The Great Lakes Entomologist

Manuscript 2442

Alderfly (Megaloptera: Sialidae) Larval Emergence and Pupation
Site Selection at Intermediate Lake, Antrim County, Michigan

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The order Megaloptera are holometabolous insects with aquatic larvae but terrestrial eggs, pupae, and adults (Flint et al. 2008, Cover and Bogan 2015, Bowles and Contreras-Ramos 2019). There are two extant families in the order including the Corydalidae (dobsonflies and fishflies) and the Sialidae (alderflies). About 400 species of Megaloptera are recognized worldwide, including 85 named species of Sialidae in 9 genera, with the genus *Sialis* having 60 named species worldwide (Martins et al. 2022). Megalopterans are found worldwide (Jiang et al. 2022), with new species being described regularly, especially in the Neotropics and southeastern Asia (Cover and Resh 2008, Martins et al. 2022). In Michigan the Megaloptera are represented by five recorded species of Corydalidae and 10 recorded species of Sialidae (Bright 2020).

Larval Sialidae occur in both lentic and lotic ecosystems. Sialid larvae are predaceous, feeding primarily on other aquatic invertebrates (Azam and Anderson 1969, Pritchard and Leischnzer 1973, Lilly et al. 1978, Rivera-Gasperin et al. 2019). As predators, megalopteran larvae have important roles in food web dynamics and energy flow in many aquatic environments (Rivera-Gasperin et al. 2019). Sialids are generally indicators of good water quality (Hilsenhoff 1988, Rivera-Gasperin et al. 2019), but some sialid species can survive in polluted conditions (Roback and Richardson 1969, Warner 1971, Nichols and Bulow 1973). Most sialids have a 1-yr life cycle (Woodrum and Tarter 1973, Krueger and Cook 1984, Locklin et al. 2006), but at times a 2-yr life cycle occurs, especially at higher latitudes or elevations, or when oviposition occurs late in summer (Azam and Anderson 1969, Pritchard and Leischner 1973).

The general sialid life cycle involves final instar larvae leaving the water in spring and early summer and entering the soil near the shoreline to pupate. Larvae usually leave the water at night (Pritchard and Leischnzer 1973, Takeuchi and Hoshiba 2012b). Soil temperatures influence pupation time, with adults typically emerging after a few weeks. Adults appear not to feed, are short-lived, and for temperate species are most active during the day. Females mate soon after emergence, usually on shoreline or emergent vegetation, and begin oviposition within a day. Females typically lay all eggs in a single egg mass that they attach to vegetation (e.g., stems, twigs, and leaves) or
even structures (bridges, boats, docks) that overhang water (Davis 1903, Ross 1937). There are often several hundred eggs in a single egg mass (Canterbury and Neff 1980). Females deposit a secretion over the egg mass to inhibit desiccation and predation (Yu et al. 2022). Eggs hatch in 1–2 weeks with larvae falling into the water below. Larvae usually burrow 1–2 cm into the bottom substrate (Charboneau and Hare 1998). There are usually 8 to 10 larval instars (Azam and Anderson 1969, Pritchard and Leischner 1973, Locklin et al. 2006).

Initiation of sialid larval emergence from their aquatic habitat in spring is strongly influenced by water temperature. In Japan, Takeuchi and Hoshiba (2012b) reported that larval emergence occurred when water temperatures in a pond were between 8–13 °C. In West Virginia, Wood-rum and Tarter (1973) reported that peak larval emergence from a creek occurred at water temperatures of 11–13 °C. Timing of when water will warm to those levels in spring and thus stimulate larval emergence vary from year to year (Elliott 1996) as well as broadly with latitude. For example, sialid larvae begin to emerge as early as January in central Texas (30.5° N Lat; Locklin et al. 2006), but not until early May in Alberta (51.3° N Lat; Pritchard and Leischner 1973). In addition, Takeuchi and Hoshiba (2012b) suggested that larval emergence was favored under wet conditions, given that about half of all sialid larvae collected in pitfall traps being captured when it had rained during the previous night or day.

In this study, I used pitfall traps during 2015–2017 to study various aspects of sialid larval emergence in Intermediate Lake, Michigan. The original objective in 2015 was to broadly document seasonal larval emergence from the lake. Timing of emergence was also monitored in 2016 and 2017, with the additional objective of evaluating a possible relationship between emergence and nightly rainfall when collections were made daily. In 2017, I evaluated the distance sialid larvae typically crawl when selecting pupation sites.

**Materials and Methods**

**Study site.** This study was conducted along an undeveloped section of shoreline at the southeastern end of Intermediate Lake (N 45.00466° and W 85.198834°; Fig. 1E). The shoreline consisted of mostly native vegetation of forbs and grasses, with the dominant woody plants being speckled alder [Alnus incana (L.) Moench], paper birch (Betula papyrifera Marshall), red-osier dogwood (Cornus sericea L.), black ash (Fraxinus nigra Marshall), and northern white cedar (Thuja occidentalis L.).

Intermediate Lake is located in Antrim County, Michigan, and is one of 14 interconnected lakes that form the Elk River Chain of Lakes (Silver et al. 2016; Fig. 1E). Intermediate Lake is over 600 ha in surface area, over 10 km long, averages about 0.6 km wide, and reaches maximum depths of about 24 m. The nearshore lake-bottom substrate is mostly sand to gravely sand, becoming silty to mucky at greater water depths. There are two dams along the Elk River Chain of Lakes, with one located downstream from Intermediate Lake along the Intermediate River (USACE 2022). Although water levels vary with season and precipitation, the dams are used to maintain somewhat uniform lakes levels throughout the year.

**2015 study.** Two barrier pitfall traps were installed along the shoreline on 19 April 2015, about 35 m apart (Table 1, Fig. 1CD). Each trap consisted of a 1-quart (0.9 l) plastic container with a square opening (about 10-cm on a side); Rubbermaid® (Atlanta) that was put into the ground so that the top was flush with the surrounding soil. The cup was installed about 1 m from the shoreline at the time of deployment. Two 1-m-long barriers, made from black plastic-resin lawn edging (Suncast®, Chicago), were partially buried along their length, and positioned flush with the center of the cup’s rim on opposite sides. The barriers were positioned so that they curved toward the shoreline from the cup (Fig. 1ACDF). Barriers were used to increase trap catch by directing ground invertebrates towards the collection cups (Skvarla et al. 2014). The cups were filled with moist sand to within 3 to 4 cm of the rim, followed by a shallow layer of organic matter (Fig. 1F). The moist sand served as a substrate for sialid larvae to enter and pupate. After the trap installation was complete, a square piece of galvanized hexagonal chicken wire (mesh aperture = 2.5 cm) screening was folded over the collection cup and secured at the corners, but not flush with the ground, to reduce disturbance by mammals (Fig. 1F). Given undulations in the shoreline, the opening of one trap faced northwest (Fig. 1C) while the other faced west (Fig. 1D).

The contents of the collection cups were inspected at intervals of 4 to 18 days during the period 19 April to 29 June 2015 (Table 1). The length of these intervals reflected the fact that during early 2015, accessibility to the study site was limited. The collection process involved removing the collection cup from the soil and emptying the contents on a large tray where I sifted through the material and removed and counted all sialid larvae (or pupae if some individuals had pupated).
Table 1. Summary data for collection methods and results by study year, including trap configuration, total length of the trapping period, total number of collections and how many were conducted in consecutive days, the total number of sialid larvae collected, and the first and last days (or periods) when larvae were collected.

<table>
<thead>
<tr>
<th>Study year</th>
<th>No. of traps</th>
<th>No. barrier arms/trap</th>
<th>Collection cup distance from shore</th>
<th>Total trapping period</th>
<th>Total collections (daily)</th>
<th>No. of sialids collected</th>
<th>First and last days (or periods) of sialid larval collections</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>2</td>
<td>2</td>
<td>1 m</td>
<td>19 April to 29 June</td>
<td>8 (0)</td>
<td>346</td>
<td>19 April−7 May to 16–31 May</td>
</tr>
<tr>
<td>2016</td>
<td>2</td>
<td>2</td>
<td>1 m</td>
<td>15 April to 9 June</td>
<td>40 (36)</td>
<td>1711</td>
<td>18 April to 7 June</td>
</tr>
<tr>
<td>2017</td>
<td>4</td>
<td>1</td>
<td>1, 2, 4, 6 m</td>
<td>14 April to 1 June</td>
<td>22 (17)</td>
<td>190</td>
<td>15 April to 1 June</td>
</tr>
</tbody>
</table>

Table 2. Summary data from various studies that used pitfall traps to estimate timing of sialid larval emergence from water bodies.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study location</td>
<td>Texas</td>
</tr>
<tr>
<td>Latitude (° N)</td>
<td>30.5</td>
</tr>
<tr>
<td><em>Sialis</em> species studied</td>
<td><em>S. itasca</em></td>
</tr>
<tr>
<td>Period of larval emergence</td>
<td>January to April</td>
</tr>
<tr>
<td>Type of barrier used in trap</td>
<td>2 boards, 1.8 m long</td>
</tr>
<tr>
<td>Collection cup distance from shoreline</td>
<td>3–8 m from shore</td>
</tr>
<tr>
<td>Number of traps or collection cups</td>
<td>5</td>
</tr>
<tr>
<td>Number of sialids collected</td>
<td>30</td>
</tr>
</tbody>
</table>
Figure 1. (A) Schematic diagram of the trap configuration used in 2015 and 2016. (B) Schematic diagram of the trap configuration and relative placement for four traps used in 2017, along with the percent of sialid larvae collected by trap distance from shore. (C and D) Traps used in the 2015 and 2016 studies. Trap in C faced northwest. Trap in D faced west. (E) Aerial view of ca. 10-km-long Intermediate Lake in Antrim County, MI (Base map: Google Earth), with white * indicating location of study site. (F) Closer view of trap arrangement showing collection cup after removal from soil and the chicken-wire screen section that had been positioned over the collection cup to reduce mammal disturbance.
Some larvae were preserved during each collection period with the others released near the shoreline but more than 25 m away from the collection cups. After the collection was complete, I refilled the cups with new moist sand (from off-site), and then rearranged the cups, barriers, and screening as before.

**2016 study.** Two barrier pitfall traps were installed along the shoreline on 15 April 2016 (Table 1). The same collection locations, materials, trap configurations, and methods used in 2015 were used in 2016. Daily collections were made in the morning from 18 April through 9 May and again from 26 May to 9 June. Collections were made at 2- to 7-day intervals during 10–25 May.

**2017 study.** Four pitfall traps were installed on 14 April 2017 near where the trap pictured in Fig. 1C was located (Table 1, Fig 1B). These four traps had only a single 1-m-long barrier each. The collection cups were placed at four different distances from the shoreline: 1, 2, 4, and 6 m (Fig. 1B). The traps were in the same general area, all with similar vegetation (mostly grasses and no woody plants), and positioned so that none of the barriers overlapped (Fig. 1B). This was done so that no individual trap barrier would interfere with another barrier as the sialid larvae walked on shore, assuming the larvae walked mostly perpendicular to the shoreline. Traps were emptied at 1- to 5-day intervals, as described above during 15 April to 1 June 2017. Daily collections were made during 15–25 April, 8–10 May, and 17–19 May.

I also related daily sialid larval emergence data in 2016 and 2017 to recent weather events, given that sialids have been noted as emerging at night under rainy conditions (Takeuchi and Hoshiba 2012b). Notes on daily weather events during the study periods, especially rainfall, were supplemented with weather observations at the two Michigan State University weather stations closest to the study site: Eastport (about 16 km NW of the study site), and Kewadin (about 11 km SW of the study site). Current and historical weather records are available online for these sites at 5-min, 1-hr, and 1-day intervals (see: https://enviroweather.msu.edu/). Daily sialid collections were made in the morning hours, usually between 9–11 am. If any larvae were found in the collection cups and it had rained the previous night from 9 pm to 5 am, then the larvae were recorded as having likely emerged during rainy conditions the previous night. If it had only rained the previous day, but before 9 pm, then any larvae collected were listed as having emerged when it had rained the previous day. However, if no rain had fallen the previous night or day, any larvae collected were recorded as having emerged from the lake under dry conditions.

**Sialid identification.** Several adult sialids were collected at the study site during May and June in 2015 and 2016 and submitted to Elwin D. Evans [Adjunct Curator, Department of Entomology, Michigan State University (MSU)], who has extensive experience with Sialidae (Evans 1972, Flint et al. 2008). Specimens were retained at the MSU Albert J. Cook Arthropod Research Collection. For the Sialidae of Michigan and nearby areas, taxonomic keys for both larvae and adults are presented in Bright (2020), with keys to the eggs found in Canterbury and Neff (1980).

**Results**

Sialid identification. All adult sialids collected at the study site were identified as *Sialis mohri* Ross. Therefore, the larvae collected during this study are presumed to be *S. mohri*, although the possibility of other species being present cannot be ruled out.

**2015 study.** A total 346 sialid larvae and pupae were collected in the two pitfall traps in 2015. Sialids were captured from the first collection period (19 April to 7 May) through the 16–31 May collection period, with no sialids captured in any of the four collections during June. After converting the collection data to sialids captured per day, the highest average daily record (21.5 sialids/day) occurred during the period 7–11 May, during which time rain was recorded at night on both 9 and 10 May. Of the 200 sialids found in both traps at the end of the 16–31 May period, 59 were larvae and 141 were pupae. Only sialid larvae were found in the earlier collections in April and May.

**2016 study.** A total of 1711 sialid larvae were collected in the two pitfall traps in 2016. Sialids were captured from 18 April through 7 June. For those sialid larvae recovered during periods when collections were made daily (N = 1633 larvae), 14.7% (N = 240) were captured when it had rained the previous night, and an additional 84.6% (N = 1382) when it had rained the previous day (Fig. 2). The proportion of larvae captured when it had rained the previous night or day was significantly greater than on days when no rain had fallen the previous night or day (z-test for two proportions: z = 56.38, P < .00001).

During the 1-day period ending on the morning of 5 May, 1182 sialid larvae were collected in the two traps (Fig. 2), which represented 69% of all sialids collected in 2016. During the period of 4–5 May about 1 cm of rain had fallen during the day on 4
May and there were steady northerly winds for nearly all of 4–5 May.

2017 study. A total of 190 sialid larvae were collected from the four pitfall traps used in 2017. Sialids were captured from 15 April through 1 June, with the highest single-day collections (all traps combined) occurring on 19 May (N = 47 larvae) and 9 May (46). It did rain on the evening of 18 May, but no rain was recorded during the entire period of 3–9 May. However, during 6–9 May there were strong northerly winds on multiple days (Fig. 2). With respect to distance from the shoreline, 135 of the 190 larvae (71.1%) were collected in the pitfall cup located 1 m from the shore, 37 (19.5%) at 2 m, 17 (8.9%) at 4 m, and 1 (0.5%) at 6 m (Fig. 1B). The proportion of larvae captured at the 1-m distance was significantly greater than the other three distances combined (z-test: z = 8.21; P < .00001). For those sialids captured during periods when collections were made daily in 2017 (N = 165), 46.1% (N = 76) were captured when it had rained the previous night, and an additional 12.1% (N = 20) when it had rained the previous day (Fig. 2). As above, the proportion of larvae captured when it had rained the previous night or previous day was significantly greater than at similar times that were dry (z-test: z = 2.97, P = 0.00298).

Discussion

Emergence of sialid larvae from Intermediate Lake was recorded from mid-April to early June in the present study. Other researchers who have used barrier pitfall traps to study timing of sialid larval emergence include Azam and Anderson (1969) in Oregon (working with *Sialis californica* Banks and *S. rotunda* Banks), Locklin et al. (2006) in Texas (*S. itasca* Ross and *S. velata*), Pritchard and Leischner (1973) in Alberta (*S. cornuta* Ross), and Takeuchi and Hoshiba (2012b) in Japan (*S. japonica* van der Weele and *S. yamatoensis* Hayashi & Suda) (Table 2). In each of the previous studies, sialid larvae were captured in pitfall traps over spans of 3 to 4 consecutive months. In the present study, traps were first deployed in mid-April, with some sialid larvae collected soon thereafter, suggesting that some *S. mohri* larvae likely begin emergence in early April or perhaps even in late March if spring temperatures are especially warm. In England, Elliott (1996) monitored adult flight of *S. lutaria* L. for 30 consecutive years along the same section of lake shoreline (N 54°) and noted that the day of first-observed adult flight varied by about a month over that timespan (23 April–25 May). In addition, Elliott (1996) estimated that sialid larvae initiated emergence when water temperatures reached 7.2 °C and was mostly complete when water temperatures reached 14.0 °C. In any future studies of *S.
mohri, traps should be installed in March and checked frequently to better identify when first emergence of larvae occurs.

Daily collections in two of the studies that used pitfalls traps (Pritchard and Leischner 1973, Takeuchi and Hoshiba 2012b) indicated high day-to-day variation in the numbers of larvae captured, which is similar to results in the present study, especially in 2016 and 2017 when daily collections were often made (Fig. 2). By comparison, in the present study, 58% of the S. mohri larvae in 2017 and 99% in 2016 were captured under similar wet conditions. Takeuchi and Hoshiba (2012b) suggest that departing the water at night under wet conditions would allow aquatic insects such as sialids to avoid desiccation while walking variable distances on land before excavating pupal chambers in the soil. Interestingly, corydalid larvae, which often pupate several meters from the water’s edge (e.g., up to 10 m), almost always emerge at night when it is raining or when it has rained the previous day (Takeuchi and Hoshiba 2012a).

Concerning the distance crawled by sialid larvae prior to constructing pupal chambers, the fact that 71% of the captured S. mohri larvae in the present study were collected in the 1-m trap and 0.5% in the 6-m trap indicates that the vast majority of S. mohri larvae pupate close to shore. In the four other studies that used pitfalls traps to monitor sialid larval emergence (Table 2), most authors simply stated that their traps were placed near the shoreline with no exact distance given. However, in the Texas study, Locklin et al. (2006) deployed 5 traps, each with two 1.8-m-long barriers on either side of the collection cup, and with the collection cups placed at distances of 3 to 8 m from the shore. Given their methods along with the results of the present study, it is understandable that Locklin et al. (2006) reported only collecting 30 sialid larvae (for both Sialis species combined) in all five traps. Collecting only 30 individuals in five traps suggests that most sialid larvae in their study entered the soil to pupate before ever reaching their traps. In Japan, S. japonica is reported to pupate at distances of 0.2–3.4 m from the shoreline (Takeuchi 2007), and similarly S. yamatoensis pupates at distances of 0.5–0.7 m from the shoreline (Takeuchi 2005). If S. mohri larvae are broadly similar to S. japonica and S. yamatoensis in their selection of pupation sites, then several S. mohri larvae may have been missed in the present study given that collection cups were always at least 1 m from the shoreline. Future studies to determine more precisely where S. mohri larvae pupate could be conducted by sampling soil cores at varying distances from shore in late spring but before initiation of adult emergence.

On a few occasions in the present study, many sialid larvae were captured on days when it had not rained the previous night but when there had been steady northerly winds (Fig. 2). Given that the study site was near the southeastern end of a 10-km-long narrow lake, such winds typically caused steady waves to form that usually wetted the shoreline up to near the collection cups that were placed at 1 m from shore. Such wave action may produce wet conditions similar to rainfall and therefore favor emergence of sialid larvae. Future research could address this topic with nighttime observations made for emerging larvae when conditions are calm vs. when there is strong wave activity.

Observations made in the current study are assumed to involve only S. mohri, given that only this species was identified among the submitted specimens. Nevertheless, it is possible that other Sialis species occur in Intermediate Lake, as is the case in other lakes that have been sampled in northern Lower Michigan (Ross 1937). For example, both S. mohri and Sialis velata Ross occur in Houghton Lake (Roscommon County, MI) (Ross 1937), which is about 70 km southeast of the study site.

Only a few other researchers have studied aspects of S. mohri biology and ecology. For example, Canterbury and Neff (1980) described the eggs and egg masses of S. mohri and stated that among the 10 eastern Nearctic Sialis species, S. mohri had the highest average number of eggs per mass (mean = 718; range 500 to 905). Ross (1937) presented collection records for S. mohri adults from several US states and Canadian provinces. For Michigan, the S. mohri records indicated that adults had been collected as early as 19 May 1936 (Detroit), and as late as 24 July 1935 (Cheboygan County). Although adult flight of S. mohri was not closely monitored in the present study, notes of the earliest adults observed at the study site when monitoring the pitfalls traps occurred on 24 May 2016. There is still much to learn about the life history of S. mohri, such as seasonal development, typical larval prey, typical time at night when larvae emerge from water, pupation depth in soil, and adult behavior and longevity.
Acknowledgments

I thank Elwin D. Evans (Michigan State University) for identification services; Fumio Hayashi (Tokyo Metropolitan University) for sending reprints from Hyogo Freshwater Biology; and Alexander B. Orfinger (Florida A&M University and University of Florida), William G. Ruesink (Michigan State University), and three anonymous reviewers for providing valuable comments on an earlier version of this paper.

Literature Cited


