Diet Composition and Prey Selectivity of Yellow Perch *Perca flavescens* from Five Lakes across a gradient of Dissolved Organic Carbon at UNDERC East

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Abstract

Dissolved organic carbon (DOC) has been increasing in lentic systems for the past 20 years across much of Europe and North America, however the causes of this increase are not entirely clear. DOC affects physical, chemical, and biological factors of lentic systems. For instance increasing levels of DOC are associated with shifts from planktivory to benthivory at smaller sizes of European perch *Perca fluviatilis*. This study examined whether similar effects are seen in yellow perch *Perca flavescens* diets. Diets from *P. flavescens* collected from five lakes at UNDERC East during May and June of 2012 were recorded and analyzed. Dietary shifts were not observed across standard lengths and differences in diet composition did not differ across size classes of *P. flavescens*, and therefore no difference in dietary shifts were observed across a gradient of DOC. Diet composition, but not prey selectivity, differed between lakes indicating that prey densities rather than levels of DOC or size of individual *P. flavescens* determine diet composition. This suggests that ontogenetic shifts in the diet of *P. flavescens* are not as fixed as some studies suggest and that *P. flavescens* are generalist predators capable of foraging on the most abundant prey taxa present throughout their juvenile life stage.

Introduction

Lentic dissolved organic carbon (DOC) has been increasing in the majority of lakes across northern Europe and North America for the past 20 years and can be affected by physical, chemical, and biological factors that can be either natural or anthropogenic. For instance, the size and soil composition of a lake's catchment, the amount of precipitation received by a lake, a lake's water renewal time, the amount of dissolved nitrogen and phosphorous, and the acidity of a lake may affect the level of DOC within it (Schindler et al. 1992). It has been hypothesized that humans may be increasing the levels of DOC by influencing a number of these factors (Sucker and Krause 2009).

Furthermore, DOC has a wide range of effects on community and ecosystem structure, such as serving as a food source for some heterotrophs, absorbing solar energy which decreases light penetration and increases temperature in turn affecting primary production, reducing the availability of heavy metals and toxic compounds, and influencing the pH of aquatic systems (Stanley et al. 2011). The reduction of light penetration by increased levels of DOC can also impact organisms that rely on sight for intraspecific and interspecific interactions. For instance the visual predator European perch *Perca fluviatilis* switches earlier in ontogeny from consuming plankton to benthic macroinvertebrates in more humic lakes than in less humic lakes. This is observed especially when juvenile *P. fluviatilis* are in competition with roach *Rutilus rutilus* for plankton as a food source, since European perch rely primarily on vision for food consumption and roach are more efficient at consuming plankton. Furthermore *P. fluviatilis* that inhabit more humic lakes feed primarily on benthic macroinvertebrates for a longer period of their life cycle than *P. fluviatilis* inhabiting less humic lakes (Estlander 2011). This switch earlier in ontogeny to consuming primarily benthic macroinvertebrates is less profitable to *P. fluviatilis,* stunting their growth and leading to higher mortality rates (Bystrom et. al. 1998).

Yellow perch *Perca flavescens* may also experience earlier ontogenetic shifts in diet as a result of higher levels of humic substances (i.e. DOC). In this study I examine the diets of *P. flavescens* from five lakes varying in DOC, located at the University of Notre Dame Environmental Research (UNDERC) East's campus. Specifically, I examine the proportion of zooplankton and macroinvertebrates along with the selectivity for a number of macroinvertebrate orders as a function of standard length and lake color, as lake color is directly related to DOC (Pace and Cole 2002). I hypothesize that juvenile *P. flavescens* shift from plankitovory to consuming benthic macroinvertebrates at a smaller standard length in lakes that have higher levels of DOC than those that inhabit lakes with lower levels of DOC. I also hypothesize that *P. flavescens* inhabiting lakes with higher levels of DOC will primarily consume benthic macroinvertebrates for a longer portion of their life than *P. flavescens* that inhabit lakes with lower levels of DOC.

Materials & Methods

Fish Sampling

The study was carried out on five lakes, Bay, Brown, Crampton, Hummingbird, and Morris on the University of Notre Dame Environmental Research Center East's property during May and June of 2012. Minnow traps were set out on lakes for eight hours and then checked for *P. flavescens*. Any *P. flavescens* caught in a minnow trap was immediately euthanized using a lethal dose of tricaine methanesulfonate (MS-222). Measurements of total length, standard length, and weight were recorded for each *P. flavescens*, and the digestive tract was then removed from each individual. Digestive tracts were preserved in 70% ethanol until dissection. The contents of each digestive tract were classified to order and occasionally family (i.e. Chironomidae), and counts were made of each category. Furthermore, each fish was placed into one of five size classes, 36-50mm, 51-65mm, 66-80mm, 81-95mm, or >95mm.

Prey Selectivity

Each lake sampled for *P. flavescens* was also sampled for benthic macroinvertebrate communities along four transects from shore at depths of one-half, one, three, eight, and 12m during May and June of 2012. Benthic communities above hypoxic depths (> 2mg/L of dissolved oxygen) were compared to the benthic macroinvertebrate portion of fish gut contents collected from the same lake during the same month. Selectivity indices for prey items of each fish were calculated using Ivlev's Electivity Index: $E=(r_i-p_i)/(r_i+p_i)$, where r_i is the proportion of prey taxa in a consumer's digestive tract and p_i is the proportion of that taxa in the consumer's environment.

Water Color

Water samples were taken from each lake and measured using a spectrophotometer at 440nm for absorbance. These absorbances were used as surrogates for levels of DOC, as the two are directly related (Pace and Cole 2002).

Statistical Analyses

A multiple regression was run on the proportion of zooplankton and macroinvertebrates in *P. flavescens* diets as a function of lake color and standard length. An ANCOVA was run for both the proportion of zooplankton and macroinvertebrates in *P. flavescens* diets with standard length and lake. Also the proportion zooplankton and macroinvertebrates in diets were analyzed with lake and size class in both a two-way ANOVA and one-way ANOVAs.

Two-way ANOVAs were run comparing selectivity for each prey taxa across lakes and size classes. ANCOVAs were run comparing the selectivity of each prey type across standard lengths between lakes. Regressions were also run to determine any relationship between prey selectivity and standard length or color. All analyses were performed using SYSTAT statistical software.

Results

Dietary Shifts

There were no relationships between the proportion of zooplankton or macroinvertebrates and standard length and lake color (p=0.65 and 0.585 respectively). The proportion of zooplankton and macroinvertebrates were also not affected by the interaction between standard length and lake (p=0.152 and 0.138 respectively). Furthermore the proportion of zooplankton and macroinvertebrates in diets did not vary with lake color or standard length (Figures 1, 2, 3, and 4; p=0.368 for proportion zooplankton vs lake color; p=0.876 for proportion zooplankton vs standard length; p=0.316 for macroinvertebrates vs lake color; p=0.511 for macroinvertebrates vs standard length). There were, however, differences in the proportion of zooplankton and macroinvertebrates in diets across lakes (Figures 5 and 6. p=0.001 and 0.004 respectively), but not between size classes (p=0.247 and 0.127 respectively). The differences in the proportion of zooplankton were specifically between Brown and Crampton (p=0.003) and between Brown and Morris (p=0.006). The differences in the proportion of macroinvertebrates were between Brown and Crampton (p=0.003), while the difference between Crampton and Hummingbird was marginally significant (p=0.099). *P. flavescens* from Bay had the largest proportion of zooplankton in their diets (31.7%), followed by *P. flavescens* from Brown (31.3%), then Hummingbird (15.4%), then Crampton (7.3%), and finally Morris (5.4%). *P. flavescens* from Crampton had the largest proportion of macroinvertebrates in their diets (91.3%), followed by Morris (83.6%), then Bay (68.3%), then Hummingbird (67.8%), and finally Brown (63.6%).

Prey Selectivity

Selectivity for odonates, coleopterans, and chironomids differed across lakes (Figures 7, 8, and 9 $p<0.001$ for each), however selection for veneroidans, ephemeropterans, trichopterans, and non-chironomid dipterans did not differ between lakes (p=0.397, 0.3, 0.11, and 0.183 respectively). Furthermore selection for odonates increases with increasing standard length of *P. flavescens*, although the model has little explanatory capability (Figure 10. p=0.013, r^2=0.0667), however selection for each of the prey taxa did not differ between size classes (p=0.565 for non-chironomid dipterans; p=0.674 for coleopterans; p=0.823 for chironomids; p=0.754 for veneroidans; p=0.825 for ephemeropterans; p=0.799 for amphipods; p=0.166 for odonates; p=0.756 for trichopterans). Also there were no relationships between selectivity for any prey taxa and lake color (p=0.328 for non-chironomid dipterans; p=0.358 for coleopterans; p=0.468 for chironomids; p=0.545 for veneroidans; p=0.836 for ephemeropterans; p=0.208 for odonates; p=0.432 for trichopterans).

Discussion

Ontogenetic shifts in the diets of *P. flavescens* did not vary across a gradient of DOC in the lakes studied. In fact a distinct dietary ontogenetic shift from consuming primarily zooplankton to primarily macroinvertebrates was not observed between standard lengths or between size classes of *P. flavescens*. Also no individual had fish in their gut contents, indicating that no size class observed had switched to piscivory. The shift to piscivory has been observed in other studies of *P. flavescens* to occur around 80mm total length (Graeb et. al. 2006; Parker et. al. 2009), whereas fish in this study ranged up to 150mm total length with no fish in their digestive tracts.

Other studies have found that *P. flavescens* and *P. fluviatilis* experience dietary shifts from planktivory to benthivory around 35mm and from benthivory to piscivory around 80mm standard length (Graeb et. al. 2006; Parker et. al. 2009). While both of these size classes were included within the range of this study, which examined fish with standard lengths varying from 37mm to 124mm. These studies suggest that differences in foraging efficiency and energetic gain associated with different prey types are the most important factors in determining when dietary shifts occur for *P. flavescens* (Galarowicz et al. 2006; Graeb et. al. 2006). Other studies, however, contend that prey densities are a determining factor in when dietary shifts occur, citing that interspecific competition for zooplankton that decreases zooplankton densities can drive earlier shifts to benthivory in *P. fluviatilis* and that dietary shifts are reversible in many fish species that are piscivorous as adults (Bystrom et. al. 1998; Schleuter and Eckmann 2008).

In this study, the proportion zooplankton and macroinvertebrates did not vary across size but did between lakes, which supports the hypothesis that prey densities are a large determining factor in diet composition. This is further supported by results of this study that selection for most benthic macroinvertebrates is neutral or negative and does not vary between lakes, indicating that *P. flavescens* is a generalist predator that consume prey consistently according to the prey's density, which has been documented in other studies as well (Schleuter and Eckmann 2008).

This study did not detect any ontogenetic dietary shift in *P. flavescens* and also did not detect any differences in the ages or sizes during which these shifts occur between different levels of DOC. However, such differences have, however, been detected in *P. fluviatilis*, where dietary shifts occur earlier in lakes with higher levels of humic material (Estlander 2011). This earlier shift from planktivory to benthivory may have been caused by poor foraging efficiency due to low light conditions and/or exacerbated by interspecific competition with planktivores (Diehl 1988). To accurately determine if such a phenomenon is occurring with *P. flavescens* it might be useful to design a controlled lab experiment that varied the levels of DOC, types and densities of prey, and the size of *P. flavescens*.

If such a phenomenon is occurring it could have serious implications to *P. flavescens* populations, as earlier switches to benthivory caused by high levels of interspecific competition can lead to retarded growth and higher mortality rates due to starvation (Bremigan et. al. 2003; Bystrom et. al. 1998; Prout et. al. 1990). Furthermore, this leads to lower recruitment into larger size classes, which may lead to lower larval recruitment in future years and a higher disparity between size classes within the population (Bystrom et. al. 1998).

The results of this study suggest that the diets of juvenile *P. flavescens* are largely determined by the densities of prey within their environment rather than factors such as lake color and DOC or size of individual. It is possible, though, that lake color and DOC are influencing the prey communities available to *P. flavescens*. However, this does not mean that these factors do not affect the diets of *P. flavescens*. The importance of these factors could be more easily separated from one another using a controlled laboratory experiment, which would complement the field observational. Such a study could elucidate whether DOC is causing differences in *P. flavescens* dietary shifts, which could allow for insights into *P. flavescens* population dynamics across gradients of DOC.

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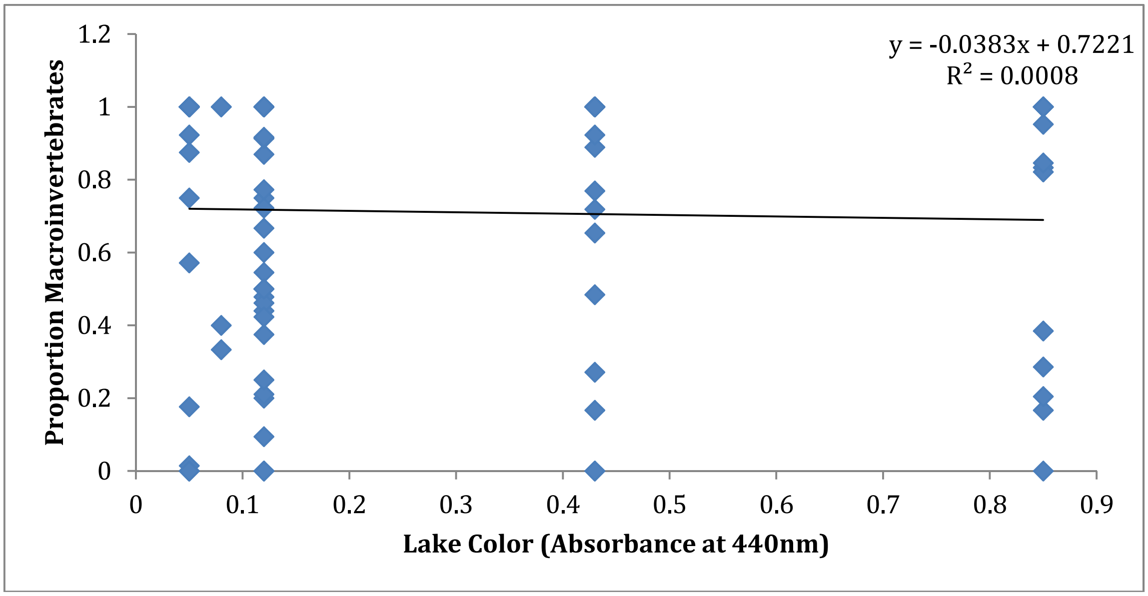

Figure 1. . Proportion of *P. flavescens* diet that is composed of macroinvertebrates across a gradient of lake color that is representative of that lake's DOC. Each point represents the diet of one fish (p=0.316, n=98).

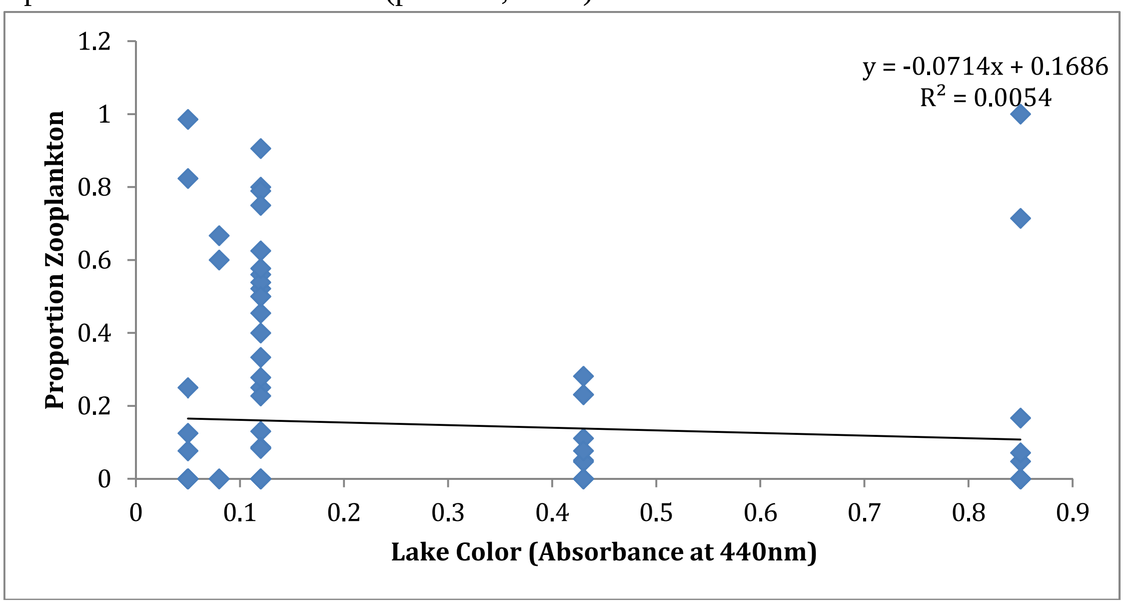

Figure 2. Proportion of *P. flavescens* diet that is composed of zooplankton across a gradient of lake color that is representative of that lake's DOC. Each point represents the diet of one fish (p=0.368, n=98).

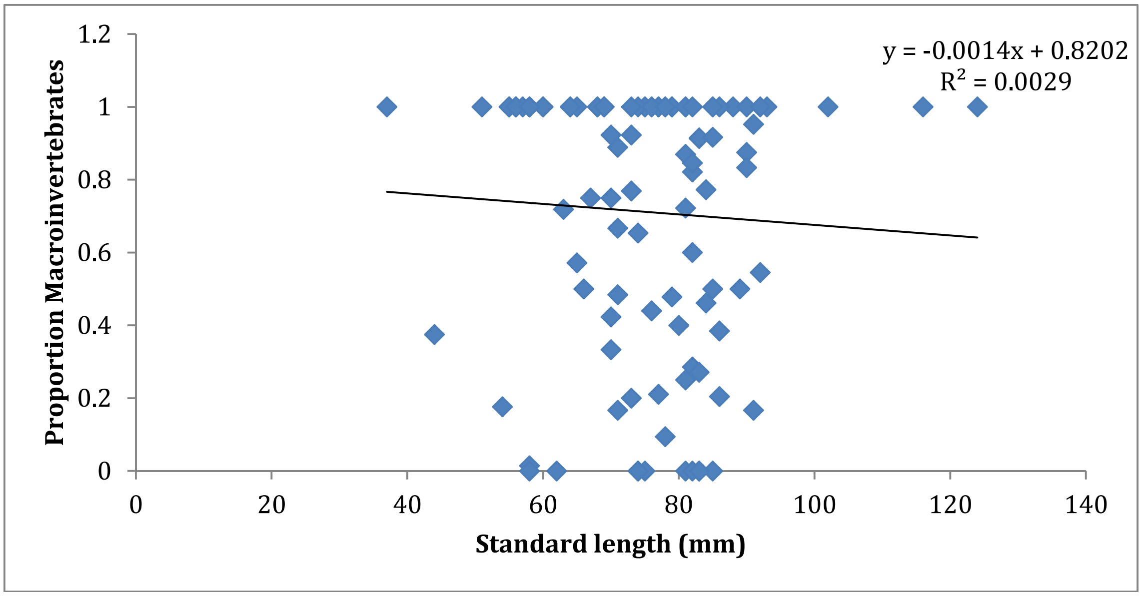

Figure 3. Proportion of *P. flavescens* diet that is composed of macroinvertebrates across the standard length of each individual. Each point represents the diet of one fish (p=0.511, n=98).

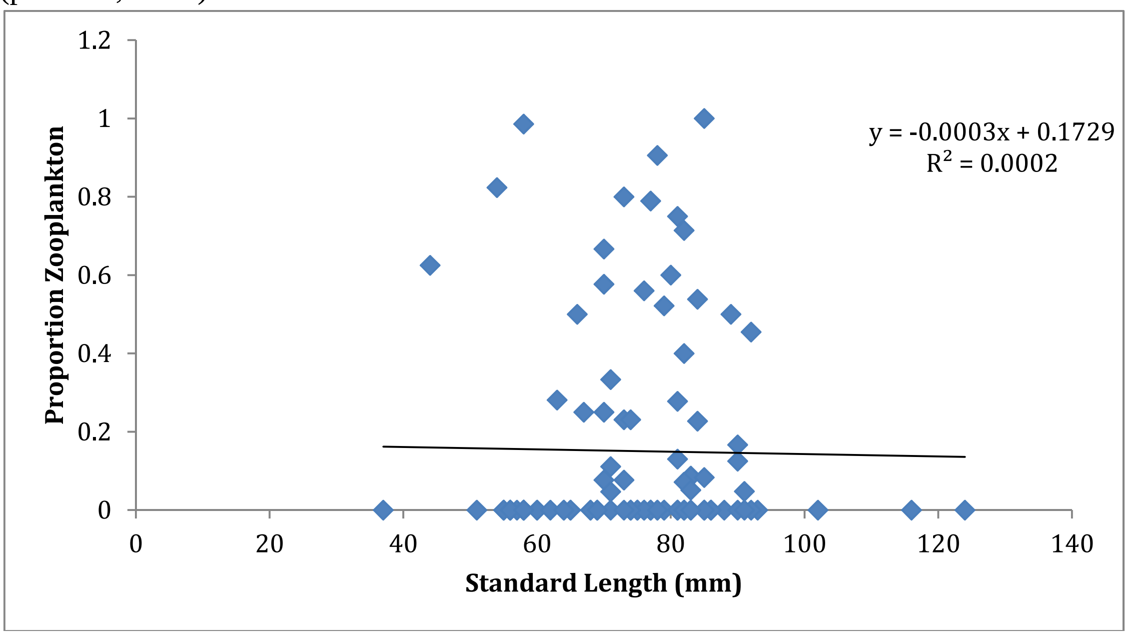

Figure 4. Proportion of *P. flavescens* diet that is composed of zooplankton across the standard length of each individual. Each point represents the diet of one fish (p=0.876, n=98).

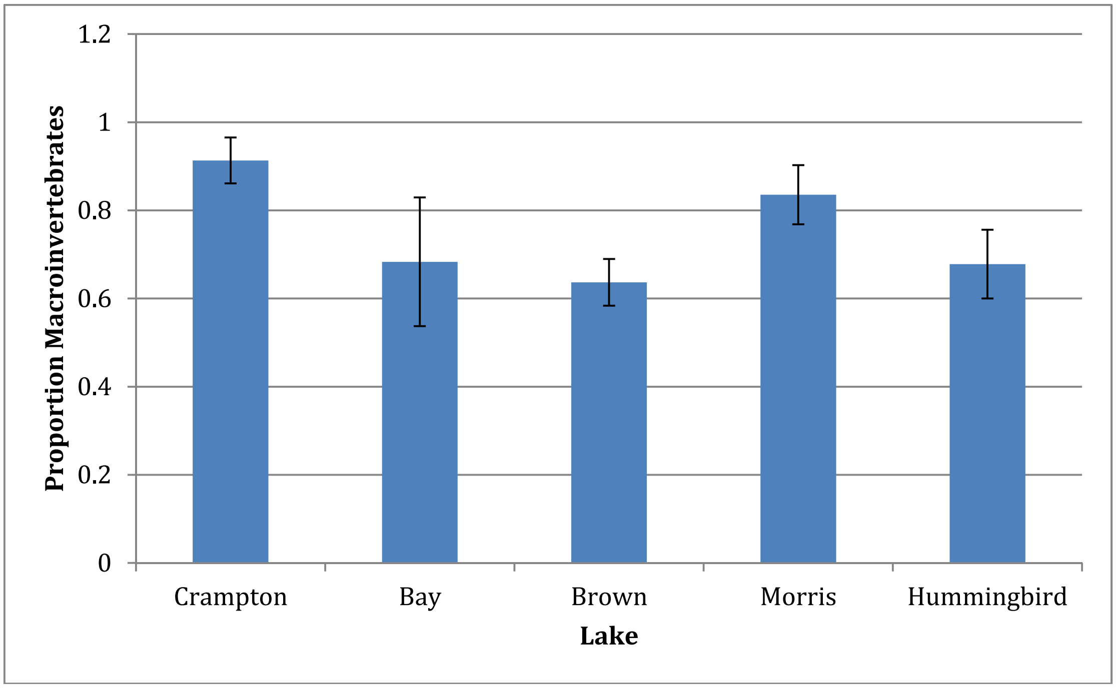

Figure 5. Proportion of macroinvertebrates in the diets of *P. flavescens* in five lakes at UNDERC East. Values are the mean proportion recorded from fish at each lake plus and minus one standard error (p=0.004, n=98).

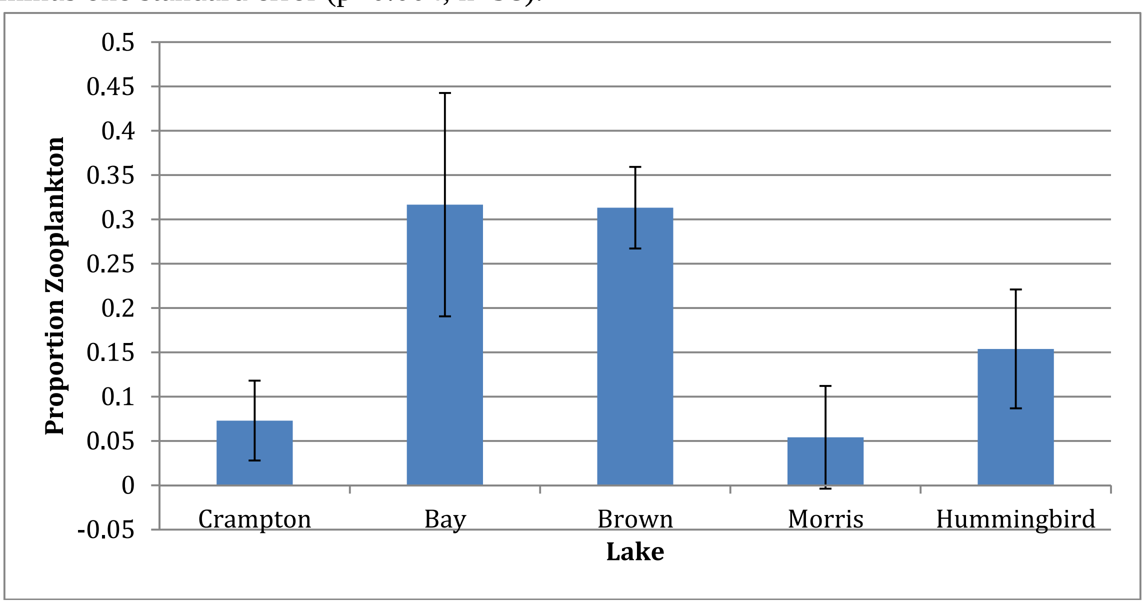

Figure 6. Proportion of zooplankton in the diets of *P. flavescens* in five lakes at UNDERC East. Values are the mean proportion recorded from fish at each lake plus and minus one standard error (p=0.001, n=98).

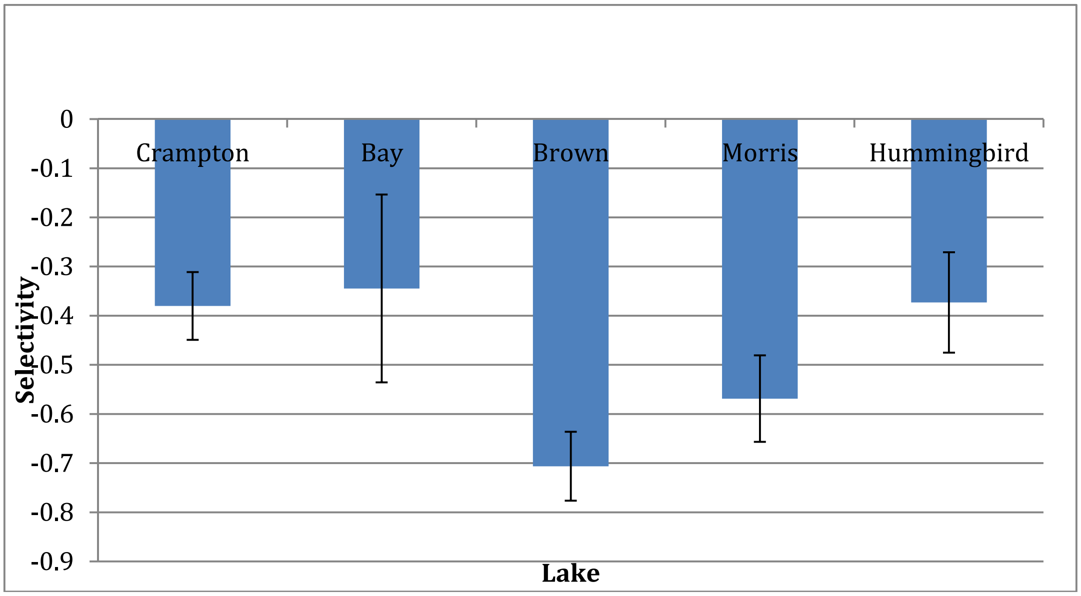

Figure 7. Selectivity indices for chironomids, with -1 indicating selecting against, 1 indicating selecting for, and 0 indicating neutral selection. The value for each lake is the mean selection index for *P. flavescens* from that lake plus and minus one standard error ($p<0.001$, $n=98$).

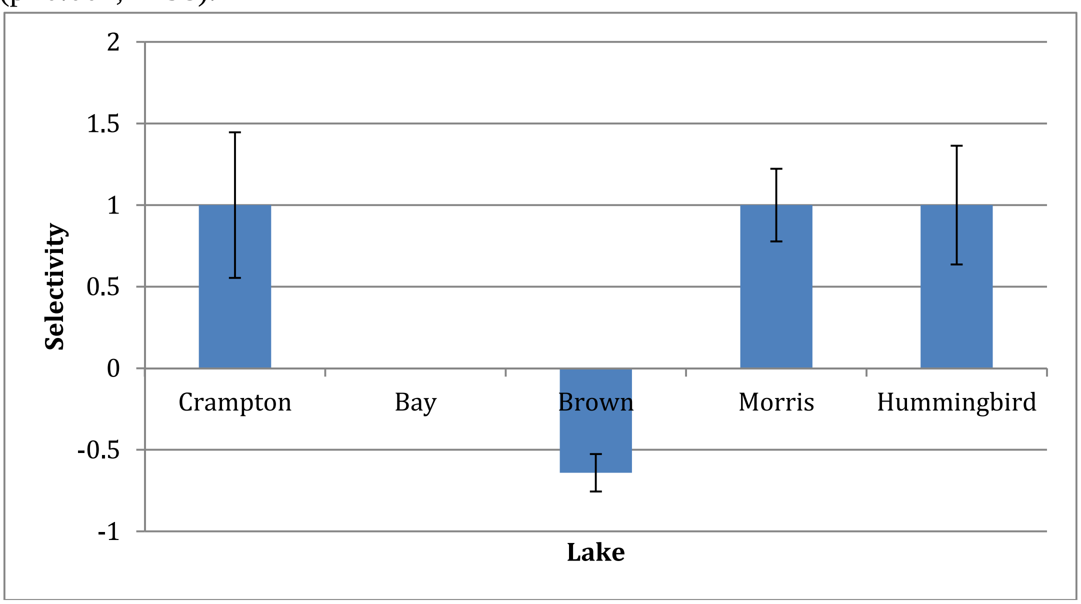

Figure 8. Selectivity indices for coleopterans, with -1 indicating selecting against, 1 indicating selecting for, and 0 indicating neutral selection. The value for each lake is the mean selection index for *P. flavescens* from that lake plus and minus one standard error ($p<0.001$, $n=43$).

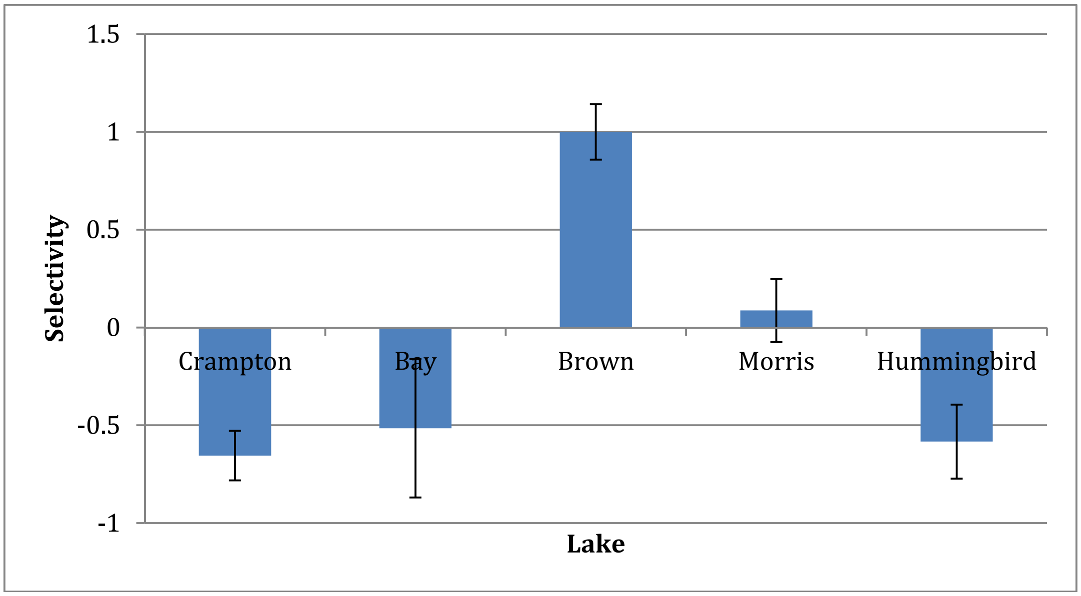

Figure 9. Selectivity indices for odonates, with -1 indicating selecting against, 1 indicating selecting for, and 0 indicating neutral selection. The value for each lake is the mean selection index for *P. flavescens* from that lake plus and minus one standard error ($p<0.001$, n=93).

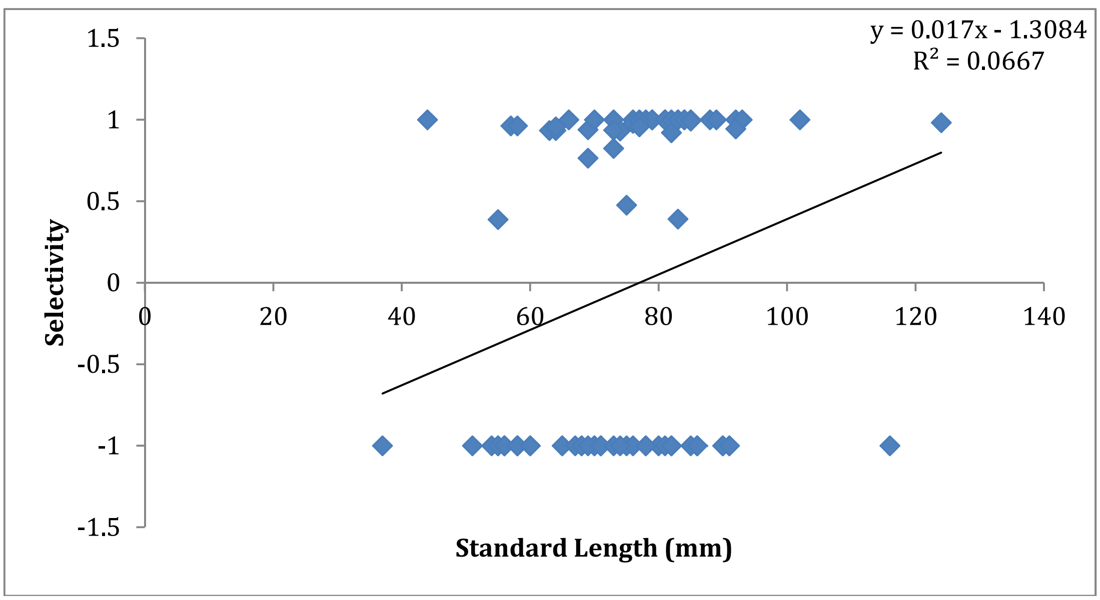

Figure 10. Selectivity indices for odonates across standard length of *P. flavescens*. Each point represents the selectivity of one fish ($p=0.013$, n=93).

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