Prey electivity of the slimy sculpin within the Lake Superior-North Watershed

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ABSTRACT
We evaluated the prey electivity of lotic slimy sculpin (Cottus cognatus) within the Lake Superior-North Watershed, an area characterized by high gradient streams and lacking the preferred prey of Gammarus. Fish and macroinvertebrates were sampled at 67 sites within 52 rivers and streams during 2013 in the Lake Superior-North Watershed by the Minnesota Pollution Control Agency. Fish sampling was conducted with the use of backpack and stream tote barge electrofishers, and macroinvertebrates were collected using qualitative multi-habitat sampling within D-Frame kick nets. Feeding electivity was calculated using Strauss’ modified feeding electivity model for three rivers. In total we sampled 174 slimy sculpins within the Lake Superior-North Watershed and found sculpins positively selected for Hydropsychidae (47.3% of total taxa consumed) and Perlidae (11% of total taxa consumed) instead of abundant Chironomidae (20% of total taxa sampled).

KEYWORDS
Slimy sculpin; prey electivity; food habits; Lake Superior; lotic

Introduction
Slimy sculpins, Cottus cognatus, are an ecologically important benthic insectivore inhabiting lentic and lotic cold-water ecosystems throughout North America. In cold-water lentic systems, slimy sculpin inhabit rocky littoral areas ranging from small headwater lakes to the Great Lakes. Lentic slimy sculpin have been found to primarily consume Gammarus spp. and feeding strategies have been found to be nocturnal (Brandt 1986), when Gammarus are most active. In addition to Gammarus, lentic slimy sculpins have also been found to consume Opossum shrimp, Mysis relicta, and Diptera spp. (Brandt 1986).

Slimy sculpin also inhabit low-order, cold-water streams with abundant cobble. Similar to lentic systems, slimy sculpin have been found to have primary consume Gammarus spp. (Mundahl et al. 2012), and nocturnal feeding upon Gammarus spp. has also been observed within streams (Holomuzki and Hoyle 1990). Slimy sculpin also selected Gammarus spp., and selected various sizes of Gammarus over other available prey (Filicky et al. 2000).

Summer food habits of both lentic and lotic slimy sculpin largely consists of Gammarus spp. when present (Filicky et al. 2000; Mundahl et al. 2012). In contrast, slimy sculpin largely consumed Chironomidae and Baetidae during October (Chalupnicki and Johnson 2016) and selected Chironomidae and trichoptera in January in a New York stream when Gammarus were not present (Johnson et al. 2017). The summer feeding preference of the slimy sculpin in systems without Gammarus spp. is unknown.
The Lake Superior-North Watershed is a unique ecoregion featuring high gradient cold-water streams and subsequently, *Gammarus* spp. populations are nearly absent. The objective of this study was to define the summer feeding prey electivity of the slimy sculpin within a *Gammarus* limited system, utilizing the ongoing sampling of an entire watershed that is uniquely without *Gammarus*.

**Methods**

**Field collection**

Sampling took place during summer daylight hours, over the three-month period of June through August 2013, in cooperation with the Minnesota Pollution Control Agency’s (MPCA) Intensive Watershed Monitoring Program (EPA tier 4 biological monitoring program). Sixty-seven sampling locations within the Lake Superior-North Watershed were sampled for fish and macroinvertebrates (Figure 1). Sampling locations were selected utilizing the pour point design, placing a station at the pour point of each 8, 12, and 14 digit HUC watersheds with a minimum drainage area of 5 square miles (MPCA 2009). Reach lengths were determined according to Lyons (1992), with a minimum reach length of 150 m and ranged from 150 m with ≤4 m median stream width (MSW) to >14 m MSW with a maximum reach length of 500 m.

Smith-Root LR-24 backpack electrofishers and stream tote barge electrofishers were used to obtain specimens in accordance with the MPCA standard operating procedure (MPCA 2009). Captured specimens were euthanized by use of carbon dioxide exposure, and a quick sharp blow to the head (IACUC# 042213). All specimens were preserved in formalin and taken to the lab for dissection. Available macroinvertebrate prey were sampled within each of the 67 cool-water stream sample
sites using the multi-habitat method with a D-Frame kick net downstream of up to four habitat types (i.e. riffles, logs, aquatic macrophytes, and undercut bank/overhanging vegetation) in accordance with the MPCA standard operating procedure (MPCA 2017). A total of 20 evenly distributed samples were taken at each sampling site in an attempt to utilize all available macroinvertebrate habitats, pooled, and preserved in ethanol.

**Feeding electivity**

Slimy sculpin stomach contents were removed and identified to family. Only prey with identifiable heads were counted and the frequency of prey in the stomach contents was quantified using the percent composition of each diet item. Prey electivity by slimy sculpin was evaluated at sites with greater than 10 sculpin collected to ensure averaged electivity values were not biased by individual fish. Prey electivity was calculated using the Strauss’ prey electivity index (1979):

\[ L = r_i - p_i \]

where \( r_i \) and \( p_i \) represent the relative abundance of prey in the diet and the environment, respectively. We determined the relative abundance of prey in the diet of slimy sculpin \( (r_i) \) by dividing the number of each macroinvertebrate group found in the stomachs of individual slimy sculpin processed from site \( i \), by the total number of macroinvertebrates consumed by each slimy sculpin. Diet item proportions in the environment \( (p_i) \) were calculated by dividing the density of each prey item family by the total density of all prey items available in the environment at site \( i \). Electivity \( (L) \) was determined for all macroinvertebrate groups found within the environment for each individual slimy sculpin at site \( i \), and then averaged. Strauss’ index value \( (L) \) can range from total avoidance \((-1)\) to absolute selectivity \((1)\) for a given prey item. Similar to previous studies (Sullivan et al. 2011; Sullivan et al. 2012; Thiessen et al. 2018), a value of ±0.15 was chosen as the cutoff to determine selectivity or avoidance. Prey items with index values between 0.15 and −0.15 represent prey consumed proportionately to their availability (Sullivan et al. 2012). Therefore, we defined opportunistic prey selection as electivity values between 0.15 and −0.15, prey selection as values >0.15, and prey avoidance as <−0.15.

**Results**

Slimy sculpin were collected (>40 mm) within 10 of the 67 sample sites indicating a presence in six river systems (Table 1). Macroinvertebrates were collected at all 67 sample sites, and the structure of the macroinvertebrate communities was determined for the six river systems containing slimy sculpin (Table 2). Throughout all of the sampling stations, only three stream reaches yielded more than 10 slimy sculpin; Cascade River (87), Devil Track River (58), and Elbow Creek (11) (Table 1). *Hydropsychidae* (25.7%), *Chironomidae* (20.0%), and *Baetidae* (10.9%) were the most abundant macroinvertebrate taxa sampled in those three streams, and *Hydropsychidae* (47.3%), *Perlidae* (11.0%), and *Chironomidae* (8.9%) were most often consumed (Table 3).

Feeding electivity was calculated using fish and macroinvertebrates sampled from three sites: Cascade River, Devil Track River, and Elbow Creek. Most macroinvertebrate taxa were consumed in proportion to their availability \((-0.15 < L > 0.15)\), however, *Hydropsychidae* were selected by slimy sculpins within two of the three investigated streams within the Lake Superior-North Watershed. *Hydropsychidae* were selected at Elbow Creek \( (L = 0.41, \text{Table 3}) \) and Devil Track River \( (L = 0.16, \text{Table 3}) \). *Perlidae* \( (L = 0.17) \), and *Hydropsychidae* \( (L = 0.13) \) were selected within the Cascade River (Table 3).

*Chironomidae* was the second most abundant macroinvertebrate taxa within the population at most of the sampling sites, but was rarely selected as a prey source by the slimy sculpin. For example,
Table 1. Locality information, sample date, water temperature, conductivity, length range and standard error, sample size, and number of empty stomach data for sites containing slimy sculpin within the Lake Superior-North Watershed.

| Site location          | Latitude, longitude   | Sample date | Water temperature (°C) | Sp. conductivity (μS/cm) | Length range (mm) | Mean length (mm) | N  | # Empty stomachs |
|------------------------|-----------------------|-------------|------------------------|-------------------------|-------------------|------------------|----|------------------|
| Cascade River          | 47.7918, -90.52752    | 9/5/2013    | 11.6                   | 71.2                    |                   |                  |    |                  |
| Cascade River          | 47.47147, -91.03616   | 7/23/2013   | 15.3                   | 78.6                    |                   |                  |    |                  |
| Cascade River          | 47.82938, -90.53031   | 9/4/2013    | 17.7                   | 41.1                    | 52–100            | 75.8 ± 1.0       | 87 | 24               |
| Cascade River          | 47.74680, -90.52498   | 9/10/2013   | 15.2                   | 74.4                    |                   |                  |    |                  |
| Temperance River       | 47.71632, -90.87783   | 9/3/2013    | 19.8                   | 45.0                    | 81–84             | 82.3 ± 0.8       | 4  | 0                |
| Baptism River, West Branch | 47.45285, -91.30735   | 7/18/2013   | 21.3                   | 72.8                    |                   |                  |    |                  |
| Baptism River, West Branch | 47.41519, -91.24901   | 7/23/2013   | 19.9                   | 60.5                    | 73–101            | 85.1 ± 4.2       | 8  | 2                |
| Devil Track River      | 47.80412, -90.30323   | 9/4/2013    | 17.2                   | 64.6                    |                   |                  |    |                  |
| Devil Track River      | 47.80662, -90.31177   | 8/5/2013    | 18.4                   | 48.8                    | 45–92             | 78.2 ± 1.8       | 58 | 21               |
| Devil Track River      | 47.77030, -90.26211   | 9/11/2013   | 19.9                   | 92.4                    |                   |                  |    |                  |
| Two Island River       | 47.54114, -90.97508   | 6/26/2013   | 16.7                   | 49.9                    | 63–82             | 70.7 ± 3.1       | 6  | 3                |
| Elbow Creek            | 47.81707, -90.3123    | 8/7/2013    | 16.9                   | 45.0                    | 54–94             | 74.3 ± 4.1       | 11 | 1                |

Table 2. Locality information, sample date, water temperature, and qualitative macroinvertebrate structure attributes for sites containing slimy sculpin within the Lake Superior-North Watershed.

| Site                        | Latitude, longitude   | Sample date | Water temperature (°C) | EPT% Filterer | EPT% Gatherer | EPT% Predator | EPT% Scraper | EPT% Shredder |
|-----------------------------|-----------------------|-------------|------------------------|---------------|---------------|---------------|--------------|---------------|
| Cascade River               | 47.7918, -90.52752    | 8/12/2013   | 17.9                   | 46.9          | 31.5          | 24.4          | 13.3         | 15.1          | 6.0           |
| Cascade River               | 47.47147, -91.03616   | 9/11/2013   | 17.6                   | 75.1          | 14.0          | 19.3          | 20.3         | 11.3          | 4.0           |
| Cascade River               | 47.82938, -90.53031   | 8/13/2013   | 18.9                   | 58.3          | 47.1          | 16.6          | 13.7         | 14.6          | 2.0           |
| Cascade River               | 47.74680, -90.52498   | 8/12/2013   | 18.3                   | 58.8          | 25.5          | 40.3          | 6.3          | 17.6          | 4.0           |
| Temperance River            | 47.71632, -90.87783   | 8/14/2013   | 13.9                   | 71.3          | 55.3          | 8.7           | 17.0         | 13.7          | 4.0           |
| Baptism River, West Branch  | 47.45285, -91.30735   | 9/12/2013   | 14.4                   | 72.7          | 27.6          | 34.2          | 11.3         | 15.4          | 3.0           |
| Baptism River, West Branch  | 47.41519, -91.24901   | 9/17/2013   | 14.6                   | 71.0          | 35.0          | 37.2          | 10.7         | 4.1           | 4.0           |
| Devil Track River           | 47.80412, -90.30323   | 8/12/2013   | 17.0                   | 85.3          | 48.2          | 28.1          | 7.0          | 10.9          | 3.0           |
| Devil Track River           | 47.80662, -90.31177   | 8/21/2013   | 21.7                   | 89.6          | 52.1          | 22.3          | 10.7         | 4.2           | 4.0           |
| Devil Track River           | 47.77030, -90.26211   | 8/13/2013   | 14.4                   | 62.7          | 22.2          | 51.6          | 8.2          | 1.3           | 4.0           |
| Two Island River            | 47.54114, -90.97508   | 8/15/2013   | 11.6                   | 37.3          | 53.8          | 25.6          | 5.4          | 7.0           | 6.0           |
| Elbow Creek                 | 47.81707, -90.3123    | 8/21/2013   | 25.4                   | 70.1          | 44.1          | 20.9          | 15.4         | 9.0           | 3.0           |
Table 3. Macroinvertebrate taxa sampled within the Cascade River, Devil Track River, and Elbow Creek with corresponding electivity values ($L$) and standard error where $L = r_i - p_i$, using the Strauss’ prey electivity index (1979) where $r_i$ and $p_i$ represent the relative abundance of prey in the diet and the environment, respectively.

| Family       | Cascade River total taxa sampled | Devil Track River total taxa sampled | Elbow Creek total taxa sampled | % of total taxa consumed | Cascade River electivity ($L$) | Devil Track River electivity ($L$) | Elbow Creek electivity ($L$) |
|--------------|---------------------------------|------------------------------------|-------------------------------|--------------------------|-------------------------------|----------------------------------|------------------------------|
| Athericidae  | 11 3 18                          | 1.5 0                              | -0.01 ± 0                    | -0.01 ± 0                | -0.06 ± 0                    |                                   |                              |
| Baetidae     | 143 71 14                         | 10.9 2.8                           | -0.08 ± 0.02                | -0.03 ± 0.05             | -0.04 ± 0                    |                                   |                              |
| Chironomidae | 262 101 55                       | 20.0 8.9                           | -0.17 ± 0.02                | 0.00 ± 0.07              | -0.18 ± 0                    |                                   |                              |
| Elmidae      | 22 1 7                           | 1.4 1.1                            | -0.01 ± 0                   | -0.01 ± 0                | -0.01 ± 0.03                |                                   |                              |
| Glossosomatidae | 72 26 32                       | 6.2 2.8                            | -0.06 ± 0                   | -0.05 ± 0                | -0.10 ± 0                    |                                   |                              |
| Heptageniidae | 24 39 24                         | 4.2 2.5                            | -0.01 ± 0.01                | -0.02 ± 0.04             | -0.08 ± 0                    |                                   |                              |
| Hydrobiidae  | 29 0 0                           | 1.4 0                              | -0.02 ± 0                   |                         |                               |                                   |                              |
| Hydrobiidae  | 313 149 74                       | 25.7 47.3                          | 0.13 ± 0.05                 | 0.16 ± 0.08              | 0.41 ± 0.10                  |                                   |                              |
| Hydriodidae  | 25 4 0                           | 1.4 0                              | -0.01 ± 0.01                | -0.01 ± 0                |                               |                                   |                              |
| Hylaeomorpha | 49 3 5                           | 2.7 8.2                            | 0.1 ± 0.04                  | 0.04 ± 0.03              | 0.00 ± 0.02                  |                                   |                              |
| Philopotamidae | 52 29 19                        | 4.8 11                             | 0.17 ± 0.04                 | 0.05 ± 0.05              | 0.05 ± 0.06                  |                                   |                              |
| Philopotamidae | 51 16 43                        | 5.3 2.5                            | 0.00 ± 0.02                 | -0.03 ± 0                | -0.14 ± 0                    |                                   |                              |
| Simuliidae   | 29 0 5                           | 1.6 0                              | -0.02 ± 0                   |                          | -0.02 ± 0                    |                                   |                              |

Elbow Creek had a *Chironomidae* electivity value of $L = -0.18$ (Table 3) and the Cascade River had a *Chironomidae* electivity value of $L = -0.17$ (Table 3).

Discussion

Some previous summer food habit studies have found that slimy sculpins feed opportunistically and consume prey in proportion to their availability in the environment (Mundahl et al. 2012). While we found that slimy sculpin consumed most invertebrate families in proportion to their availability, our results suggest that slimy sculpins can display instances of selective feeding behavior. Slimy sculpins in the Lake Superior-North Watershed actively selected for caddisflies (*Hydropsychidae*) and stoneflies (*Perlidae*) during summer. Similarly, slimy sculpin were selective during October (Chalupnicki and Johnson 2016) and January in a New York stream (Johnson et al. 2017). Indeed, slimy sculpin diets and prey selectivity likely change due to fish community structure and seasonal prey availability.

When present, *Gammarus* spp. are commonly the prey of choice for *Cottus* spp. within both lentic (Brandt 1986) and lotic systems (Holomuzki and Hoyle 1990; Filicky et al. 2000; Mundahl et al. 2012). *Gammaridae* were not known to inhabit our study area and indeed no *Gammaridae* were collected throughout all 67 sampling locations within the Lake Superior-North Watershed. In the absence of *Gammarus* spp., slimy sculpin positively selected for *Hydropsychidae* and *Perlidae* and negatively selected *Chironomidae* within the Lake Superior-North Watershed during summer. Interestingly, Chironomids were an important diet item and selected by slimy sculpins in October (Chalupnicki and Johnson 2016) in a stream without *Gammarus* spp. present. There are several likely reasons for this difference in prey selection. This could be related to the fact that both New York studies (Chalupnicki and Johnson 2016; Johnson et al. 2017) were conducted in a stream with a fairly low drainage area (<10 sq mi). In contrast, the streams used in this study had larger drainage areas ranging from 19 to 105 sq mi., which likely affect the structure of the macroinvertebrate communities (Vannote et al. 1980). Macroinvertebrate communities in lower order streams (small drainage areas) are generally comprised of shredders compared to higher stream orders where scrapers, gatherers, and filterers are more common. Filterer and gatherer macroinvertebrate taxa are prevalent (Table 2) within the Lake Superior-North Watershed indicating a shift in the macroinvertebrate community to utilize autochthonous and particulate material in the higher order systems. Conversely, the studies at the New York stream were heavily comprised of *Branccentridae*.
(shredders/gatherers) and *Rhyacophilidae* (predators) in the fall (Chalupnicki and Johnson 2016), and coleoptera, ephemeroptera, and diptera in the winter (Johnson et al. 2017).

There is also a possibility that the discrepancies are simply due to seasonal changes in macroinvertebrate abundance or availability. Previous studies suggest that slimy sculpin feed upon ephemeroptera and trichoptera taxa during the winter (Johnson et al. 2017), and *Chironomidae* and *Baetidae* in the fall (Chalupnicki and Johnson 2016). Slimy sculpins in the Lake Superior-North Watershed primarily selected trichoptera and plecoptera taxa during the summer. Shorter-lived taxa such as *Hydropsychidae* are univoltine (Mackay 1986), with only one brood of offspring each year. *Hydropsychidae* emerge in the fall, and therefore would not be available as a prey source for slimy sculpin. It is at this time that slimy sculpin feeding habits may shift to *Chironomidae* and *Baetidae* in the fall. Another shift may then occur when ephemeroptera and trichoptera taxa reach later instars and become large enough to consume during the winter months.

We agree with Johnson et al. (2017) that extending the understanding of slimy sculpin food habits to additional seasons would assist in developing a more complete understanding of sculpin feeding ecology. While acknowledging the potential sampling difficulties, we recommend future efforts investigating the feeding ecology of slimy sculpin within the Lake Superior-North Watershed be directed at environmentally critical times of year such as winter; especially given the northern latitude of the Lake Superior-North Watershed.

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**Disclosure statement**

No potential conflict of interest was reported by the authors.

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