EMERGENCE OF EPHEMEROPTERA FROM FINDLEY LAKE IN THE CONIFEROUS FOREST OF THE CASCADE MOUNTAINS, USA

TRUMAN SHERK[1] & GREG RAU[2]

[1]Department of Zoology, University of Washington, Seattle, Washington 98195, USA
Present address: P. O. Box 331, Branford, Connecticut 06405, USA
[2]College of Forest Resources, University of Washington, Seattle, Washington 98195, USA

Ephemeroptera were collected in emergence traps on Findley Lake in the coniferous forest of the Cascade Mountains from 1972 to 1975. *Paraleptophlebia* emerged from all depths between 0 and 19.3 m each year, even in 1974 when the lake did not thaw until July 30 and there was a maximum surface temperature of 12.5 °C. Ephemeroptera are generally absent from arctic-alpine lakes that have a maximum surface temperature of less than 14°C (KAJAK *et al.*, 1980). *Callibaetis* emerged from 0 to 5.6 m in the warm summer of 1973, but from only 0 to 0.5 m in 1974.

INTRODUCTION

Ephemeroptera and other insects (SHERK & RAU, 1991; SHERK & RAU, 1992; SHERK, 1993; SHERK & RAU, 1996) were collected in floating emergence traps on Findley Lake in the coniferous forest of the Cascade Mountains, USA, from 1972 to 1975. Findley Lake is in a temperate maritime climate, but it usually does not thaw until July due to the heavy snowfall (HENDREY & WELCH, 1974).

We had two goals: (1) to compare the emergence of Ephemeroptera in years in which there was an early thaw and warm surface temperatures to the emergence in other years when there was a late thaw and cool surface temperatures; and (2) to compare the emergence from Findley Lake to the emergence from lakes in forested watersheds at lower elevations (JUDD, 1964; FLANNAGAN & LAWLER, 1972; PAASIVIRTA, 1975; HARPER & CLOUTIER, 1985; HARPER & CLOUTIER, 1986; FLANNAGAN & COBB, 1995). Ephemeroptera are generally absent from arctic-alpine lakes that have a maximum surface temperature of less than 14 °C (KAJAK *et al.*, 1980), but are present in Øvre Heimdalsvatn, Norway, which has an elevation of 1090 m and a maximum surface temperature of 20 °C (BRITTAIN, 1980) and in Lac de Port-Bielh, France) (LAVILLE, 1971b), which has an elevation of 2285 m and a maximum surface temperature of at least 17.5 °C (LAVILLE, 1971a).

STUDY AREA AND METHODS

Findley Lake is at an elevation of 1128 m in the Cascade Mountains of Washington, USA. It is surrounded by coniferous forest, talus slopes and wet meadows (Fig. 1). The lake has a maximum depth of 27,5 m, a mean depth of 7.8 m and an area of 11.4 ha. The clear lake is oligotrophic (HENDREY & WELCH, 1974). There is hardly any aquatic vegetation. Detritus from the forest enters the lake near the shore (RAU, 1976; WISSMAR *et al.*, 1977). The lake is well-oxygenated (BIRCH, 1974, cited in WISSMAR *et al.*, 1977) and has an average annual pH of 6.4 at the outlet (WISSMAR *et al.*, 1982). There is a high precipitation, mainly in the form of snow during winter (HENDREY & WELCH, 1974), and a high rate of water replacement from melting snow during the June or July thaw (RICHEY & WISSMAR, 1979; WISSMAR *et al.*, 1982). The minimum flow is in early August when the melt-water tributaries (Fig. 1) are usually dry.

There was considerable yearly variation of the date when the lake thawed and of the maximum temperature of the water (Fig. 2). The surface water warmed rapidly after the thaw, but the deeper water did not reach its maximum temperature until later in the year when the surface water had started to cool. The entire lake mixed after the thaw and again in the fall when there was an even temperature at all

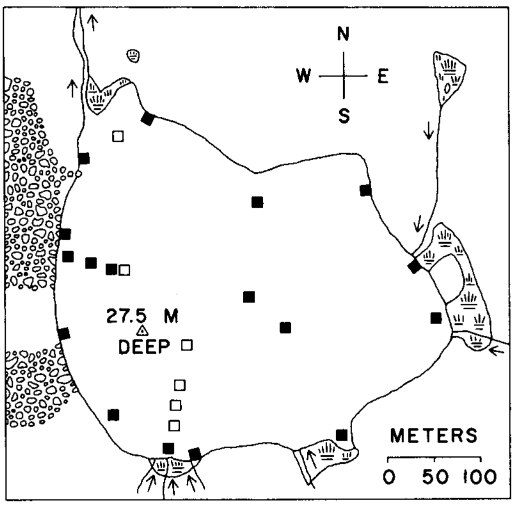

Fig. 1. Map of Findley Lake. Locations of emergence traps at Findley Lake in 1972 (solid squares). Locations of traps in different positions in 1973 or 1974 (hollow squares). Maximum depth (triangle).

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depths. The warmest surface temperature of 21.0 °C occurred in 1972 (HENDREY, 1973), but the warm temperatures were of short duration. The maximum temperatures at all other depths occurred in 1973 when the warm temperatures were of longer duration. In 1974 most of the lake did not thaw until July 30-31, and the surface water reached a maximum temperature of only 12.5 °C in August. However, the maximum temperature of 10 °C at a depth of 10 m on October 4, 1974, was as warm as the maximum temperature of 10 °C at a depth of 10 m on September 15, 1972. The maximum surface temperature of 17.4 °C in 1975 was more than in 1974, but less than in 1972 or 1973.

Ephemeroptera and other insects were collected in 1.0 square meter floating emergence traps that were covered with fiberglass screening that had a 1.0 mm mesh that was small enough to retain the smallest Diptera. Similar traps were placed with one side on the shore to capture those aquatic insects that only emerged on shore. Collections were usually made at one to five day intervals during the entire ice-free periods. Ten floating traps and seven shore traps were used on Findley Lake in 1972 (Fig. 1). Fewer traps were used in other years (Tables 1 and 2). The collections from the shore traps were averaged in Figs 3 and 4.

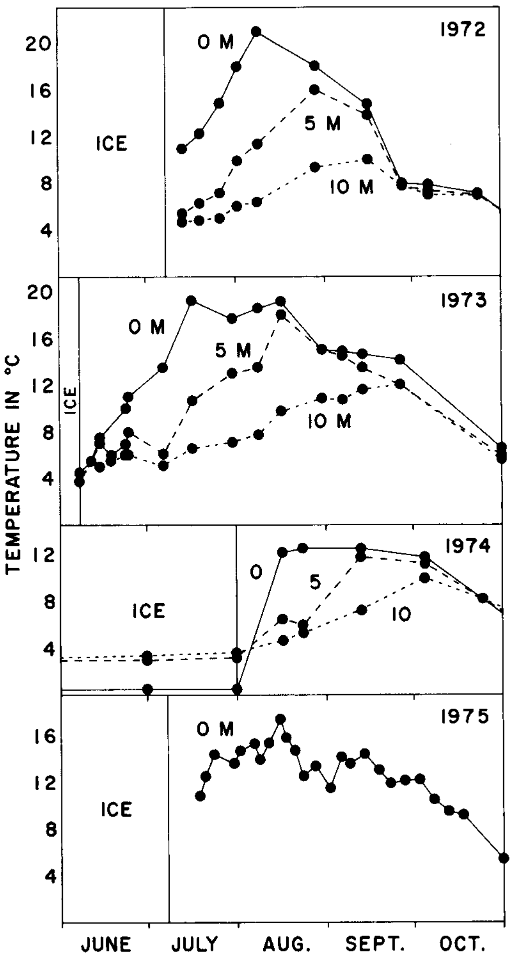

Fig. 2. Temperatures at 0 m, 5 m and 10 m depths at Findley Lake from 1972 to 1974 and at 0 m in 1975. Temperatures are from HENDREY (1973), SHERK & RAU (1996) and unpublished data of the Coniferous Forest Biome at the University of Washington.

RESULTS

More Ephemeroptera emerged per square meter from Findley Lake in years when there were early thaws and warm temperatures than in years when there were late thaws and cool temperatures (Table 1). There was a better correlation between the number of Ephemeroptera that emerged (Table 1) and the duration of warm temperatures at most depths (Fig. 2) than between the number of Ephemeroptera that emerged and the maximum surface temperature (Table 1). In 1973 when most of the lake

Table 1. Number of Ephemeroptera that emerged per square meter in the floating traps at Findley Lake from 1972 to 1975. Temperatures are from HENDREY (1973), SHERK & RAU (1996) and unpublished data of the Coniferous Forest Biome at the University of Washington.

Year	1972	1973	1974	1975
Date of thaw	July 7	June 7	July 30	July 7
Max. surface temp. °C	21.0	19.3	12.5	17.4
Number of traps	10	10	7	4
Paraleptophlebia	16.6	29.0	7.9	8.3
Callibaetis	1.6	2.8	1.1	1.5
Total Ephemeroptera	18.2	31.8	9.0	9.8

Table 2. Number of Ephemeroptera that emerged per square meter in the shore traps at Findley Lake from 1972 to 1974. Temperatures are from HENDREY (1973), SHERK & RAU (1996) and unpublished data of the Coniferous Forest Biome at the University of Washington.

Year	1972	1973	1974
Date of thaw	July 7	June 7	July 31
Max. surface temp. °C	21.0	19.3	12.5
Number of traps	7	2	1
Paraleptophlebia	161.7	70.0	47
Callibaetis	8	71.5	4
Total Ephemeroptera	169.7	141.5	51

thawed by June 7 and the surface water reached a maximum temperature of 19.25 °C in July, the 31.8 Ephemeroptera that emerged per square meter in the floating traps included 29.0 *Paraleptophlebia* LESTAGE (Leptophlebiidae) and 2.8 *Callibaetis* EATON (Baetidae). In 1974 when most of the lake did not thaw until July 30-31 and the surface temperature reached a maximum of only 12.5 °C in August, only 9.0 Ephemeroptera emerged per square meter. These included 7.9 *Paraleptophlebia* and 1.1 *Callibaetis*. More Ephemeroptera emerged per square meter in the shore traps in 1972 when there was the maximum surface temperature and in 1973 when there was the longest duration of warm surface temperatures than in 1974 when there was a late thaw and cold surface temperatures (Table 2).

The total biomass of Ephemeroptera that emerged per square meter in the floating traps varied from a maximum of 44.2 mg dry weight in the warm year of 1973 to a minimum of only 12.6 mg in the cold year of 1974. The total biomass of Ephemeroptera that emerged per square

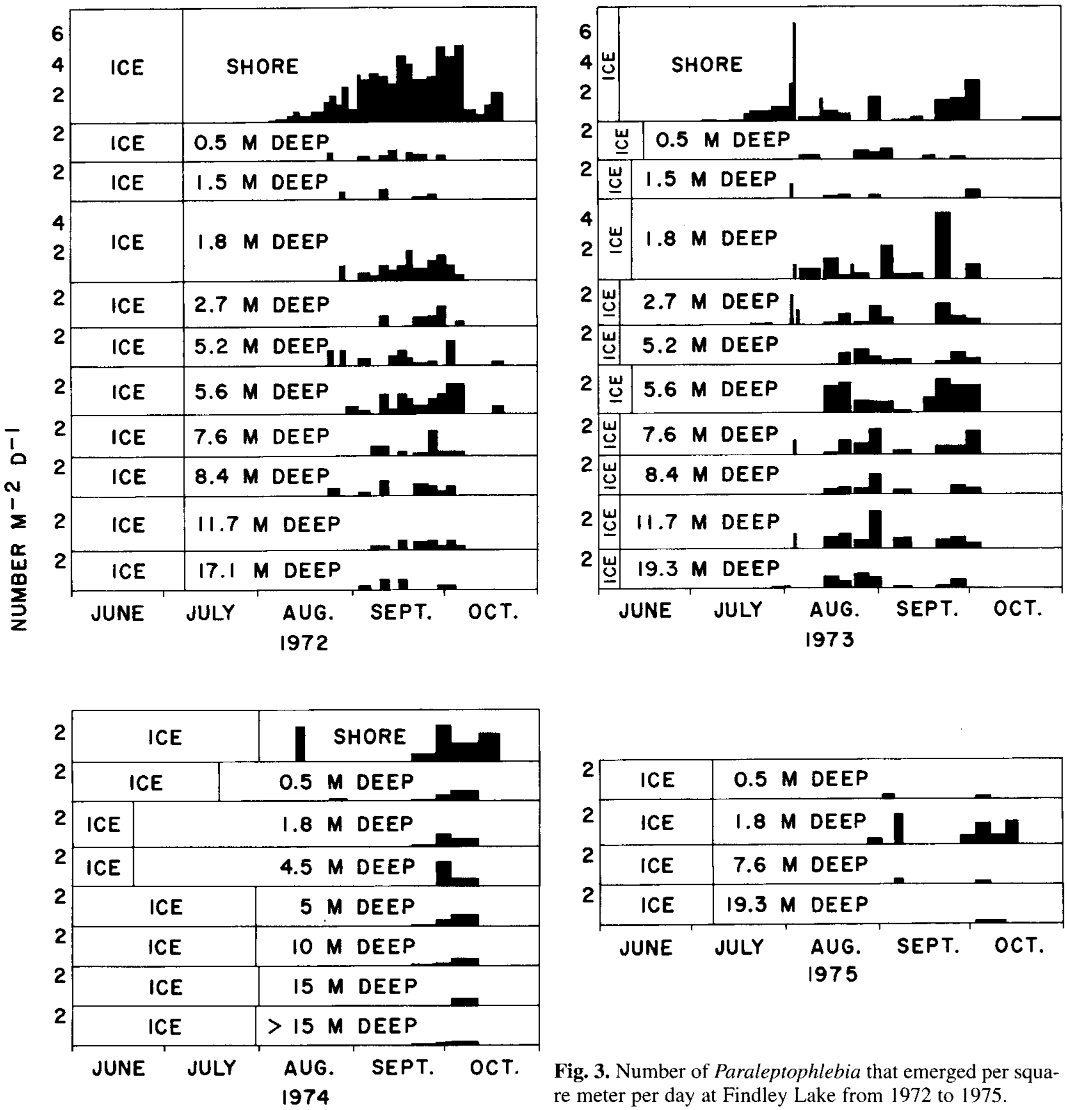

Fig. 3. Number of *Paraleptophlebia* that emerged per square meter per day at Findley Lake from 1972 to 1975.

meter in the shore traps varied from a maximum of 235.8 mg dry weight in 1972 when there were the maximum surface temperatures to a minimum of only 70.9 mg in the cold year of 1974.

Paraleptophlebia emerged from all depths between 0 and 19.3 m each year (Fig. 3), even in 1974 when most of the lake did not thaw until July 30 and there was a maximum surface temperature of only 12.5°C. Most of the *Paraleptophlebia* emerged from August to October, especially during the fall when there was an even temperature (Fig. 2) and a high oxygen concentration (Birch, 1974, cited in WISSMAR *et al.*, 1982) at all depths. The maximum emergence seemed to be from the shore and from the two sites at the depths of 1.8 and 5.6 m in the southwestern part of the lake (Fig. 1) where the lake bottom was covered with the most large organic detritus from the surrounding forest (RAU, 1976), although too few individuals emerged per square meter per day at each site to be completely convincing. In the two warmest years of 1972 and 1973, the maximum emergence was from the shore, the large organic detritus at 1.8 m and the large organic detritus at 5.6 m. In 1975 when there were only four traps, the maximum emergence was from the large organic detritus at 1.8 m. In 1974 when there was a late thaw and cool temperatures, the maximum emergence was from the shore. The minimum emergence of *Para-*

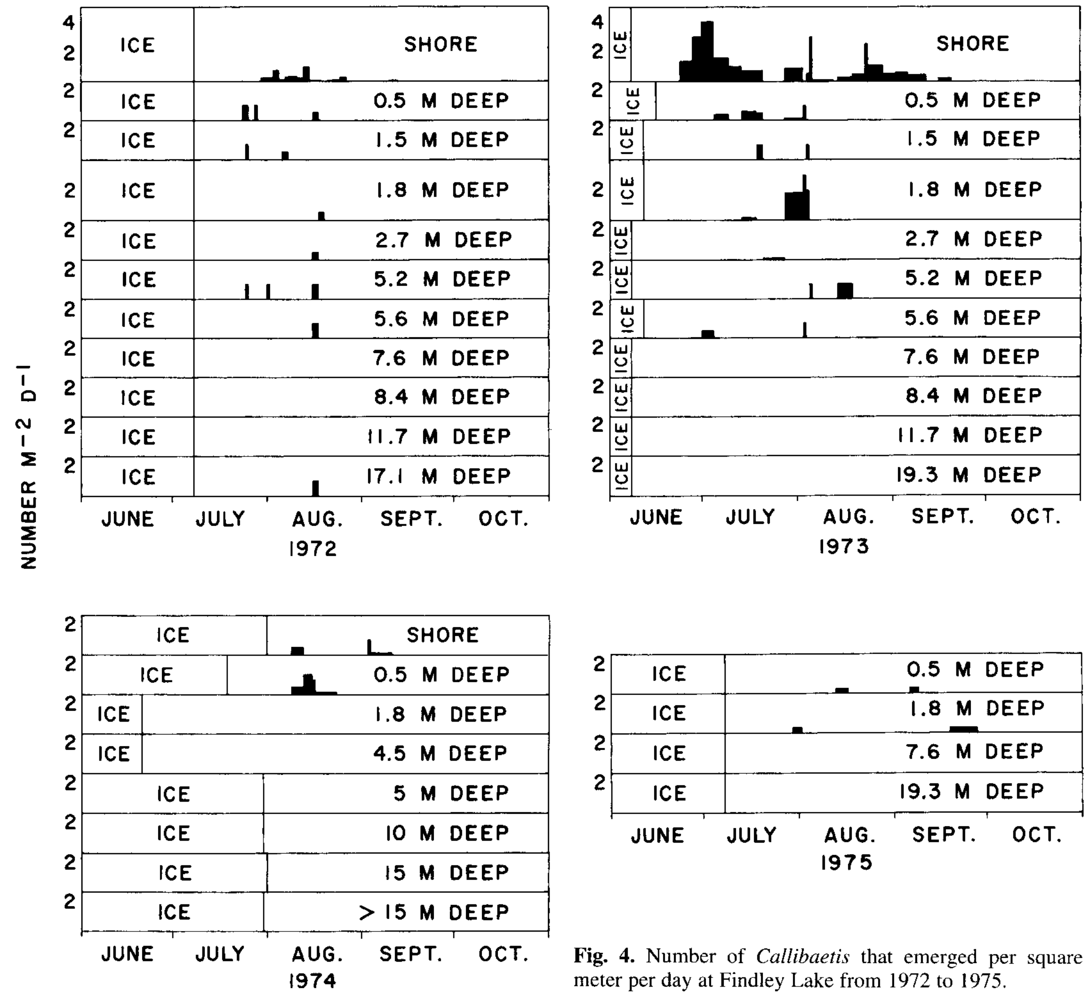

Fig. 4. Number of *Callibaetis* that emerged per square meter per day at Findley Lake from 1972 to 1975.

leptophlebia (Fig. 3) tended to be from the deepest water where there were the coldest temperatures (Fig. 2) and from the two sites at the depths of 0.5 and 1.5 m in the southeastern part of the lake.

Most of the *Callibaetis* emerged from the shallow water (Fig. 4) when there were the highest temperatures in the shallow water (Fig. 2). Over a four year period, only two individuals emerged from water that was deeper than 5.6 m (Fig. 4). During the warm summer of 1973 when there was the longest duration of warm temperatures at all depths, *Callibaetis* emerged from 0 to 5.6 m. During the cold summer of 1974, *Callibaetis* emerged from only 0 to 0.5 m.

In 1972 when the total number of males and females that emerged from the entire lake was counted, 1.02 *Paraleptophlebia* males emerged for each female, but 2.64 *Callibaetis* females emerged for each male.

DISCUSSION

Although Ephemeroptera are generally absent from arctic-alpine lakes that have a maximum surface temperature of less than 14°C (KAJAK *et al.*, 1980), the number of Ephemeroptera that emerged per square meter from Findley Lake was similar to the number that emerged from lakes in forested watersheds at lower elevations, even in 1974 when most of Findley Lake did not thaw until July 30-31 and there was a maximum surface temperature of only 12.5°C.

The 31.8 Ephemeroptera that emerged per square meter in the floating traps at Findley Lake during the warm summer of 1973 (Table 1) were more than the 2.5 that emerged from one of the experimental lakes in northwestern Ontario (FLANNAGAN & COBB, 1995), the 5.0 that emerged from Saunders Pond in the deciduous woods of southern Ontario (JUDD, 1964) and the 6.8 that emerged from eutrophic Lake Cromwell, Québec (HARPER & CLOUTIER, 1986). They were similar to the 33.4 and 39.9 that emerged from two of the other experimental lakes in northwestern Ontario (FLANNAGAN & COBB, 1995) and the 39.8 that emerged from Heming Lake in Manitoba (FLANNAGAN & LAWLER, 1972), but were less than the 49.4 that emerged from Lac Hélène in sub-arctic Québec (HARPER, 1990) and the 101 that emerged from dystrophic Lac Geai, Québec (HARPER & CLOUTIER, 1985). The 9.0 Ephemeroptera that emerged per square meter in the floating traps at Findley Lake in 1974 when there was a maximum temperature of only 12.5°C were more than the number that emerged from three of the above lakes.

The 284 and 373 Ephemeroptera that emerged per square meter in the two most productive shore traps at Findley Lake in 1972 were similar to the 356 that emerged from Mack Creek at an elevation of 800 m in the old-growth coniferous forest in the Cascade Mountains of Oregon (HARPER *et al.*, 1995), but were less than the 620 that emerged from the shore of Øvre Heimdalsvatn, Norway (BRITTAIN & LILLEHAMMER, 1978), the 733 that emerged from Grasshopper Creek at an elevation of 880 m in a recently clear-cut area of Oregon (HARPER *et al.*, 1995) and the 770 that emerged from Breitenbach, Germany, in 1969 (ILLIES, 1971).

The 13 to 20 Ephemeroptera that emerged per square meter from the 0.5 m deep water at Findley Lake in 1972 and 1973 were considerably less than the 213 to 453 that emerged from the 0.1 to 0.5 m deep water near the shore of oligotrophic Lake Pääjärvi in southern Finland which was ice-free from early May to October (PAASIVIRTA, 1975). The duration of the warm surface temperatures was much shorter at Findley Lake than at Lake Pääjärvi.

Paraleptophlebia had a deeper distribution in clear Findley Lake (Fig. 3) than the Ephemeroptera in some other oligotrophic lakes. Ephemeroptera emerged from 0.1 to 3 m at 87 m deep Lake Pääjärvi, with most of the emergence from 0.1 to 1.0 m (PAASIVIRTA, 1975). Ephemeroptera were present as deep as 7 m in 13 m deep Øvre Heisdalsvatn, Norway (BRITTAIN, 1978). BRUNDIN (1949) found Ephemeroptera nymphs from 0.2 to 11 m in 19 m deep Lake Innaren, Sweden. *Hexagenia limbata occulta* nymphs were as deep as 17.5 m in Lake Winnipeg, Manitoba (Neave, 1932).

Paraleptophlebia had a more even distribution throughout well-oxygenated Findley Lake, especially during the warm summer of 1973 (Fig. 3), than the Ephemeroptera in lakes where the deepest water was completely deoxygenated during the summer. Most of the Ephemeroptera emerged from the shallow water in eutrophic Lake Cromwell, Québec, where the hypolimnion was deoxygenated from mid-July until the fall turnover (Harper & Cloutier, 1986). However, well-oxygenated Lake Pääjärvi also had its emergence of Ephemeroptera concentrated in the shallow water (PAASIVIRTA, 1975).

There were no fish in Findley Lake that preyed upon the Ephemeroptera and reduced the number that emerged, but there were amphibians, including *Taricha granulosa* (Salamandridae) throughout the lake, some *Ambystoma gracile* (Ambystomidae) in the lake, *Rana cascadae* (Ranidae) along the shore and *Bufo boreas* (Bufonidae) on the shore. There were also Odonata, especially between the shore and a depth of 1.2 m, including *Aeshna palmata* HAGEN (Aeshnidae), *Somatochlora albicincta* (BURMEISTER) (Corduliidae) and a few *Aeshna umbrosa* WALKER (Aeshnidae). All of these predators, along with a few Plecoptera, Coleoptera and Hemiptera, were present within the area covered by the shore traps and might have reduced the number of Ephemeroptera that emerged in the shore traps. The low emergence of Ephemeroptera between the depths of 0.5 and 1.5 m might have been partially due to predation by *T. granulosa* and Odonata. Ephemeroptera were the main prey of *T. granulosa* that were collected within 1 m of shore in August. The stomach contents of 5 *T. granulosa* that were collected at Findley Lake on August 2-3, 1972, included 82 Ephemeroptera, 2 Trichoptera, 4 Diptera and 7 other invertebrates. The other amphibians also ate some Ephemeroptera. *Aeshna* spp. and *S. albicincta* ate Ephemeroptera (WALKER, 1925; PRITCHARD, 1964; KIME, 1974). *T. granulosa* and a few *A. gracile* were probably the only important predators between the depths of 1.8 and 19.3 m.

The slightly higher than average emergence of *Paraleptophlebia* from the two sites at the depths of 1.8 and 5.6 m where the bottom was covered with the most large organic detritus from the surrounding forest was probably because of the greater supply of food. *Paraleptophlebia* is associated with wood and leaf detritus in coniferous forest streams (ANDERSON *et al.*, 1978). *Paraleptophlebia* ate soft woody detritus (PEREIRA *et al.*, 1982), other detritus, diatoms and filamentous algae (CHAPMAN & DEMORY, 1963; GILPIN & BRUSVEN, 1970; SHAPAS & HILSENHOFF, 1976). In the Findley Lake *Paraleptophlebia* either ate periphyton or a mixture of plankton that had settled to the bottom and detritus from the surrounding forest (RAU, 1980).

Callibaetis is a herbivore that feeds on filamentous algae (MORGAN, 1913), diatoms (EDMUNDS *et al.*, 1976) and other plant material (BERNER & PESCADOR, 1988). *Callibaetis floridanus* Banks nymphs ate algae and dying terrestrial plants that had been flooded when the water level rose (TROST & BERNER, 1963). CUSHING & RADER (1983) found that *Callibaetis* also ate fine particulate matter from a stream bottom.

We regret that we were unable to save our entire collection of Ephemeroptera for later identification at the species level. The Ephemeroptera were used for dry weight determinations and food source studies (RAU, 1980) after they had been identified at the generic level. Keys are presently available for *Paraleptophlebia* (HARPER & HARPER, 1986) and *Callibaetis* (CHECK, 1982). Findley Lake probably had a late-emerging species of *Paraleptophlebia* such as *P. debilis* which was the last species of *Paraleptophlebia* to emerge at Mack Creek in the old growth coniferous forest in the Cascade Mountains of Oregon (HARPER *et al.*, 1995), the cold stream B in the experimental lakes of northwestern Ontario (FLANNAGAN & COBB, 1995) and the headwaters of a Laurentian watershed (HARPER & HARPER, 1982). *P. debilis* started emerging when both the photoperiod and the temperature were declining (HARPER & HARPER, 1982). Findley Lake also might have had at least one of the earlier emerging species of *Paraleptophlebia* that were present in the Cascade Mountains of Oregon (HARPER *et al.*, 1995) and had at least one species of *Callibaetis*. Other Ephemeroptera were present below the outlet from Findley Lake and might have been present in Findley Lake, although none were collected in the emergence traps. The temporary melt-water tributaries did not contribute any additional species to Findley Lake. The number of species of Ephemeroptera in each of the experimental lakes of northwestern Ontario varied from two to nine (FLANNAGAN & COBB, 1995). The number of species in some mountain lakes varied from two in Lac de Port-Bielh, France (LAVILLE, 1971b), to seven in

Øvre Heimdalsvatn which had Ephemeroptera in its inlet streams (BRITTAIN, 1978; 1979).

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