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SUMMER EMERGENCE OF MAYFLIES, STONEFLIES, AND CADDISFLIES FROM A COLORADO MOUNTAIN STREAM

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ABSTRACT—The summer emergence patterns of mayfly, stonefly, and caddisfly species are described for a second order, southern Rocky Mountain Colorado stream. Frequent, standardized, sweepnetting and emergence trap samples provided 1,779 adults of 45 taxa consisting of 11 mayfly, 15 stonefly, and 19 caddisfly species. The five most dominant species were, in order of importance, *Suwallia* nr. *lineosa, Sweltsa coloradensis, Oligophlebodes minutus, Paraleuctra vershina,* and *Baetis bicaudatus.* Stoneflies contributed 70% of all adults collected. Peak species richness of all orders occurred near the summer solstice and maximum water temperatures. The range of slope values generated by simple linear regression of cumulative percentage catch revealed that emergence was extended (slopes < 4%/day) for five of the seven most abundant species. Two caddisflies, *O. minutus* and *Rhyacophila pellisa,* displayed a synchronous emergence pattern. This study adds 35 new records for the Rio Conejos drainage and Conejos County and provides a baseline of comparison against future changes in species richness among these orders.

Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera) are among the dominant insect orders in Rocky Mountain stream ecosystems, yet there are no published accounts of the species-level diversity or emergence phenology of all three groups in any stream of the region. Ward and Kondratieff (1992) state that most of the comprehensive knowledge of aquatic insects in Colorado has been amassed only recently, and that much work on insect life histories and distribution patterns remains to be conducted.

Emergence is an important aspect of the life histories of aquatic insects in that it sets the stage for the next generation (Corbet, 1964; Sheldon and Jewett, 1967). Patterns of emergence may affect the allocation of resources and avoidance of competition through temporal segregation of morphologically or functionally similar species (Grant and Mackay, 1969).

Corbet (1964) described four types of emergence patterns: continuous, rhythmic, sporadic, and seasonal. Most aquatic insects of high latitudes and altitudes exhibit a seasonal emergence pattern. The interaction of temperature, photoperiod, and local climate conditions helps to determine aquatic insect seasonal phenology in temperate regions (Masteller, 1983, 1993).

Our objectives were to characterize the summer emergence patterns and emergence synchrony of the adult mayflies, stoneflies, and caddisflies in Massey Gulch, a small tributary of the Rio Conejos of south-central Colorado. There are no published reports of previous collections or studies of this stream. Few species records are available for the Rio Grande, Rio Conejos, and adjacent streams of the San Juan Mountains (Stark et al., 1973*a*, 1973*b*; Baumann et al., 1977; and Szczytko and Stewart, 1979 for stoneflies; Herrman et al., 1986 for caddisflies; Ward and Kondratieff, 1992; McCafferty et al., 1993 for mayflies).

MATERIALS AND METHODS—Massey Gulch is a second-order stream located at 106°15'W longitude and 37°03'N latitude. Emergence was monitored along an approximate 100 m stretch of the stream about 1.5 km upstream from its confluence with the Rio Conejos, 23 km west of Antonito, Colorado. The stream was no more than 3 m wide, and it had a permanent flow at this 2,700 m elevation, mixed-coniferous forest site.

A Ryan® model J, continuous recording thermograph was placed in the stream on 21 May 1989 and

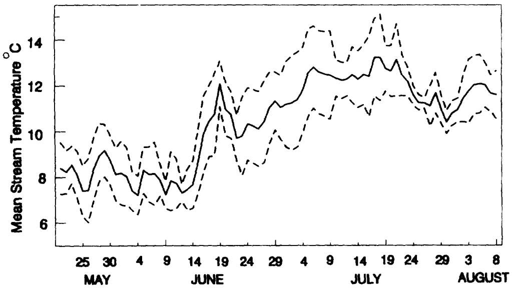

FIG. 1—Mean stream temperature (solid line) ± *SD* for Massey Gulch, 21 May through 8 August 1989.

remained until 9 August 1989. Mean daily temperatures were determined from records at 0600, 1200, 1800 and 2400 h.

Emergence traps and sweeping of riparian vegetation were used to collect adults. Harper and Pilon (1970) indicated that emergence traps were the only devices that yielded true emergence periods. All other methods documented adult presence. The combination of emergence trap catches and sweepnetting of riparian vegetation should therefore yield a good indication of the time period encompassing actual emergence and the duration of adult presence.

Two floating emergence traps (0.25 m^2, each) were deployed on the stream 27 May through 6 August 1989. These were placed within 10 m of each other on an extensive riffle. No attempt was made at a random placement since the stream was small and only two traps were used. Both traps were fitted with an aluminum screen attached to the downstream side of the trap and weighted to the substrate with stream cobble. This augmented the catch of mayflies and caddisflies whose pre-emergent drifting and midstream emergence might allow them to drift past a floating trap. This screen also provided emergence substrate for stoneflies.

Teneral adults climbed upward to a terminal collection container filled with an 80% ethanol and ethylene glycol (to retard evaporation) mixture. The traps were emptied at 2- to 5-day intervals. Sweepnetting of a 30-m stretch of riparian vegetation was conducted with equal effort over the same vegetation zone on those days when emergence traps were emptied. Adults were stored in 80% ethanol. Wet weather prevented sweepnetting on 8 and 10 June, 27 July, and 1 and 6 August.

All individuals were identified to the lowest level possible. The temporal pattern of species richness was plotted for all dates covered by the two collection methods. Sex-specific kite diagrams were constructed for species for which 13 or more individuals were collected. For each species, the number of males and females collected per date was converted to a percentage of the total number (males plus females of the species).

Synchrony of emergence was analyzed for species with 30 or more individuals and where the emergence was complete. Numbers collected per date were transformed to cumulative percentage catch for each species. This was plotted against the total number of days since first capture and subjected to a simple linear regression as a means of describing the emergence curve. This approach provided ranges of slope values for the categorization of emergence synchrony.

The seasonality of the study period precluded assessment of adult presence of winter stoneflies and some fall emerging limnephilid caddisflies. However, we feel confident that the majority of the mayfly, stonefly, and caddisfly species at this site were collected due to their largely summer emergence and our experience collecting in the area during other seasons on other streams. Vouchers of all species have been deposited in the University of North Texas Entomological Museum or in the personal collection of the senior author.

RESULTS—Mean stream temperatures (Fig. 1) at the beginning of the collection season oscillated near 8°C, decreased to 7.0°C during the cool, cloudy weather of 9 to 11 June and warmed gradually to 13.2°C by 17 July. Stream temperatures dropped erratically thereafter.

The 1,779 adults collected consisted of 70% stoneflies (15 species), 20% caddisflies (19 species), and 10% mayflies (11 species) (Table 1). Twenty-five (54.3%) species were represented by five or fewer individuals. The five numerically dominant species, including *Suwallia* nr. *lineosa* (Banks), *Sweltsa coloradensis* (Banks), *Oligophlebodes minutus* Banks, *Paraleuctra vershina* Gaufin and Ricker, and *Baetis bicaudatus* Dodds, contributed 71% of all individuals collected. Summer samples were dominated by chloroperlid stoneflies that accounted for 56% of all individuals collected.

The temporal pattern of species richness for adults was similar among the three orders studied (Fig. 2). Stoneflies attained peak diversity from 27 June to 6 July, while caddisfly and mayfly peaks appeared at 6 July. Peak diversity for all species combined occurred in advance of peak mean stream temperature by slightly more than 1 week.

All three orders demonstrated a typical succession of species throughout the summer. Mayflies showed marked succession among the baetids (Fig. 3). Separation of systematically-related species was most evident among the numerically dominant stoneflies (Fig. 4). A morphologically similar species pair, *S. coloradensis* and *S. lamba* (Needham and Claassen), were well separated by peak flight periods, while *S. coloradensis* and the morphologically distinct *S. borealis* (Banks)

TABLE 1—Number and percentage of total Ephemeroptera, Plecoptera and Trichoptera adults collected from Massey Gulch, Colorado, summer, 1989. All taxa marked with an asterisk represent new county and drainage records. Total number collected = 1,779.

Taxon	Number	Percent
Ephemeroptera		
Heptagenioidea		
Siphlonuridae		
Siphlonurus occidentalis Eaton*	1	
Ameletidae		
Ameletus sp.	1	
Baetidae		
Baetis bicaudatus Dodds*	94	5.3
B. tricaudatus Dodds*	17	1.0
Baetis sp.	2	
Diphetor hageni (Eaton)*	9	
Heptageniidae		
Cinygmula mimus (Eaton)*	25	1.4
Iron albertae (McDunnough)*	33	1.9
Leptophlebioidea		
Leptophlebiidae		
Paraleptophlebia heteronea (McDunnough)*	1	
Ephemerellidae		
Drunella doddsi (Needham)*	4	
Ephemerella sp.	1	
Plecoptera		
Euholognatha		
Capniidae		
Eucapnopsis brevicauda Claassen*	1	
Leuctridae		
Paraleuctra vershina Gaufin and Ricker*	105	5.9
Nemouridae		
Malenka coloradensis (Banks)	19	1.1
Podmosta delicatula (Claassen)*	89	5.0
Zapada frigida (Claassen)*	5	
Taeniopterygidae		
Taenionema pallidum (Banks)*	3	
Systellognatha		
Chloroperlidae		
Plumiperla diversa (Frison)*	3	
Suwallia nr. *lineosa* (Banks)*	657	37.0
Suwallia pallidula (Banks)*	25	1.4
Sweltsa borealis (Banks)*	31	1.7
Sweltsa coloradensis (Banks)*	205	11.5
Sweltsa lamba (Needham & Claassen)*	16	0.8
Triznaka pintada (Ricker)*	59	3.3
Perlidae		
Hesperoperla pacifica (Banks)	21	1.2
Perlodidae		
Isoperla fulva Claassen	3	
Trichoptera		
Rhyacophiloidea		
Rhyacophilidae		
Rhyacophila alberta Banks*	2	
Rhyacophila brunnea Banks*	5	
Rhyacophila coloradensis Banks*	1	
Rhyacophila pellisa Ross*	46	2.5

TABLE 1—Continued.

Taxon	Number	Percent
Hydroptiloidea		
Glossosomatidae		
Anagapetus debilis (Ross)*	13	
Glossosoma verdona Ross*	7	
Hydroptilidae		
Hydroptila rono Ross*	32	1.8
Stactobiella delira (Ross)*	2	
Hydropsychoidea		
Hydropsychidae		
Arctopsyche grandis (Banks)	18	1.0
Ceratopsyche oslari (Banks)*	5	
Limnephiloidea		
Limnephilidae		
Dicosmoecus atripes (Hagen)*	1	
Hesperophylax occidentalis (Banks)*	1	
Onocosmoecus unicolor (Banks)	2	
Uenoidae		
Neothremma alicia Dodds & Hisaw	1	
Oligophlebodes minutus (Banks)*	194	10.9
Brachycentridae		
Micrasema bactro Ross*	1	
Lepidostomatidae		
Lepidostoma cascadense (Milne)*	14	
Lepidostoma prob. *ormeum* Ross	1	
Lepidostoma pluviale (Milne)*	3	

showed nearly complete overlap. *Suwallia* nr. *lineosa* and *S. pallidula* (Banks) were also well separated by time. Caddisflies also succeeded each other (Fig. 5), but temporal segregation was difficult to demonstrate due to low numbers of individuals in the morphologically-similar and diverse species within *Rhyacophila* and *Lepidostoma.*

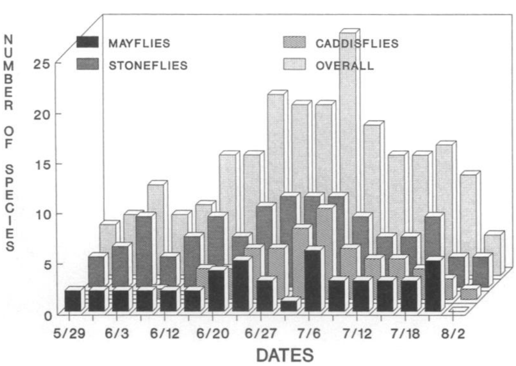

FIG. 2—Temporal pattern of species richness for each order and for all taxa combined from Massey Gulch.

Synchrony analysis produced slopes varying from 1.7%/day to 6.2%/day. An arbitrary cutoff was set at 4.0%/day to distinguish between extended and synchronous emerging species (Table 2). Plots of cumulative emergence revealed that the five extended emerging species had S-shaped curves (Fig. 6A), while the two synchronous emerging species displayed J-shaped curves (Fig. 6B).

DISCUSSION—Thirty-five species of mayflies, stoneflies, and caddisflies that were collected from Massey Gulch have never been reported from the parent drainage, the Rio Conejos, or from any drainage in Conejos County (Table 1). McCafferty et al. (1993) listed 97 mayfly species from Colorado but only *Rhithrogena hageni* Eaton from the Rio Conejos drainage and Conejos Co. Our work adds eight additional species (Table 1) for the county and drainage. Only nine species of stoneflies were listed from the county by Stark et al. (1973*a*, 1973*b*), Baumann et al. (1977), Szczytko and Stewart (1979), and Nelson and Baumann (1989) from the county. Our study has

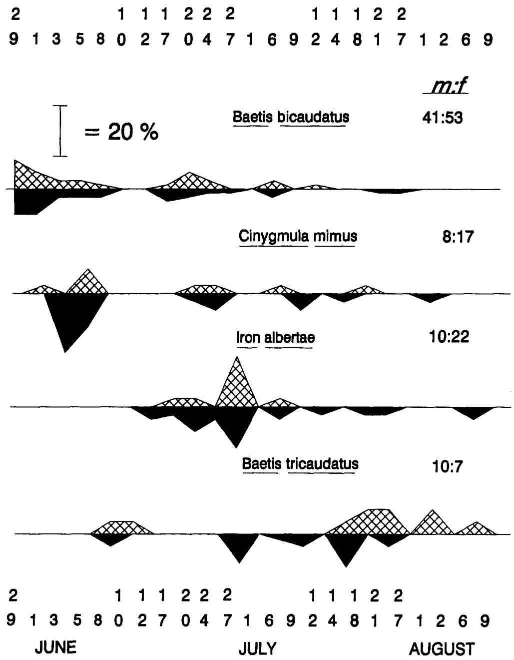

FIG. 3—Percentage catch of adult mayflies from Massey Gulch. Cross-hatched pattern = females, black = males. Sex ratios (male : female) are listed for each species.

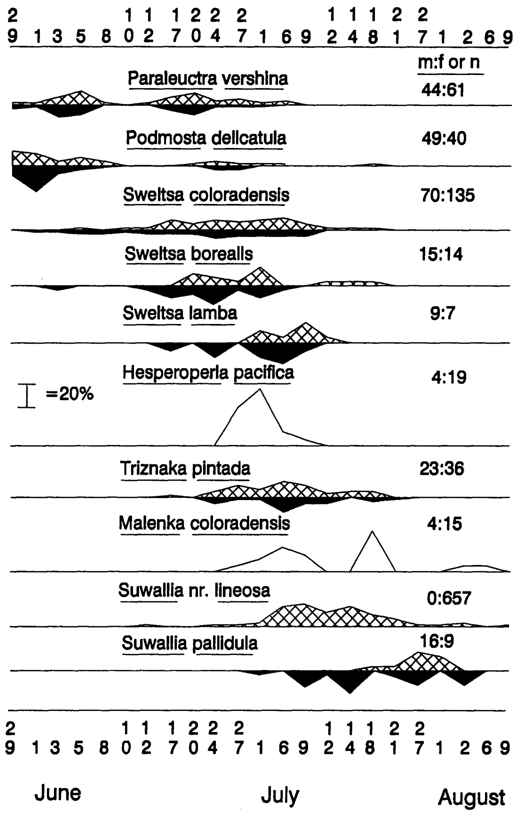

FIG. 4—Percentage catch of adult stoneflies from Massey Gulch. Cross-hatched pattern = females, black = males. Empty polygons represent combined sexes. Sex ratios (male : female), or total individuals are provided.

added 13 new county records (Table 1) to bring the total to 22. Herrman et al. (1986) listed only 13 caddisfly species from the county. Fifteen new species records of caddisflies were added for this region (Table 1).

This small tributary was surprisingly diverse in comparison with previous studies on the altitudinal distribution of aquatic insects in Colorado (Dodds and Hisaw, 1925; Knight and Gaufin, 1966; Stanford and Ward, 1983; Ward, 1984, 1986). Species richness in these studies peaked in stream orders five and six in the cooler climates of central and northern Colorado. A lower order stream, roughly comparable to Massey Gulch contained less than 20 species of these three orders; however, many were not identified to species (Ward, 1986).

Extended emergence patterns were more prevalent in this stream than synchronous ones (Fig. 6A, B). Corbet (1964) proposed that synchrony of emergence may be tied to synchronous growth in immatures of aquatic insects. Those that matured before winter may emerge more synchronously than species with less synchronous development. This may be the case for *O. minutus* and *Rhyacophila pellisa* Ross (Fig. 6B). Unfortunately, no growth data exist for these species. Life history and larval growth studies are needed to correlate the relationships of larval development, physical conditions, and synchrony of emergence.

The synchrony of aquatic insect emergence patterns has often been based on the subjective assignment of species to a synchrony based on various vague criteria such as 90% emergence within a "few" days (Harper and Pilon, 1970), or by simple inspection of curves (Masteller and Flint, 1980; Masteller, 1983). We have attempted to alleviate the subjective nature of this analysis by the use of simple linear regression to describe synchrony patterns. Inspection of the range of slope, given a significant model, should yield a more objective classification. Although this method is not foolproof, it does give a standardized measure. Caution must be taken in interpreting

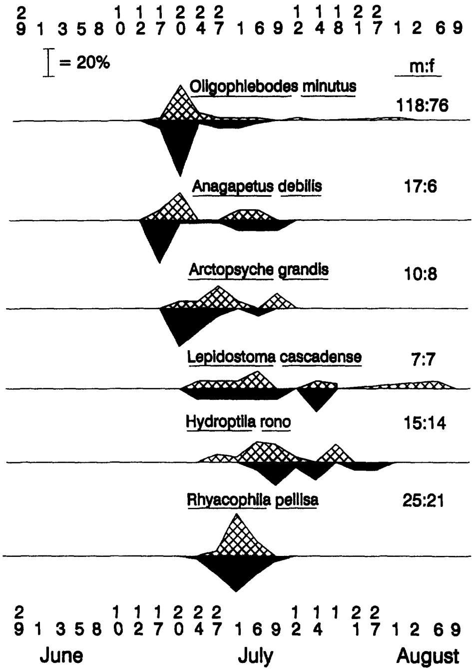

FIG. 5—Percentage catch of adult caddisflies from Massey Gulch. Cross-hatched pattern = females, black = males. Sex ratios (male : female) are listed for each species.

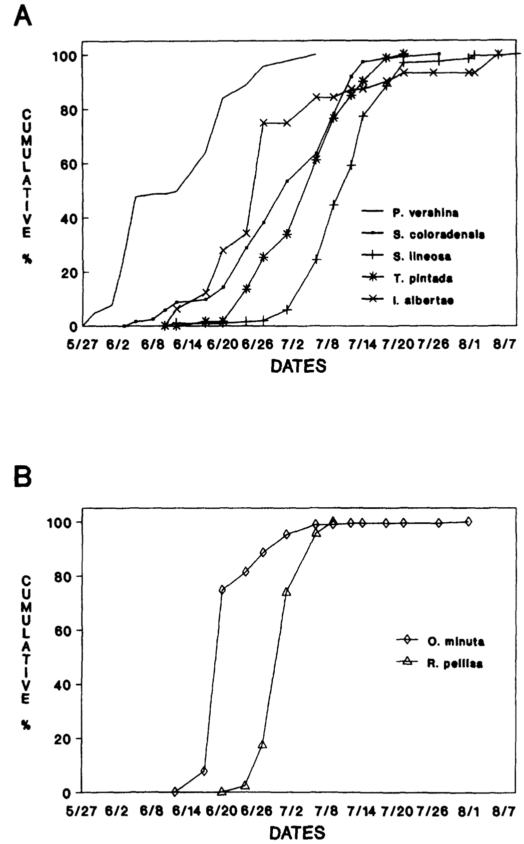

FIG. 6—A) Cumulative percentage emergence for several extended emerging stoneflies and one mayfly species. B) Synchronous emerging caddisflies of Massey Gulch.

emergence curves without additional life history information and with single-year data, since year and trap variance may be great (Harper and Pilon, 1970; Masteller and Flint, 1980; Masteller, 1983). However, in the present study, "patterns" and not quantitative features of emergence were used to describe synchrony; thus, year-to-year variation may be reduced since it is expected that qualitative features of synchrony are more robust than abundances. Analysis of synchrony using simple linear regression shows promise for the comparison of such year-to-year variation in emergence within species, possibly due to introduction of thermal effluents or yearly climate variation (DeWalt and Stewart, in press), or it may also be used to study pattern differences among species as was done here.

Sex ratios were roughly equivalent for most of

TABLE 2—Regression statistics and synchrony classification for seven species of aquatic insects from Massey Gulch. The last 10% of the emergence of *O. minutus* was truncated from the analysis in order to remove an extended component of an otherwise synchronous emergence pattern.

Species	Days	Slope	R^2	P	Synchrony
I. alberta	58	1.71	0.79	0.0001	extended
S. coloradensis	55	2.29	0.95	0.0001	extended
S. lineosa	61	2.18	0.89	0.0001	extended
T. pintada	40	3.10	0.96	0.0001	extended
P. vershina	41	2.70	0.93	0.0001	extended
O. minutus	32	4.2	0.76	0.0024	synchronous
R. pellisa	20	6.22	0.92	0.0024	synchronous

the 20 species presented in Figs. 3, 4, and 5, although some striking differences existed. *Suwallia* nr. *lineosa* had a sex ratio of 657 females. Sex-specific differences in emergence substrate preferentia, or adult behavior and habitat usage may explain this aberrant sex ratio. However, we expected some males to be caught with the combination of both emergence traps and sweepnetting. Parthenogenesis was another possibility, but no eggs were incubated to test this hypothesis. Parthenogenesis is an uncommon strategy among Plecoptera, but Harper (1973) provided some evidence for its occurrence in *Paragnetina media* (Walker).

It is apparent that more study of aquatic insects is needed in the small streams of southern Colorado and the Southwest in general. This area represents the southernmost extension of many cordilleran species. These species have adapted to the conditions of high summer air temperatures, a combination of low annual rainfall, spontaneous spring discharge from high-elevation snowmelt, and possibly a relatively high historical frequency of fire modification of watersheds. Further documentation of aquatic insect biodiversity and distribution within the southern Rocky Mountain region will also contribute to the efforts to reconstruct post-glacial dispersals relative to southwestern North America (Stewart et al., 1974; Sargent et al., 1991). This area of Colorado is relatively pristine with low tourism due to its great distance from large population centers. Our study contributes to a baseline against which future changes in species richness of the orders can be measured.

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