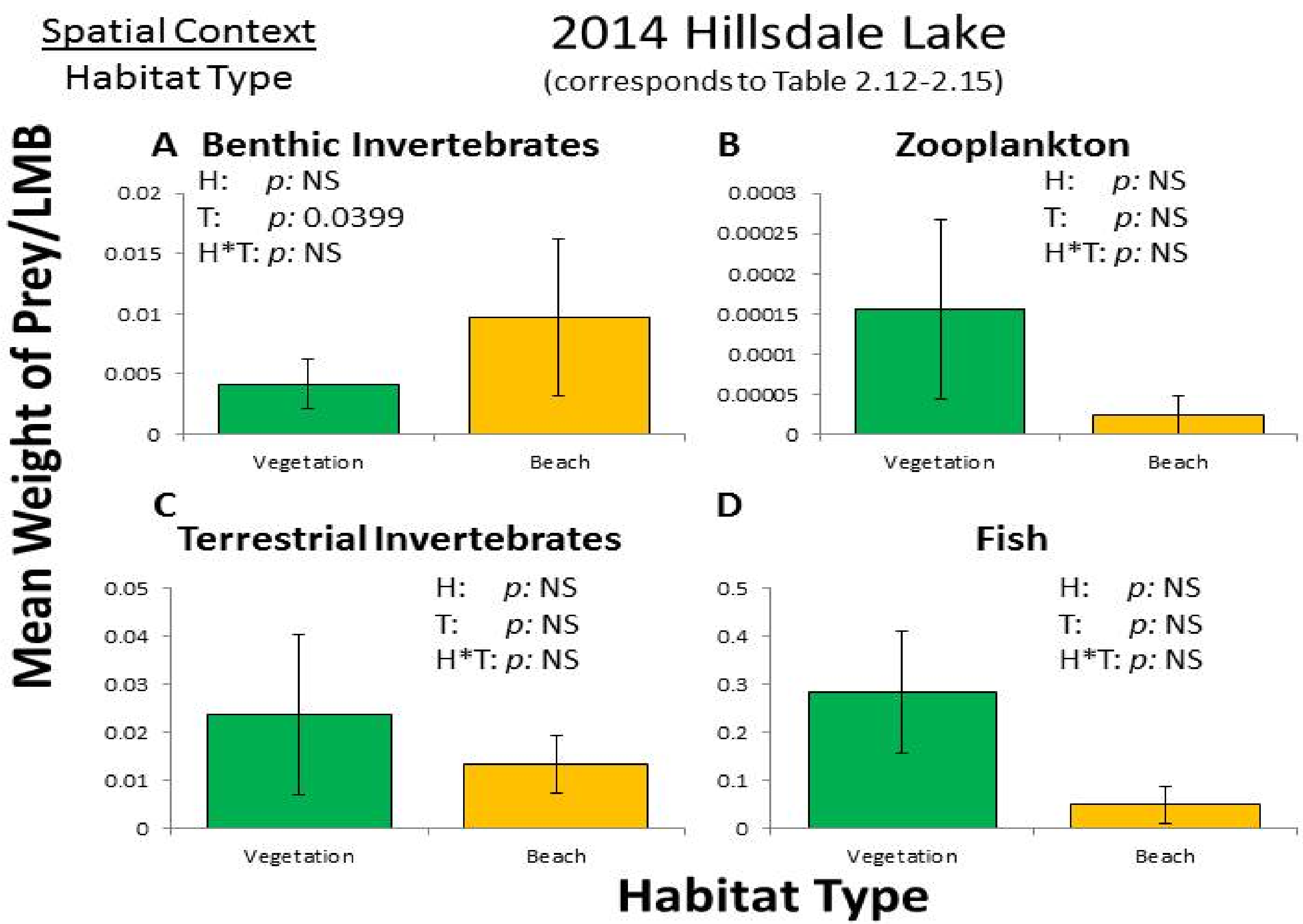

Figure 2.17: Mean weight of prey eaten by young of year largemouth bass across two habitat types (vegetation and beach) in Hillsdale Lake during 2014. Data are mean and standard error.

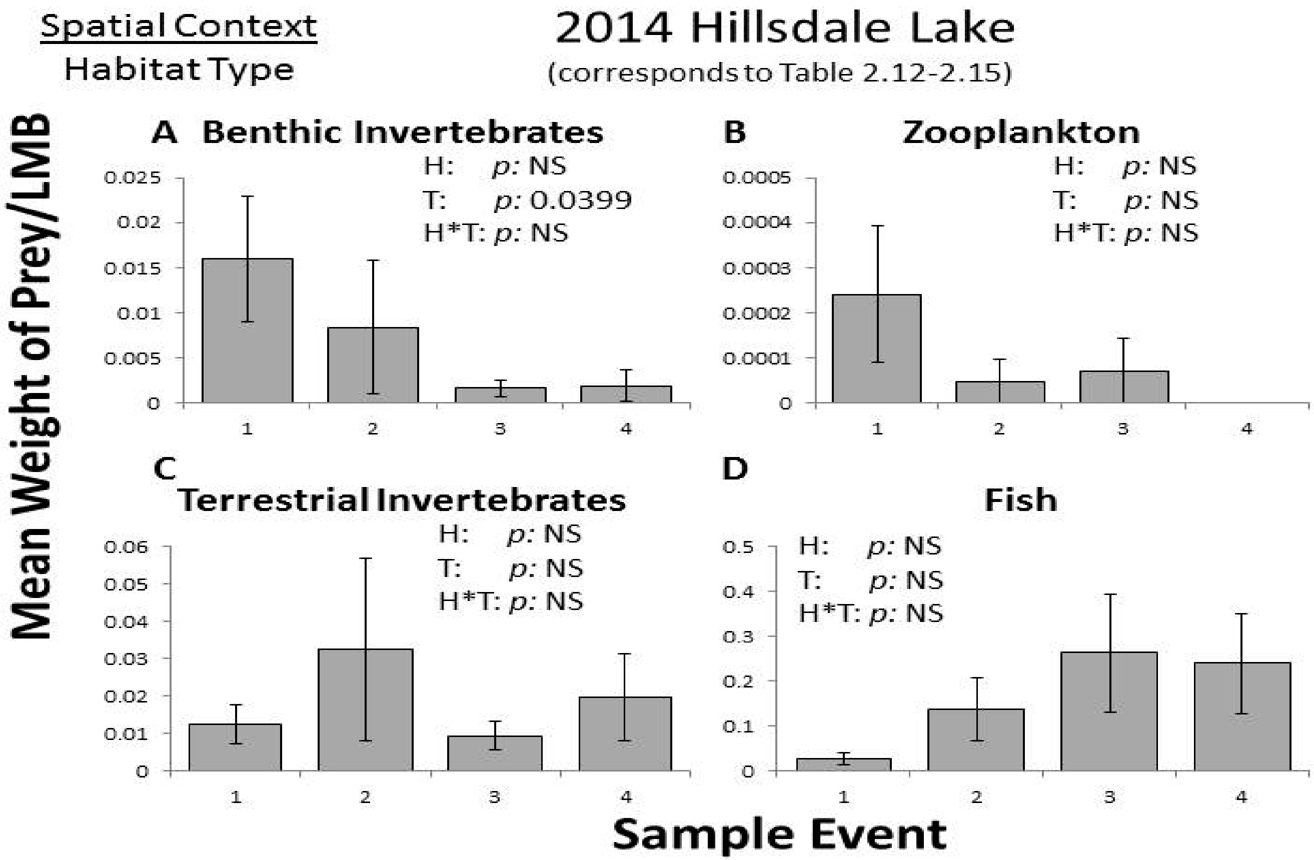

Figure 2.18: Mean weight of prey eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

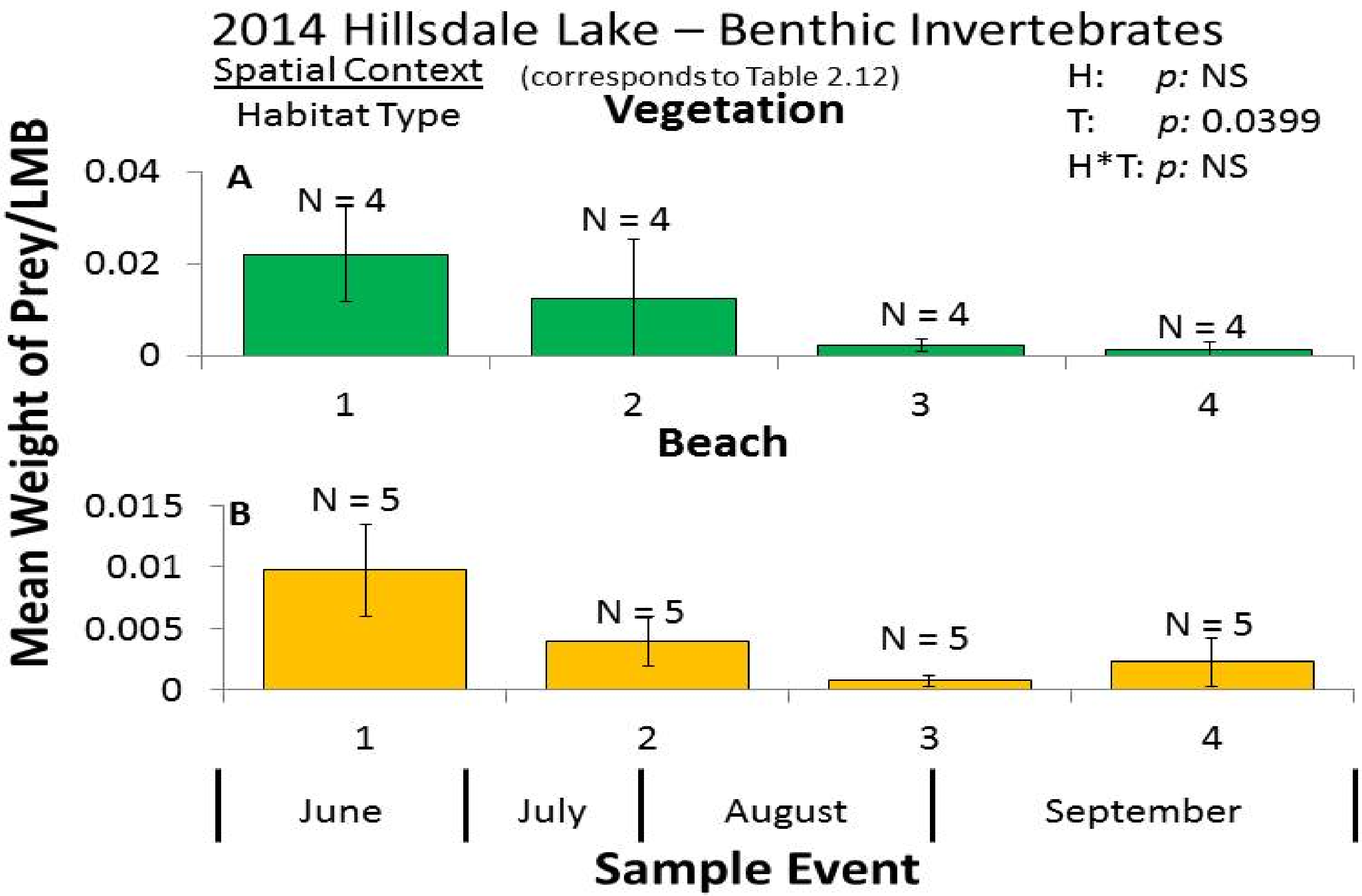

Figure 2.19: Mean weight of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

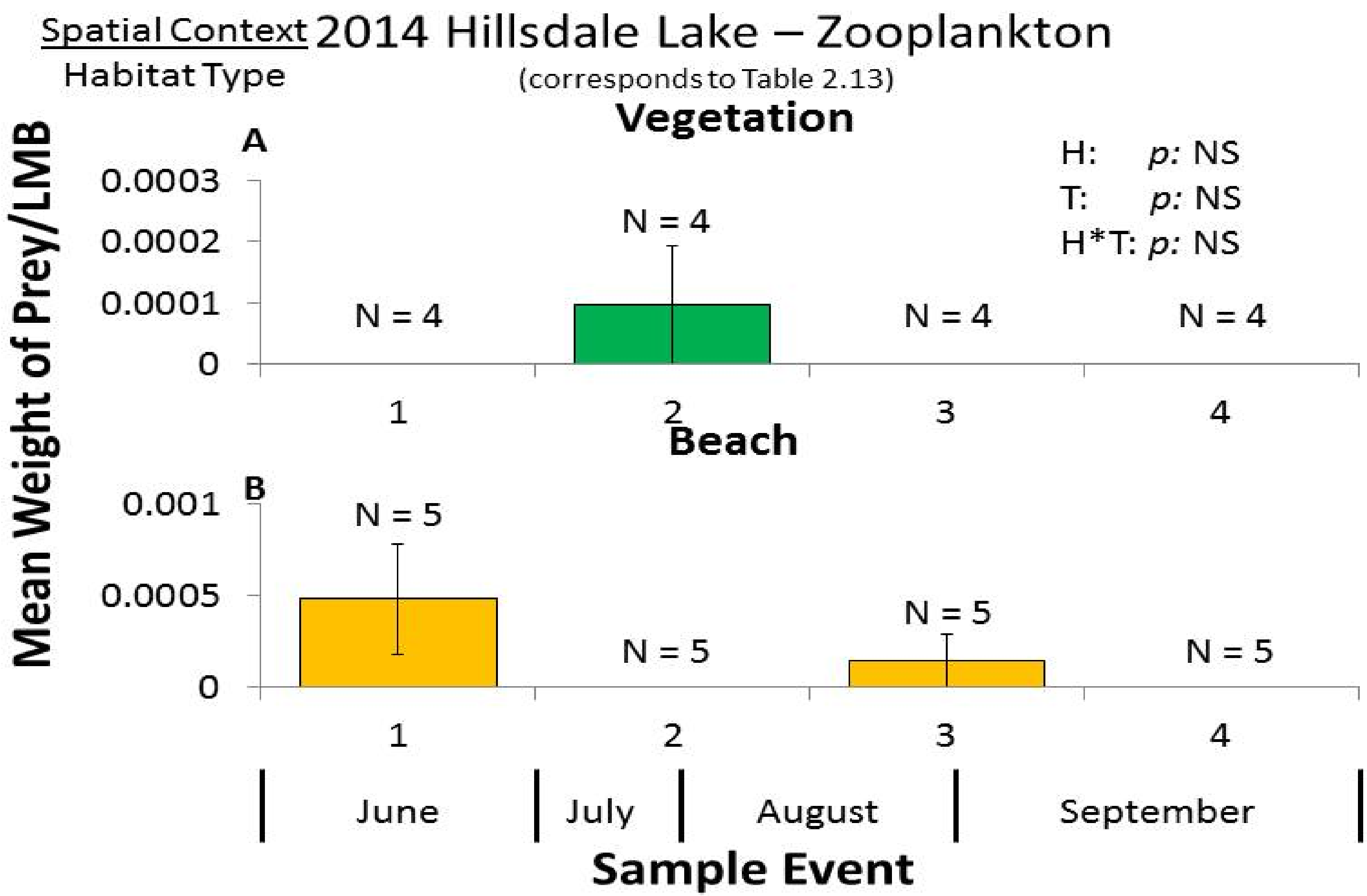

Figure 2.20: Mean weight of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

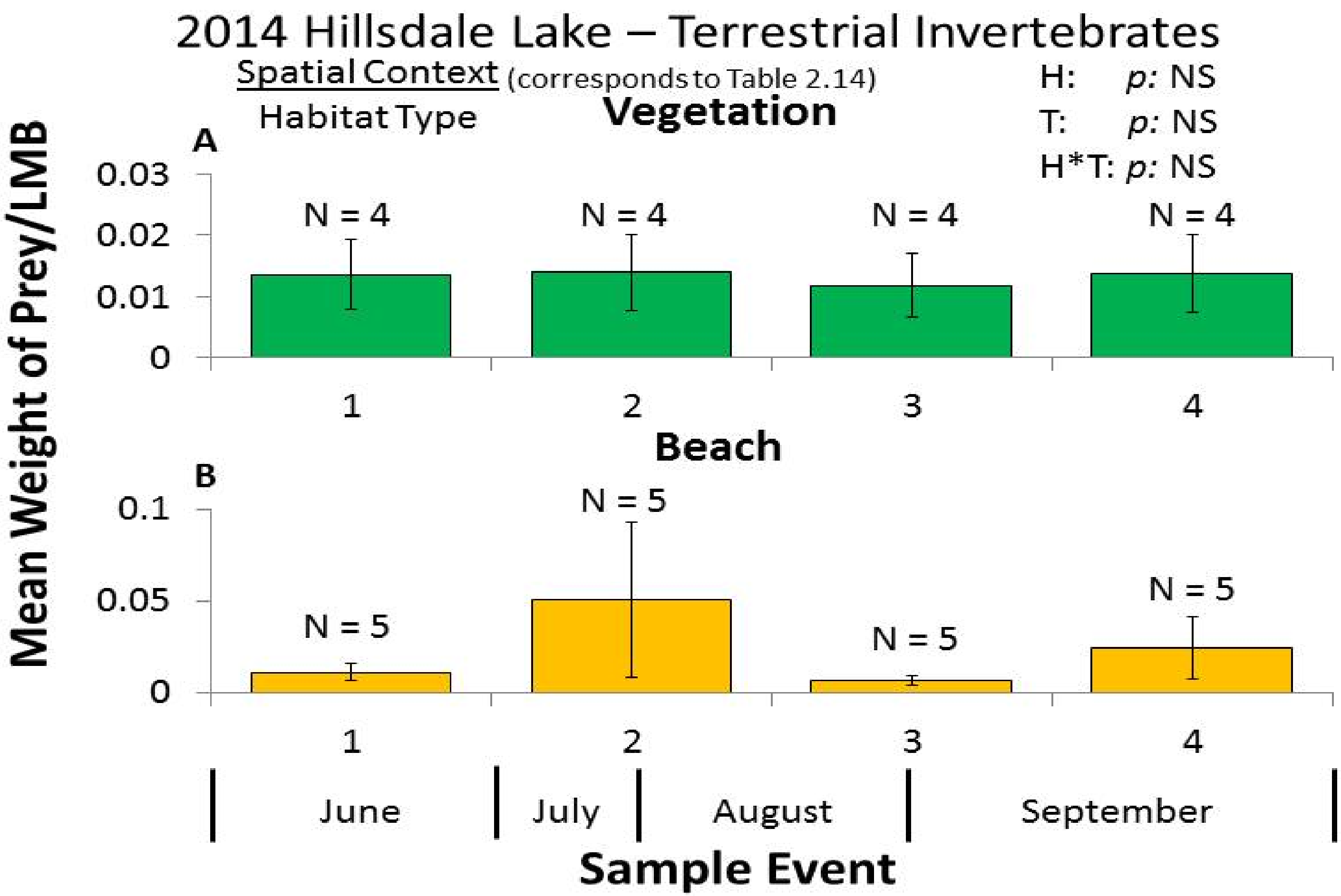

Figure 2.21: Mean weight of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

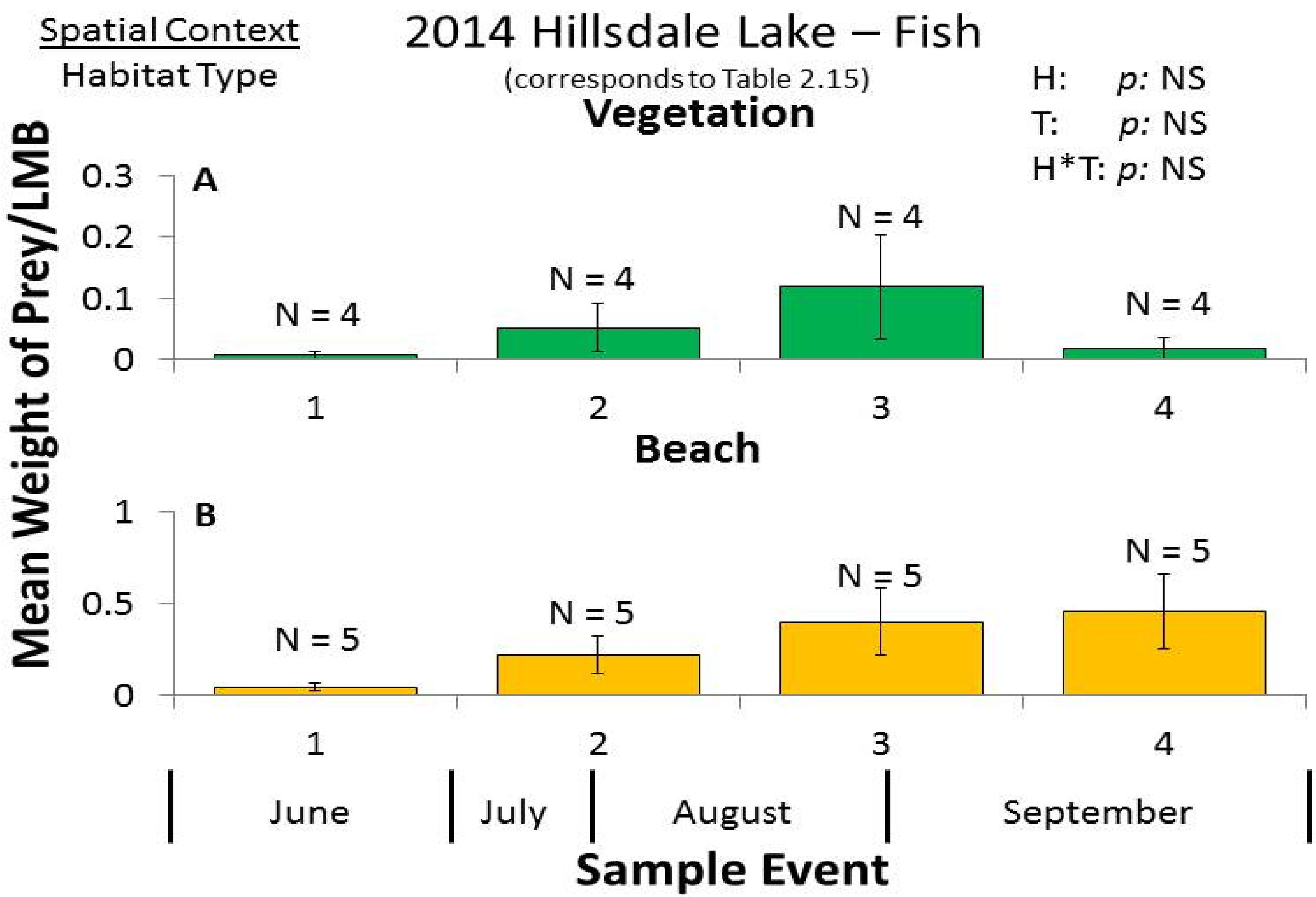

Figure 2.22: Mean weight of fish eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

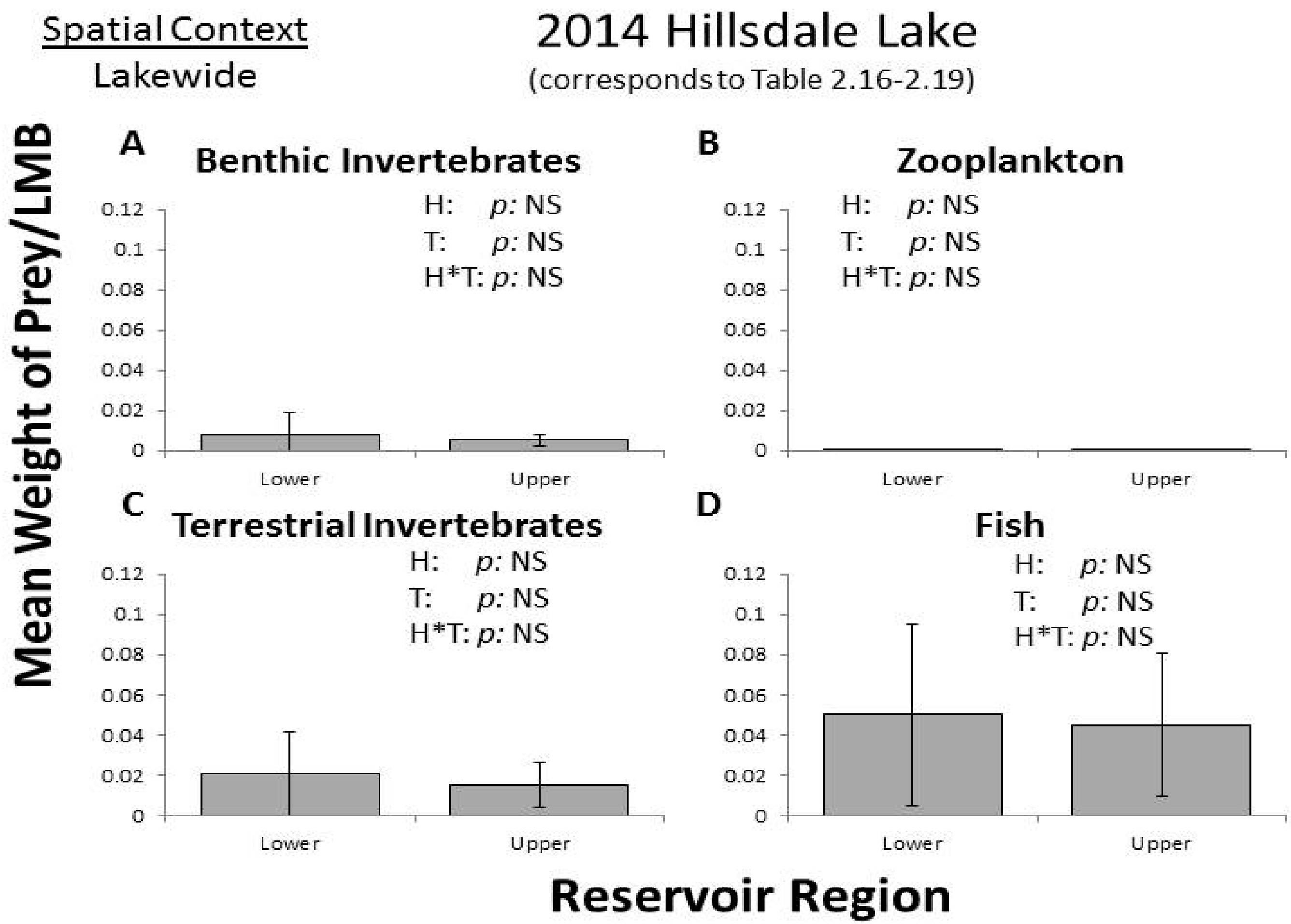

Figure 2.23: Mean weight of prey eaten for two reservoir regions (lower, upper) across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

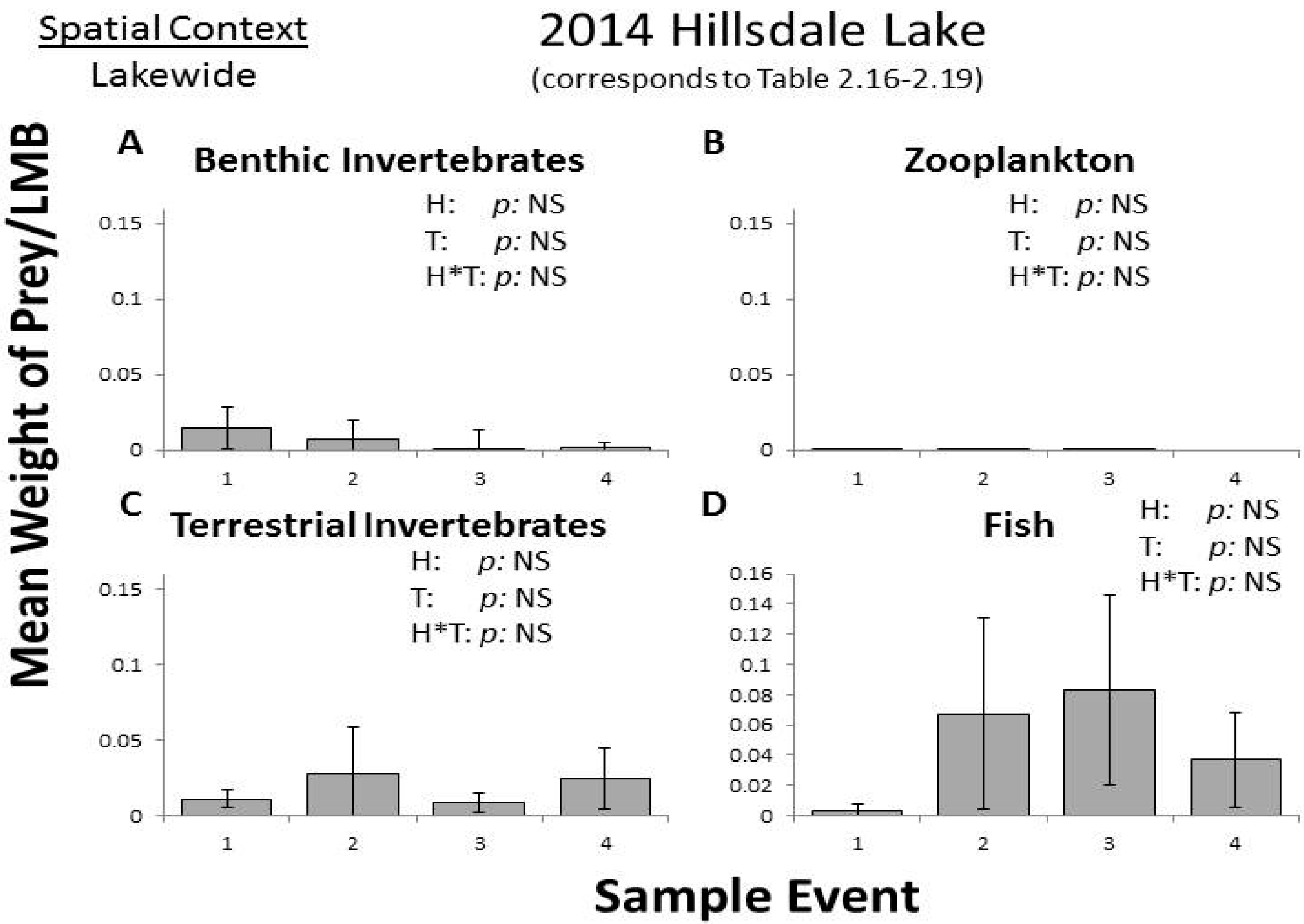

Figure 2.24: Mean weight of prey eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

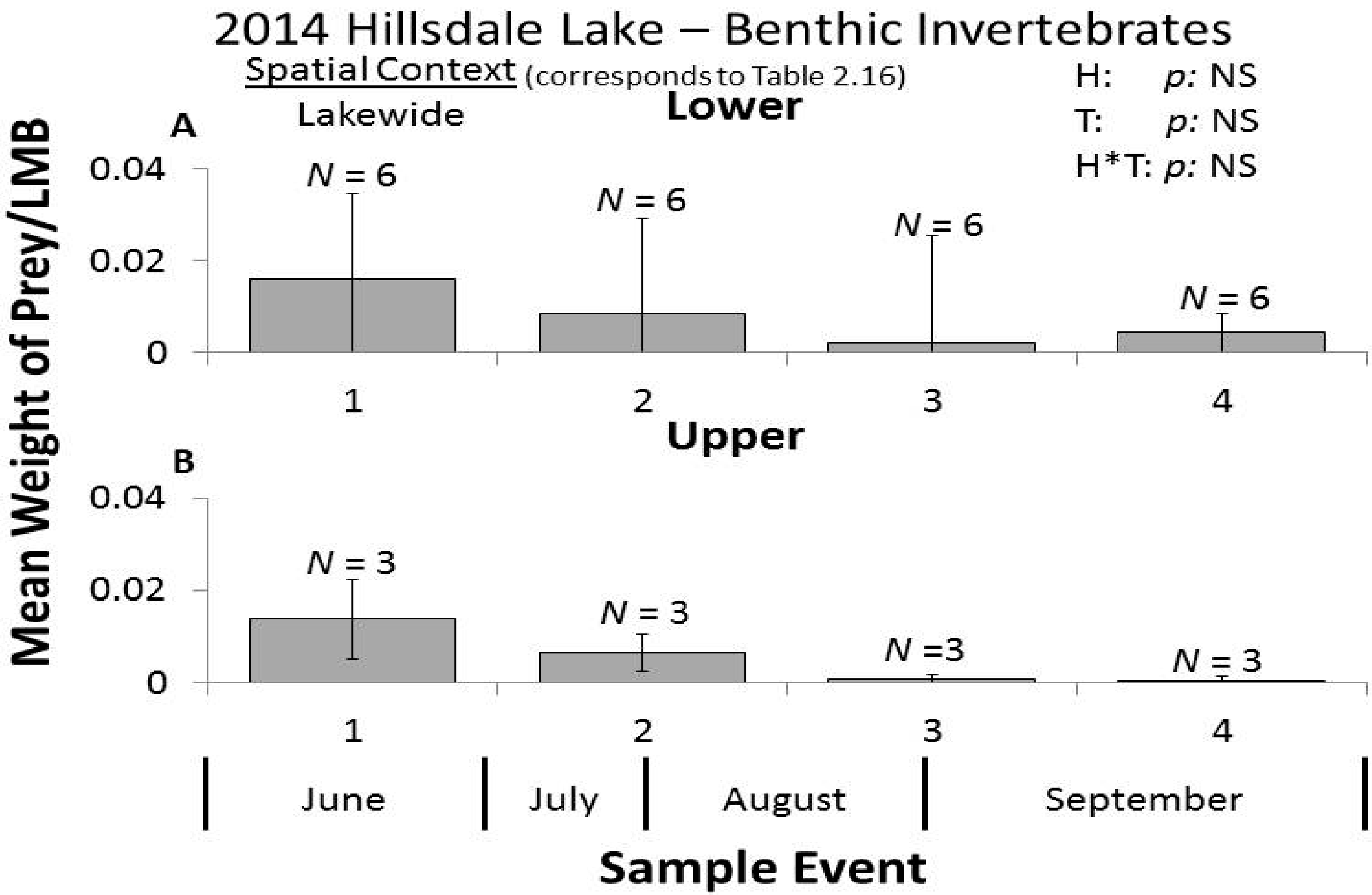

Figure 2.25: Mean weight of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

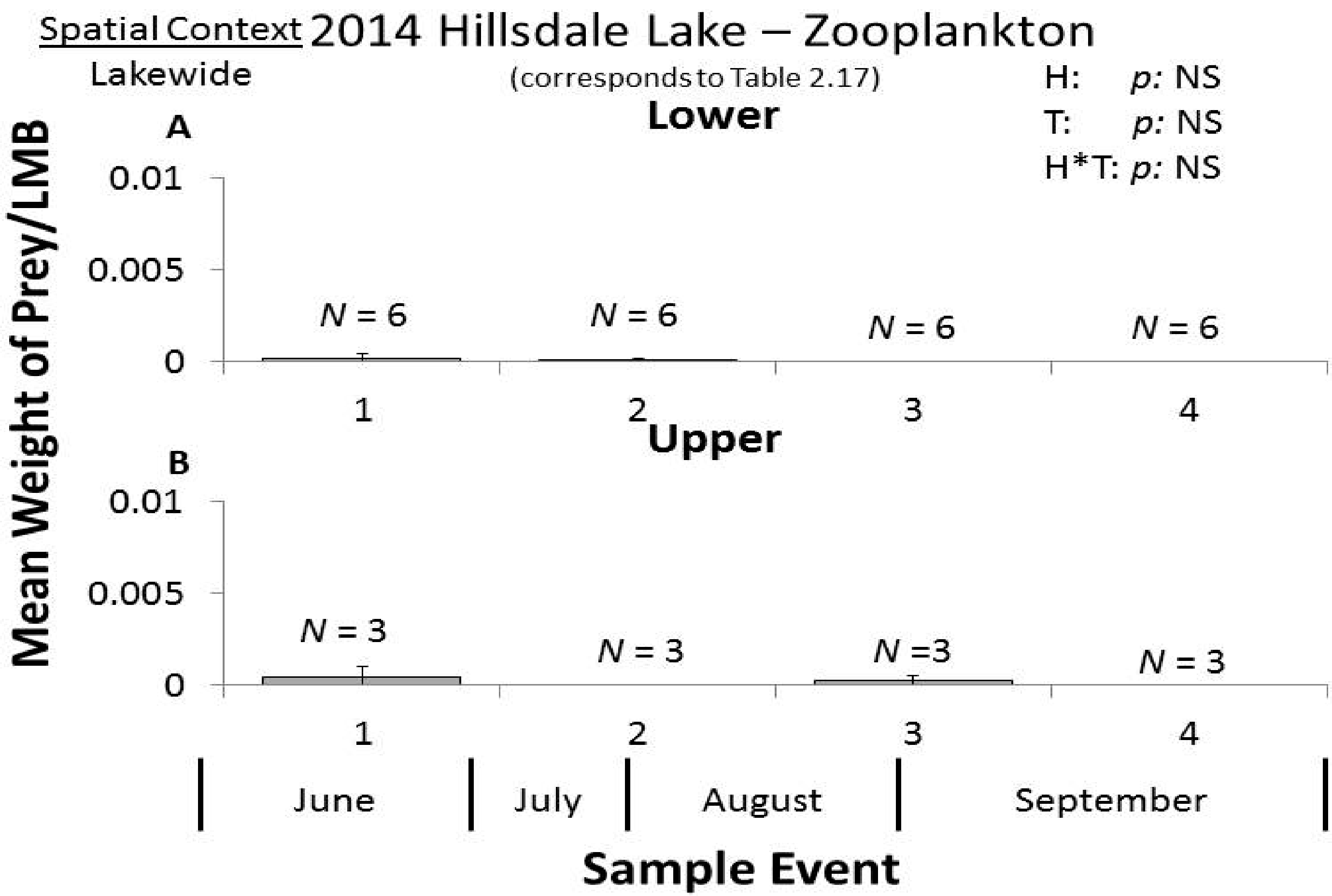

Figure 2.26: Mean weight of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

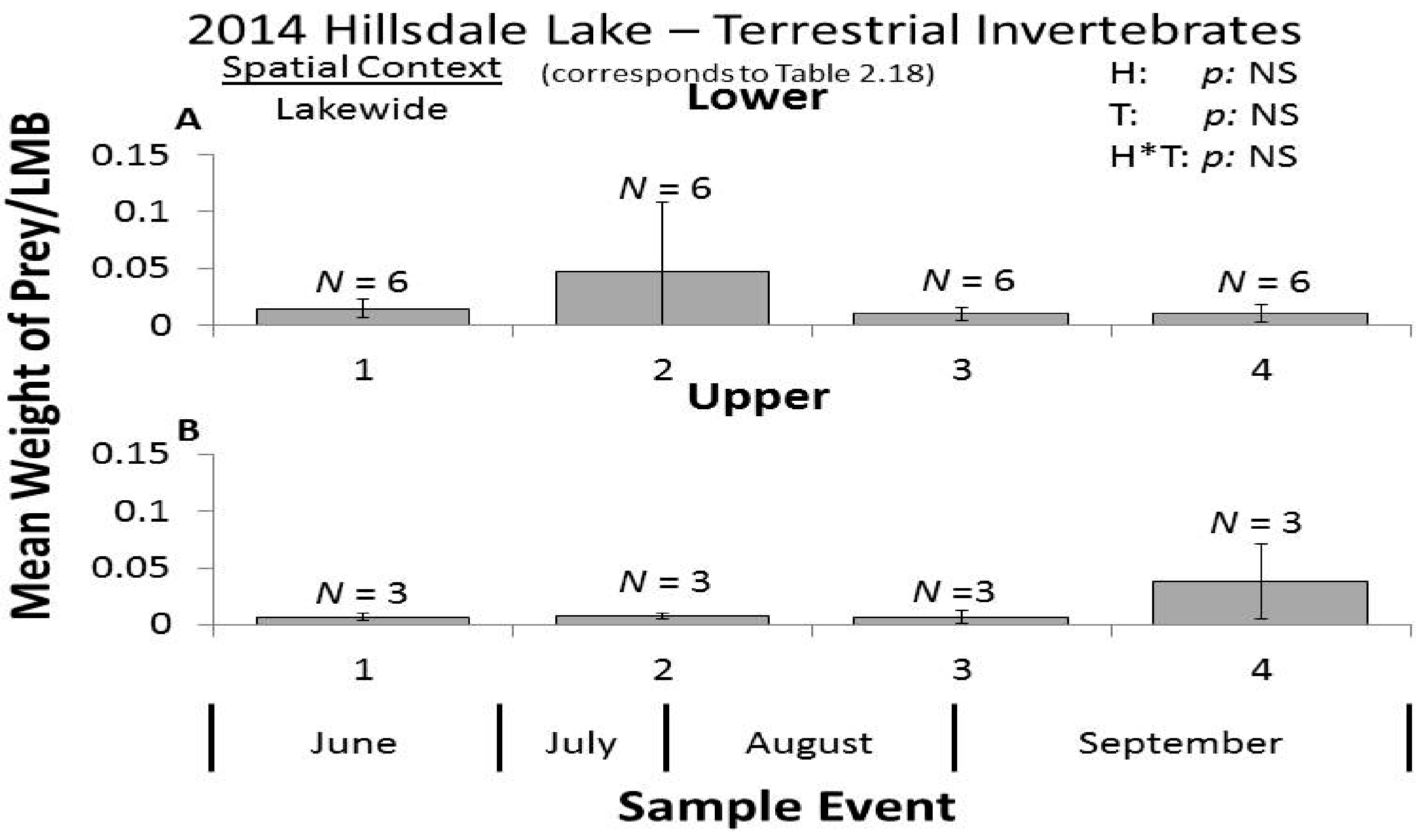

Figure 2.27: Mean weight of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

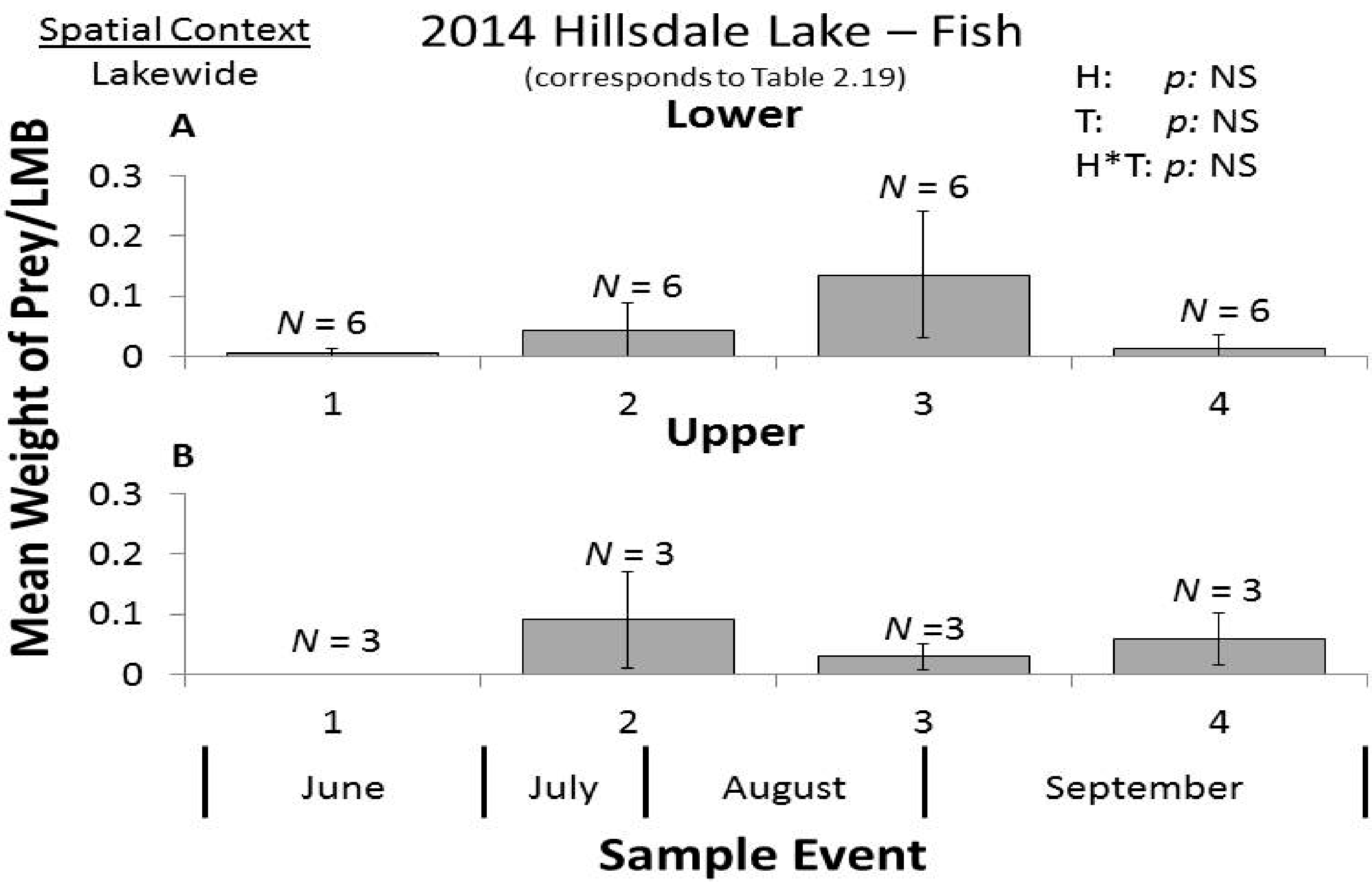

Figure 2.28: Mean weight of fish eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2014. Data are mean and standard error.

Appendix A - Size and Stocking

Goals

What Follows: In this appendix, I provide detailed plots related to young of year largemouth bass body size and stocking treatment. These plots provide substantial detail not seen elsewhere in the thesis. However, the take home messages are the same as those developed in detail earlier in Chapters 1-2. Because the synthesis and interpretation of overall trends are the same as developed and discussed earlier, I do not repeat that synthesis and interpretation here.

Background

Background – Body Size. Largemouth bass, like many fish, have size structured populations. Specifically, habitat use, diet, and predation risk can be affected by body size. However, it is critically important to recognize that the role of body size relative to habitat use and fish diet is most often examined over a large size range (often including multiple age classes) and a long time period (multiple seasons and years). The role of body size for a narrowly defined cohort (young of the year largemouth bass) over a limited time horizon (the first summer) is unclear. Trends during this narrow time period for a specific cohort is my focus here.

Much attention has been focused on the role of largemouth bass body size in the fall-winter transition, but less is known about patterns and consequences of differences in size of largemouth bass during the first summer. Overwinter survival during the first winter of life has been related to lipid content in the fall in some (Ludsin & DeVries 1997), but not all systems (Jackson & Noble 2000). Although larger fish accumulate greater lipid reserves during the fall (Miranda & Hubbard 1994), small and large largemouth bass can enter winter with similar lipid reserves despite the difference in body size (Jacobs et al. 2011). My study contributes substantially to a rigorous test of the role of body size but focuses on the summer period only.

Body size and gape limitation <u>can</u> be important drivers of young of year largemouth bass distribution, habitat use (Ludsin and DeVries 1997), but diet and habitat are <u>not always</u> correlated with young of year largemouth bass size (Olson et al. 2003). Diet can change as largemouth bass transition from larvae to small juvenile to larger juvenile during the first summer of life. For example, during the first year of life largemouth bass often undergo ontogenetic niche shifts that follow a predictable pattern of feeding on zooplankton, then invertebrate prey, and finally fish are added to the diet (Ludsin & DeVries 1997). Because largemouth bass are gape limited predators, the size of their mouth limits the maximum size of prey that young of year largemouth bass can consume (Post 2003). Specifically, small largemouth bass eat only small prey whereas larger bass can eat both larger and smaller prey. However, diet and habitat are <u>not always</u> correlated with young of year largemouth bass size (Olson et al. 2003) and the relationship among size, distribution, and diet can be complex and dynamic (Bettoli et al. 1992).

Background – Largemouth Bass Stocking. Supplemental stocking of early spawned largemouth bass can provide stocked fish with a size advantage that could lead to increased growth and survival (Olson 1996, Parkos and Wahl 2002). Thirteen states stock largemouth bass to either supplement poor recruitment or to satisfy anglers. Except for the current Kansas Department of Wildlife. Parks, and Tourism stocking program, only West Virginia stocks multiple size classes of fish (Siepker and Casto-Yerty 2008).

Relatively little is known about how stocked largemouth bass behave. Stocked largemouth bass can disperse more than 600 m from the stocking location, but after approximately 10 – 14 days, habitat use of stocked largemouth bass is similar to that of wild largemouth bass (Hoffman & Bettoli 2005). During this post stocking period when fish are more mobile, stocked largemouth bass can experience high mortality. After approximately seven days, however, mortality stabilizes (Thompson et al. 2016). Diet composition and growth is often similar between wild and stocked largemouth bass during the first summer (Hoffman & Bettoli 2005, Diana & Wahl 2009). Wild largemouth bass that naturally hatch earlier in the season can have increased growth, survival, and include more fish in the diets (Parkos & Wahl 2002, Post 2003), but these differences have not been tested in early spawned hatchery fish.

Methods.

The methods for data collection and analysis are described in Chapters 1-2.

Size and Stocking Specific Results.

Size by Stocking Treatment. During both sample years, phase 2 fish were larger on average than the other two stocking treatments (2014: $p < 0.0001$, Fig. A.1; 2015: $p < 0.0001$, Fig. A.2). Wild fish were smallest on average during 2015 ($p < 0.0001$, Fig. A.2). Phase 1 fish, were variable, and on average, were smaller than expected during 2014 ($p < 0.0001$, Fig. A.2) and intermediate, as expected, in 2015 (Fig. A2).

Size and Stocking Treatment Trends Through Time. Through time, wild fish were smaller initially and remained the smallest group at the end of the summer sampling season in both 2014 (Fig. A.3) and 2015 (Fig. A.4). Phase 2 fish started larger in early summer and were large at the end of the summer sampling season. Phase 1 fish had a more variable response.

CPUE. CPUE of wild largemouth bass was slightly higher than CPUE of either stocking treatment during both sample years (2014: $p < 0.0001$, Fig. A.5; 2015: $p < 0.0001$, Fig. A.6). CPUE across habitats reflected similar patterns during both sample years (NS, Figs. A.7 - A.8).

Diet. In both years, diet composition was similar across stocking treatments for all habitats (NS, Fig. A.9-2014; Fig. A10-2015), for fish in vegetation (NS, Fig. A.10-2014; Fig. A.11-2015), and for fish caught in the beach habitat (NS, Fig. A.11-2014; Fig. A.12-2015).

Numbers of Prey Eaten Relative to Largemouth Bass Size. Numbers of prey eaten (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish prey) were not related to young of year largemouth bass body size in 2014 (Fig. A.15) or 2015 (Fig. A.16). Nor was a relationship observed between numbers of prey and largemouth bass body size within and across habitats for benthic invertebrates (Fig. A.17-2014; A.20-2015), zooplankton (Fig. A.18-2014; A.22-2015), terrestrial invertebrates (Fig. A.19-2014; A.23-2015), or fish prey (Fig. A.20-2014; A.24-2015).

Weight of Prey Eaten Relative to Largemouth Bass Size. Weight of prey eaten (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish prey) also was not related to young of year largemouth bass body size in 2014 (Fig. A.25) or 2015 (Fig. A.26). Nor was a relationship observed between weight of prey and largemouth bass size within and across habitats for benthic invertebrates (Fig. A.27-2014; A.31-2015), zooplankton (Fig. A.28-2014; A.32-2015), terrestrial invertebrates (Fig. A.29-2014; A.33-2015), and fish prey (Fig. A.30-2014; A.34-2015).

For both number and weight of a prey, a few largemouth bass often ate more (e.g., Fig. A.25-A.30), but this pattern was related to unique individuals not general changes in body size.

Overall Take Home Messages - Size and Stocking

- **Size.** Early spawned largemouth bass fish were larger than wild largemouth bass. Early spawned largemouth bass were larger at stocking and remained larger throughout the summer.
- **Numbers**. Hillsdale Lake had many young largemouth bass in 2014-2015. Wild fish were more abundant than early spawned largemouth bass but all groups (wild and hatchery) performed well.
- **Habitat**. Both wild and early spawned largemouth bass used vegetated and beach habitats in the same way. Both habitats were suitable for young of year largemouth bass.
- **Diet by Habitat**. No difference existed in diet by habitat (all fish are did well in both habitats).
- **Diet by Stocking Treatment**. No difference existed in diet by stocking treatment. Wild and early spawned largemouth bass both fed well.
- **Diet by Size.** No difference existed in diet by size. However, relatively speaking, all largemouth bass were relatively small.
- **Management Implications**. The hatchery and stocking programs were very effective. Whether any largemouth bass survive to creel/trophy size will need to be assessed by the agency as these young fish survive through the years

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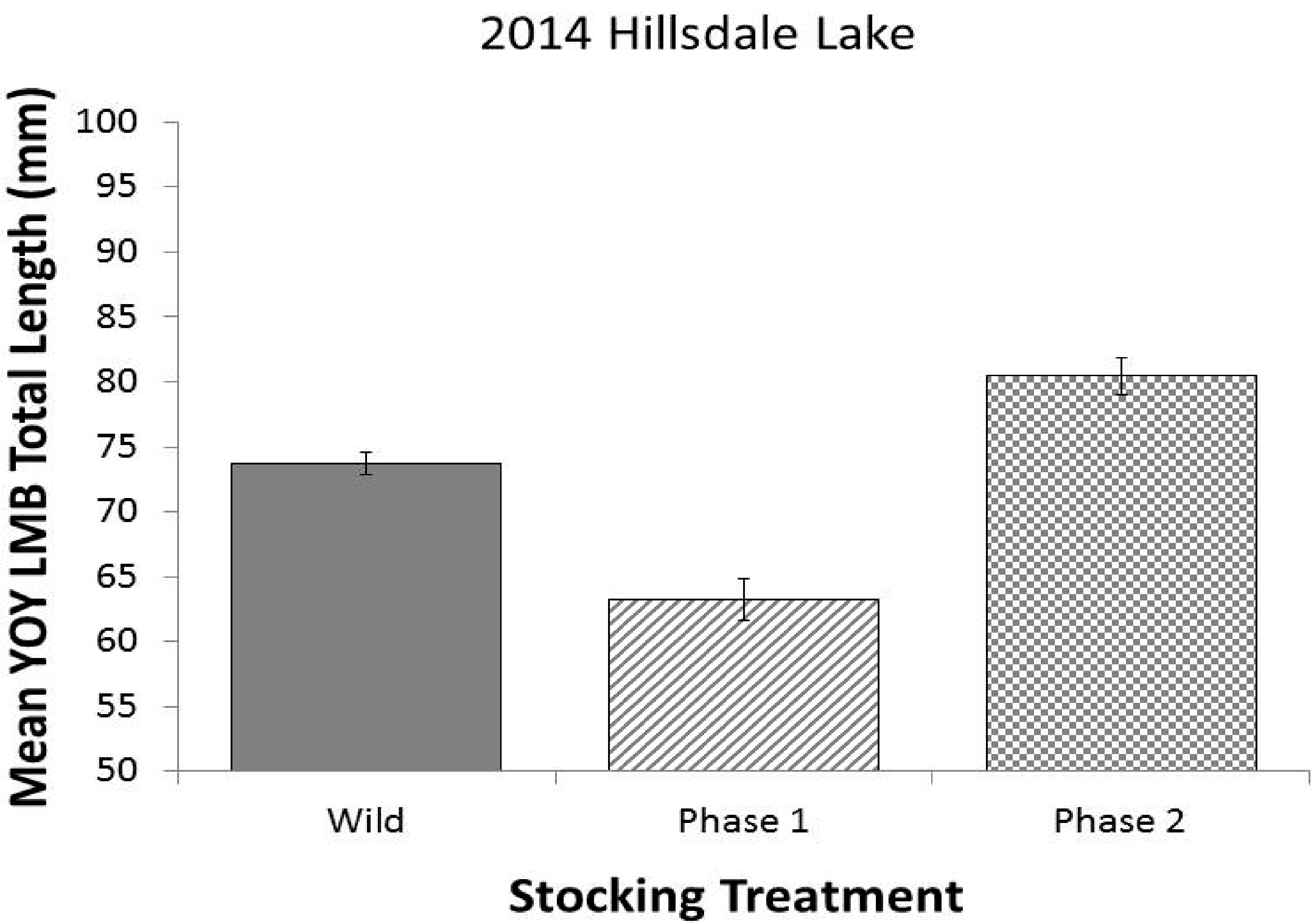

Figure A.1: Mean total length (mm) of young of year largemouth bass by stocking treatment in Hillsdale Lake, KS during 2014.

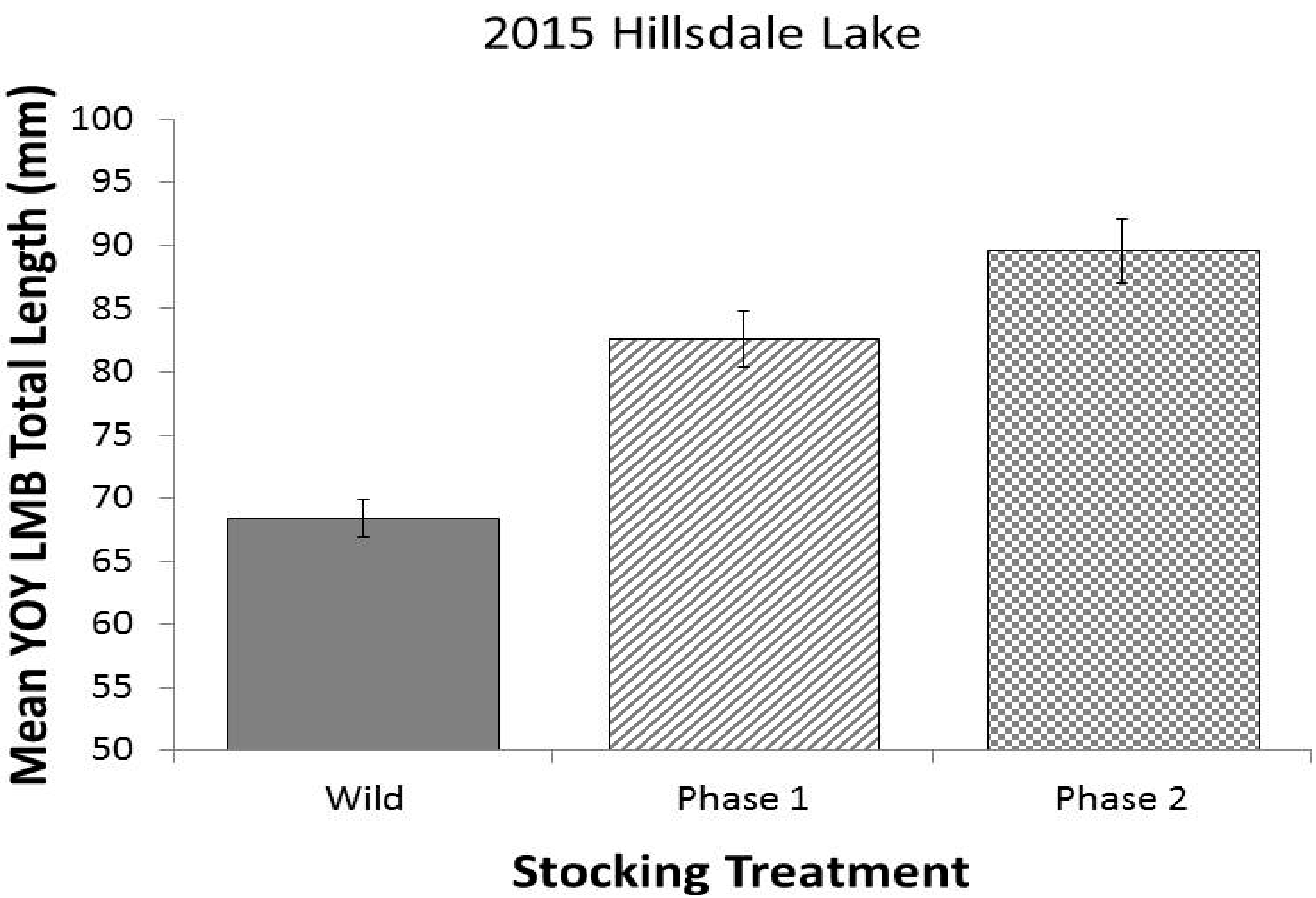

Figure A.2: Mean total length (mm) of young of year largemouth bass by stocking treatment in Hillsdale Lake, KS during 2015.

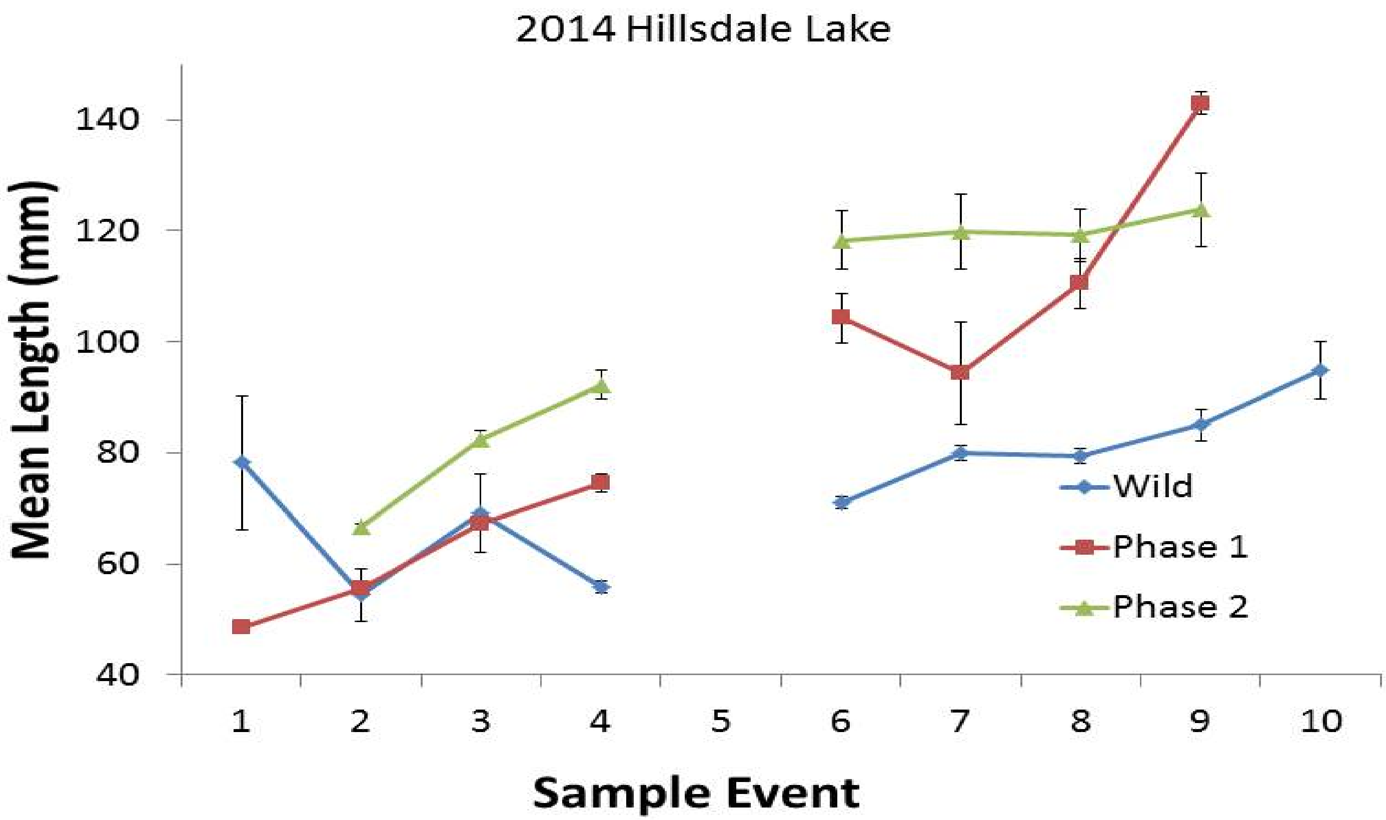

Figure A.3: Mean total length of three stocking treatments (wild, phase 1, phase 2) of young of year largemouth bass across four sample events in Hillsdale Lake, KS during 2014. Data are mean and standard error.

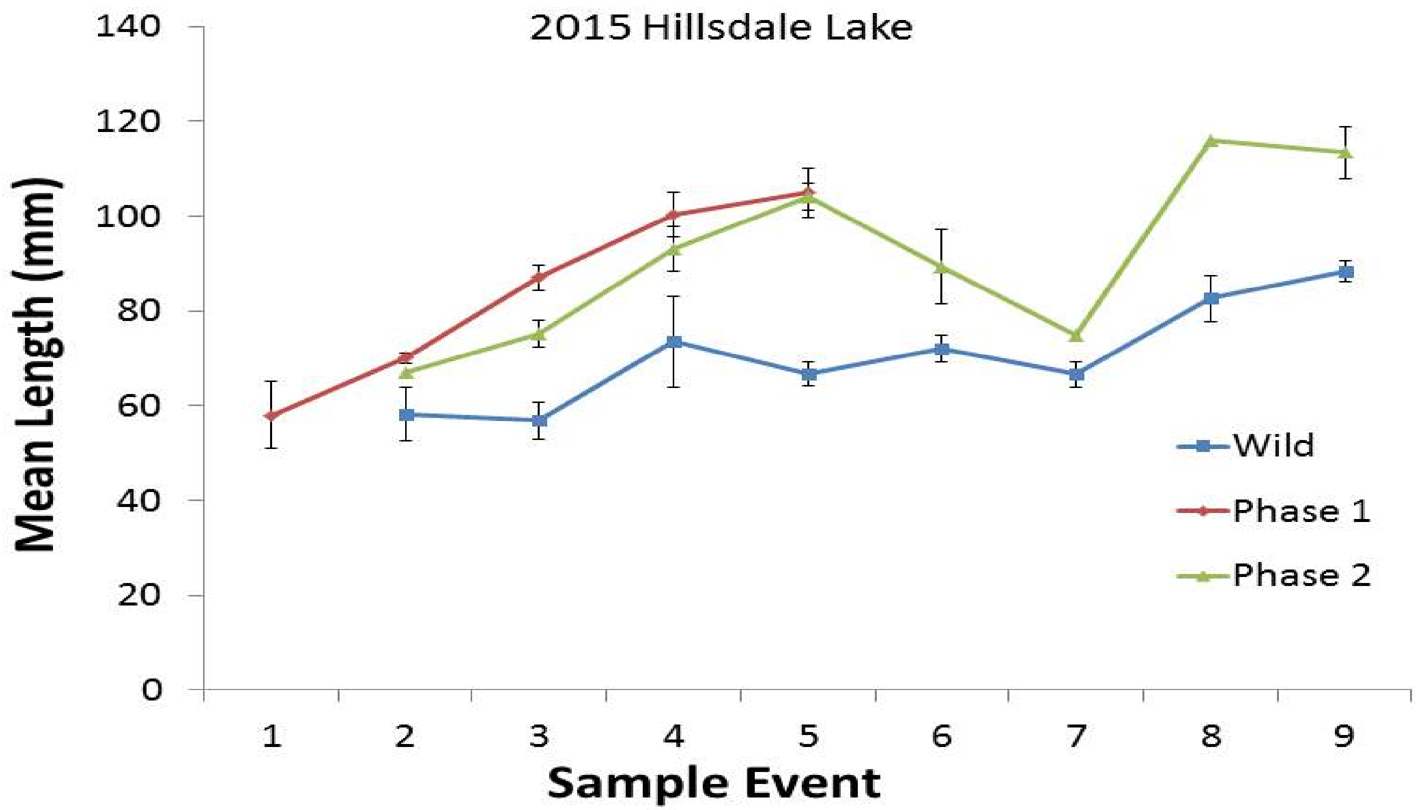

Figure A.4: Mean total length of three stocking treatments (wild, phase 1, phase 2) of young of year largemouth bass across four sample events in Hillsdale Lake, KS during 2015. Data are mean and standard error.

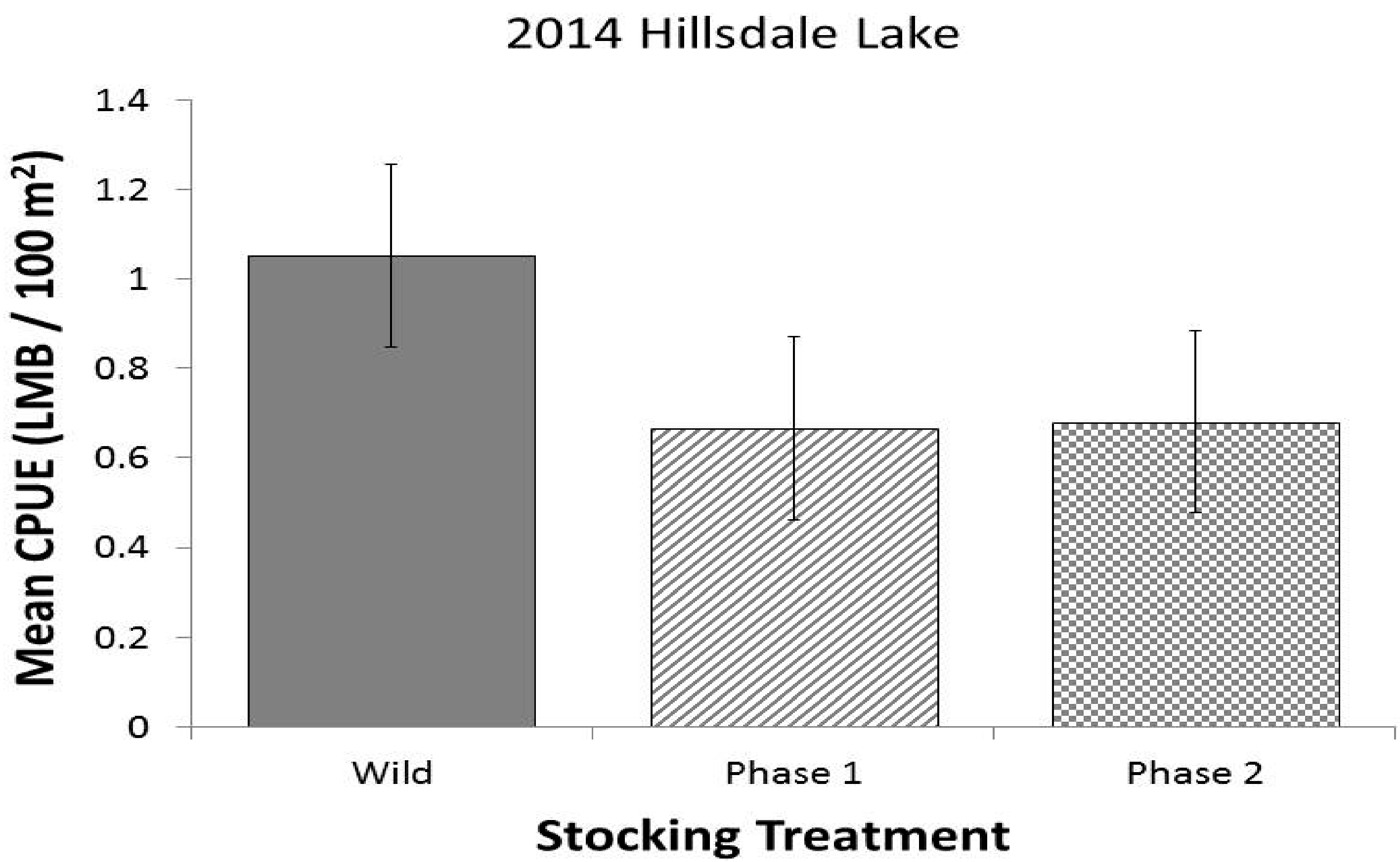

Figure A.5: Mean CPUE of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2014.

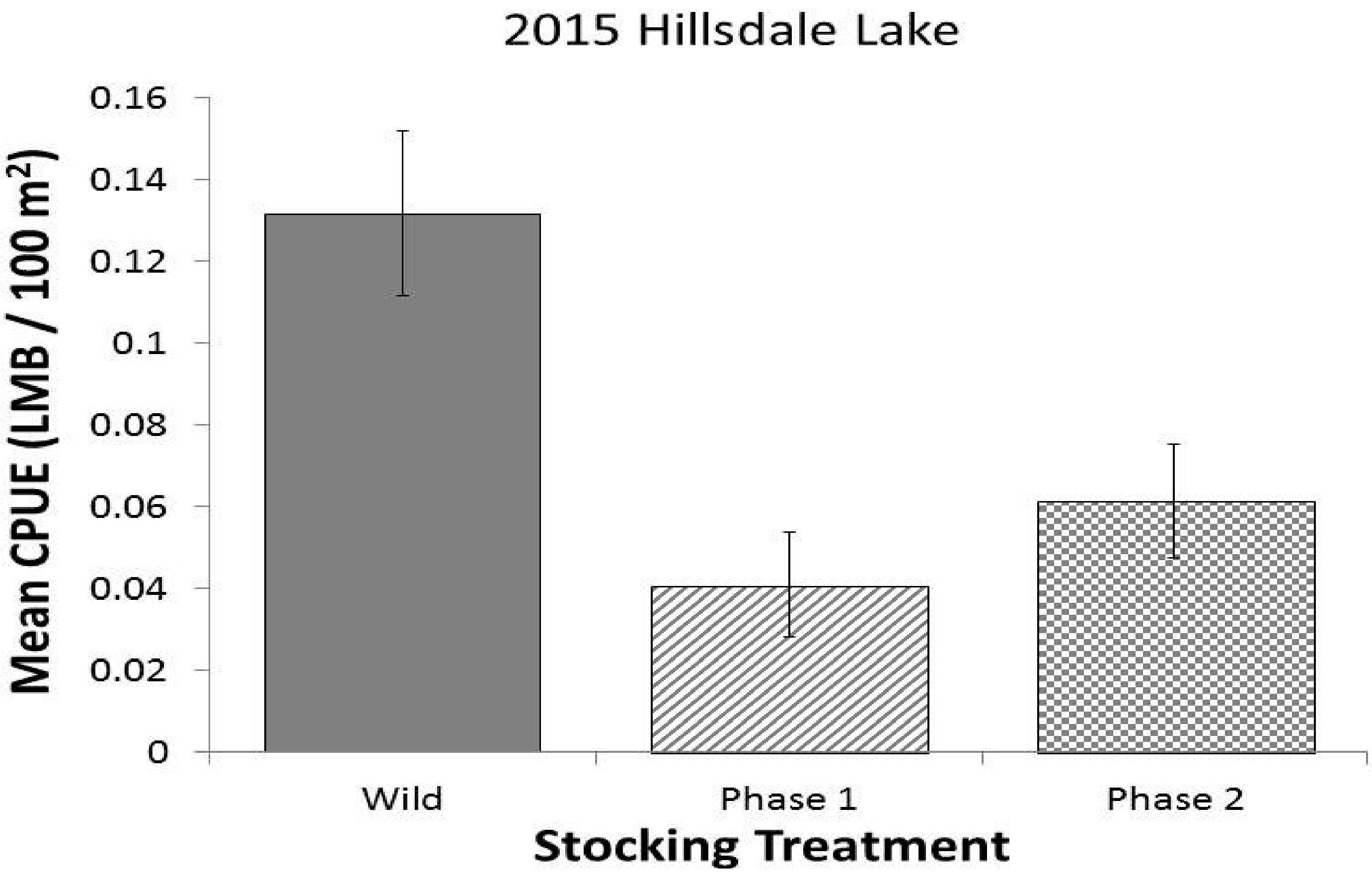

Figure A.6: Mean CPUE of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2015.

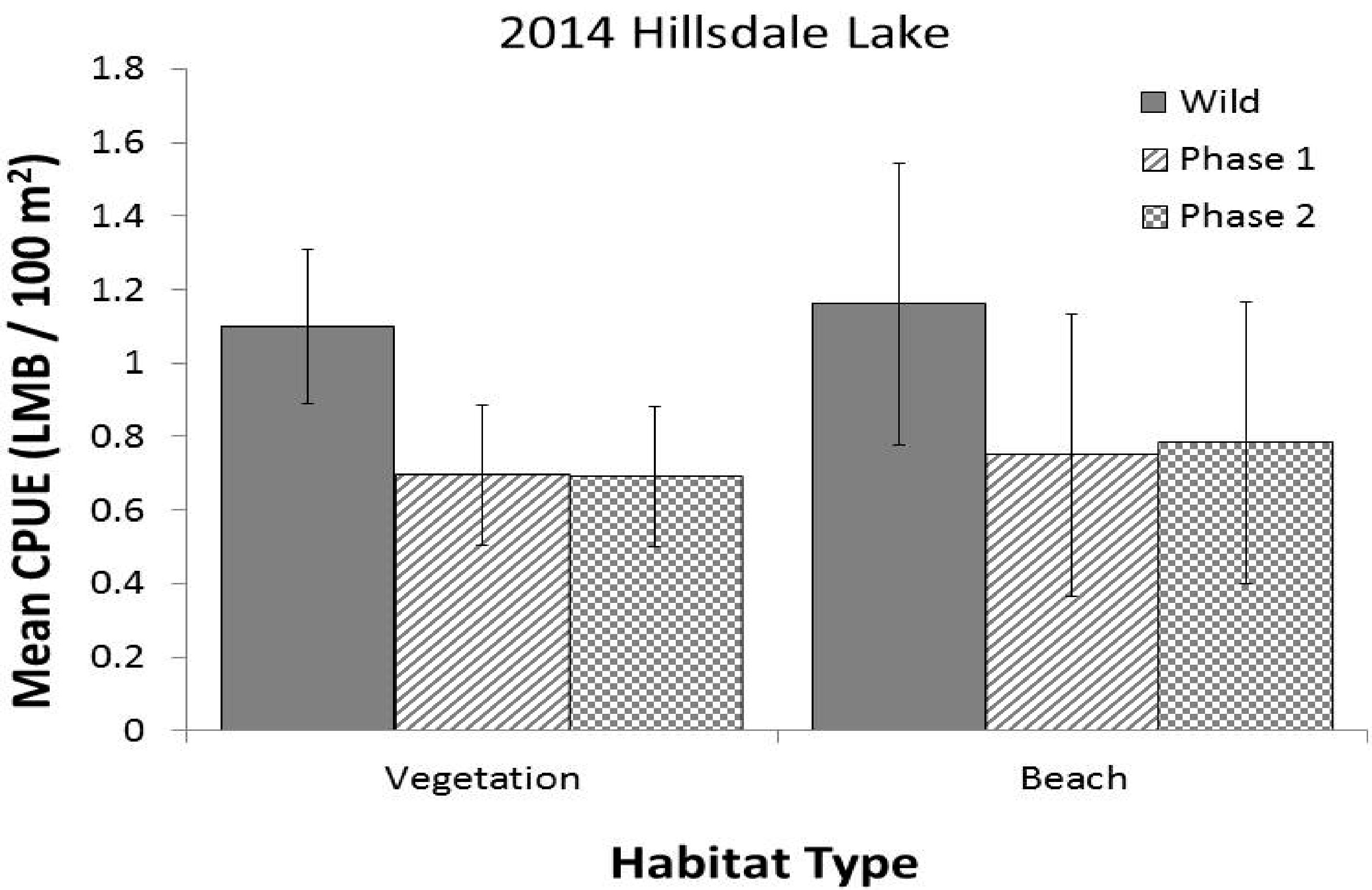

Figure A.7: Mean CPUE of three stocking treatments of young of year largemouth bass across two habitat types (vegetation, beach) in Hillsdale Lake, KS during 2014.

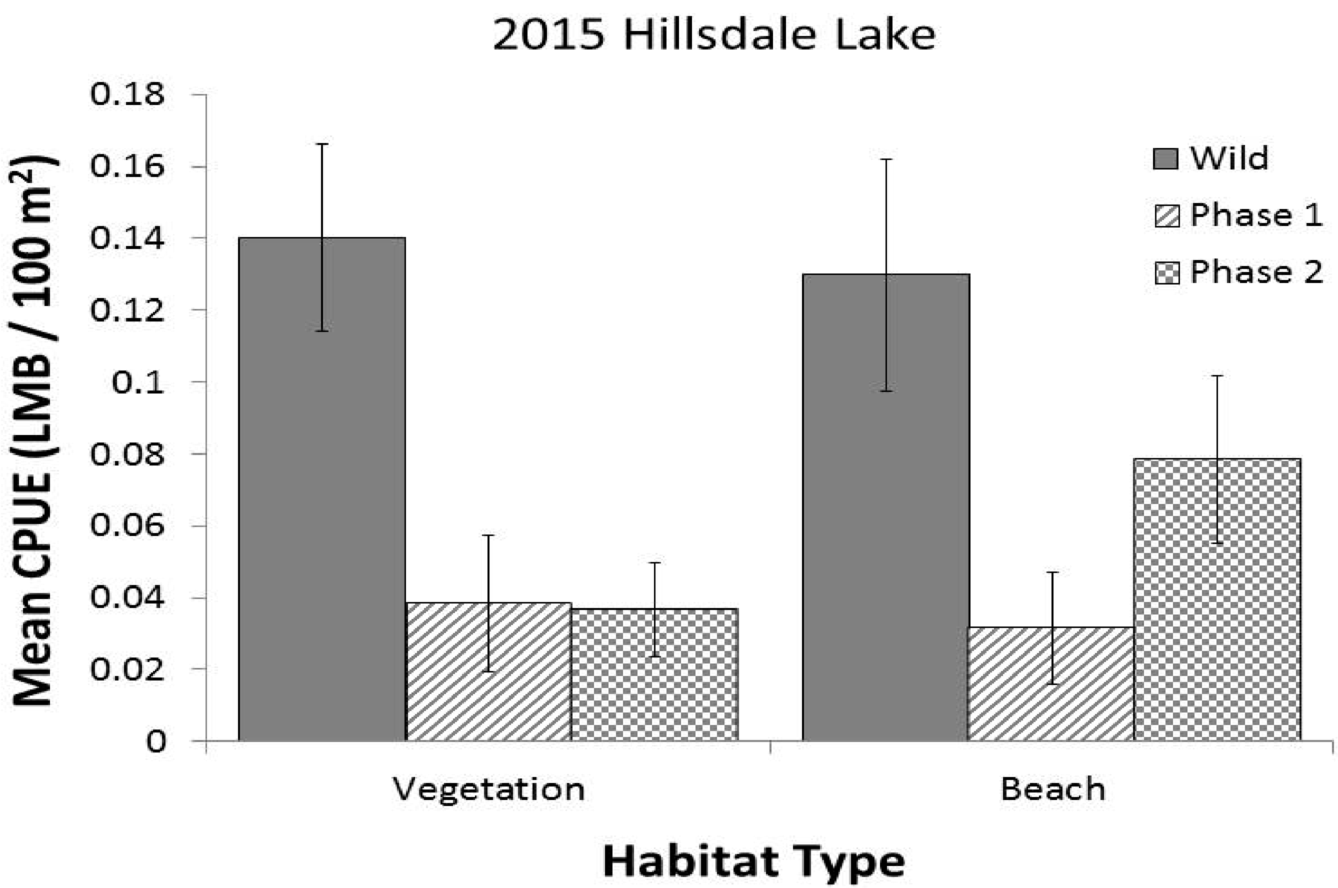

Figure A.8: Mean CPUE of three stocking treatments of young of year largemouth bass across two habitat types (vegetation, beach) in Hillsdale Lake, KS during 2015.

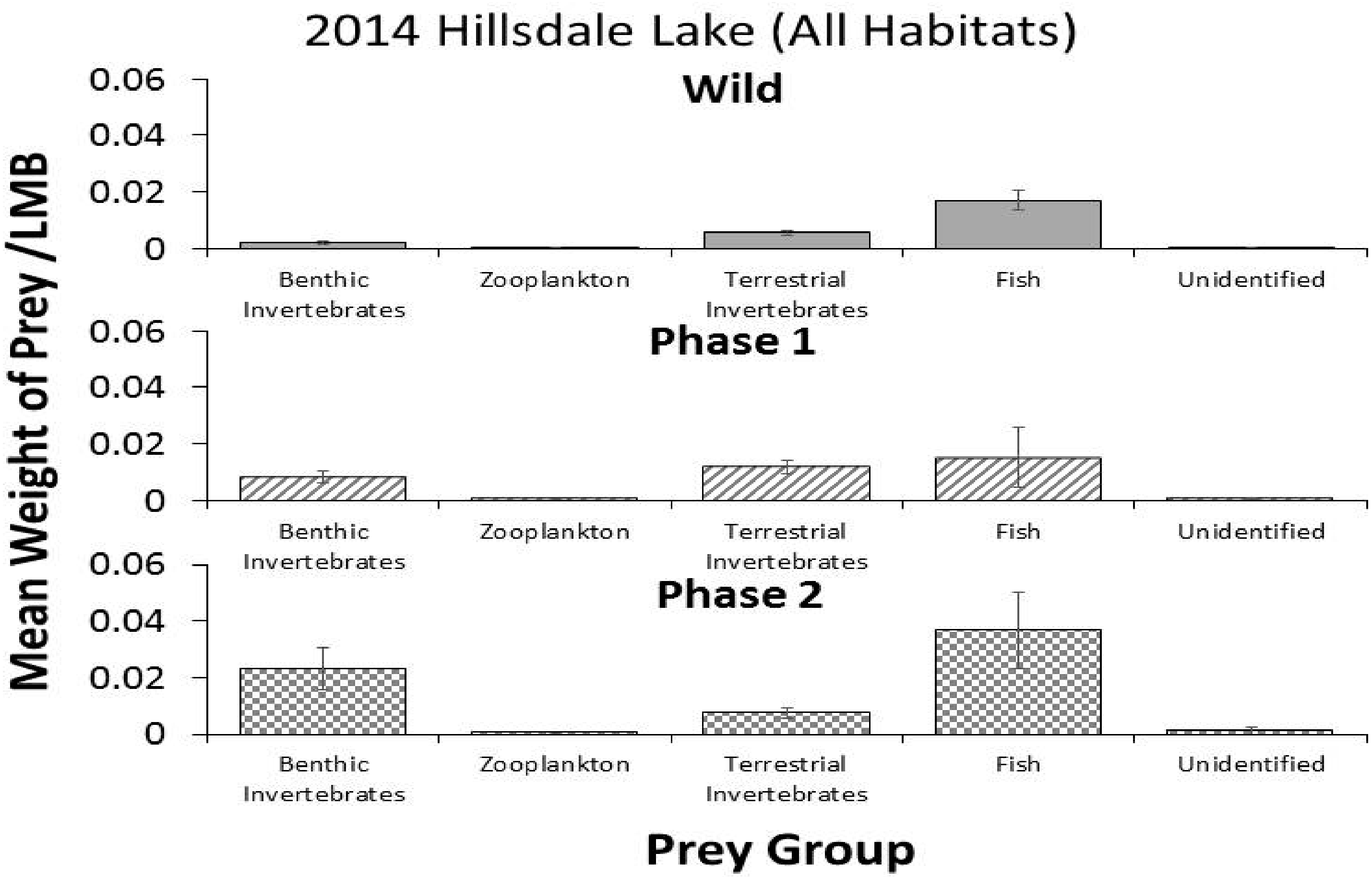

Figure A.9: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) across all habitats in Hillsdale Lake, KS during 2014.

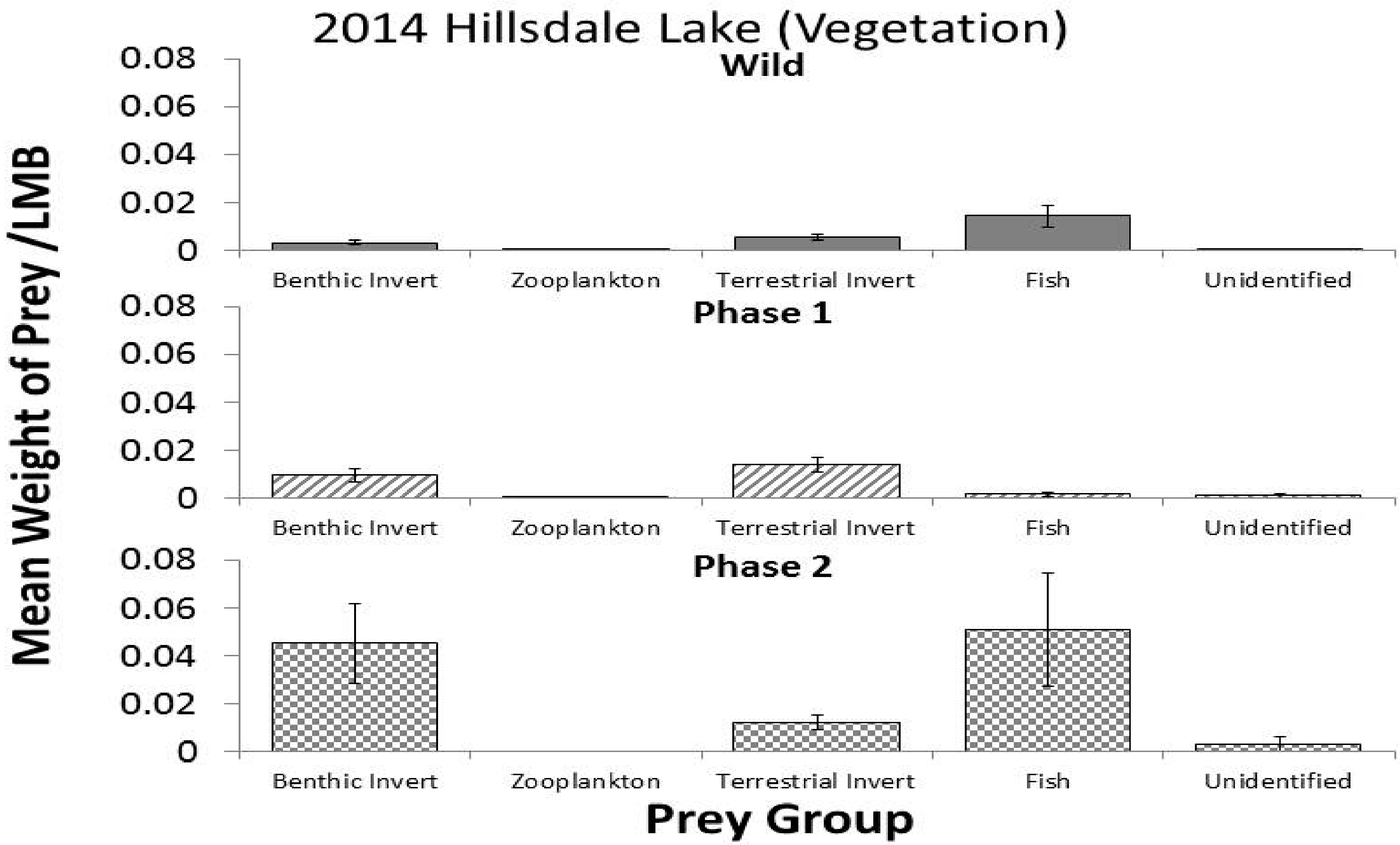

Figure A.10: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) in vegetated habitats in Hillsdale Lake, KS during 2014.

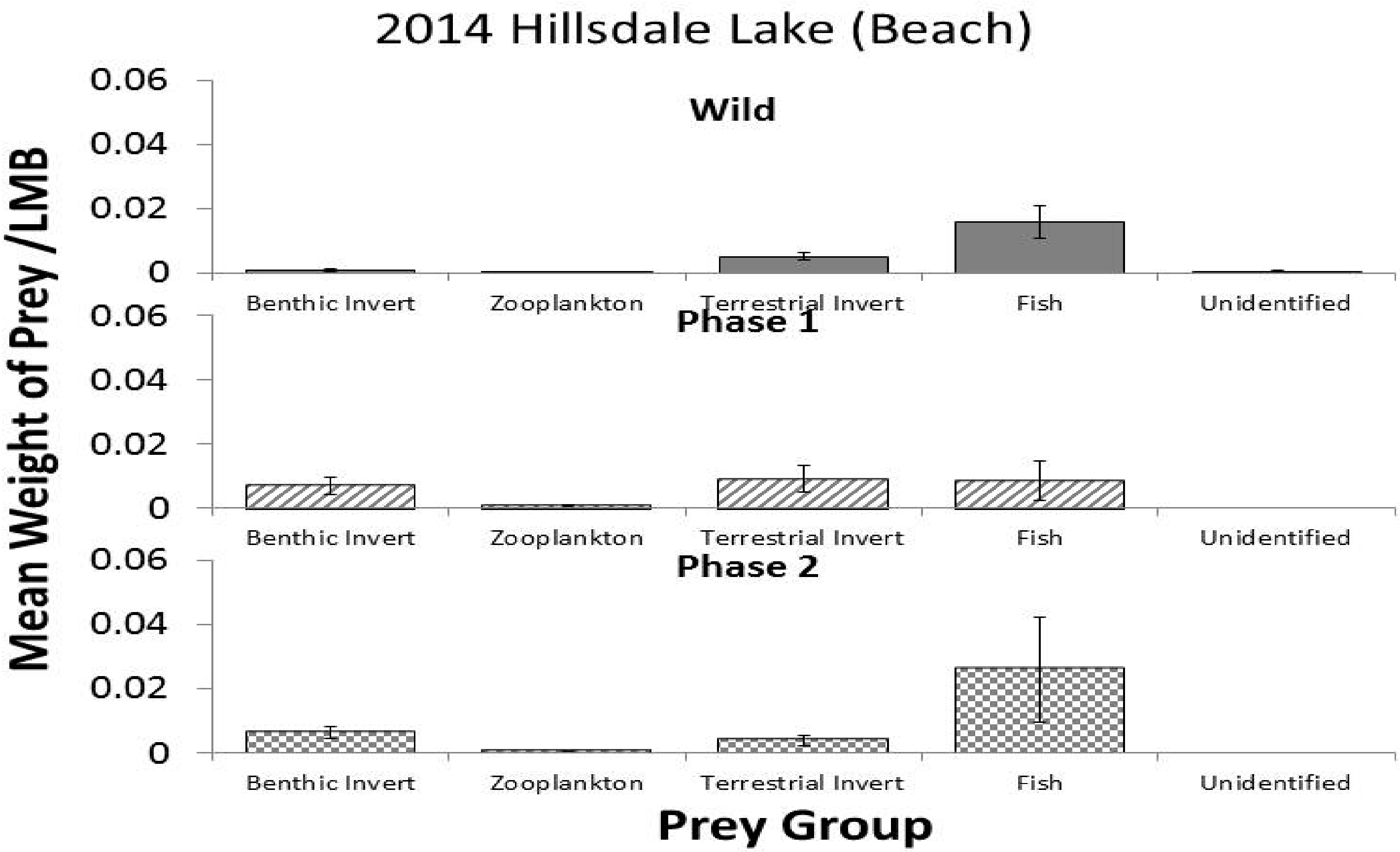

Figure A.11: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) in beach habitats in Hillsdale Lake, KS during 2014.

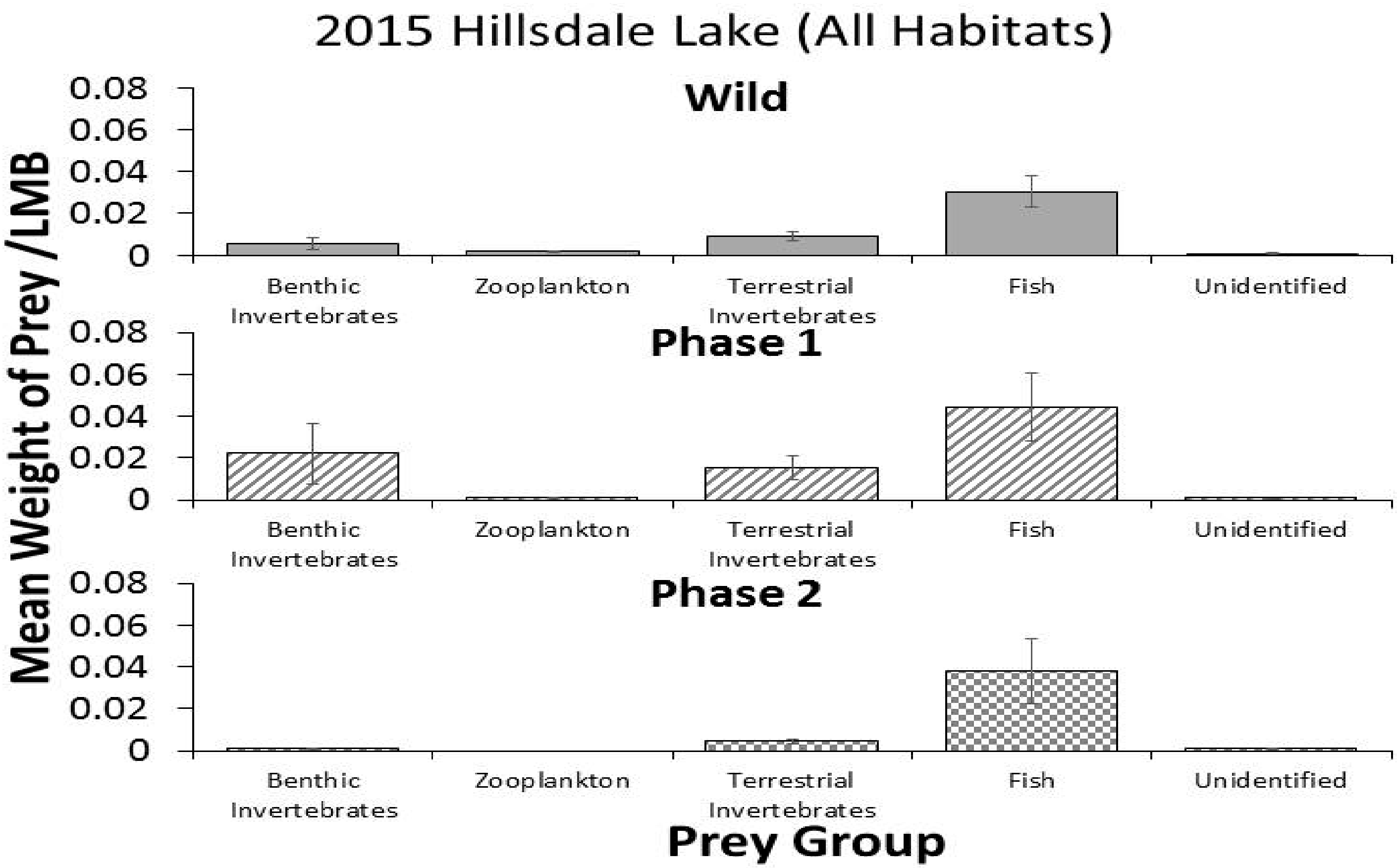

Figure A.12: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) across all habitats in Hillsdale Lake, KS during 2015.

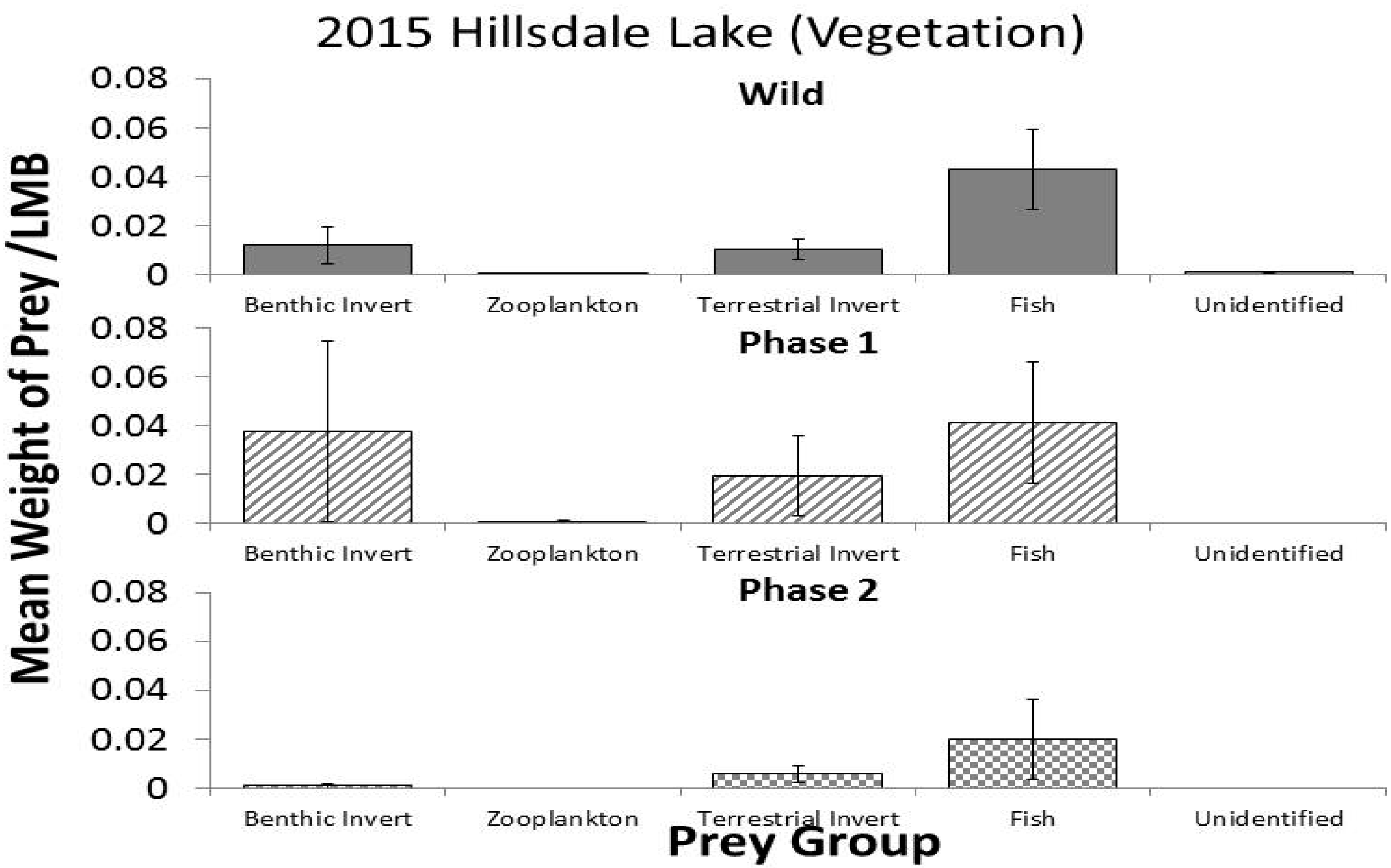

Figure A.13: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) in vegetated habitats in Hillsdale Lake, KS during 2015.

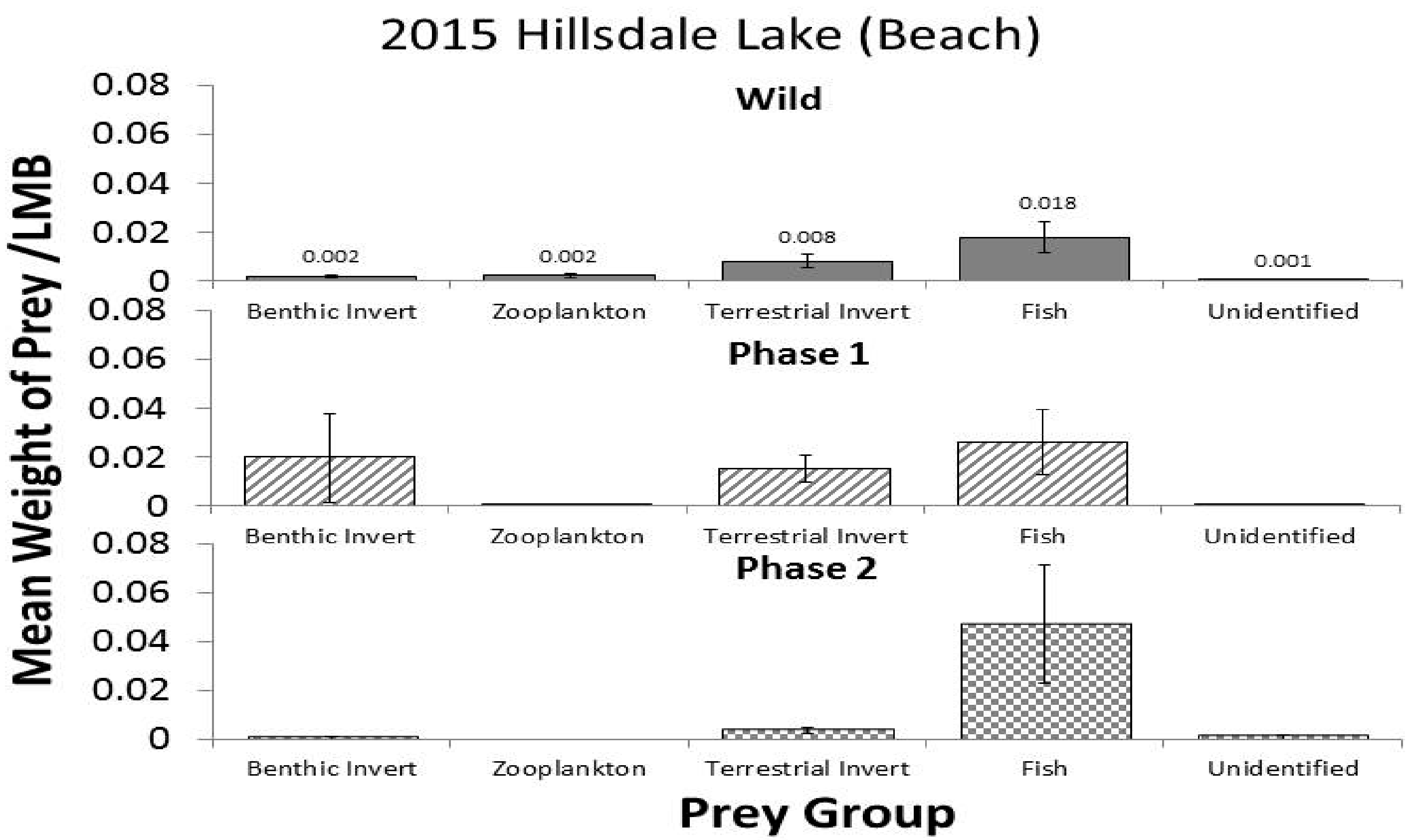

Figure A.14: Mean weight of prey consumed by prey group (benthic invertebrates, zooplankton, terrestrial invertebrates, fish, and unidentified) for three stocking treatments (wild, phase 1, phase 2) in beach habitats in Hillsdale Lake, KS during 2015.

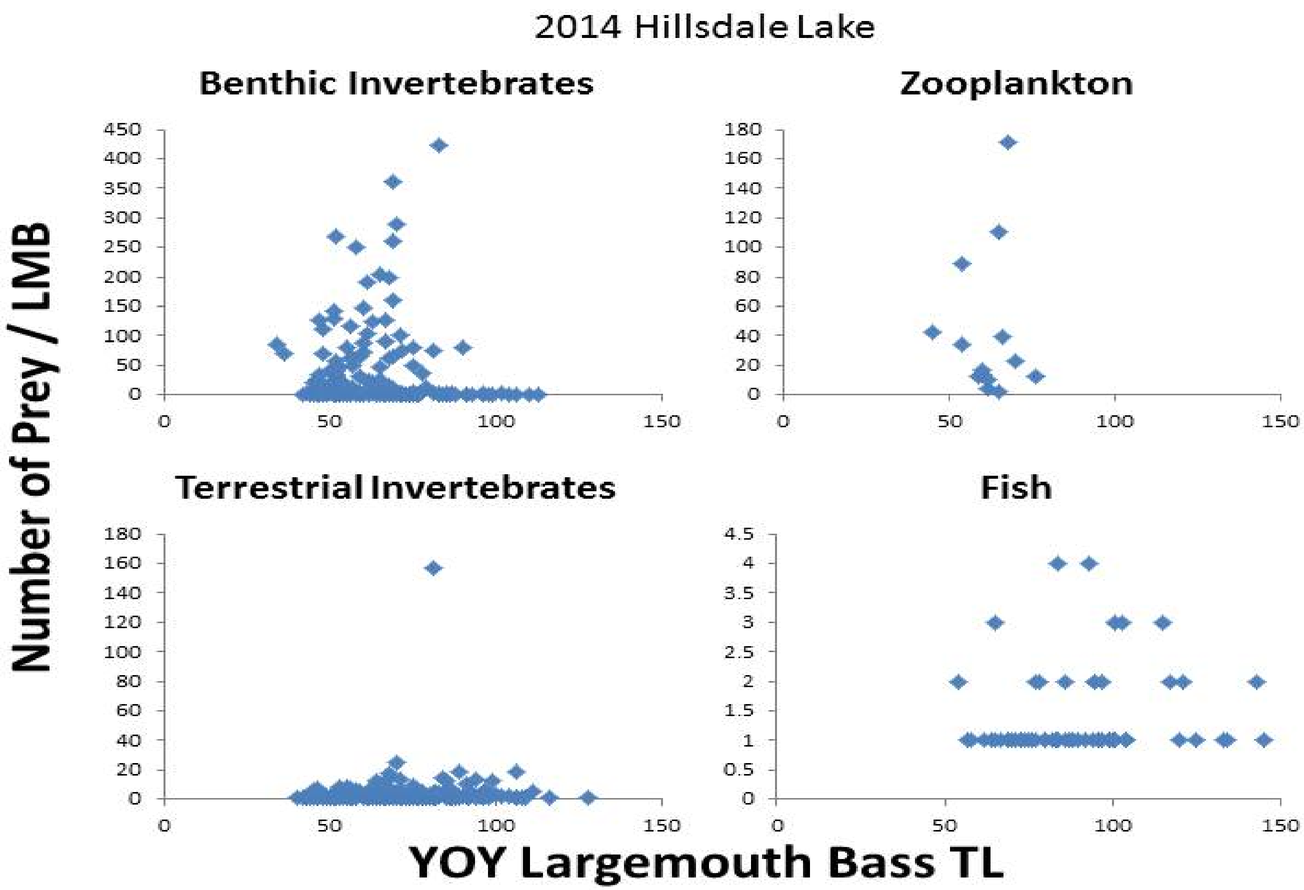

Figure A.15: Number of prey consumed by young of year largemouth bass total length (mm) for four prey groups (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish) in Hillsdale Lake, KS during 2014.

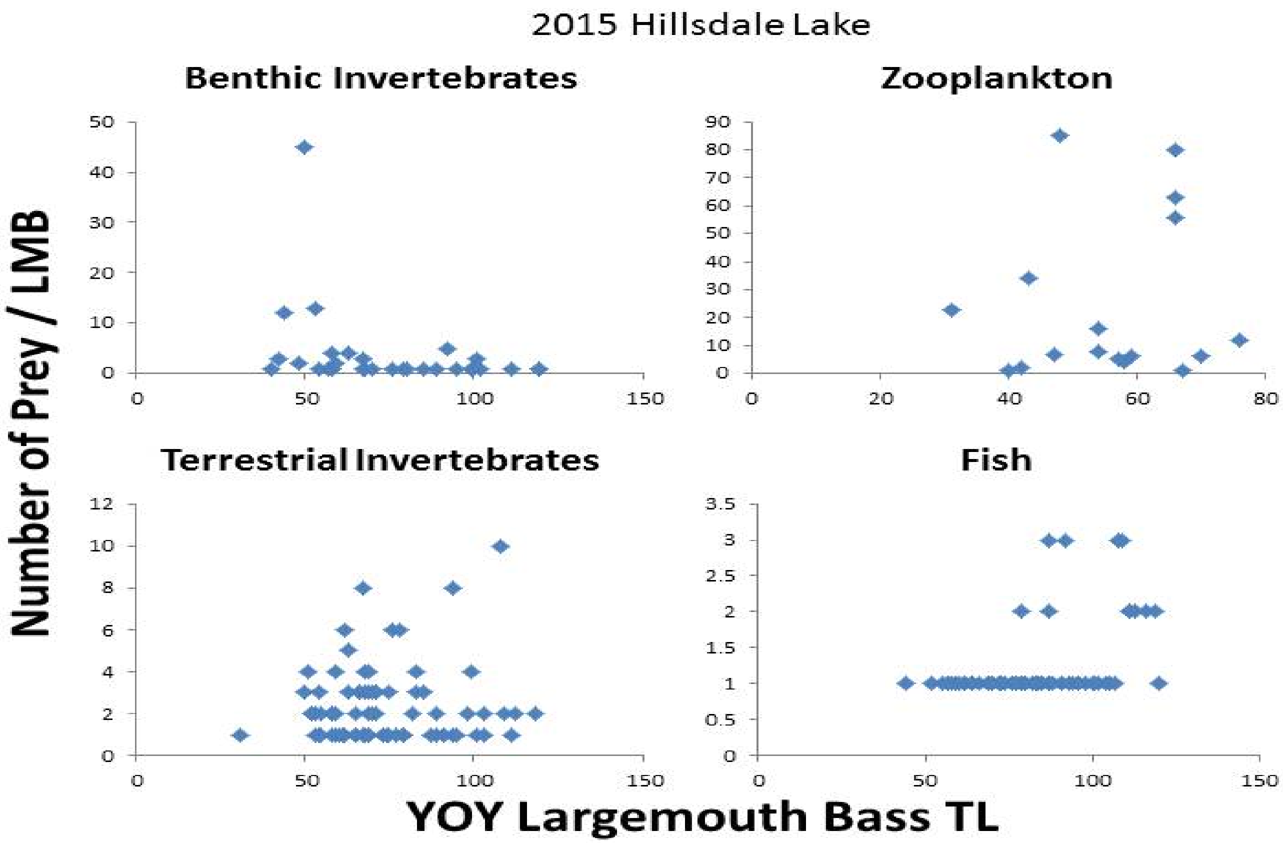

Figure A.16: Number of prey consumed by young of year largemouth bass total length (mm) for four prey groups (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish) in Hillsdale Lake, KS during 2015.

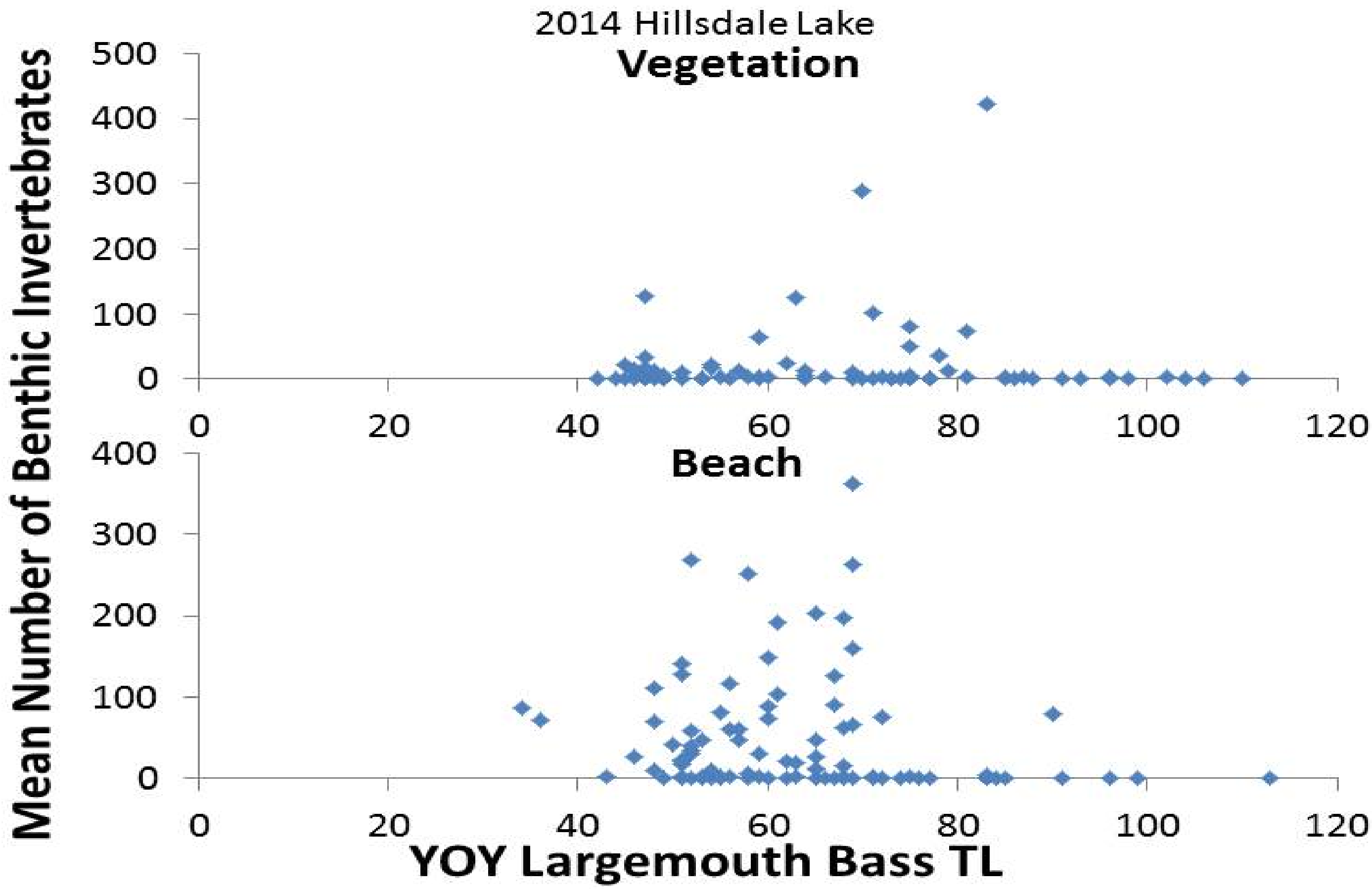

Figure A.17: Number of benthic invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

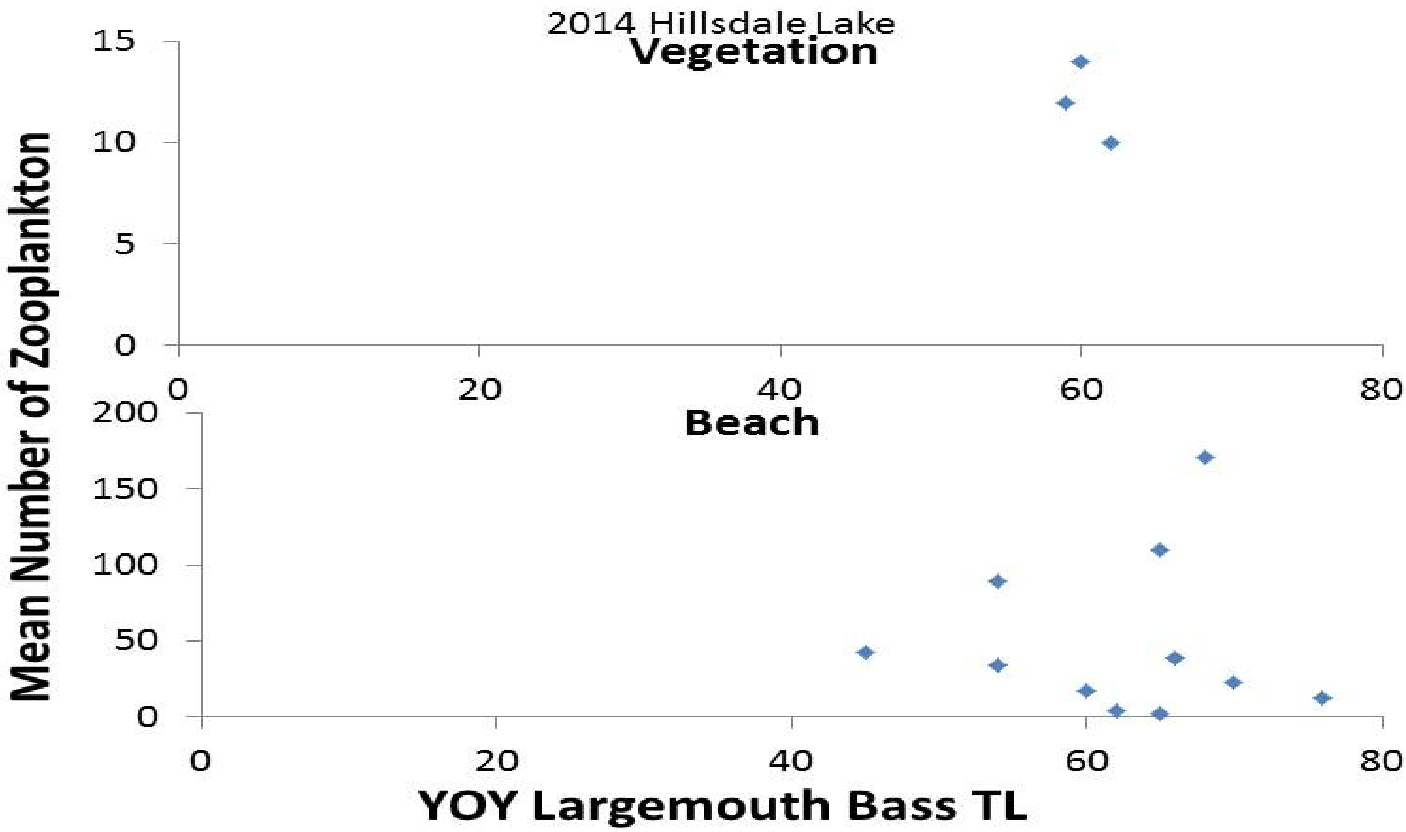

Figure A.18: Number of zooplankton consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

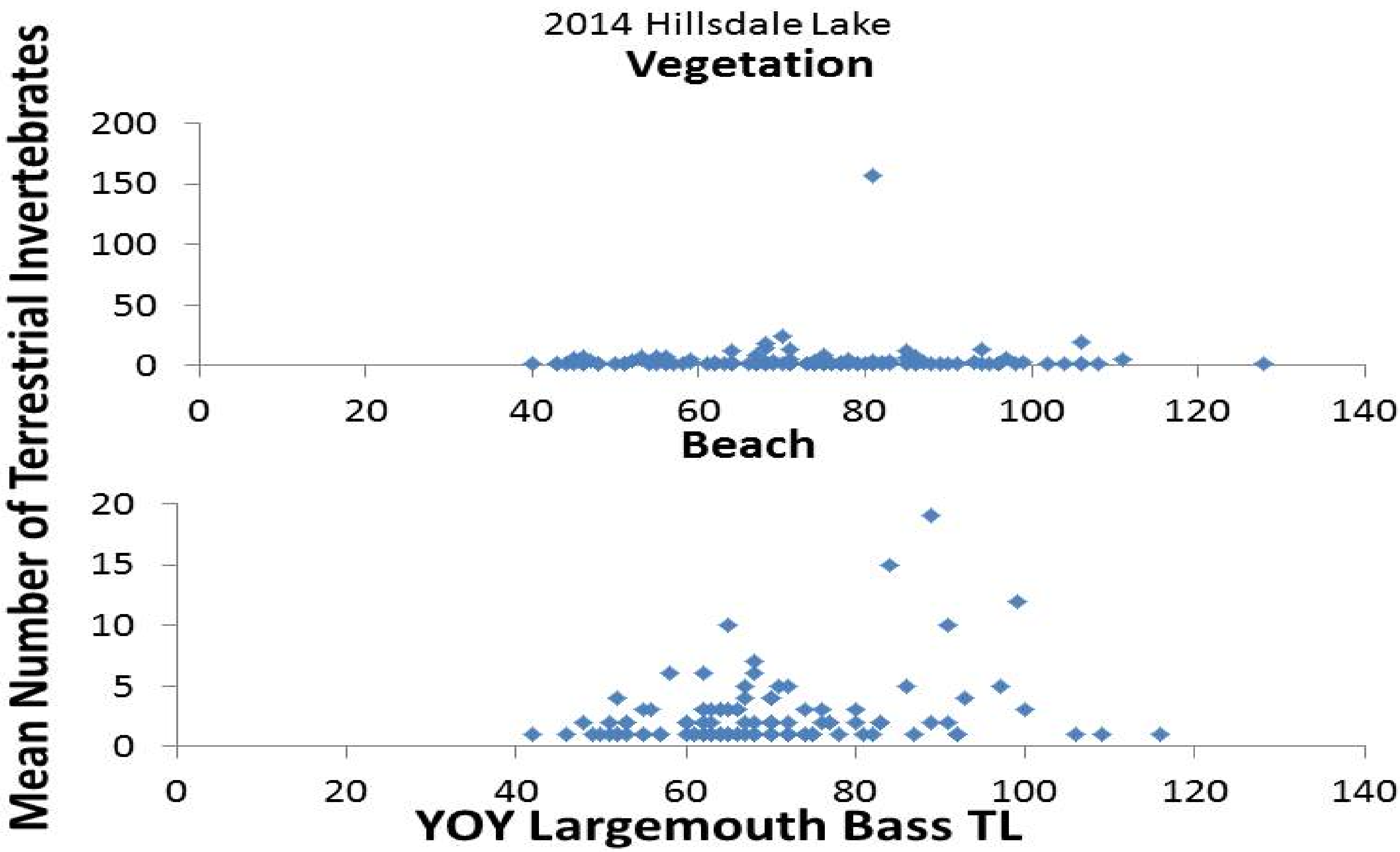

Figure A.19: Number of terrestrial invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

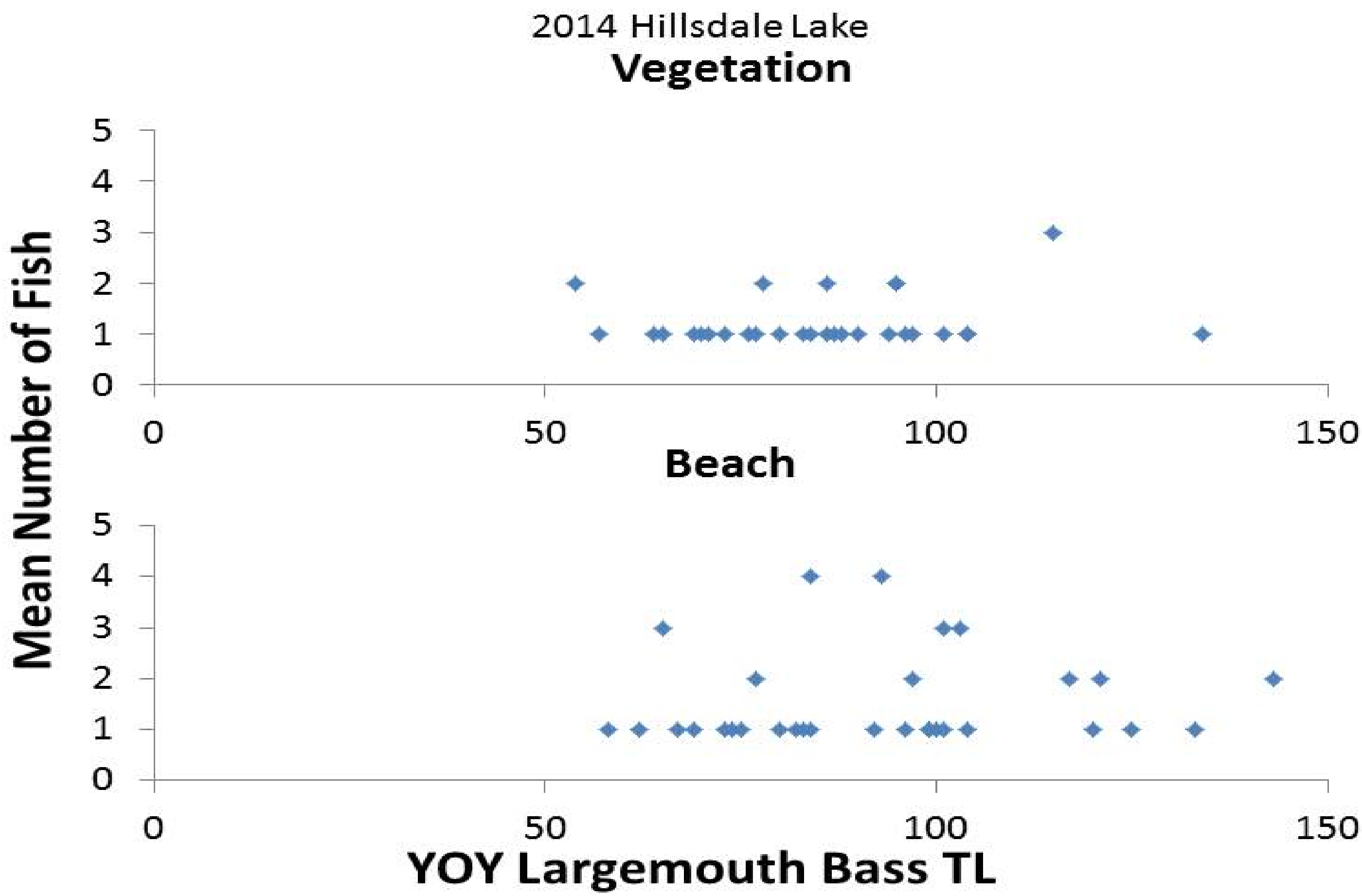

Figure A.20: Number of fish consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

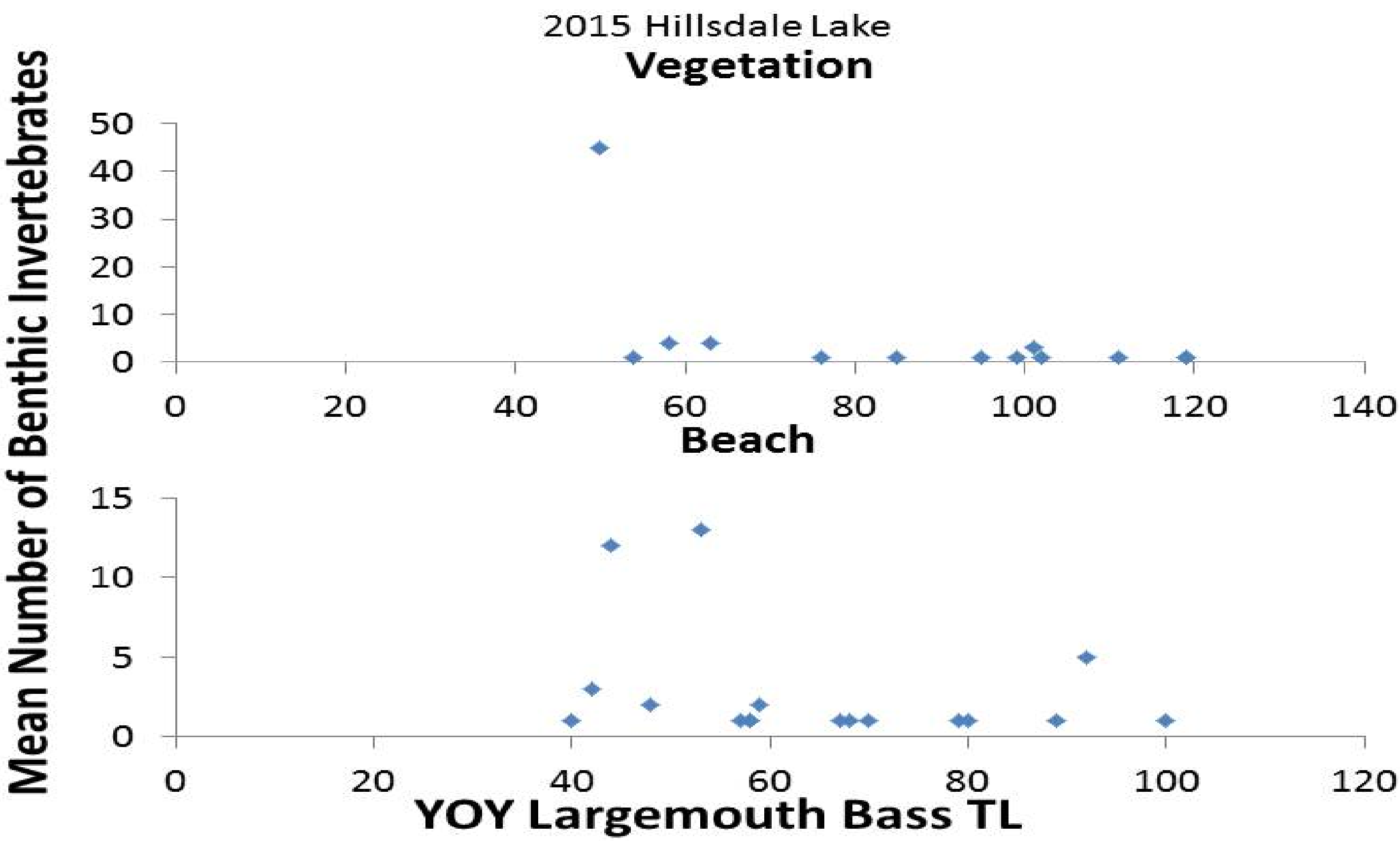

Figure A.21: Number of benthic invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

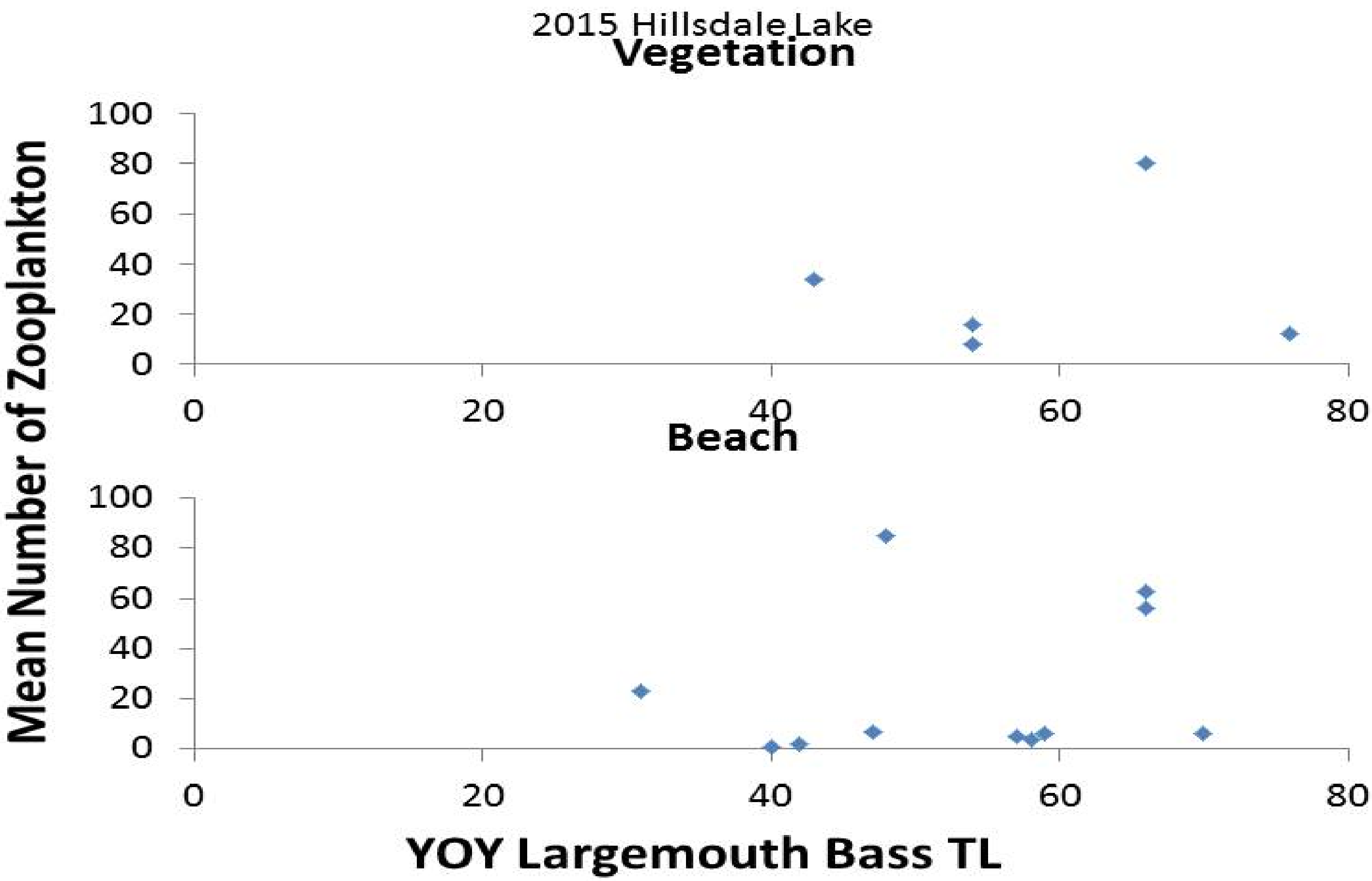

Figure A.22: Number of zooplankton consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

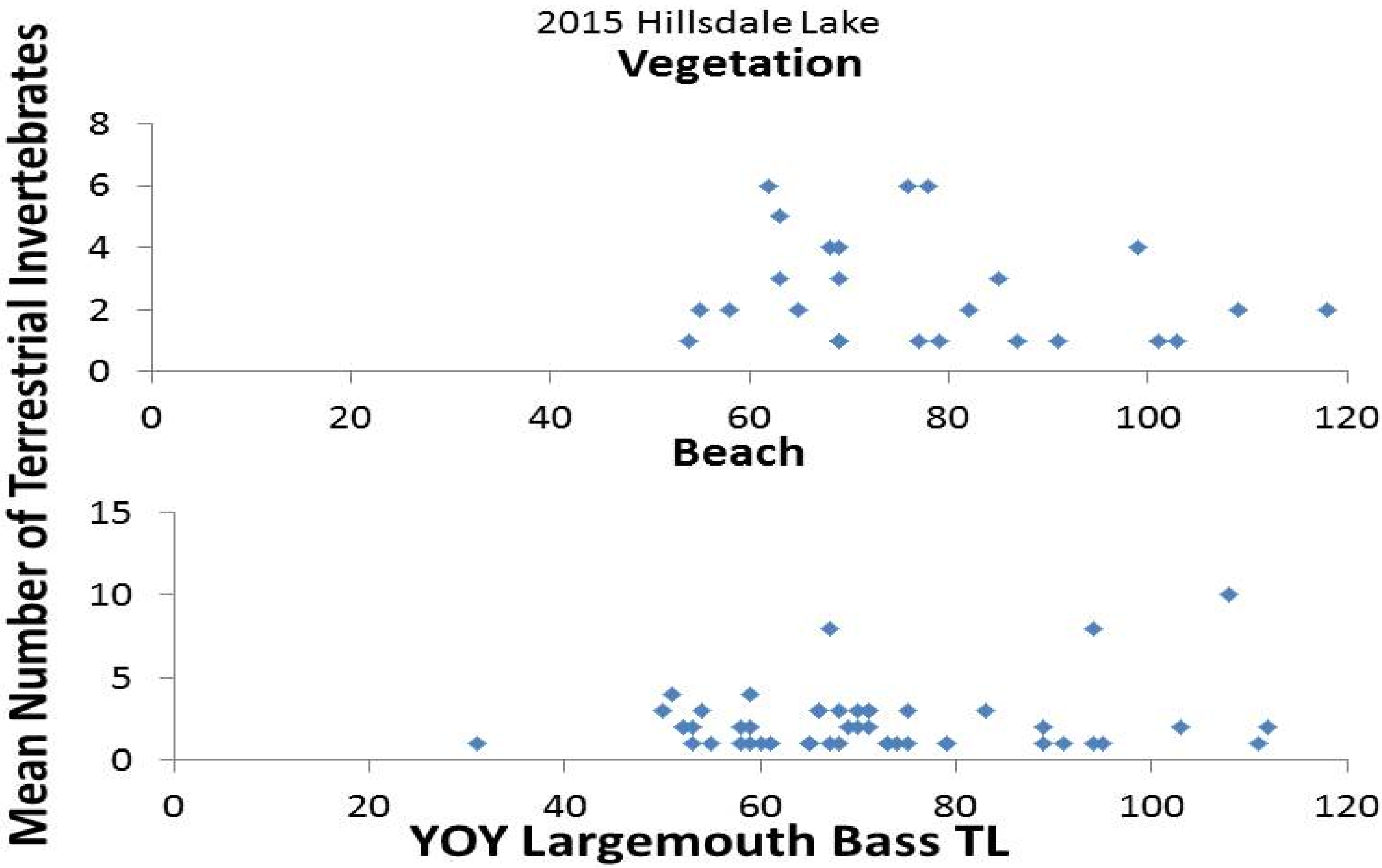

Figure A.23: Number of terrestrial invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

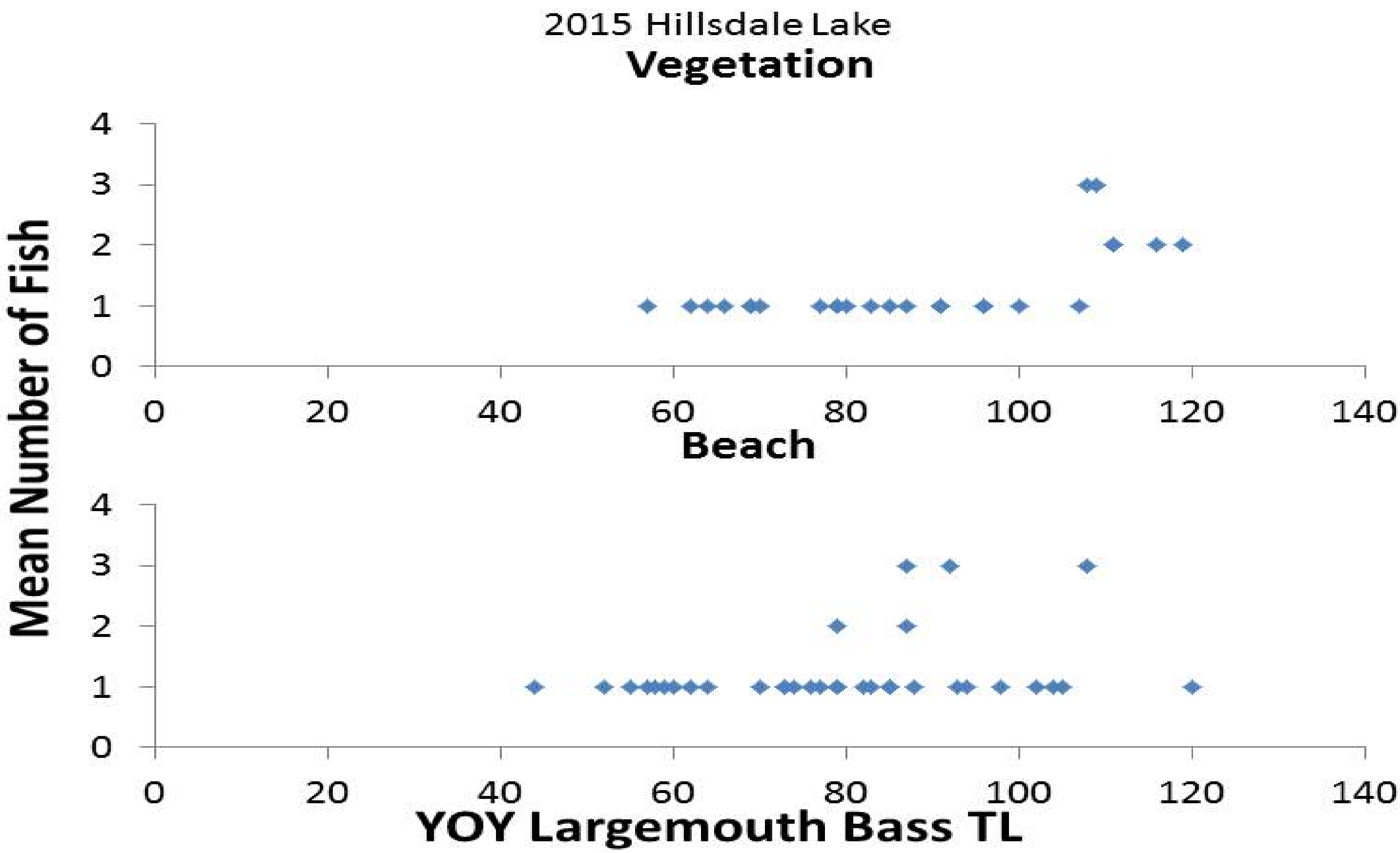

Figure A.24: Number of fish consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

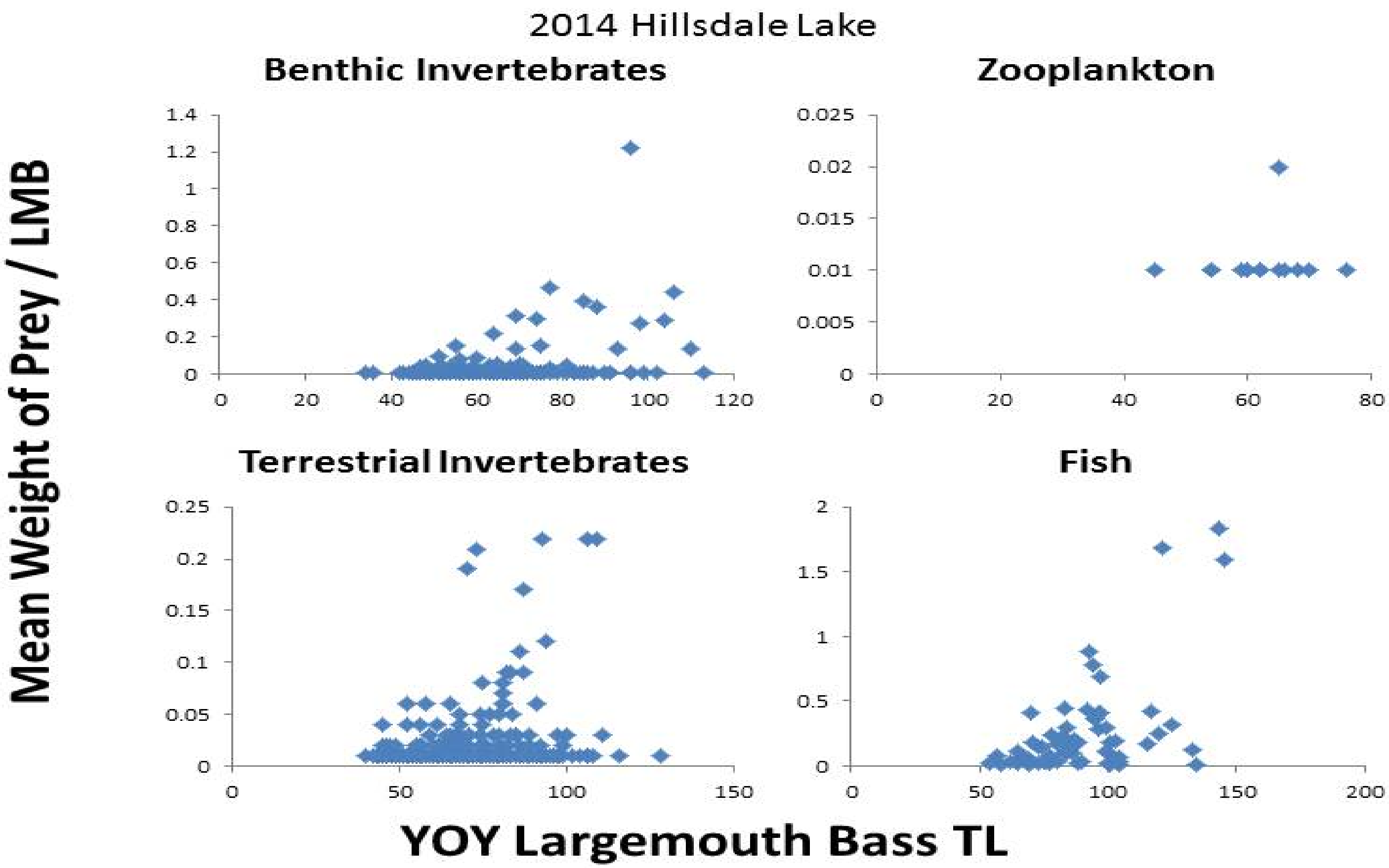

Figure A.25: Weight of prey consumed by young of year largemouth bass total length (mm) for four prey groups (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish) in Hillsdale Lake, KS during 2014.

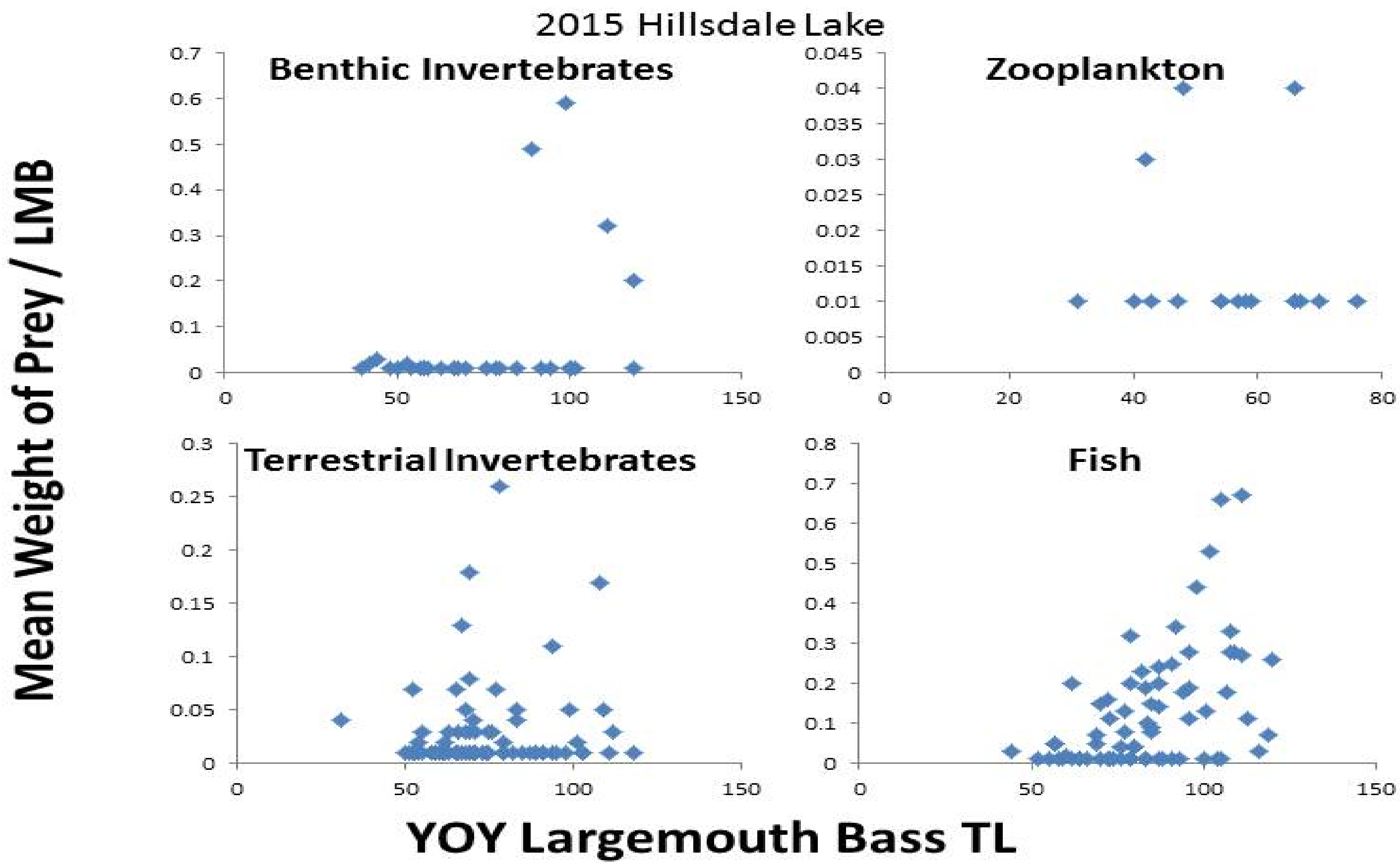

Figure A.26: Weight of prey consumed by young of year largemouth bass total length (mm) for four prey groups (benthic invertebrates, zooplankton, terrestrial invertebrates, and fish) in Hillsdale Lake, KS during 2015.

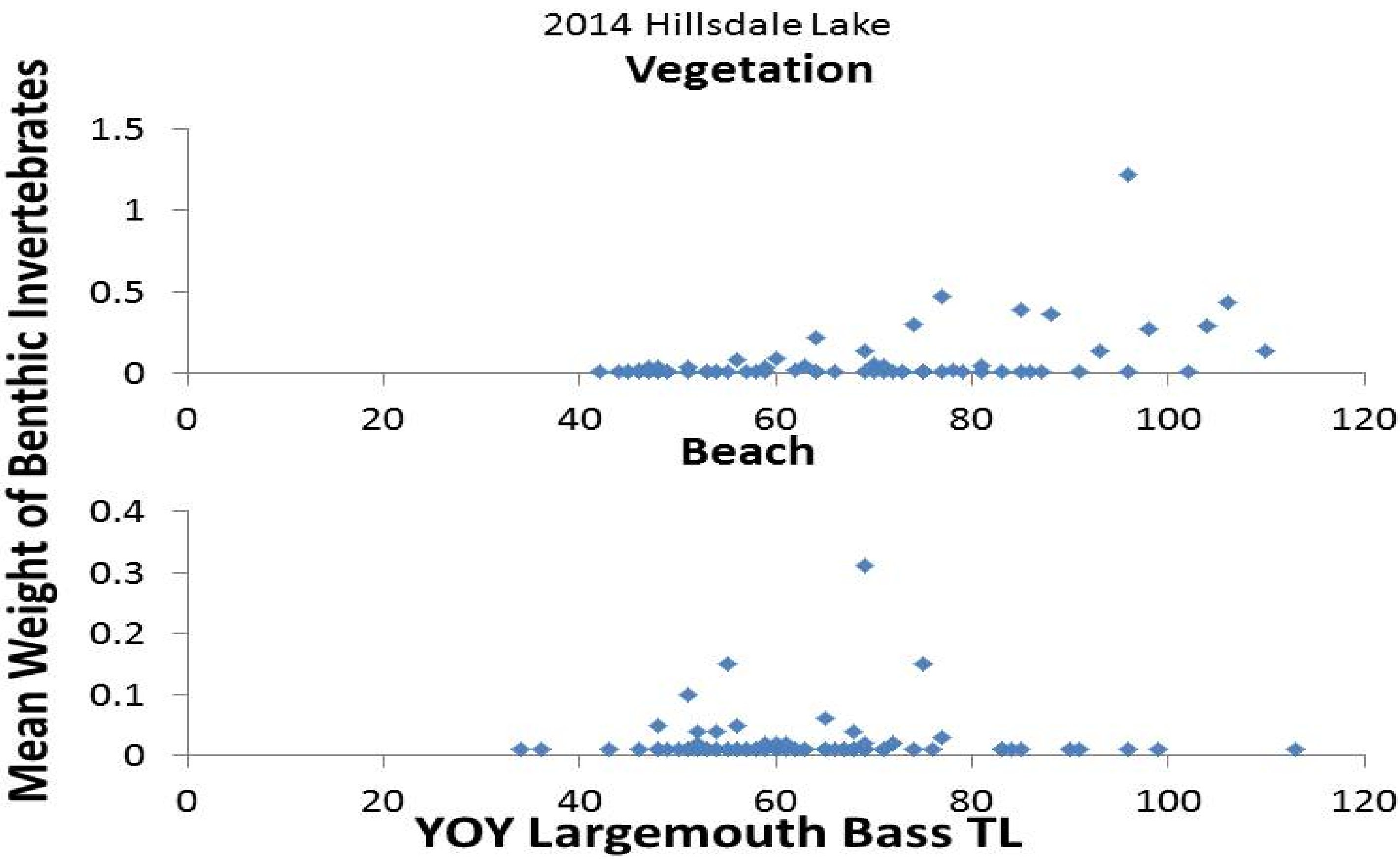

Figure A.27: Weight of benthic invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

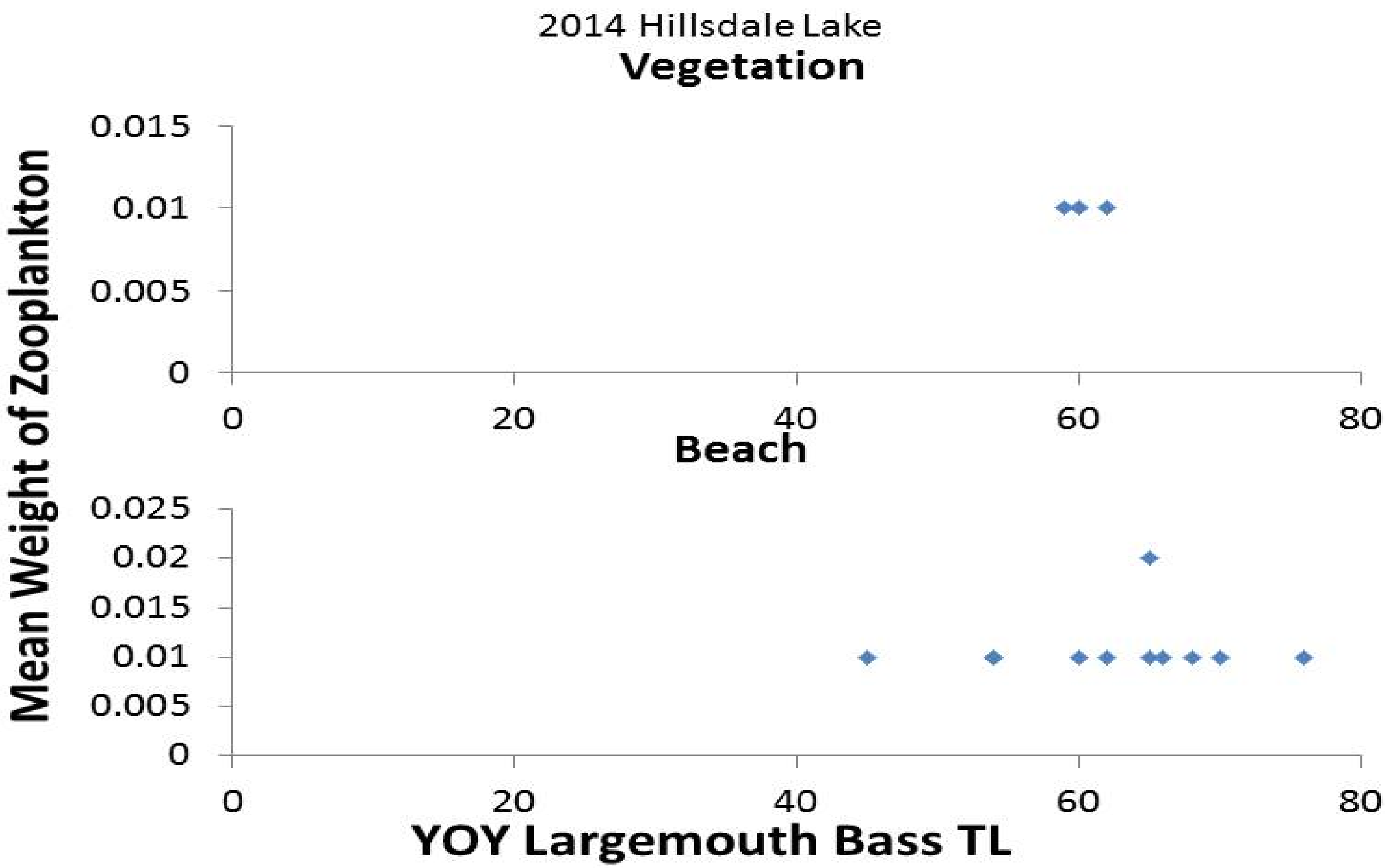

Figure A.28: Weight of zooplankton consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

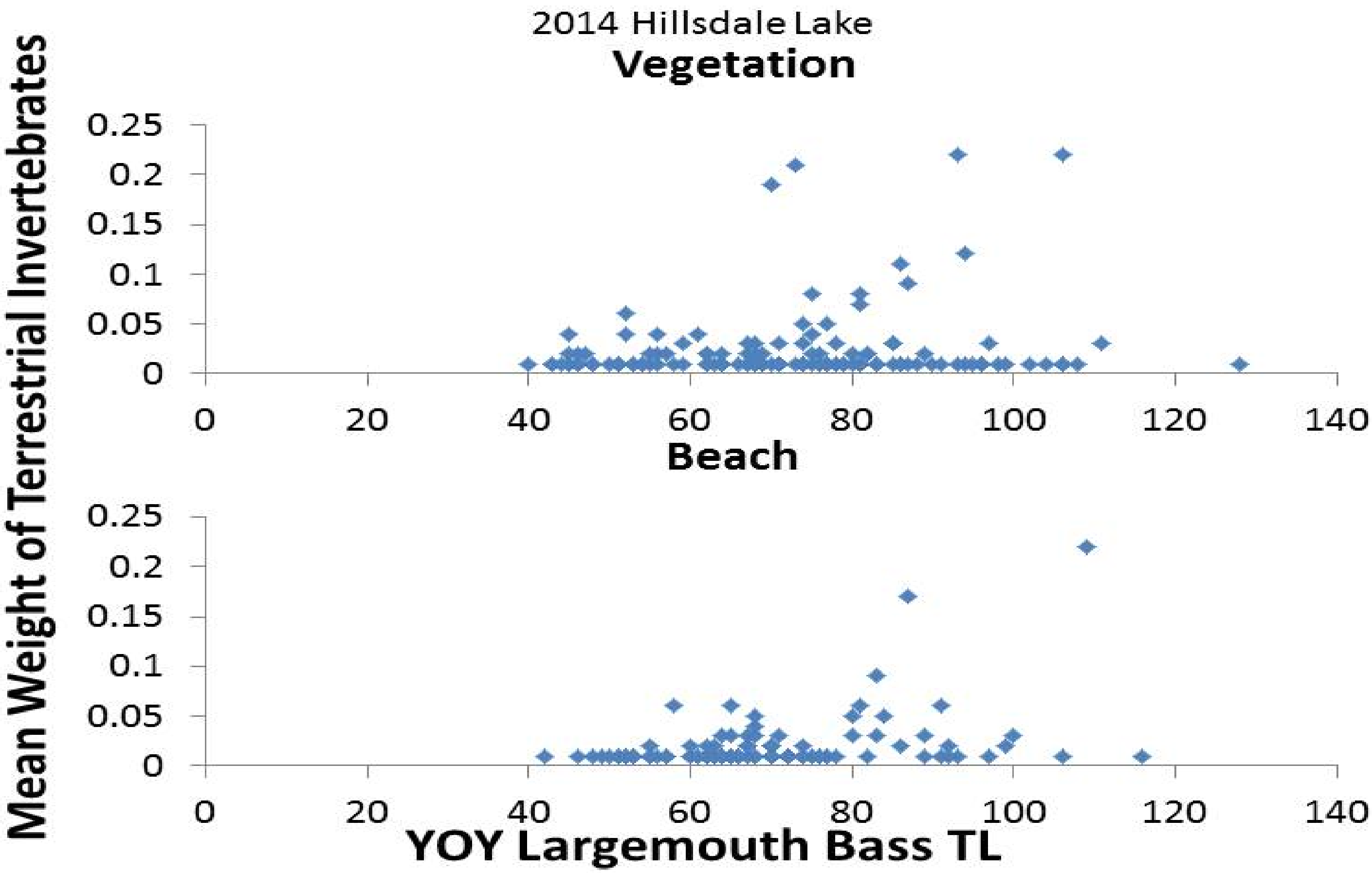

Figure A.29: Weight of terrestrial invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

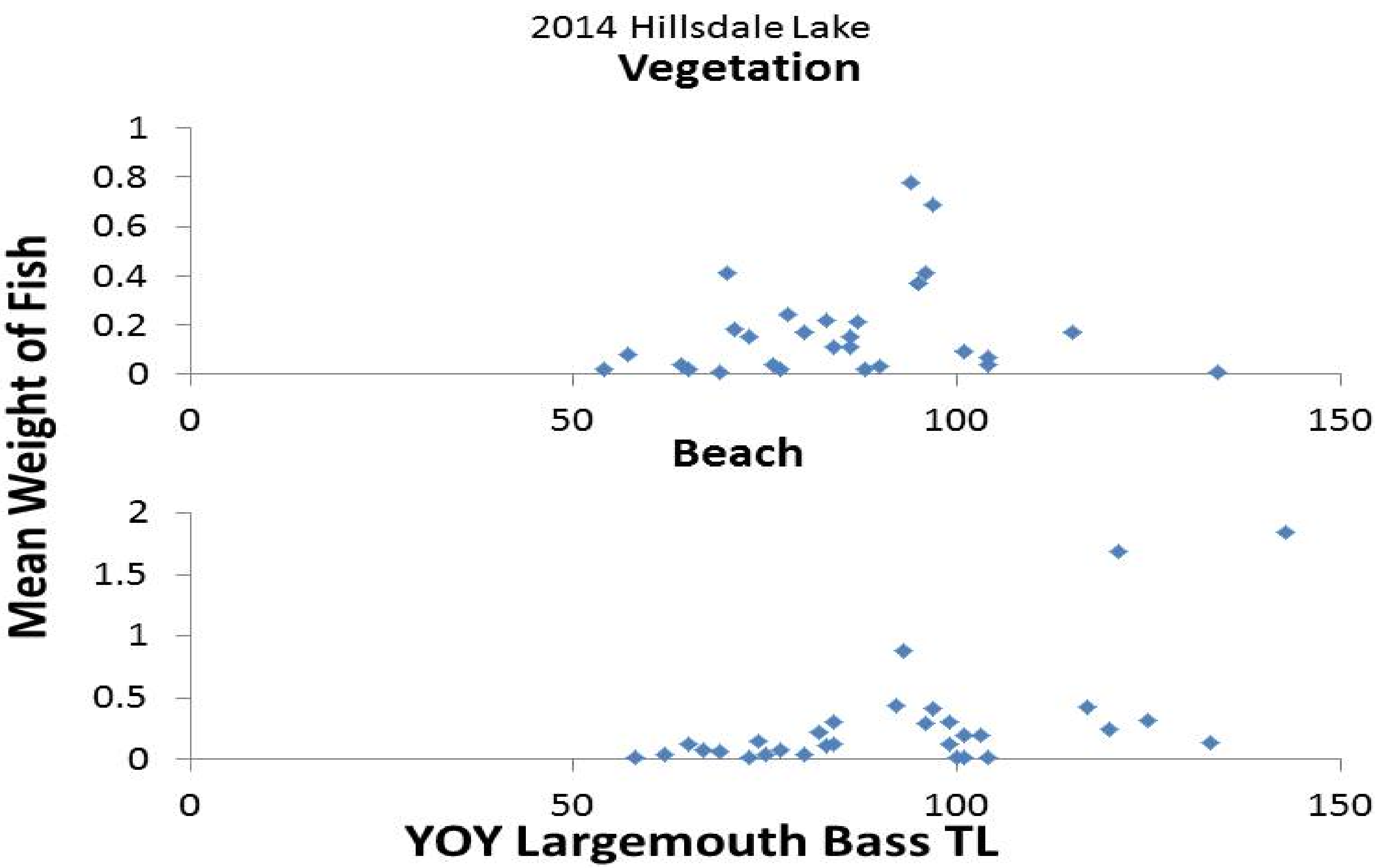

Figure A.30: Weight of fish consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2014.

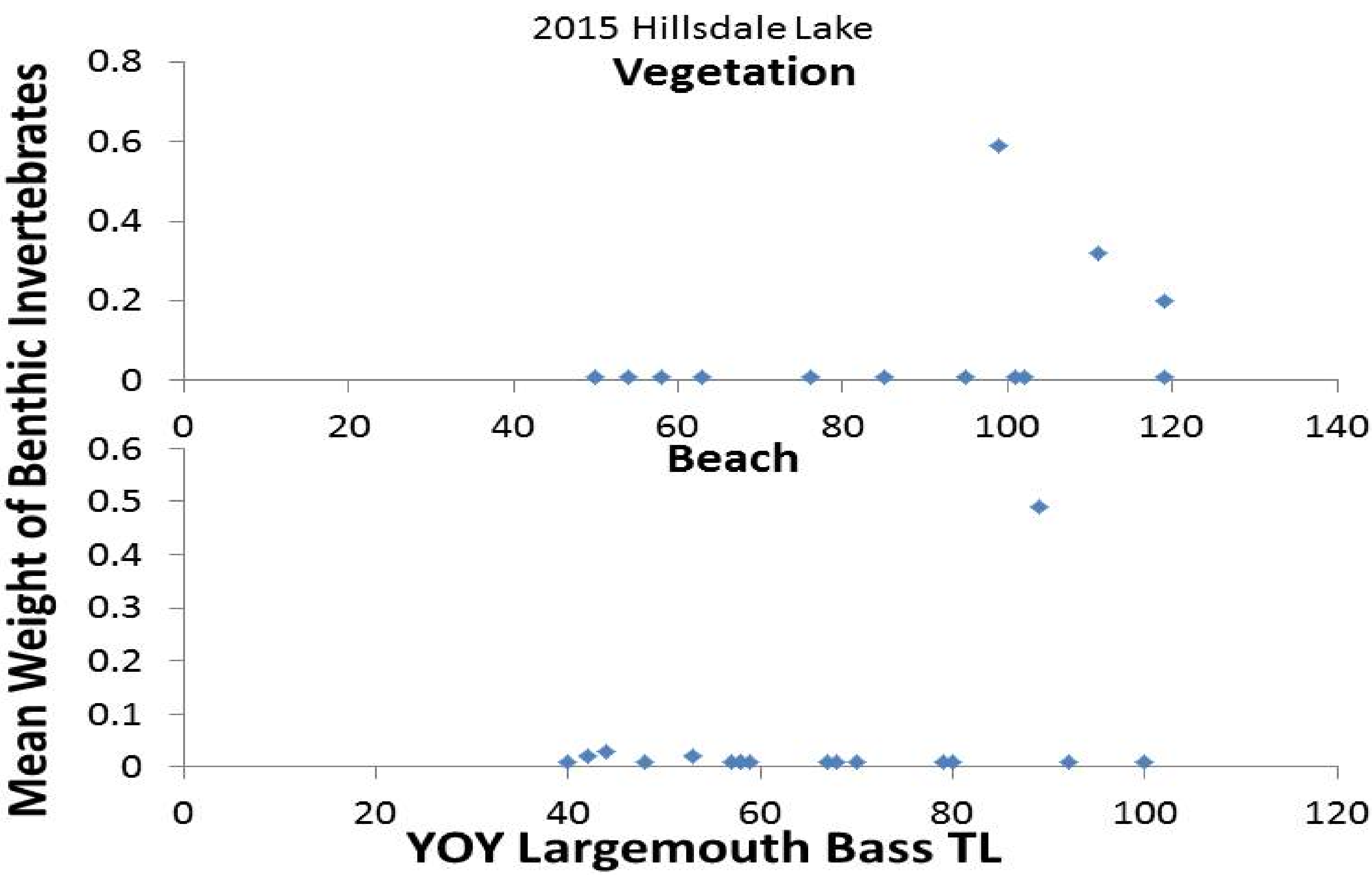

Figure A.31: Weight of benthic invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

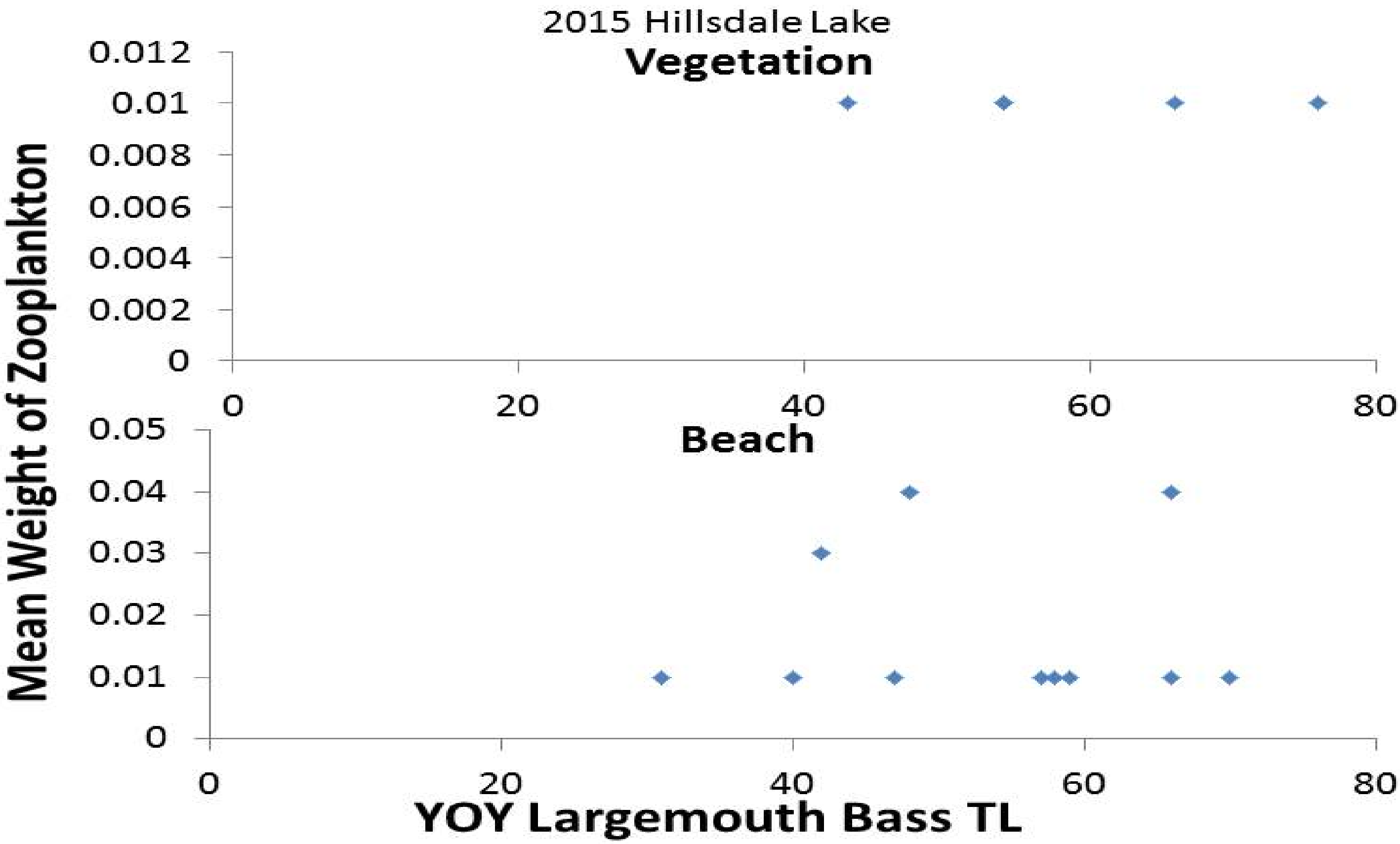

Figure A.32: Weight of zooplankton consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

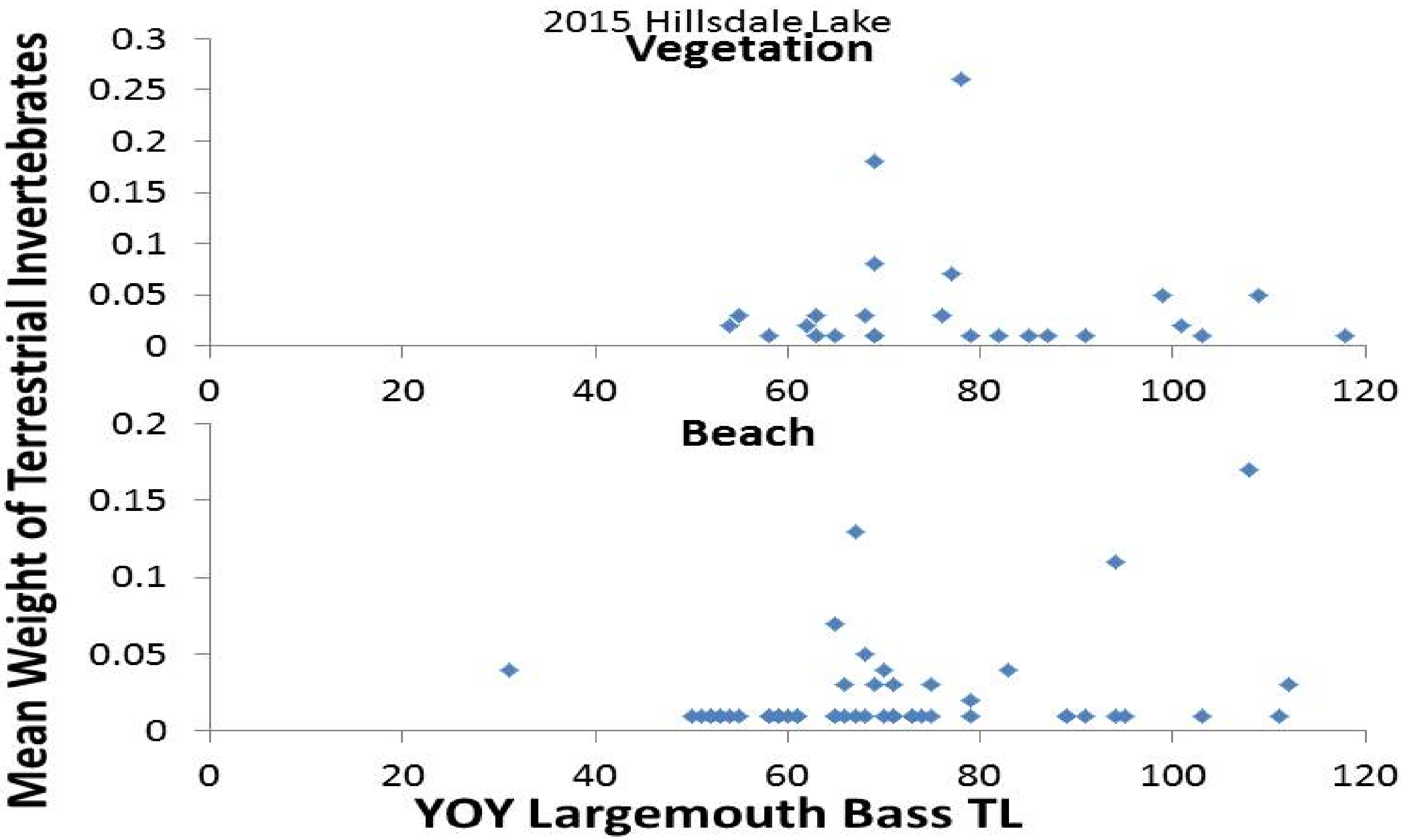

Figure A.33: Weight of terrestrial invertebrates consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

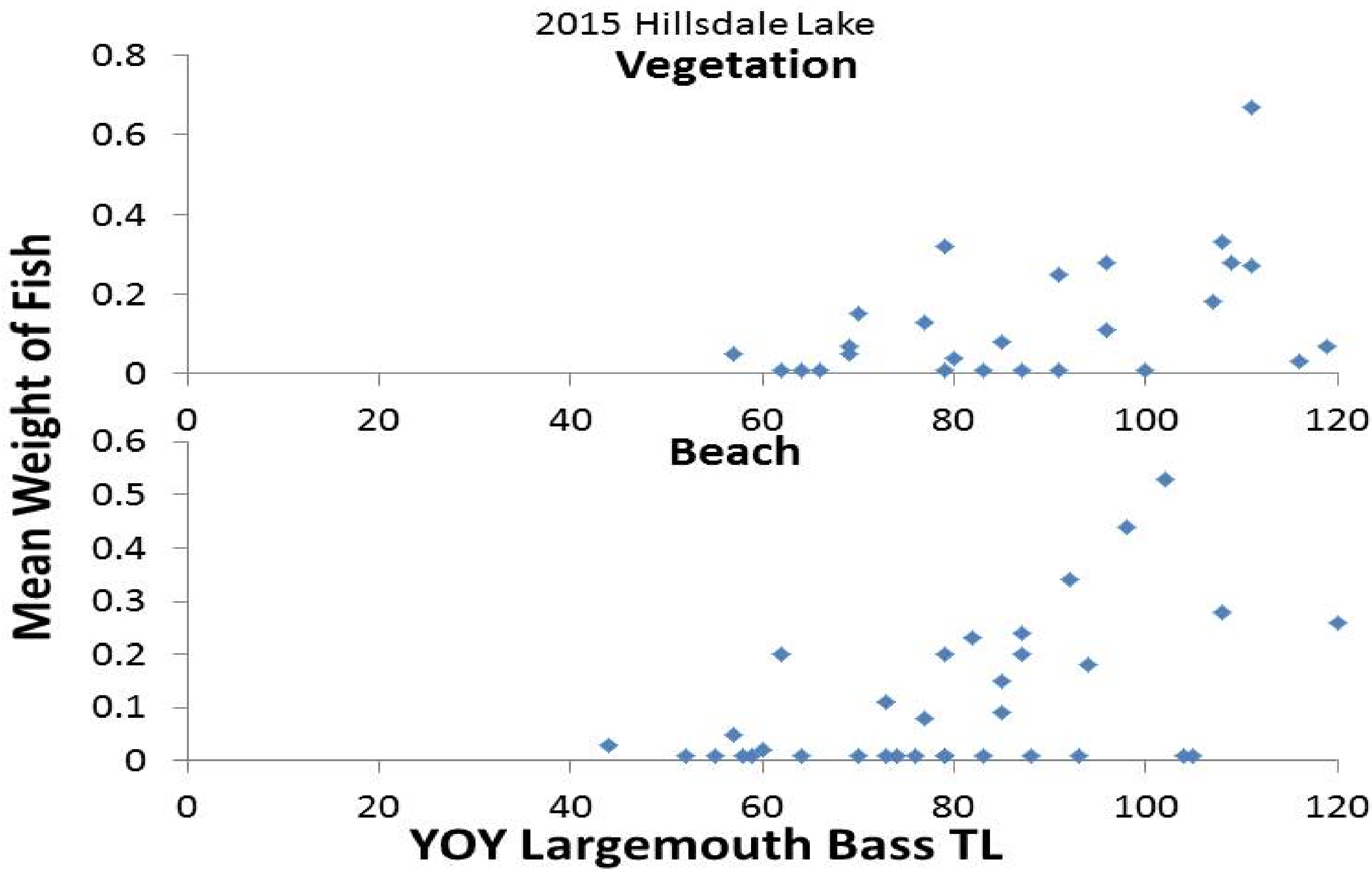

Figure A.34: Weight of fish consumed by young of year largemouth bass by total length (mm) in vegetation and beach habitats in Hillsdale Lake, KS during 2015.

Appendix B - 2015 Trends

Goal

The purpose of this appendix is to present data from the 2015 sample year in Hillsdale Lake even though trends and interpretation for all research questions (presented in Chapters 1-2) are the same across years.

Methods

Specific methods are described in chapter 1 and the same methods were used in both sample years.

Results

CPUE. During 2015, CPUE exhibited similar trends as during 2014 and was similar across vegetation and beach habitats and both of those habitats had higher CPUE than offshore or wood ($p < 0.0001$, Fig. B.1). Additionally, the sample event main effect was significant (p: 0.0021, Fig. B.2) but the habitat and time interaction was not significant (NS, Fig. B.3). During both sample years, young of year largemouth bass utilized beach and vegetation habitats similarly.

Diet. In 2015, diet composition by number was not significantly different across habitat types (NS, Fig. B.4) or sample events (NS, Fig. B.5) for any diet groups and the habitat by time interaction was also not significant (NS, Figs. B.6 – B.9).

In 2015, diet composition by weight was also not significantly different across habitat types (NS, Fig. B.10), sample event, (NS, Fig. B.11), or the habitat by time interaction (NS, Figs. B.12 – B.15). The lack of a diet response across both sample years suggest that largemouth bass diets are utilizing prey resources in the same way across habitats and sample years. This finding is consistent with the findings of other young of year largemouth bass diet studies.

Prey. Similarly to 2014, in 2015, there were no significant differences in abundance of prey in Hillsdale Lake during 2015. Specifically, benthic invertebrate abundance was not significantly different across habitat (NS, Fig. B.16) or sample event (NS, Fig. B.17); zooplankton abundance was not significantly different across habitat type (NS, Fig. B.18) or sample event (NS, Fig. B.19); and fish prey abundance was not significantly different across habitats (NS, Fig. B.20) or sample event (NS, Fig. B.21). The equal distribution of prey across habitats in Hillsdale Lake could be contributing to the similar diet composition of young of year largemouth bass. Prey distribution was similar across both years suggesting that there is sufficient prey in Hillsdale Lake to support young of year largemouth bass in multiple habitats.

Size. All body size data for the 2015 sample year can be found in Appendix A.

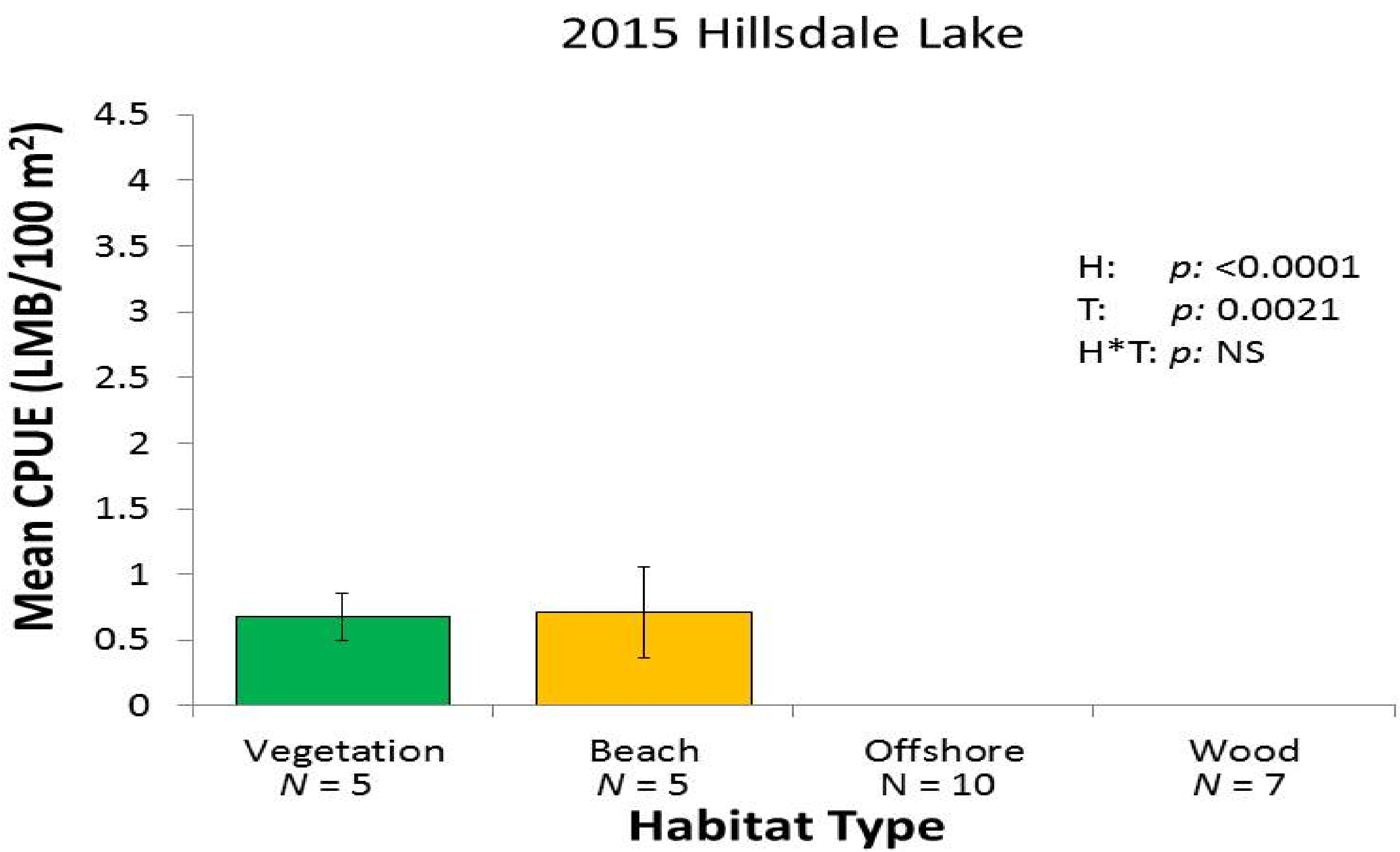

Figure B.1: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for four habitat types (vegetation, beach, offshore, wood) in Hillsdale Lake, KS during 2015.Data are mean and standard error.

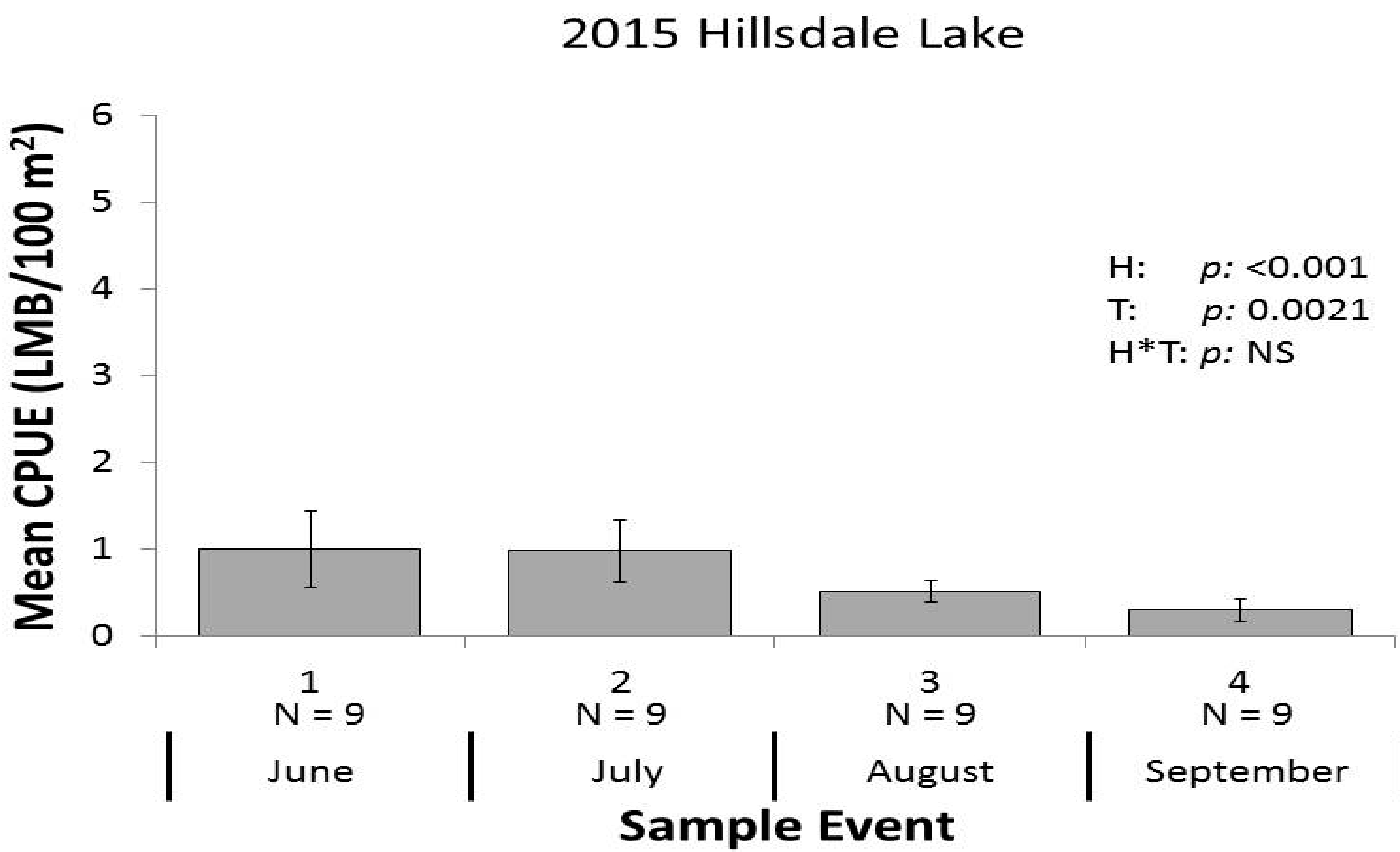

Figure B.2: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for four sample events in Hillsdale Lake, KS during 2015.Data are mean and standard error.

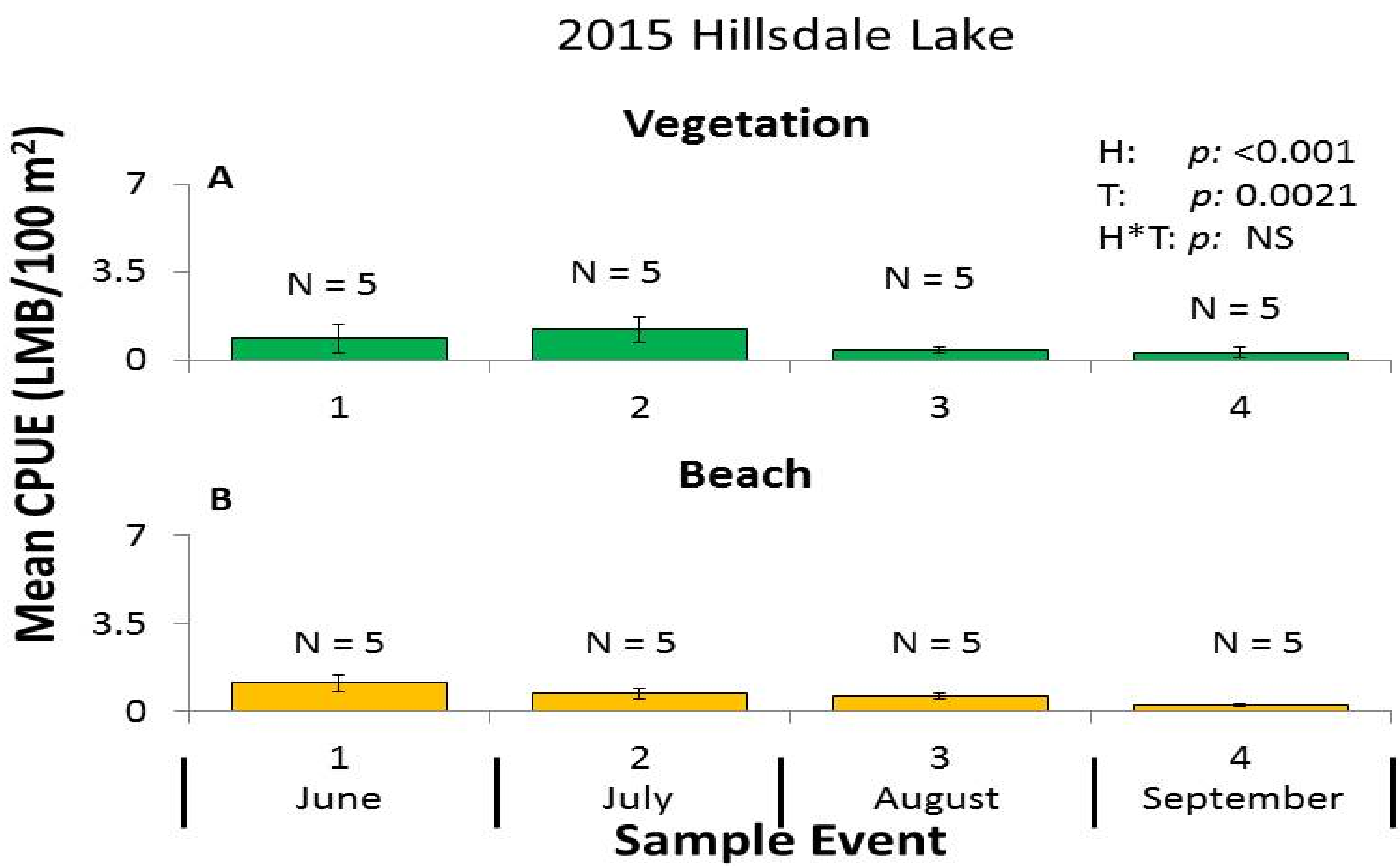

Figure B.3: Mean catch per unit effort (CPUE, largemouth bass per 100 m^2) for two habitat types (vegetation, beach) across four sample events in Hillsdale Lake, KS during 2015.Data are mean and standard error.

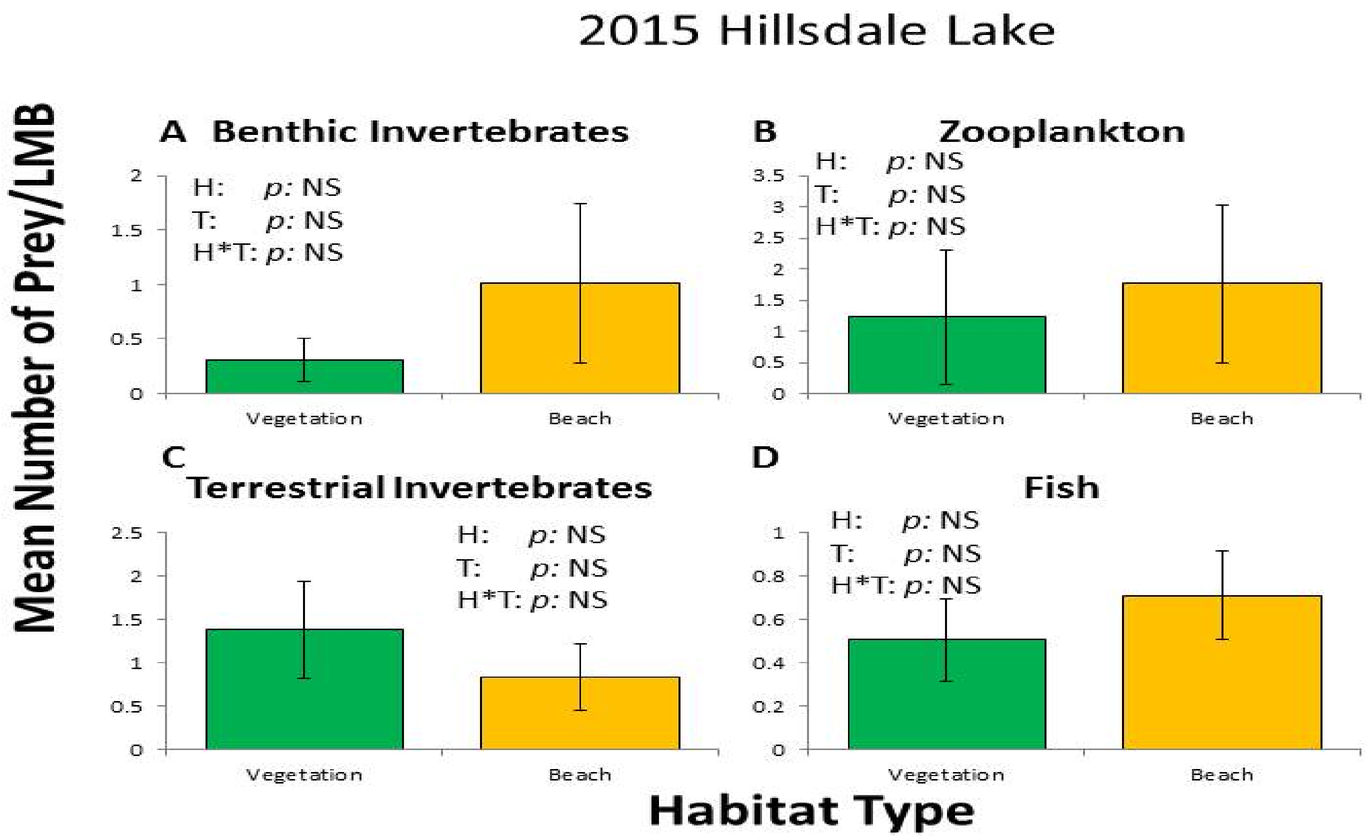

Figure B.4: Mean number of diet items eaten by young of year largemouth bass across two habitat types (vegetation and beach) in Hillsdale Lake during 2015 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

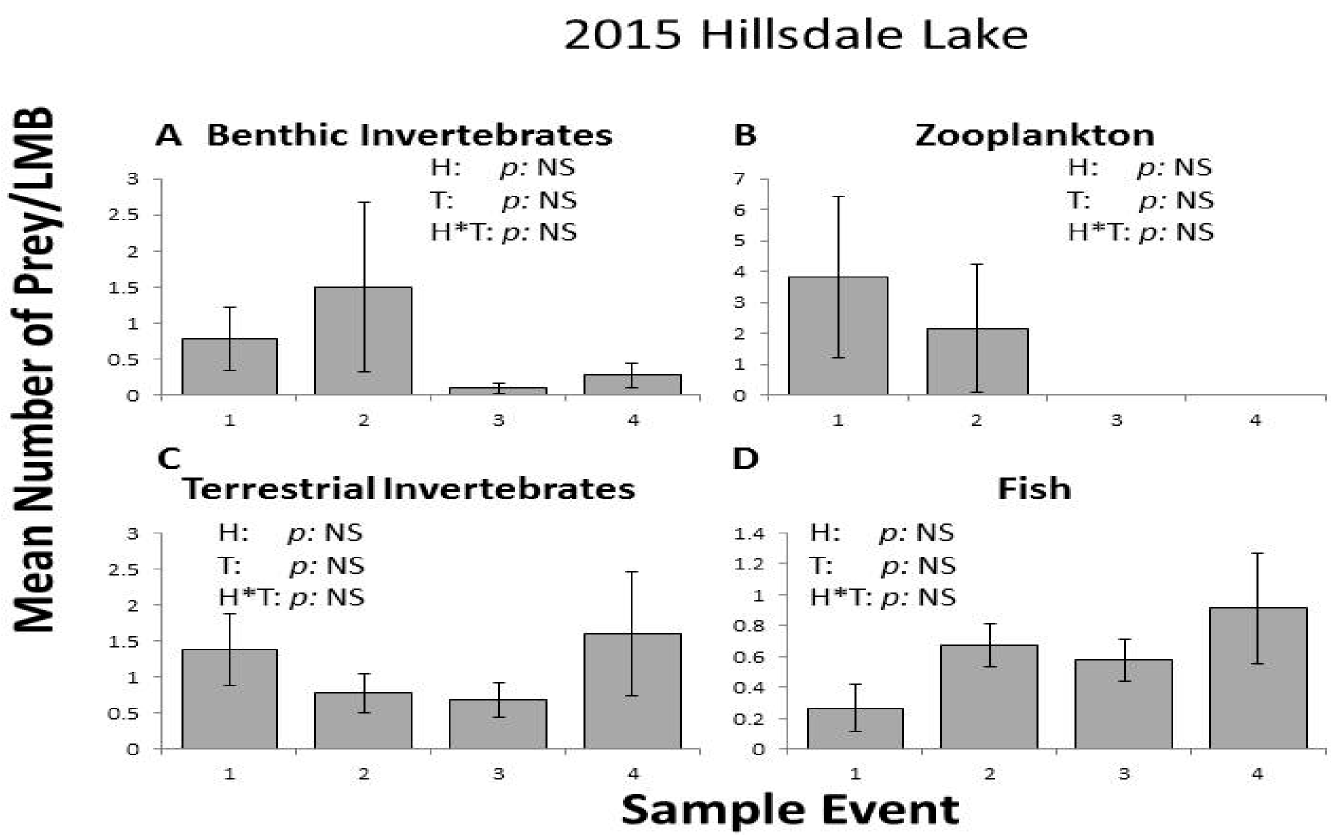

Figure B.5: Mean number of diet items eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2015 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

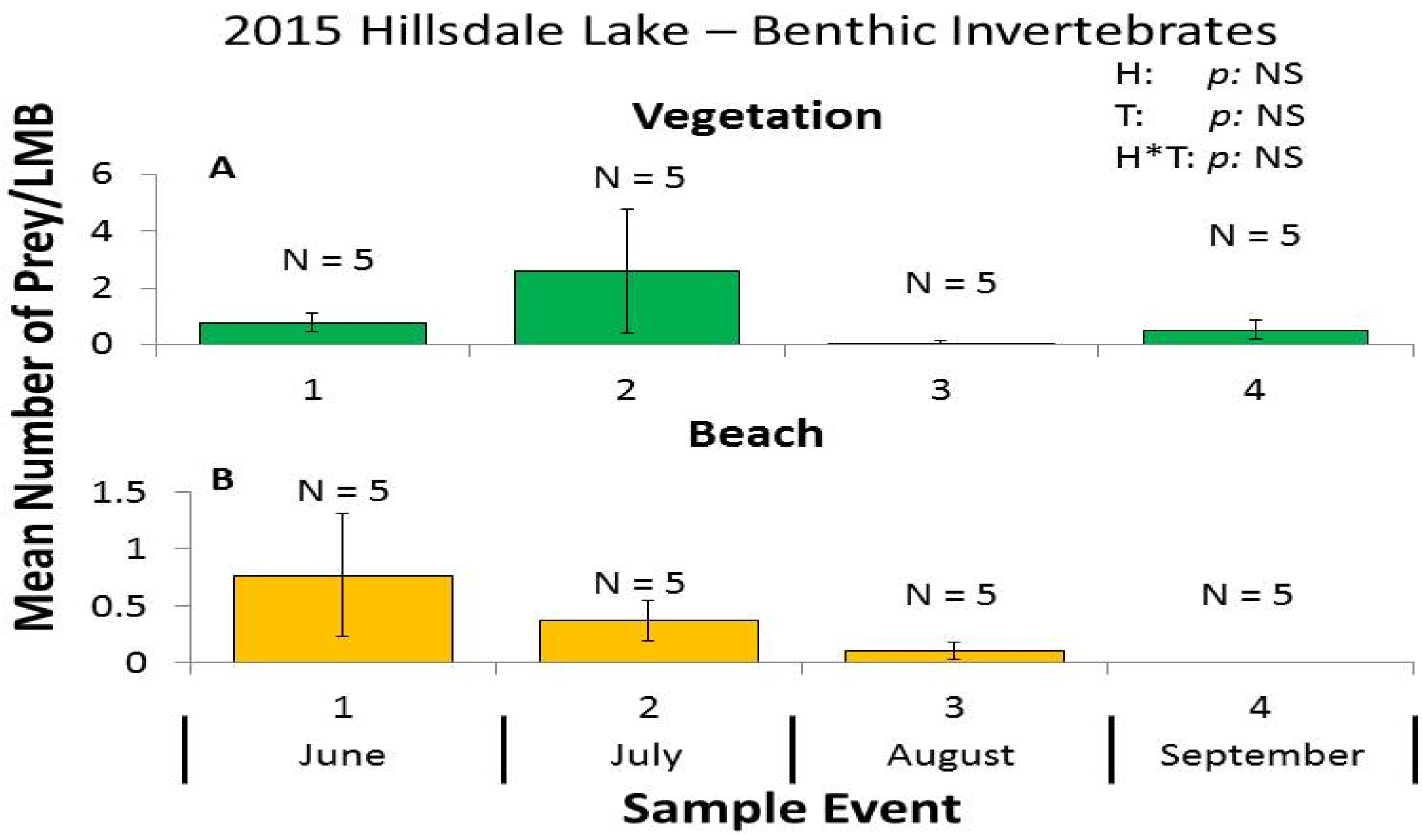

Figure B.6: Mean number of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

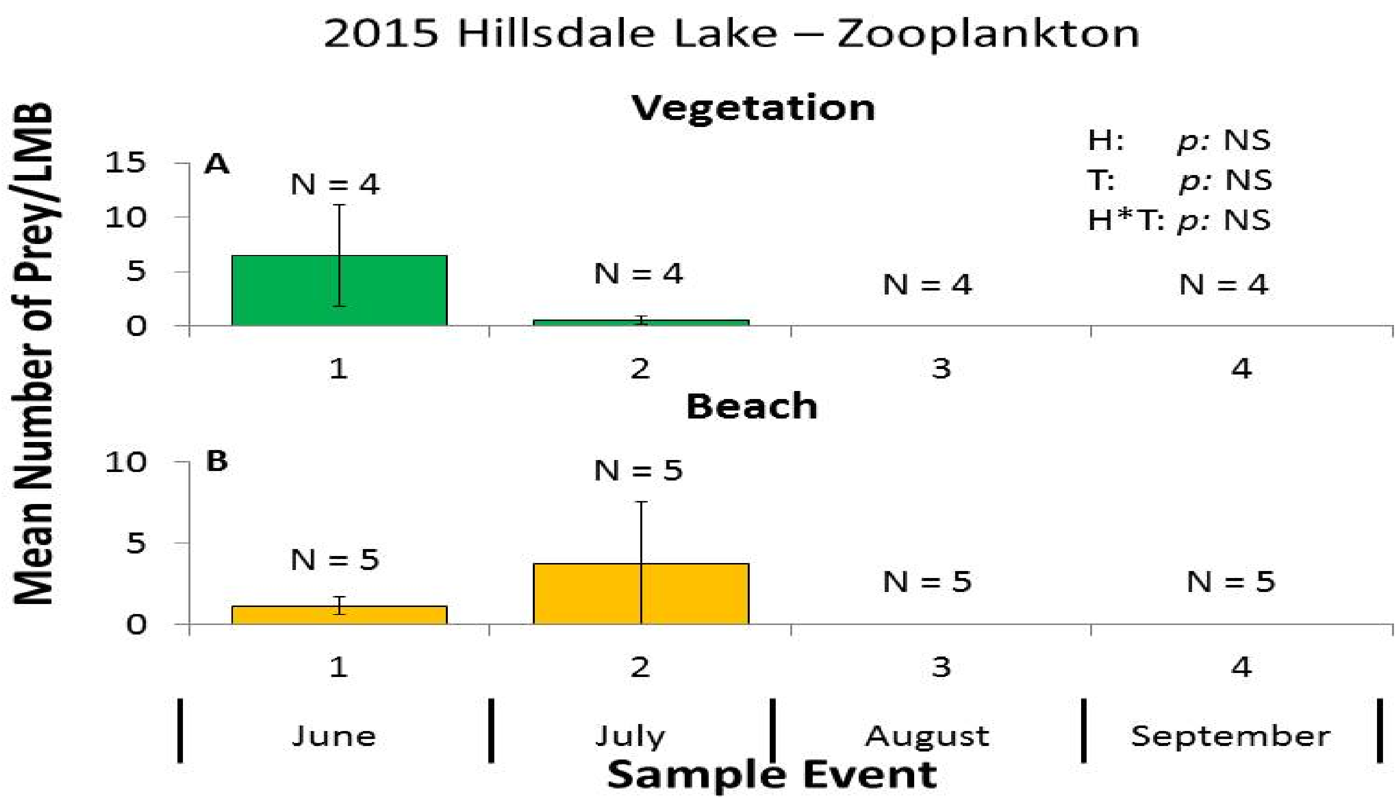

Figure B.7: Mean number of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

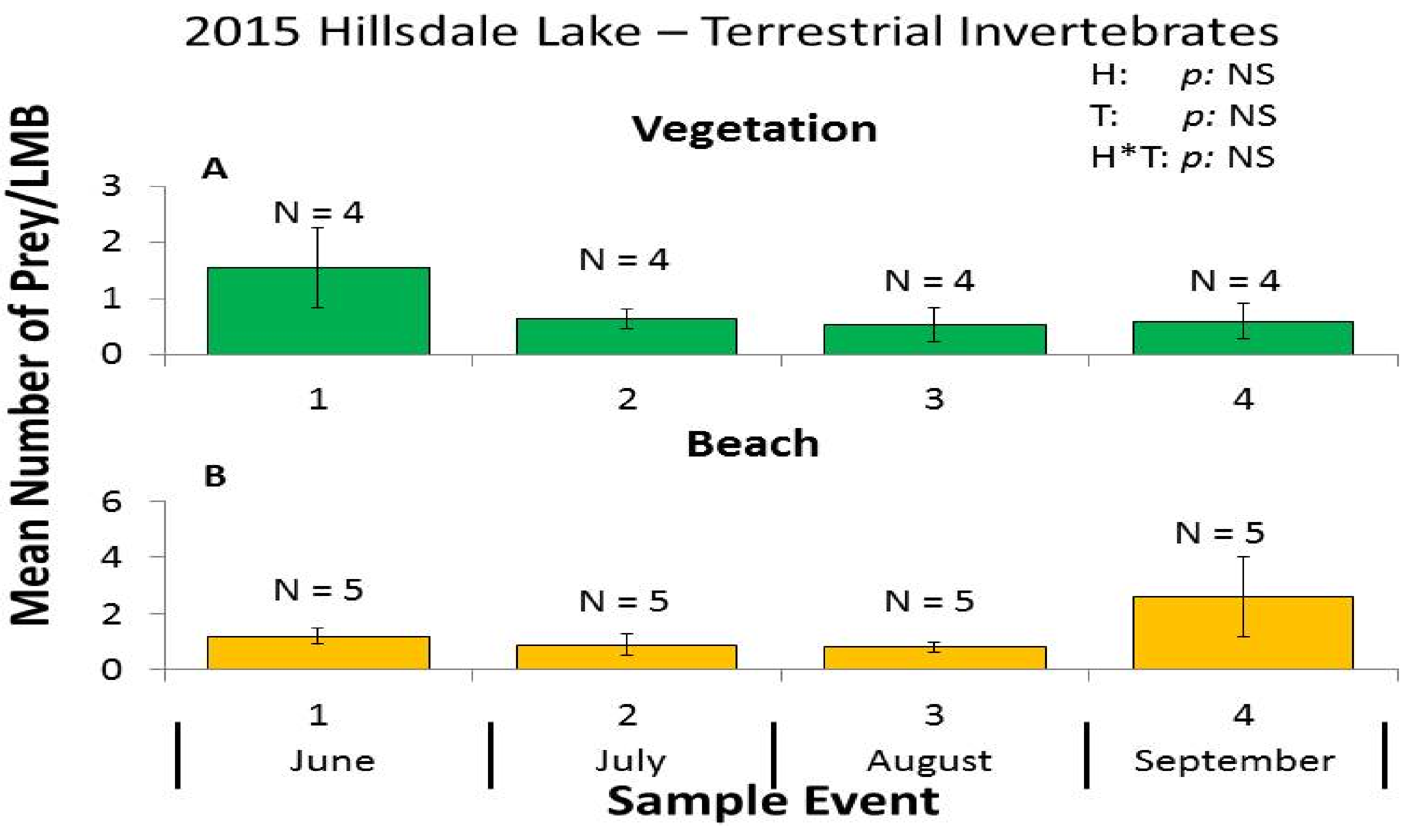

Figure B.8: Mean number of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

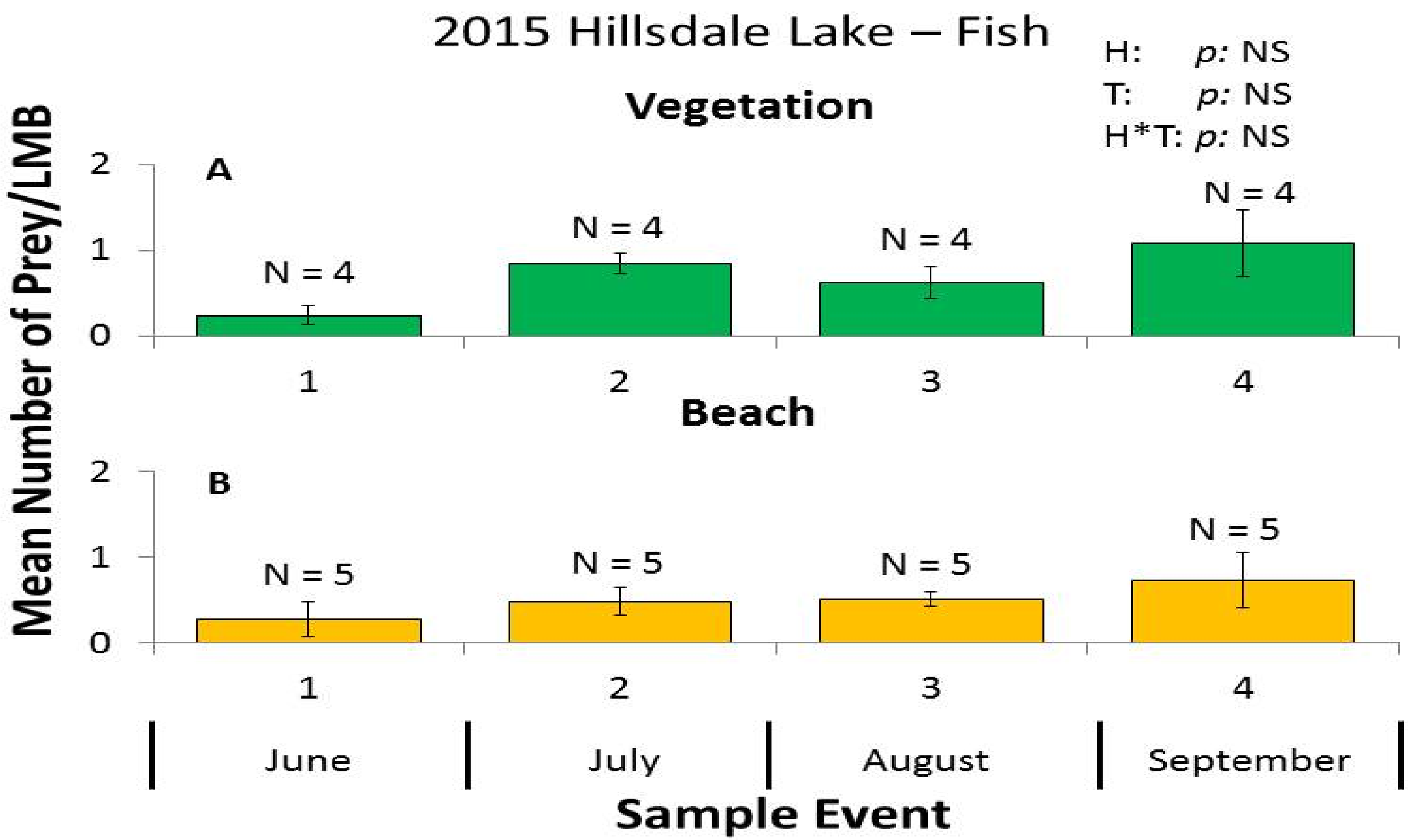

Figure B.9: Mean number of fish prey eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

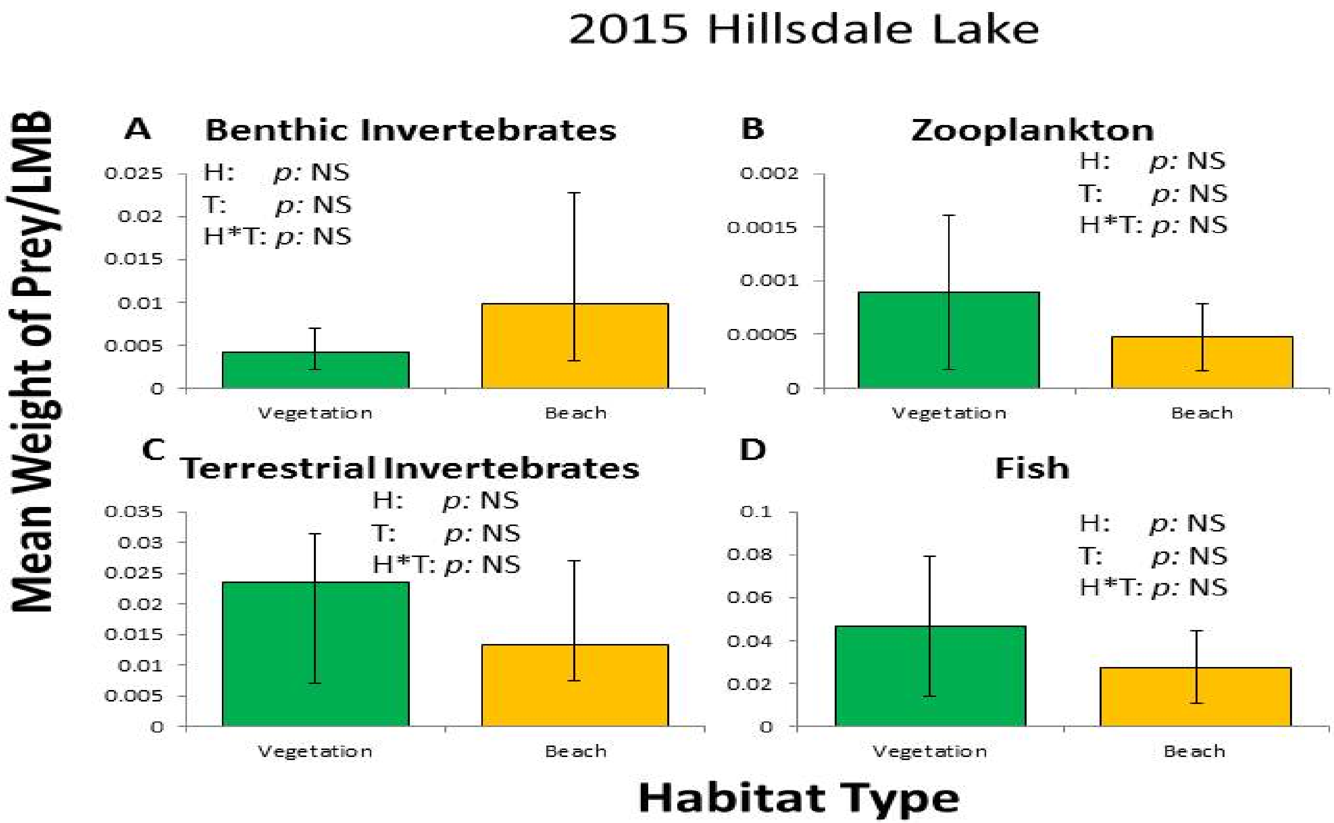

Figure B.10: Mean weight of diet items eaten by young of year largemouth bass across two habitat types (vegetation and beach) in Hillsdale Lake during 2015 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

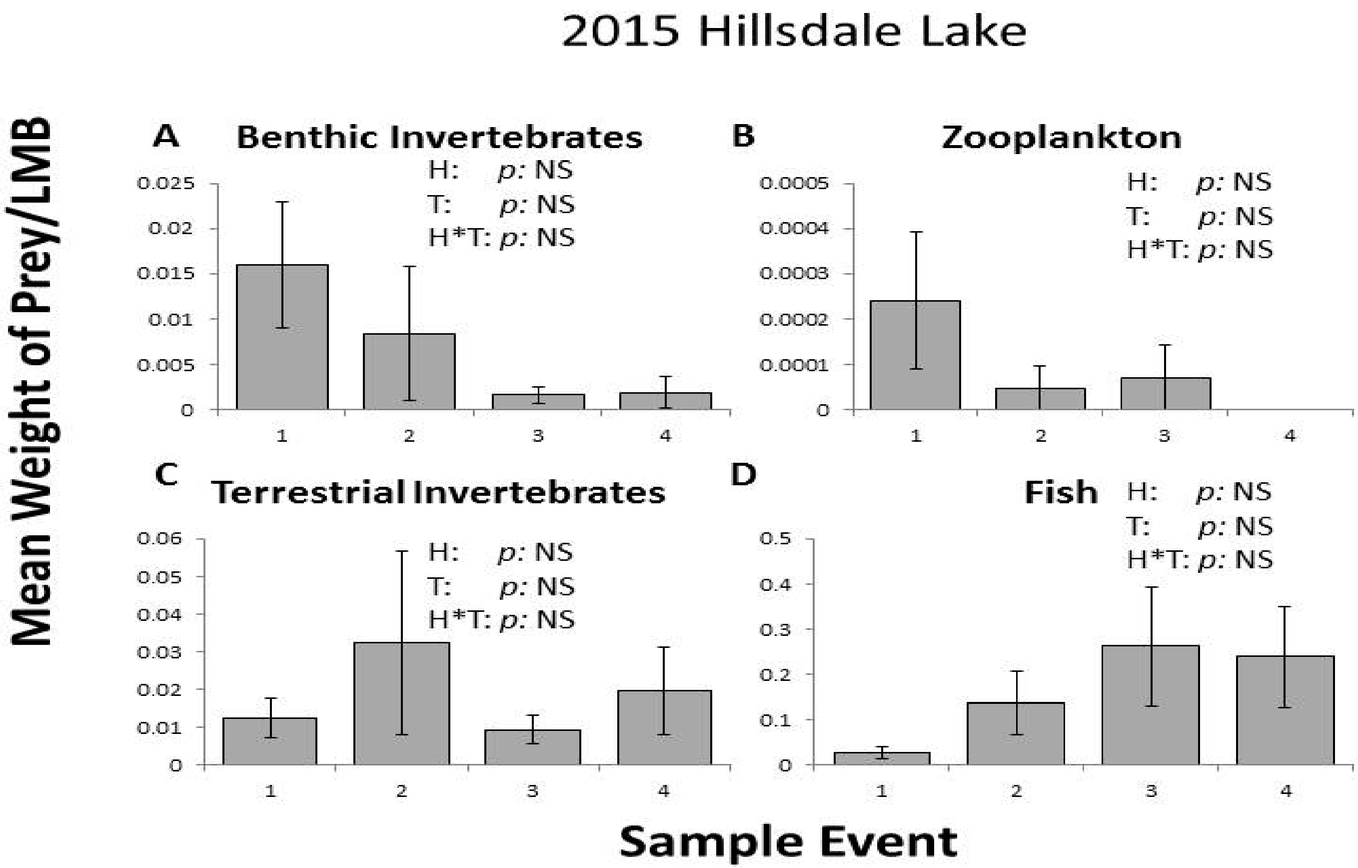

Figure B.11: Mean weight of diet items eaten by young of year largemouth bass across four sample events in Hillsdale Lake during 2015 by prey group [Benthic invertebrates (A), zooplankton (B), terrestrial invertebrates (C), fish(D)]. Data are mean and standard error.

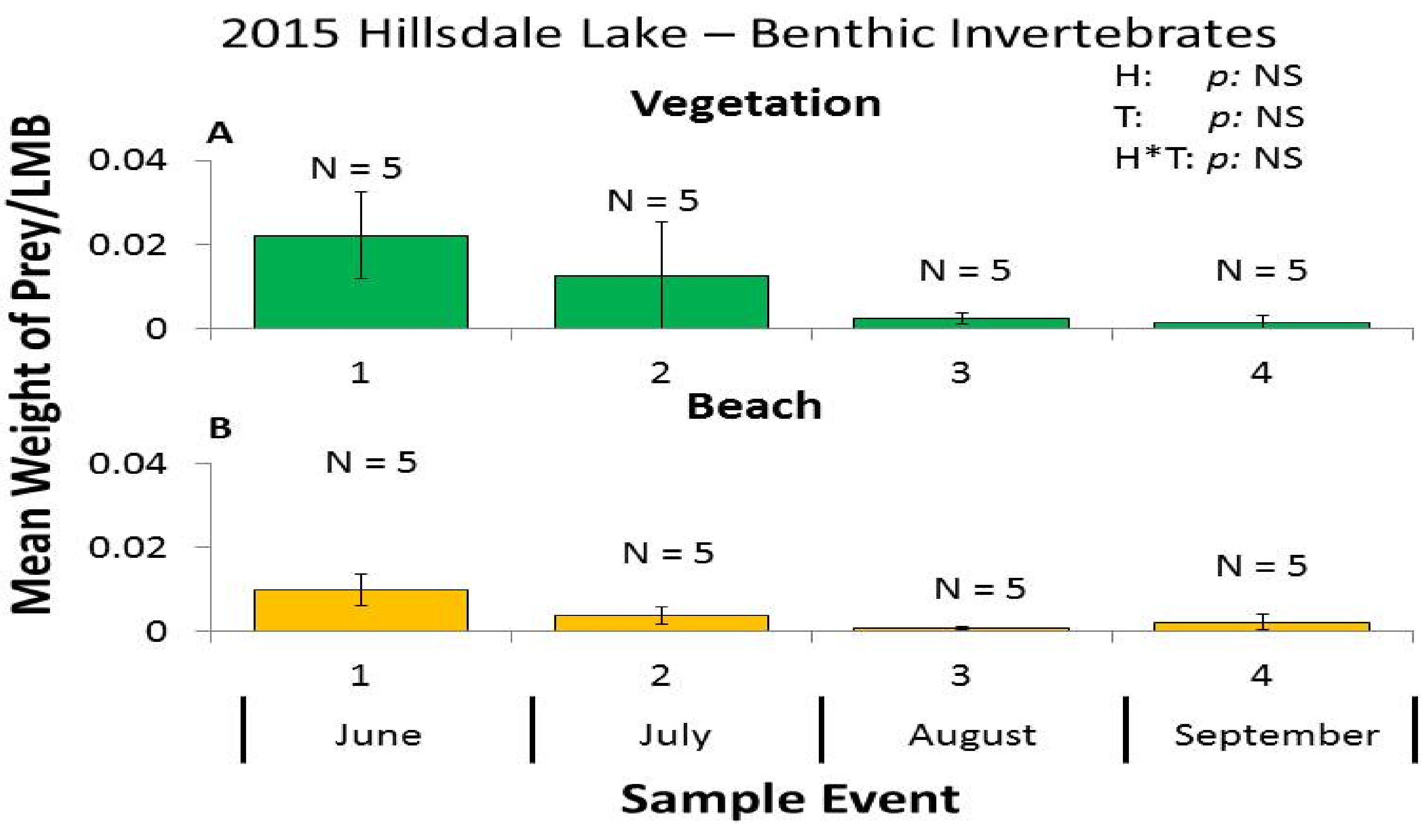

Figure B.12: Mean weight of benthic invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

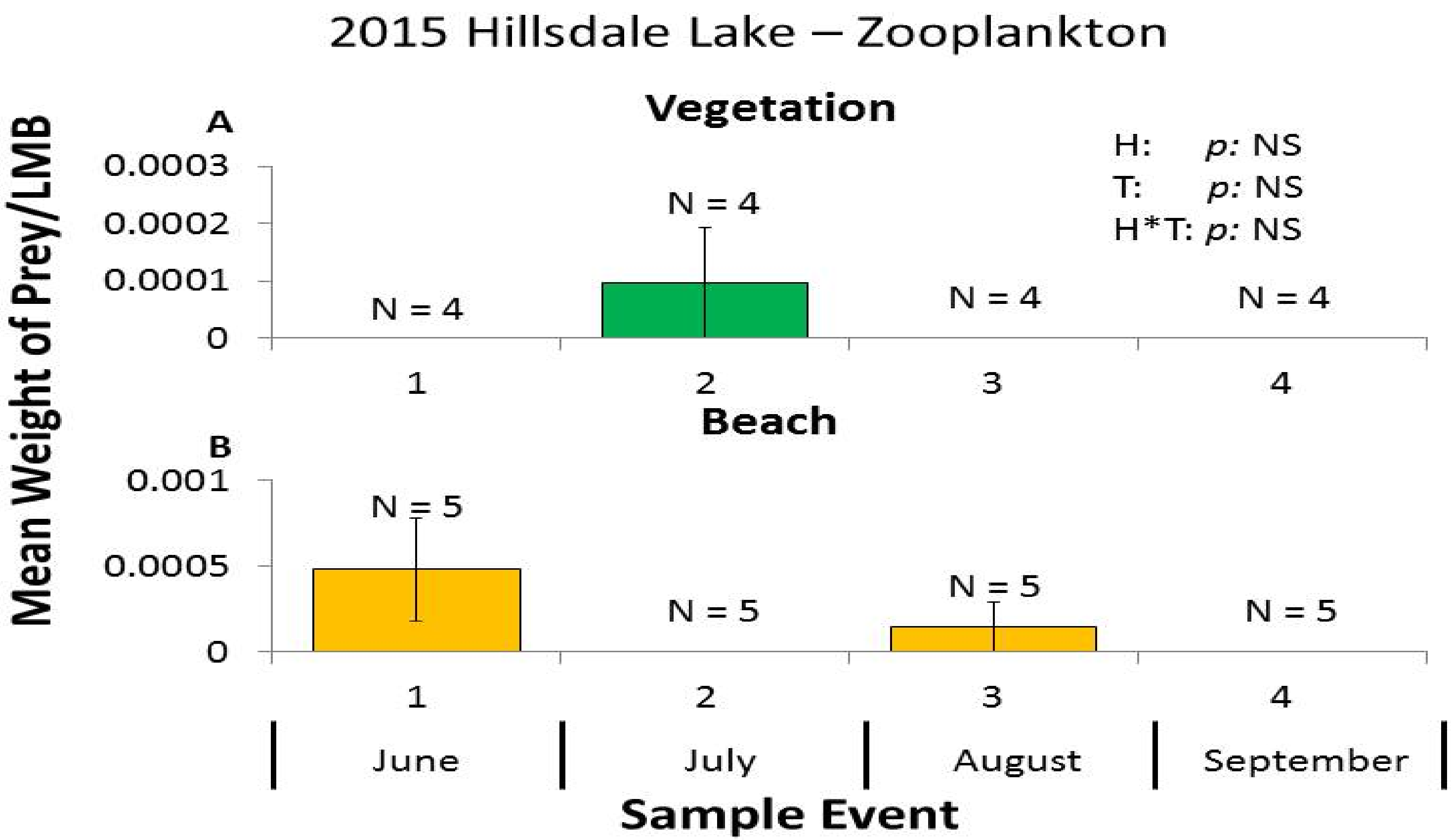

Figure B.13: Mean weight of zooplankton eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

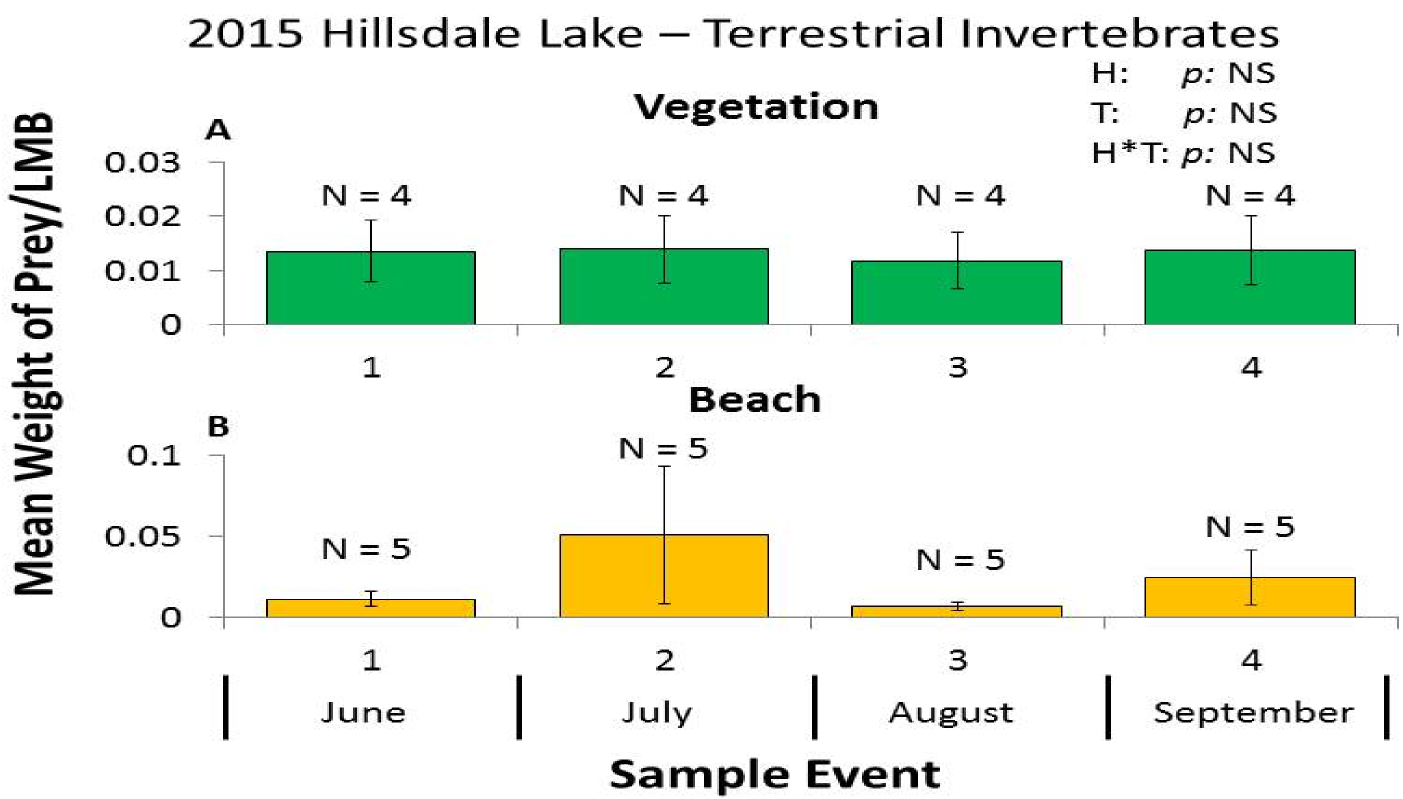

Figure B.14: Mean weight of terrestrial invertebrates eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

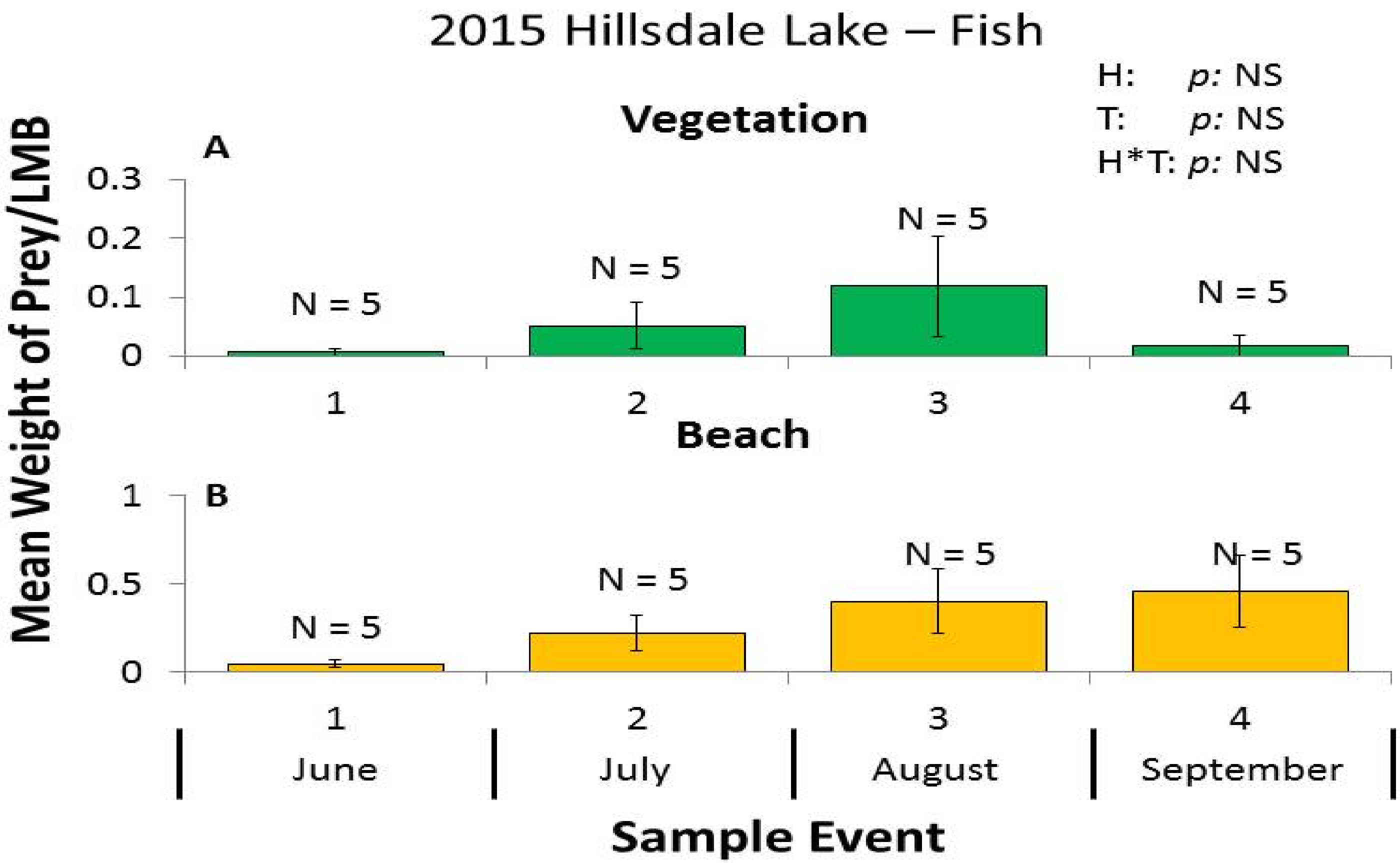

Figure B.15: Mean weight of fish prey eaten by young of year largemouth bass across two habitat types (vegetation and beach) and four sample events in Hillsdale Lake during 2015. Data are mean and standard error.

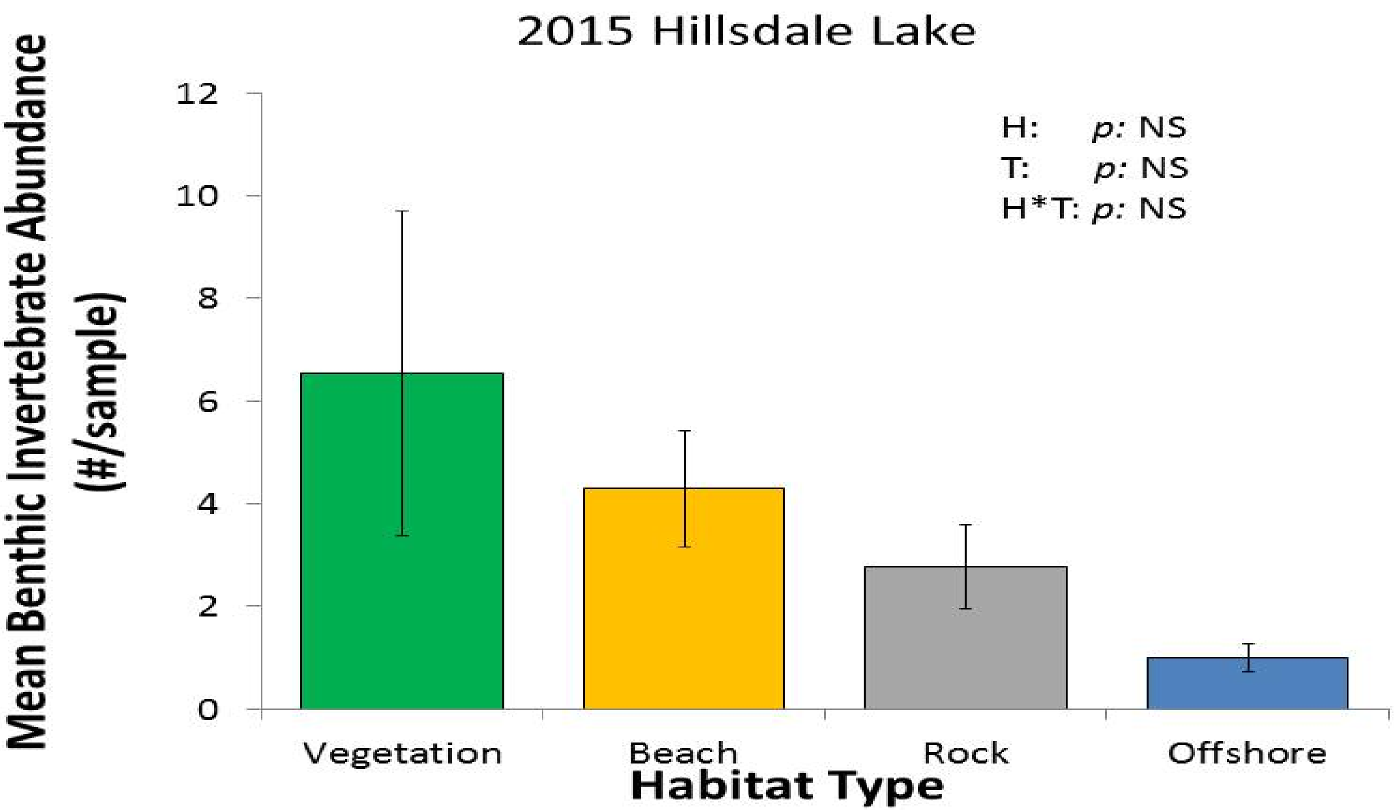

Figure B.16: Mean benthic invertebrate abundance (number/sample) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2015. Data are mean and standard error.

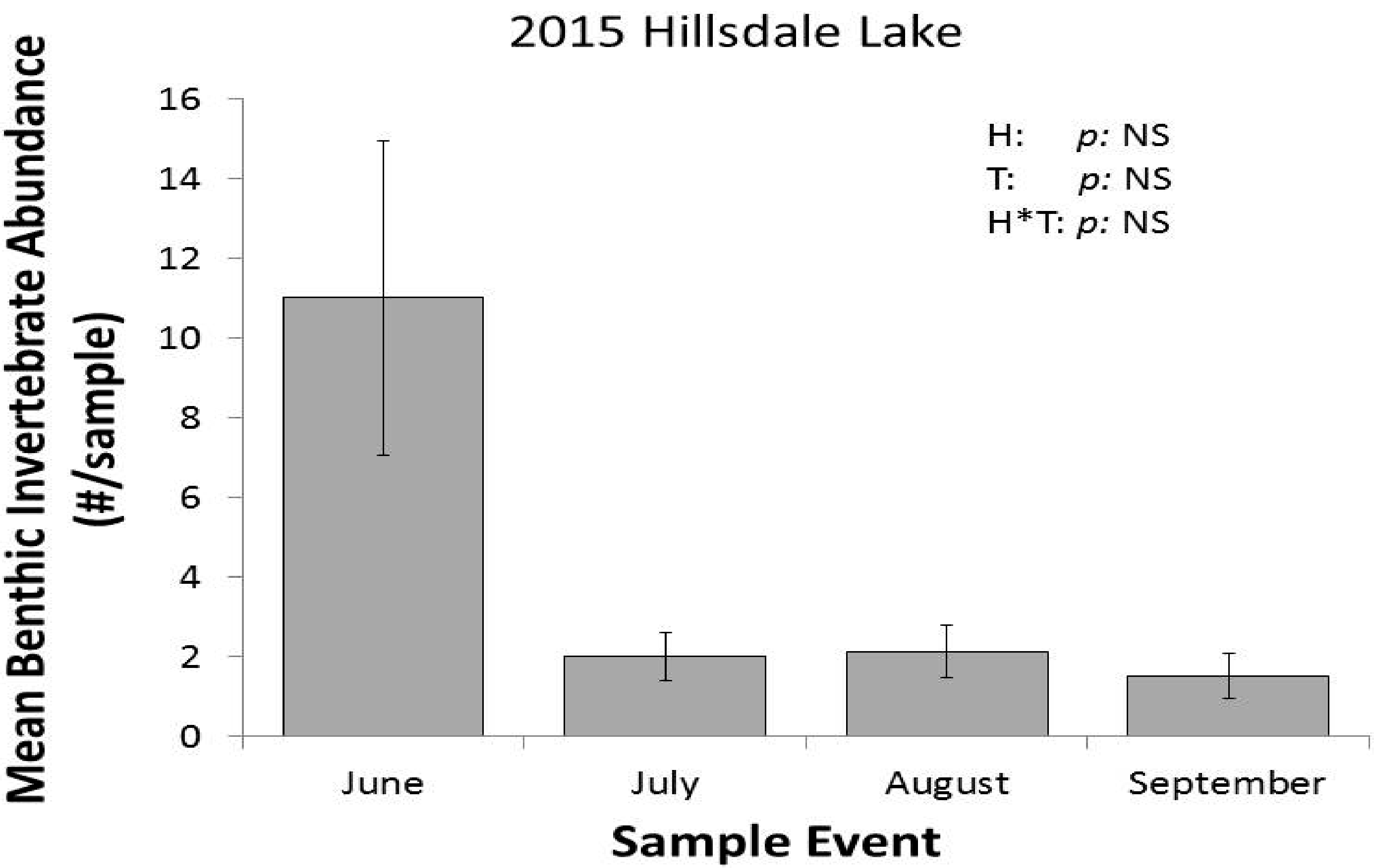

Figure B.17: Mean benthic invertebrate abundance (number/sample) across four sample months in Hillsdale Lake, KS during 2015. Data are mean and standard error.

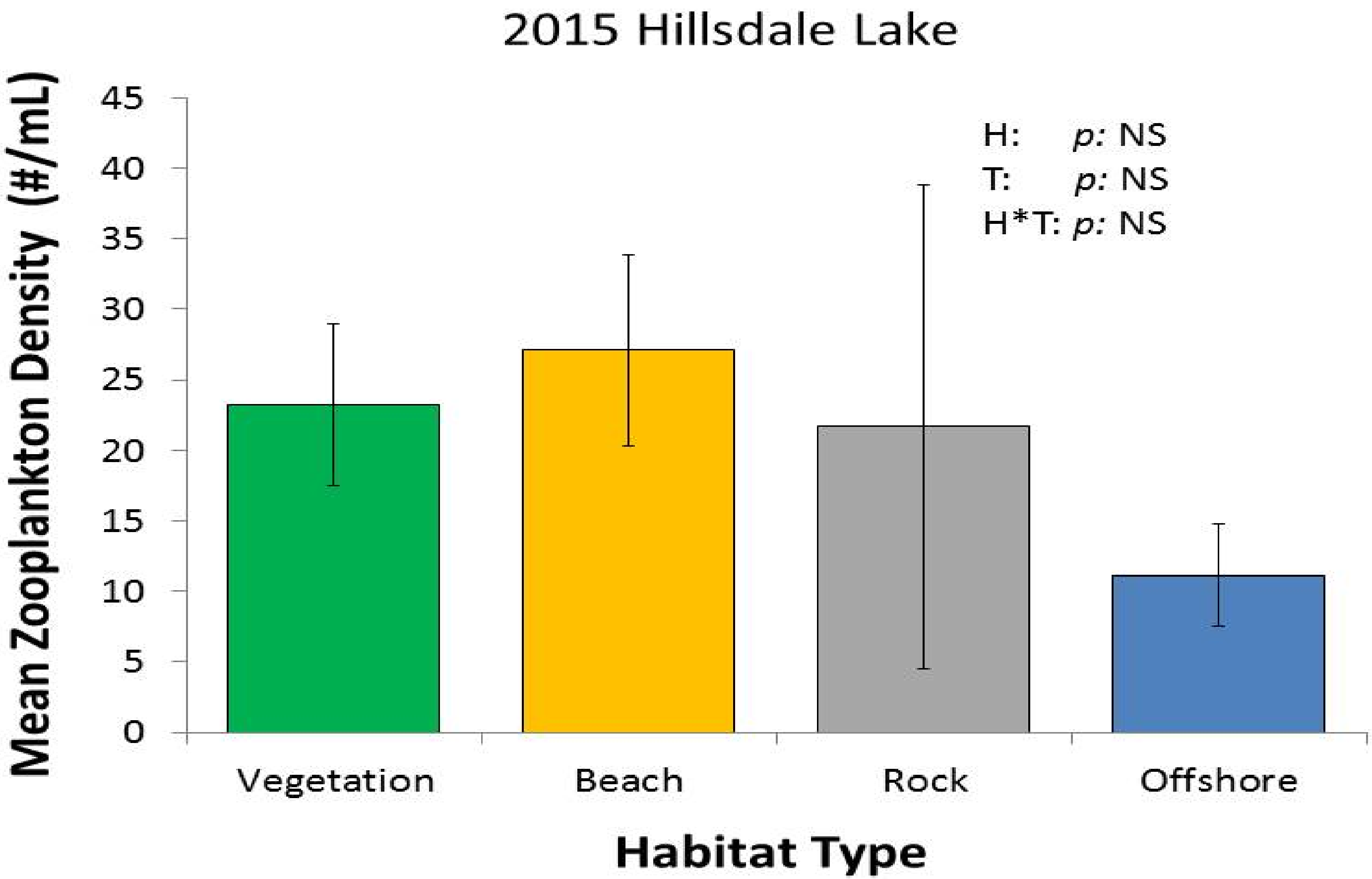

Figure B.18: Mean zooplankton density (number/mL) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2015. Data are mean and standard error.

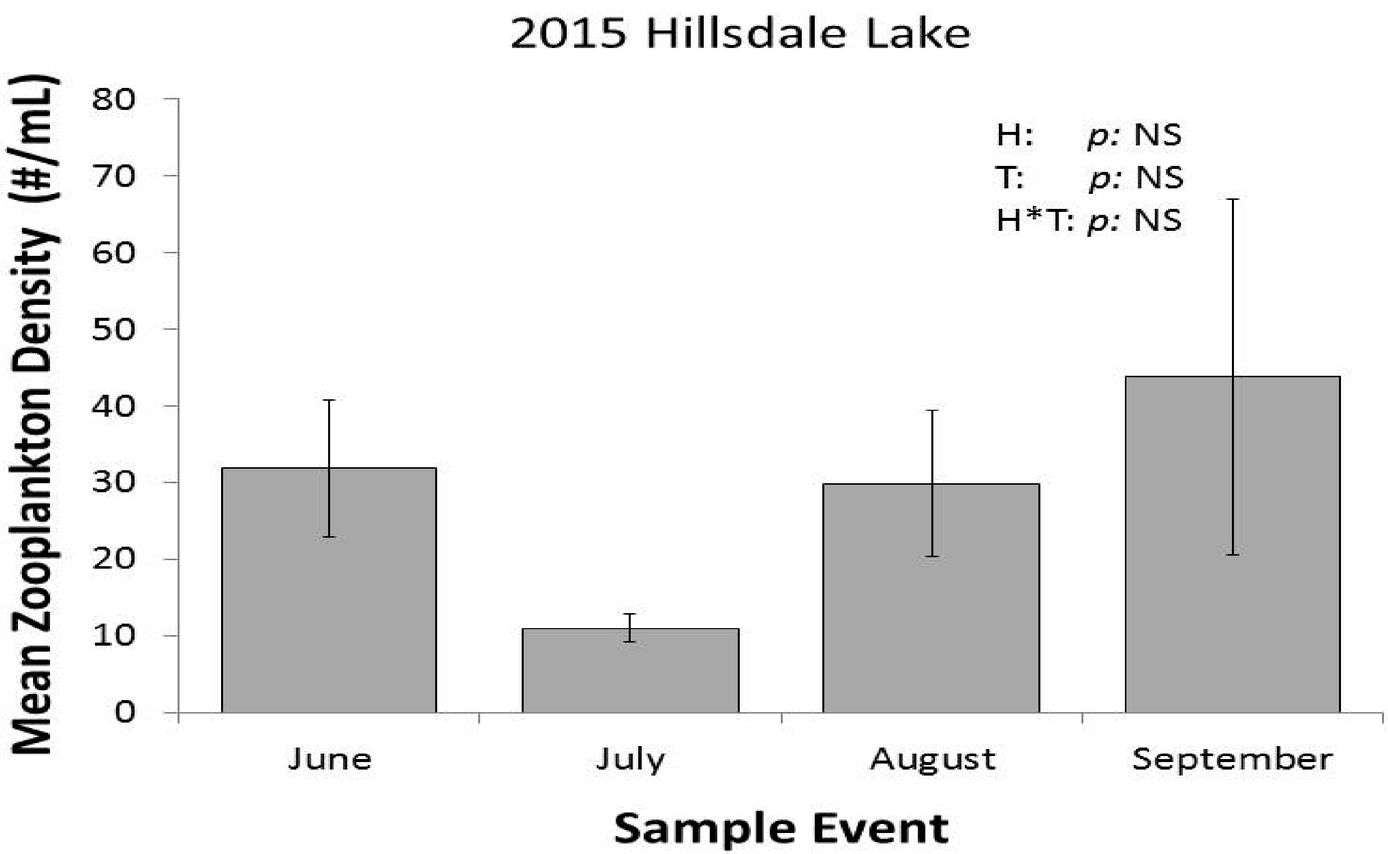

Figure B.19: Mean zooplankton density (number/mL) across four sample months in Hillsdale Lake, KS during 2015. Data are mean and standard error.

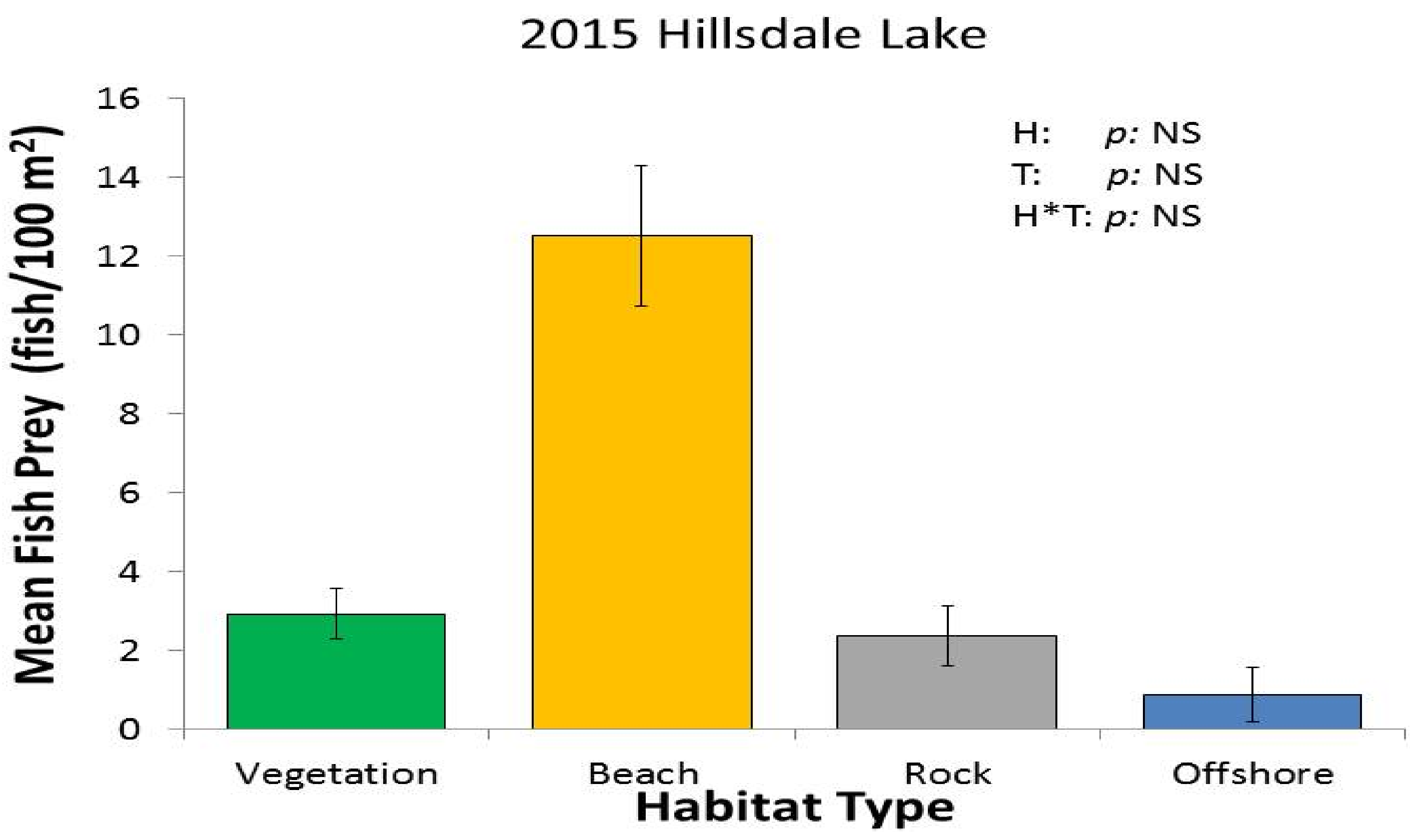

Figure B.20: Mean prey fish density (number/ 100 m^2) across four habitat types (vegetation, beach, rock, offshore) in Hillsdale Lake, KS during 2015. Data are mean and standard error.

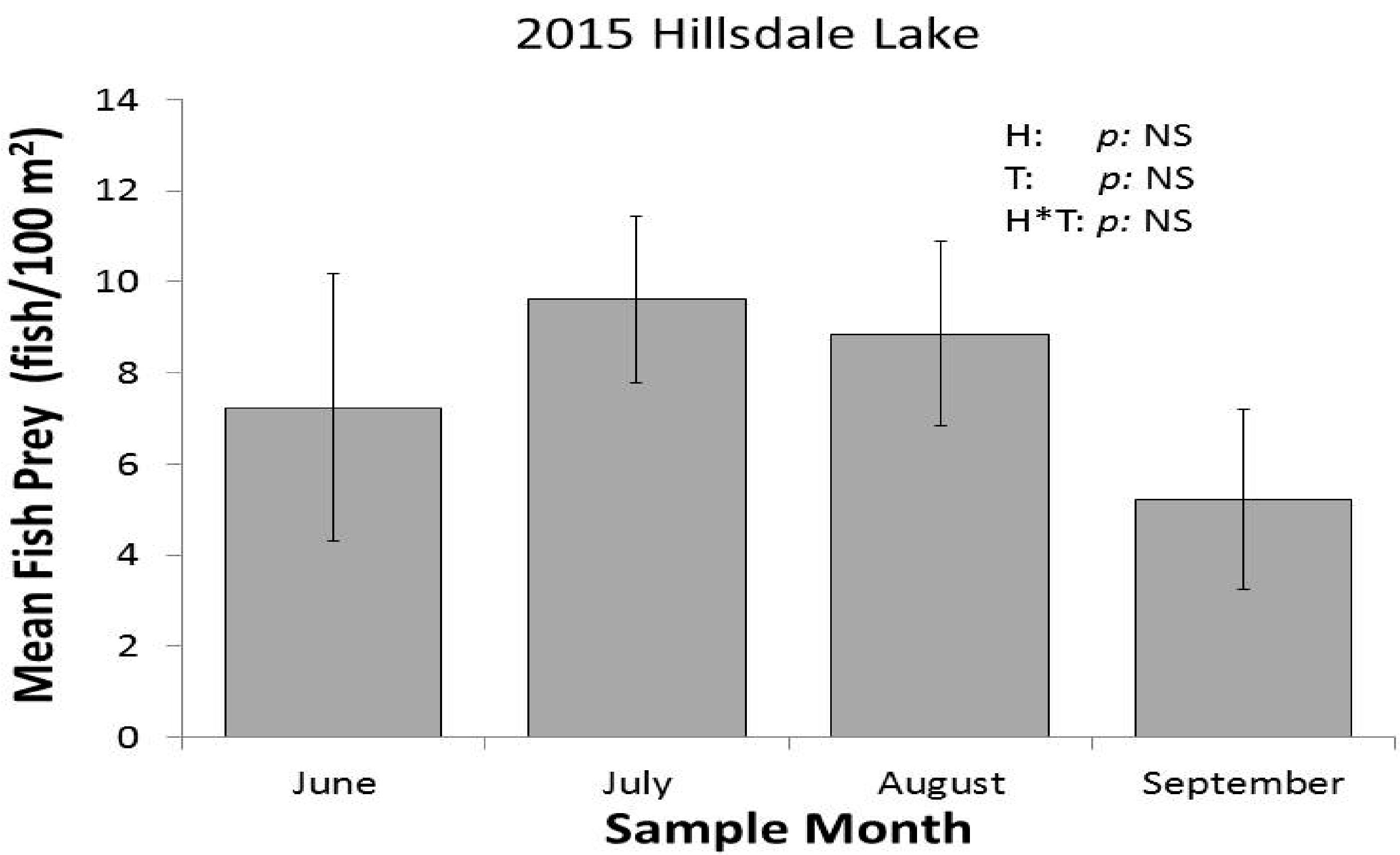

Figure B.21: Mean prey fish density (number/ 100 m^2) across four sample months during Hillsdale Lake, KS during 2015. Data are mean and standard error.

Appendix C - Stable Isotopes

Goal. The original goal of the stable isotope analysis was to assess if this tool that integrates prey over a longer (monthly) time period can detect the relatively subtle differences that occur in diets of largemouth bass through the summer. Stable isotopes have been effective in discriminating among consumers with consistently large differences in diet type (piscivory vs invertivory) or diets originating from different carbon sources (autochthonous vs allocthonous). However, the literature has shown that this tool is not well designed to detect the subtle, temporally variable differences in young of year largemouth bass diets for fish (like young of year largemouth bass) that are eating a mixture of fish and invertebrates throughout the summer.

Background. Stable isotope analysis can identify trophic position and resource utilization of an organism (Layman et al. 2007; Boecklen et al. 2011) if the isotopic signature of the producers and prey food chain lengths are different (Boecklen et al. 2011). Isotopes of nitrogen and carbon are the most commonly analyzed, however oxygen and hydrogen have also been analyzed (Cabana & Rasmussen 1996; Soto et al. 2013). Nitrogen is useful in estimating trophic position whereas carbon can identify the ultimate source of carbon (Post 2002). Processing of stable isotopes involves a small amount of fish material (dorsal muscle or mucus) that is dried and homogenized before being analyzed in a mass spectrometer (Post 2002; Church et al. 2008). Stable isotope samples are often taken from muscle tissue that is slow to reflect changes in diet. In order to be effective stable isotope analysis must be coupled with other diet analysis to completely describe food web structure (Layman et al. 2007). Stable isotope analysis cannot distinguish among consumers that regularly eat a mix of organisms (fish and invertebrates) or that switch between a mix of organisms through time.

Methods. After fish were collected using methods described in chapter 1, fish were then taken to the laboratory at Kansas State University. One or two muscle fillet samples were dried for 24 h at 60^{o}C then ground into a fine powder for stable isotope analysis of carbon and nitrogen. Stable isotope analysis was conducted at Kansas State University in the Nippert Lab.

Results. Baseline values of invertebrates, prey fish, macrophytes, and zooplankton were taken in Hillsdale Lake (Table. C.1). During 2014, stable isotopes of largemouth bass $\leq$ 150 mm TL clustered primarily between – 22, and -27 δC and 7-19 δN (Fig. C.1). During 2015, stable isotopes of largemouth bass < 120 mm TL clustered primarily between – 23 and -30 δC and 10-18 δN (Fig. C.2).

Overlap in stable isotopes among habitats was substantial during both years (2014: Fig. C.3, 2015: Fig. C.4). Mean values of both carbon and nitrogen isotopes were similar across habitats during both years (2014: Fig. C.5, 2015 Fig. C.6).

Substantial variation in stable isotopes existed within and across stocking treatments during both years (2014: Fig. C.7, 2015: Fig. C.8). During 2014, mean carbon was very similar across stocking treatments (Fig. C.9). Surprisingly, phase 2 fish had lower N values than other stocking treatments (Fig.C.9). During 2015, mean isotope absolute values were similar across phase 1 and phase 2, whereas wild fish had higher absolute values of both isotopes (Fig. C.10).

Overall summary. Carbon and nitrogen isotopes from individual largemouth bass were variable, but were not consistently different across habitat, time, stocking treatment, or body size.

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Table C.1: Baseline stable isotope values for invertebrates, prey fish, macrophytes, and zooplankton in Hillsdale Lake, KS.

	δC^{13}			δN^{15}		
	Mean	Min	Max	Mean	Min	Max
Invertebrates	-24.19	-28.08	-21.76	9.80	8.78	11.16
Prey Fish	-24.24	-25.99	-22.79	15.34	14.73	15.80
Macrophytes	-25.84	-31.86	-12.10	7.76	5.19	10.49
Zooplankton	-23.88	-24.54	-23.22	7.25	4.81	9.68

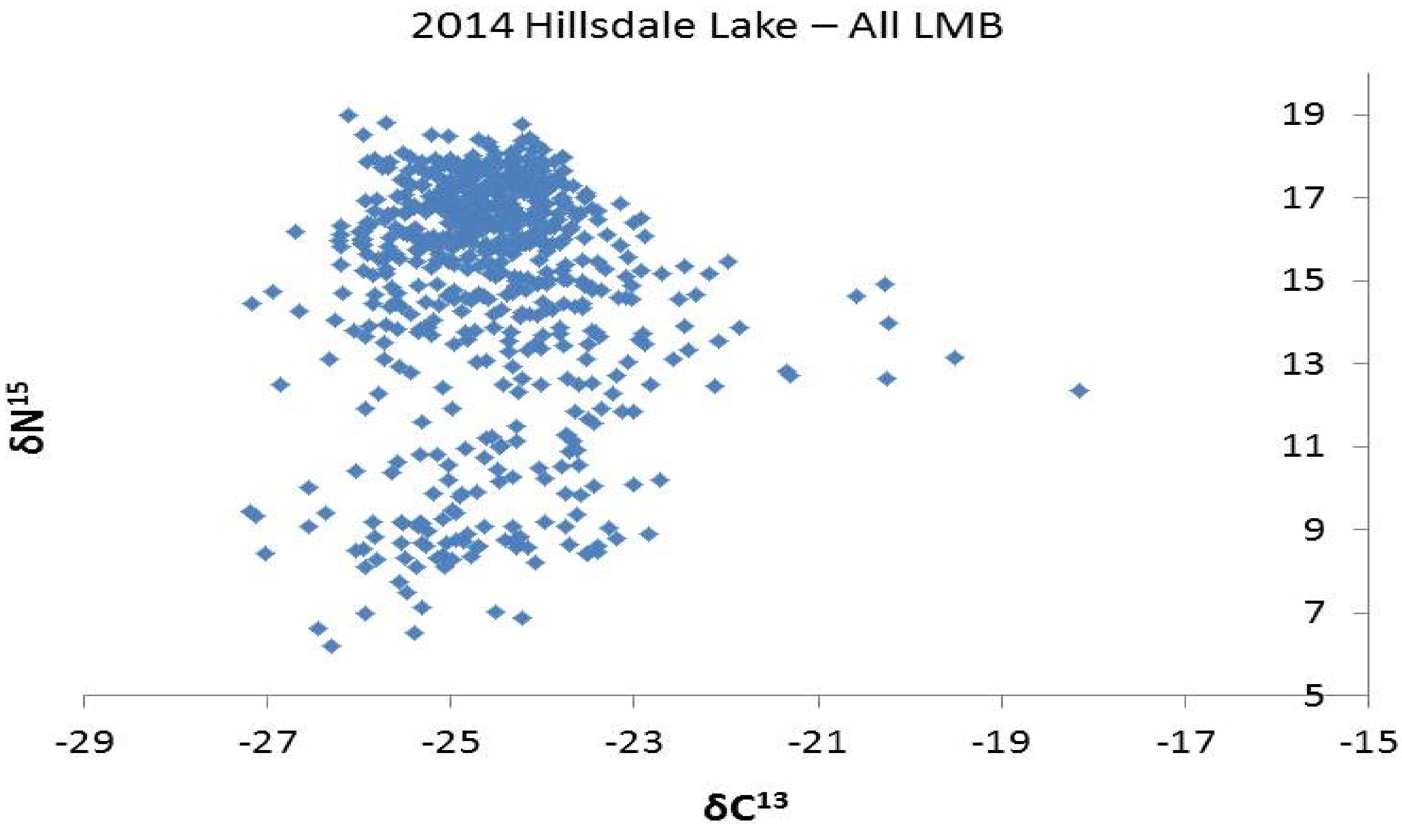

Figure C.1: Stable isotope values of young of year largemouth bass in Hillsdale Lake, KS during 2014.

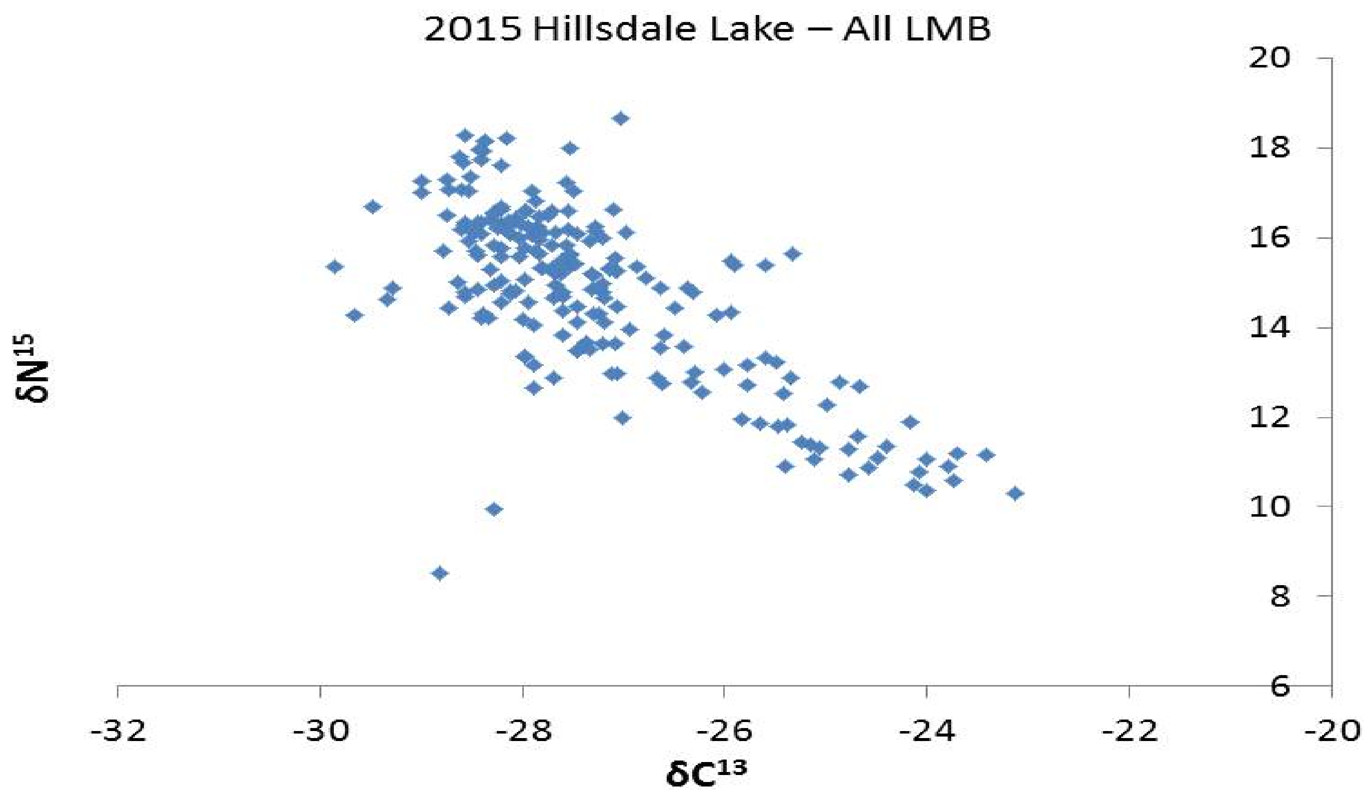

Figure C.2: Stable isotope values of young of year largemouth bass in Hillsdale Lake, KS during 2015.

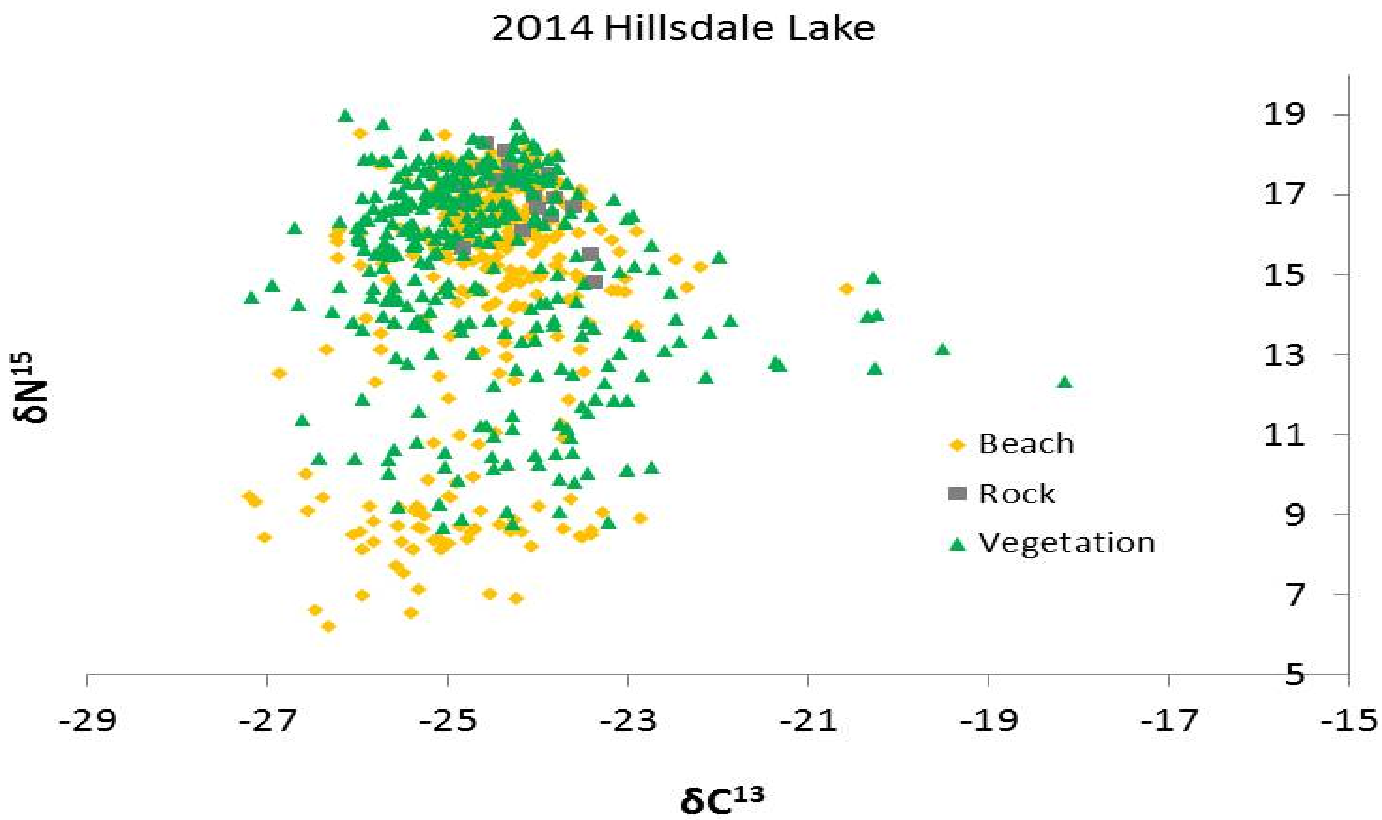

Figure C.3: Stable isotope values of young of year largemouth bass across three habitats in Hillsdale Lake, KS during 2014.

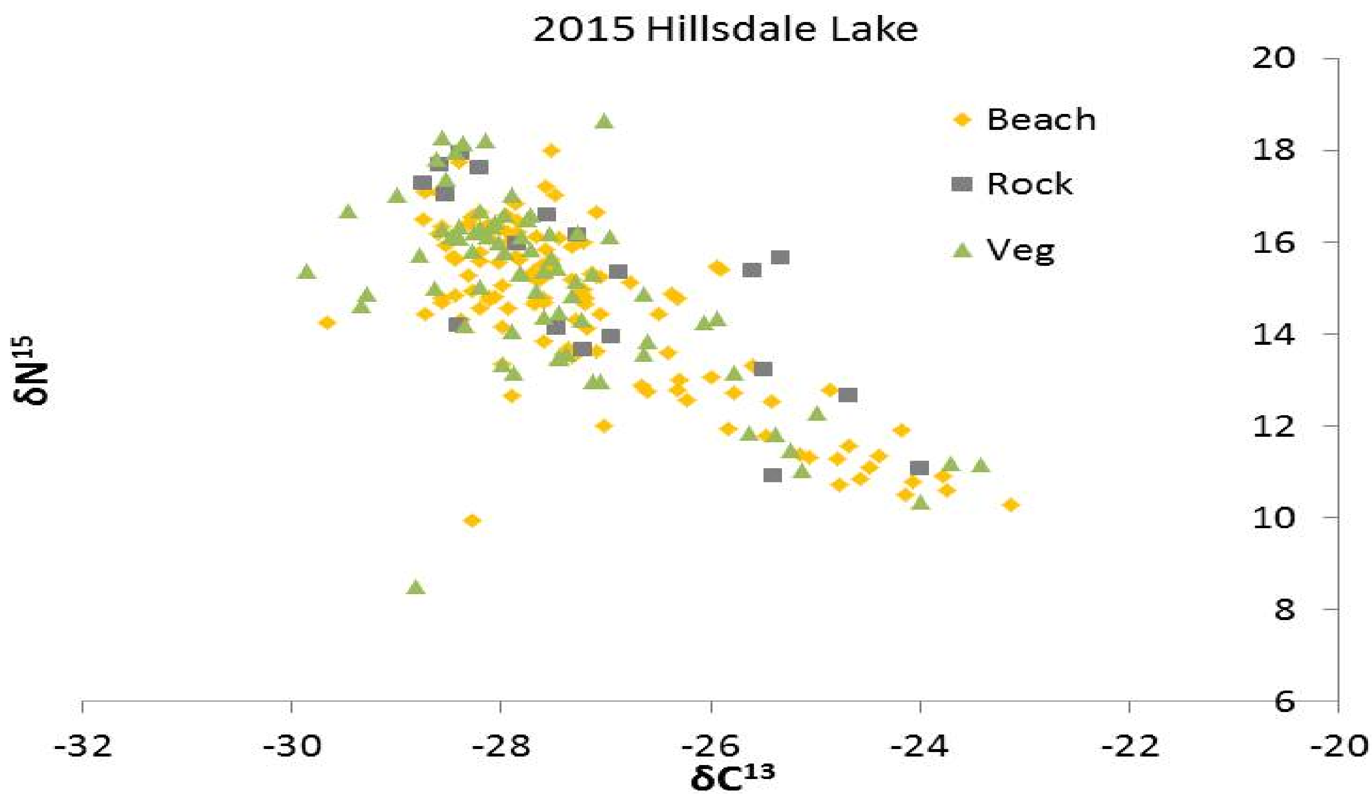

Figure C.4: Stable isotope values of young of year largemouth bass across three habitats in Hillsdale Lake, KS during 2015.

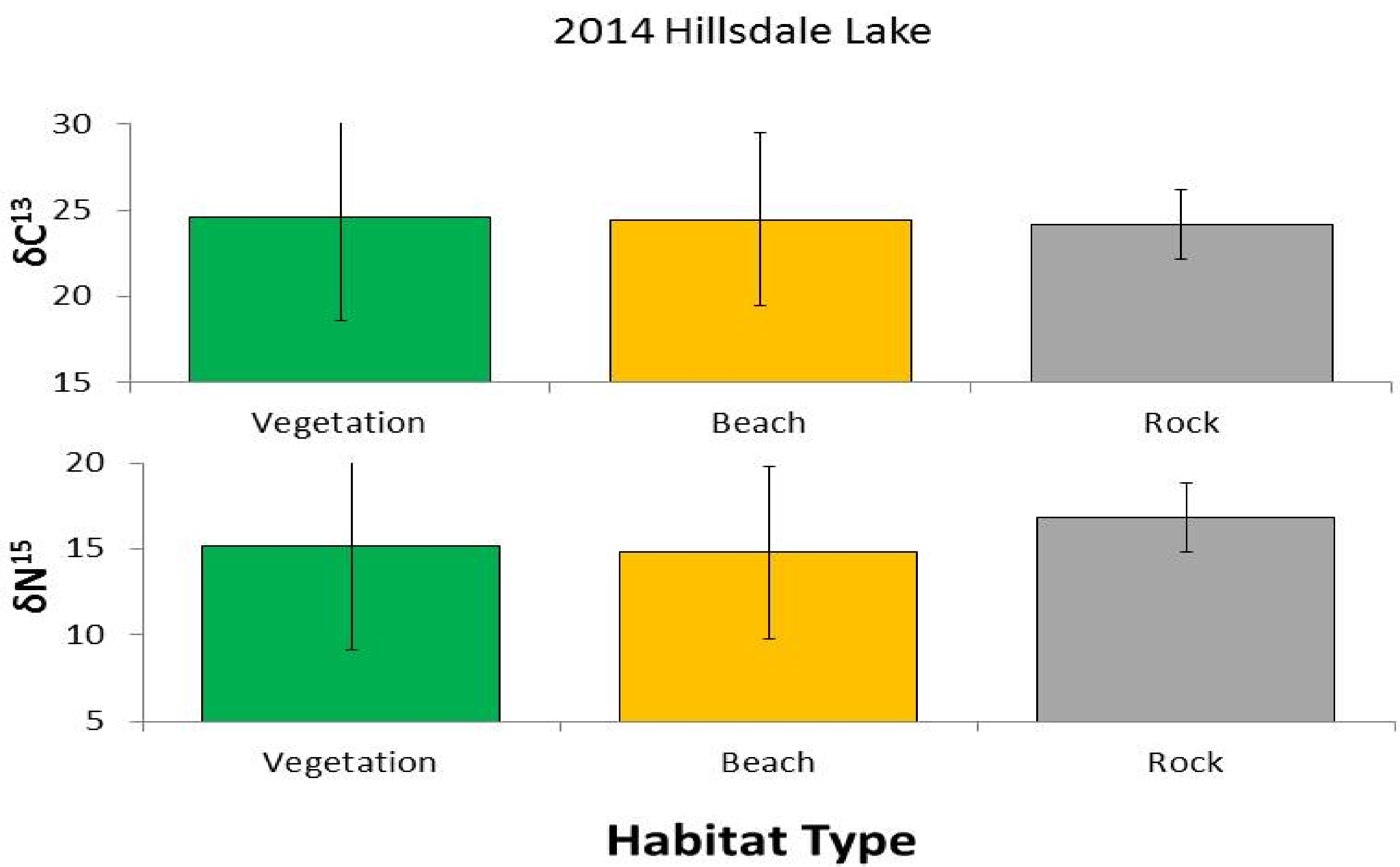

Figure C.5: Mean stable isotope values of young of year largemouth bass across three habitats in Hillsdale Lake, KS during 2014.

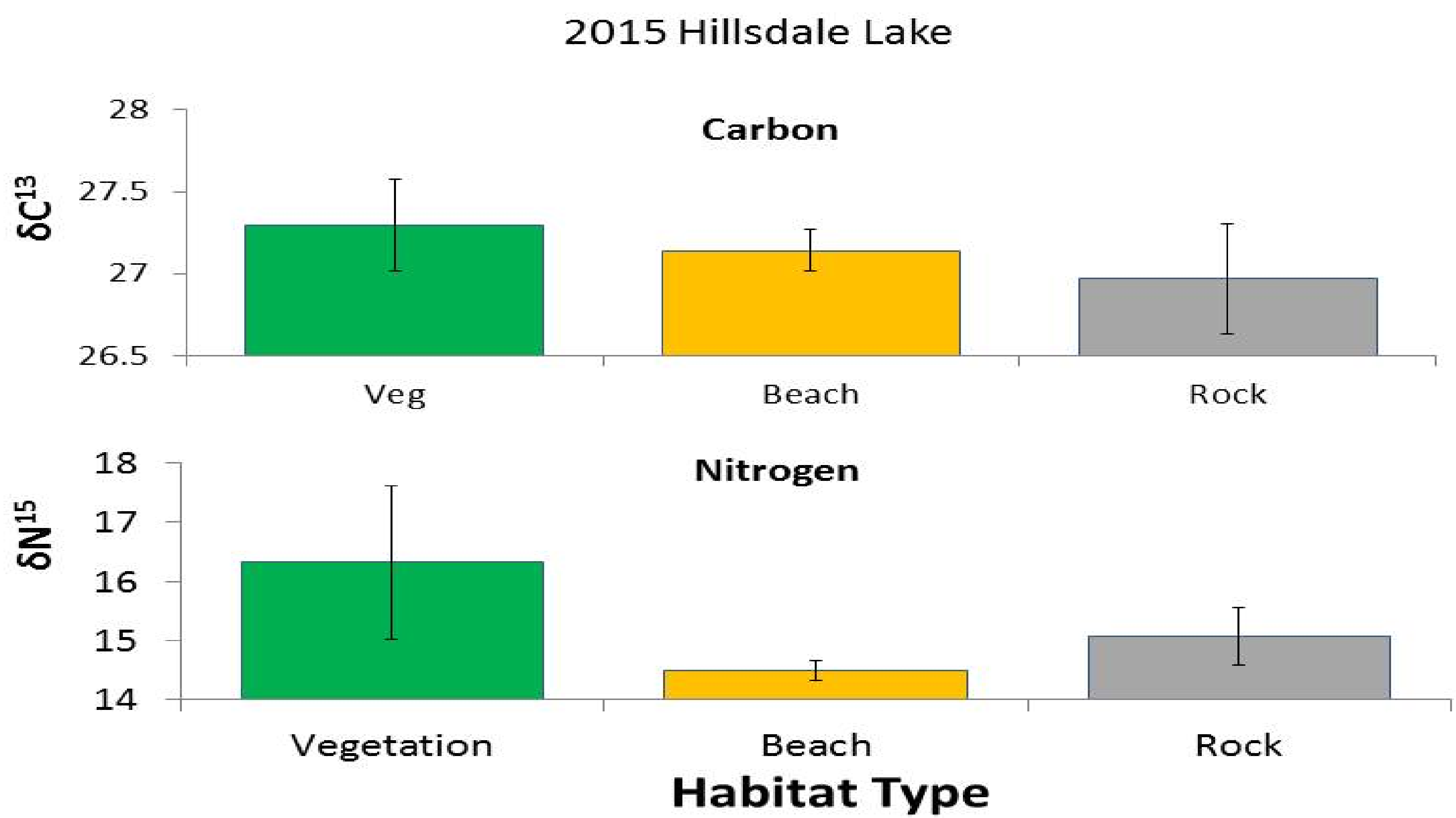

Figure C.6: Mean stable isotope values of young of year largemouth bass across three habitats in Hillsdale Lake, KS during 2015.

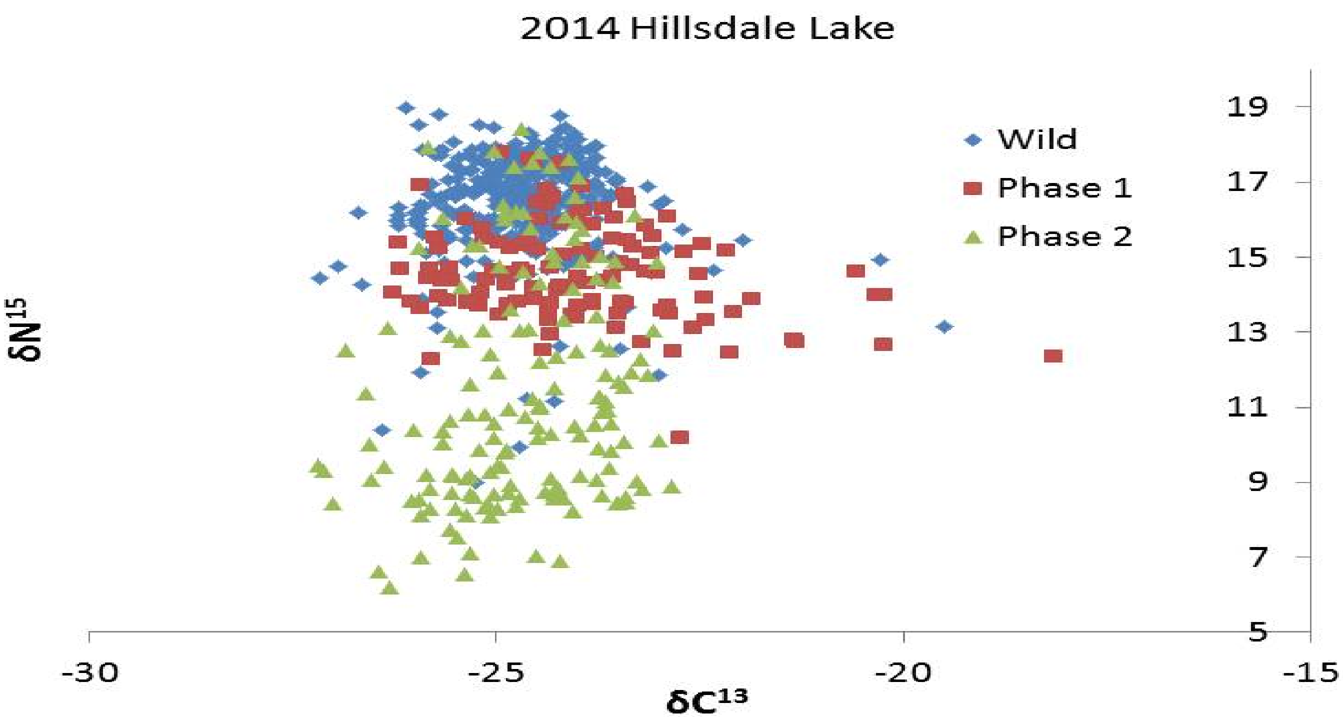

Figure C.7: Stable isotope values of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2014.

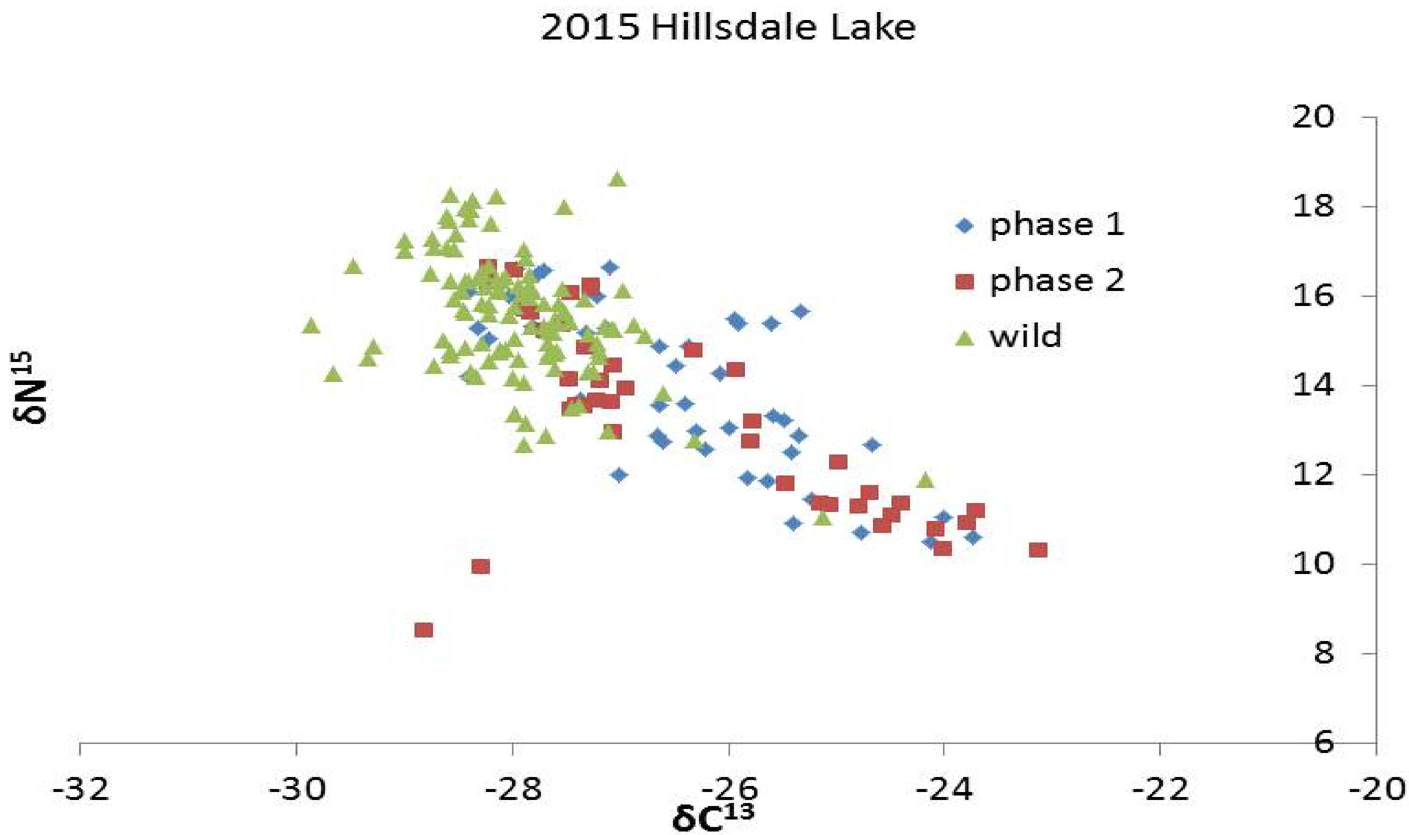

Figure C.8: Stable isotope values of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2015.

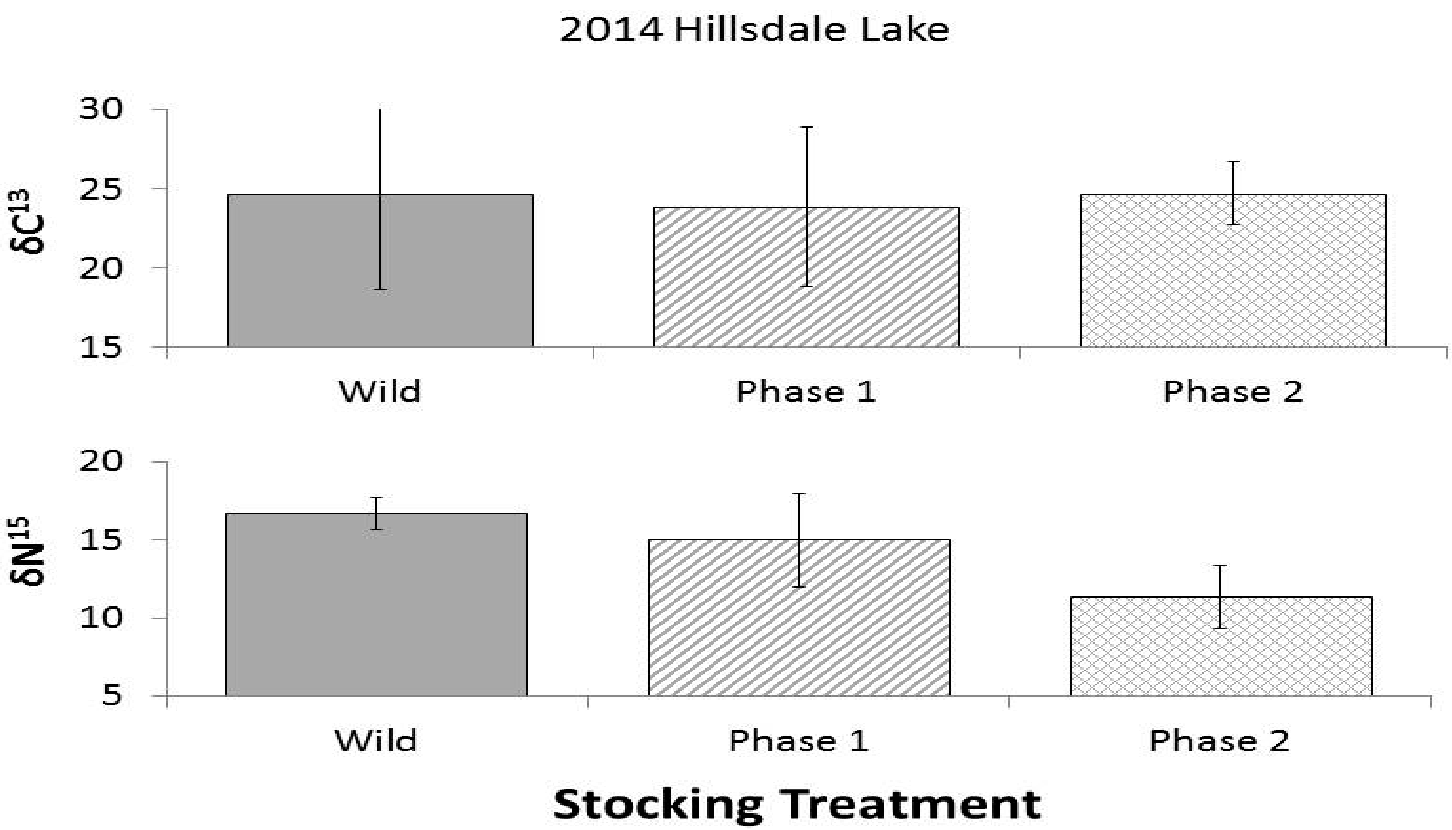

Figure C.9: Stable isotope values of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2014.

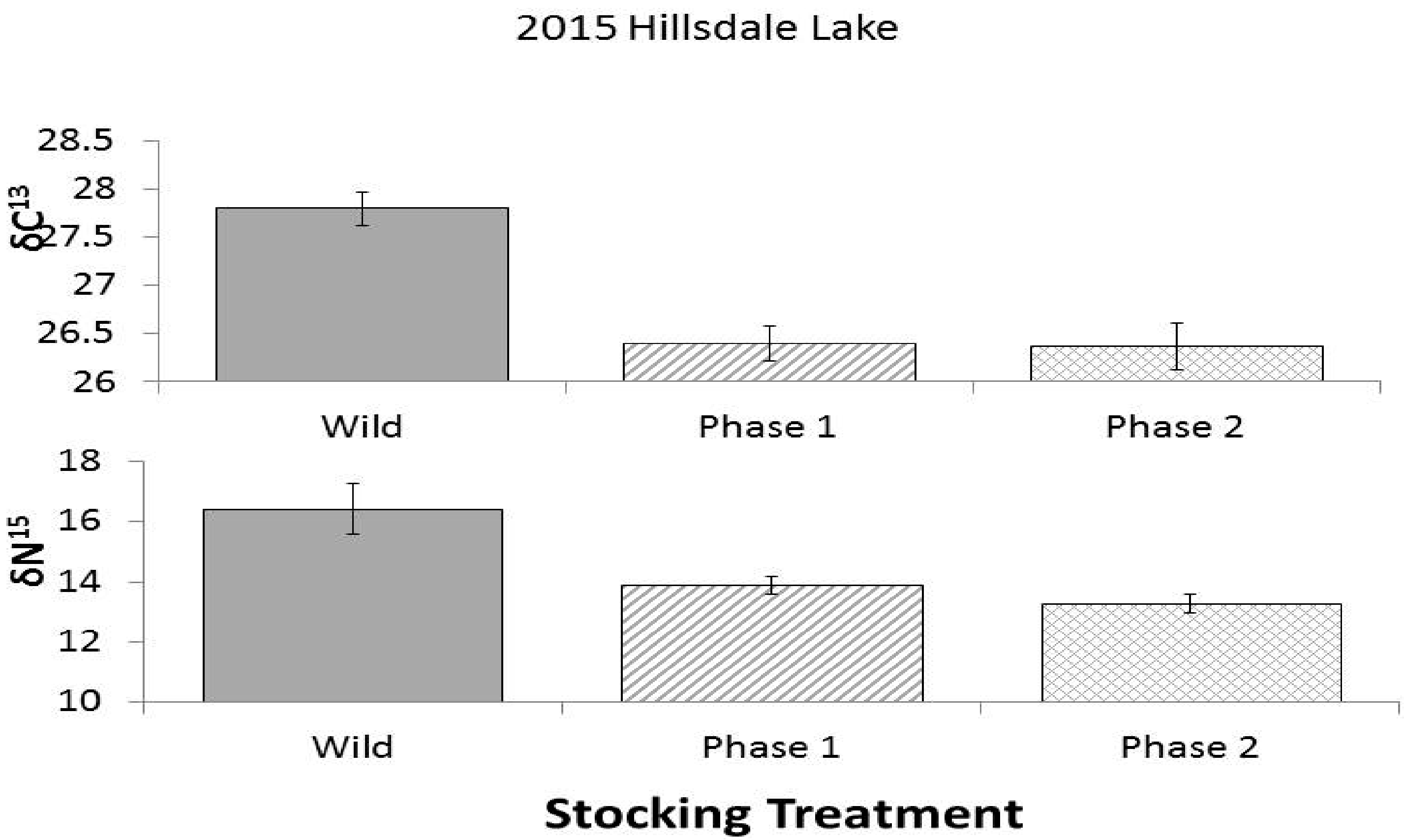

Figure C.10: Stable isotope values of three stocking treatments of young of year largemouth bass in Hillsdale Lake, KS during 2015.

Appendix D - Species of Fish Prey in Young of Year Largemouth Bass Diets

Goal. My goal was to assign species identification to digested fish prey in largemouth bass stomachs based on backbone counts.

Methods. Fish in diets were identified to species using morphological features when possible. When fish were too digested for accurate identification visually, vertebrae counts were used to identify species. I obtained backbone counts for common freshwater fish in my seine samples (Resh et al. 1976, McDowall 2007). I used specific counts to identify species (Tables D.1 & D.2). There was some overlap between vertebrae counts for some fish species and backbone counts that were in the overlap range were reported separately. Backbones with vertebrae counts less than 27 were considered partial because no prey species in Hillsdale Lake had vertebrae counts that low.

Results. Young of year largemouth bass ate a range of fish species in Hillsdale Lake, KS during 2014 and 2015. Across both years, young of year largemouth bass ate green sunfish, red shiners, emerald shiners, gizzard shad, and other largemouth bass (Tables D.1 & D.2). During 2014, largemouth bass were the most common fish species eaten (Table D.1). During 2015 emerald shiners were the most common fish species eaten (Table D.2).

During 2014, emerald shiners were the most common fish species eaten in vegetated habitats and largemouth bass were the most common fish species eaten in beach habitats (Table D.1). During 2015, gizzard shad were the most common fish species eaten in vegetated habitats and emerald shiners were the most common fish species eaten in beach habitats (Table D.2).

References

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Table D.1: Fish species found in young of year lagrmeouth bass stomachs in Hillsdale Lake, KS during 2014.

	Backbone Range 1			Backbone Range 2			Backbone Range 3			Backbone Range 4			Backbone Range 5			Backbone Range 6			Backbone Range 7			Backbone Range 8		
	Range	28-29		Range	30-32		Range	32-36		Range	36-42		Range	47-51		Range	36		Range	32		Range	<27	
	Species	Green Sunfish		Species	LMB		Species	Red Shiner		Species	Emerald Shiner		Species	Shad		Species	Red Shiner Emerald Shiner		Species	LMB Red Shiner		Species	Partial	
	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N
	Mean			Mean			Mean			Mean			Mean			Mean			Mean			Mean		
Overall	**0.78**	4.91	4	**4.47**	28.13	10	**1.07**	6.73	5	**1.08**	**6.80**	9	**1.78**	**11.20**	3	**0.00**	**0.00**	2	**2.98**	**18.75**	6	**3.73**	**23.47**	42
HATCHERY																								
Wild	0.46	7.67	3	0.80	13.33	3	1.07	17.83	4	0.45	7.50	3	0.02	0.33	1	0.00	0.00	0	1.15	19.17	2	2.05	34.17	28
Phase 1	0.00	0.00	0	0.00	0.00	0	0.00	0.00	1	0.16	7.08	3	1.59	70.35	1	0.00	0.00	1	0.18	7.96	1	0.33	14.60	8
Phase 2	0.32	4.19	1	3.67	48.10	7	0.00	0.00	0	0.47	6.16	3	0.17	2.23	1	0.00	0.00	1	1.65	21.63	3	1.35	17.69	6
HABITAT																								
Vegetation	0.35	7.53	2	1.13	24.30	4	0.20	4.30	3	0.31	6.67	7	0.00	0.00	0	0.00	0.00	1	0.86	18.49	4	1.80	38.71	22
Beach	0.43	4.77	2	3.34	37.03	6	0.42	4.66	1	0.77	8.54	2	0.19	2.11	2	0.00	0.00	1	2.12	23.50	2	1.75	19.40	19
Rock	0.00	0.00	0		0.00	0	0.45	20.27	1	0.00	0.00	0	1.59	71.62	1	0.00	0.00	0	0.00	0.00	0	0.18	8.11	1
WEEK																								
1	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0
2	0.00	0.00	0	0.00	0.00	0	0.00	0.00	1	0.00	0.00	0	0.00	0.00	0	0.00	0.00	2	0.00	0.00	0	0.00	0.00	1
3	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	1
4	0.00	0.00	0	0.70	24.31	2	0.00	0.00	0	0.41	14.24	4	0.17	5.90	1	0.00	0.00	0	0.18	6.25	1	1.42	49.31	5
6	0.32	7.84	1	1.94	47.55	3	0.45	11.03	1	0.09	2.21	1	0.02	0.49	1	0.00	0.00	0	0.69	16.91	1	0.57	13.97	11
7	0.00	0.00	0	1.36	49.10	3	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0	0.96	34.66	1	0.45	16.25	8
8	0.46	11.62	3	0.00	0.00	0	0.60	15.15	2	0.46	11.62	3	0.00	0.00	0	0.00	0.00	0	1.15	29.04	3	1.29	32.58	14
9	0.00	0.00	0	0.47	21.36	2	0.02	0.91	1	0.12	5.45	1	1.59	72.27	1	0.00	0.00	0	0.00	0.00	0	0.00	0.00	1

Table D.2: Fish species found in young of year lagrmeouth bass stomachs in Hillsdale Lake, KS during 2015.

	Backbone Range 1			Backbone Range 2			Backbone Range 3			Backbone Range 4			Backbone Range 5			Backbone Range 6			Backbone Range 7			Backbone Range 6		
	Range	28-29		Range	30-32		Range	32-36		Range	36-42		Range	47-51		Range	36		Range	32		Range	<27	
	Species	Green Sunfish		Species	LMB		Species	Red Shiner		Species	Emerald Shiner		Species	Shad		Species	Red or Emerald Shiner		Species	LMB or Red Shiner		Species	Partial	
	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N	Wt (g)	%	N
	Mean			Mean			Mean			Mean			Mean			Mean			Mean			Mean		
HATCHERY																								
Wild	0.03	1.538	1		0.000			0.000		0.67	34.359	4	0.32	16.410	1	0.13	6.667	1		0.000	0	0.8	41.026	17
Phase 1		0.000		0.12	7.362	1	0.12	7.362	2	0.15	9.202	1	0.65	39.877	4	0.59	36.196	1		0.000	0		0.000	
Phase 2	0.3	14.286	1	0	0.000	1		0.000		0.7	33.333	2	0.04	1.905	1		0.000			0.000	0	1.06	50.476	7
HABITAT																								
Vegetated		0.000		0	0.000	1		0.000		0.07	3.608	1	0.9	46.392	3		0.000			0.000	0	0.97	50.000	8
Beach	0.03	1.271	1	0.12	5.085	1	0.12	5.085	1	0.75	31.780	4	0.07	2.966	2	0.59	25.000	1		0.000	0	0.68	28.814	10
Rock	0.3	21.739	1		0.000		0	0.000	1	0.7	50.725	2	0.04	2.899	1	0.13	9.420	1		0.000	0	0.21	15.217	5
WEEK																								
1		0.000			0.000			0.000			0.000			0.000			0.000			0.000	0		0.000	
2	0.03	27.273	1		0.000			0.000			0.000		0.07	63.636	1		0.000			0.000	0	0.01	9.091	2
3		0.000			0.000		0	0.000	1	0.35	51.471	2	0.25	36.765	2		0.000			0.000	0	0.08	11.765	1
4	0.3	21.739	1	0	0.000	1		0.000		0.7	50.725	2	0.37	26.812	2		0.000			0.000	0	0.01	0.725	3
5		0.000		0.12	4.598	1	0.12	4.598	1	0.27	10.345	2	0.32	12.261	1	0.59	22.605	1		0.000	0	1.19	45.594	11
6		0.000			0.000			0.000			0.000			0.000		0.13	27.083	1		0.000	0	0.35	72.917	4
7		0.000			0.000			0.000			0.000			0.000			0.000			0.000	0		0.000	
8		0.000			0.000			0.000			0.000			0.000			0.000			0.000	0	0.22	100.000	3
9		0.000			0.000			0.000			0.000	1		0.000			0.000			0.000	0		0.000	