Bottorff, Richard L., Loren D. Bottorff, 2007. Phenology and diversity of adult stoneflies (Plecoptera) of a small coastal stream, California. *Illiesia*, 3(1):1-9. Available online: http://www2.pms-lj.si/illiesia/Illiesia03-01.pdf

PHENOLOGY AND DIVERSITY OF ADULT STONEFLIES (PLECOPTERA) OF A SMALL COASTAL STREAM, CALIFORNIA

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ABSTRACT

Collections of adult stoneflies over a full year at Irish Gulch Creek, Mendocino Co., California, revealed 23 species. Adults were present at all times of the year. Species number varied from an autumnal low of 2 to a spring peak of 13. Adults of most species were present for less than 3 months, but *Malenka depressa* adults were present year-round. *Hesperoperla hoguei* was the only strictly autumnal-emerging species. The report of *Suwallia dubia* from Irish Gulch Creek represents a new California record. The stonefly faunas of Irish Gulch Creek (low coastal) and Sagehen Creek (high Sierra Nevada) were compared. Both creeks had similar numbers of species, but the species composition differed greatly, reflecting dissimilar environments (elevation, water temperature, thermal accumulation, and discharge). Irish Gulch Creek had uniform warmer temperatures; Sagehen Creek had variable colder temperatures. Peak emergence at Irish Gulch Creek occurred 2 months earlier than at Sagehen Creek.

Keywords: Plecoptera, seasonal flight period, biodiversity, thermal stability, North Coast bioregion

INTRODUCTION

As might be expected from its varied topography, climate, and geologic history, California has a diverse assemblage of 177 stonefly species, 37% being endemic to the state (Jewett 1960; Stewart & Stark 2002). Stonefly larvae are especially abundant in the small-medium cool streams found throughout the state's mountain ranges and in portions of the Central Valley (Bottorff & Knight 1988, 1989). Only the most inhospitable streams (warm, heavily silted, tidally influenced, or polluted) lack stoneflies. Despite their overall richness and wide distribution in California, stonefly diversity in specific streams or bioregions of the state remains largely unstudied, and the life history and ecology of very few species are known. Sheldon and Jewett (1967) described the seasonal occurrence of stonefly adults at Sagehen Creek in the Sierra Nevada, but the applicability of their results to other areas of California is unknown. To determine the seasonal occurrence and diversity of stonefly adults in a completely different bioregion, we studied these aspects for a small stream on the north coast of California.

STUDY STREAM

This study was done at Irish Gulch Creek, a perennial second-order stream that discharges directly to the Pacific Ocean 6 km north of Manchester, Mendocino County, California. Over 95% of the 5.4 km^2 drainage basin (elevation range, 0-590 m) is densely covered by a second-growth forest of Coast Redwoods (*Sequoia sempervirens*), Douglas Fir (*Pseudotsuga menziesii*), and Grand Fir (*Abies grandis*); only a small part of the lower basin is low-density residential. The old-growth forest was first cut about 1900; a second cut occurred in the 1950s. Because the watershed has remained undisturbed and closed to public access for about 50 years, the basin and creek channel appear to be in an undisturbed condition, except for several old logging roads. As the creek approaches the ocean, the conifer forest gives way to dense riparian thickets of alder

(*Alnus rubra*) and willow (*Salix sitchensis*) that enclose and shade the creek year-round. The stream (1m wide, 10-40 cm deep) has a constant low base flow (<0.06 m^3/s) during the summer-autumn dry season and a variable higher discharge during the winter-spring rainy period (mean annual flow, 0.12 m^3/s). The natural flow regime closely follows seasonal precipitation (Fig. 1) and is not affected by a small municipal diversion (< 0.001 m^3/s). Essentially all precipitation occurs as winter-spring rains; very rarely, sparse snowfall briefly dusts the upper watershed. Air and water temperatures are remarkably uniform in the region (annual range, 6C°). The substrate is a mixture of gravel, pebbles, and cobbles. Native fishes include coastrange sculpin (*Cottus aleuticus*); unlike nearby larger streams, Irish Gulch Creek is too small to support anadromous salmon or steelhead (*Oncorhynchus*). Mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera) and dipteran flies (Diptera) compose most of the benthic macroinvertebrate community, in addition to dense populations of two crustaceans, the amphipod *Ramellogammarus ramellus* and the isopod *Gnorimosphaeroma*. Both crustaceans are unique faunal components of California's coastal streams and seldom occur far inland from the ocean.

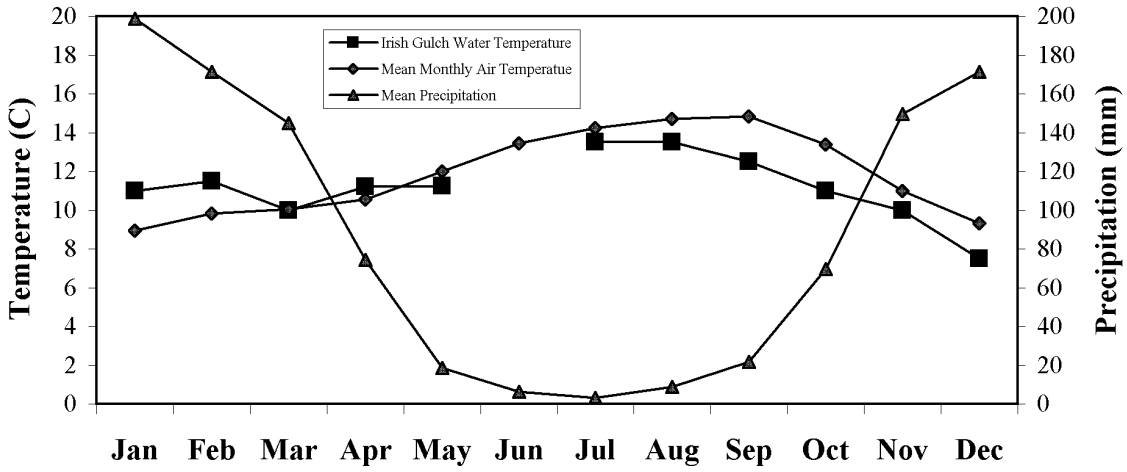

Fig. 1. Climatic conditions at Irish Gulch Creek, Mendocino Co., California. The data shown are (1) water temperatures of Irish Gulch Creek (July 2005-May 2006) and (2) mean monthly air temperatures and precipitation derived from 40 years of records (1948-1988) at the Point Arena weather station about 12 km south of Irish Gulch.

METHODS

We collected adult stoneflies approximately every two weeks for one year at one site on lower Irish Gulch Creek (latitude 39° 01.209'N, longitude 123° 41.268'W, elevation 5-11 m). In total, we made 26 field collections between 15 October 2004 and 30 September 2005 from the same 94 m sample reach using an insect beating net (0.6m square). Sample effort was the same on each collecting date. The sample site was surrounded by dense riparian vegetation and was located 73 m upstream from the high tide level of the ocean, which of course entirely lacked stoneflies. In addition, we continued to sample adult stoneflies less frequently at this site from 30 October 2005 until 16 September 2006 (18 field collections).

To monitor the emergence of larger stonefly species in such genera as *Calineuria, Hesperoperla, Kathroperla,* and *Pteronarcys*, we regularly searched the creek banks for shed exuviae of final instar larvae, a useful method after spring freshets had cleared away old skins. We also occasionally collected

stonefly larvae in the creek with a kick net to check whether the adult samples included all species present in the system.

RESULTS

We collected 23 stonefly species at the one collecting site on lower Irish Gulch Creek (Table 1), 22 species during the first year and 1 additional species during the second year. This assemblage represented 13% of California's entire stonefly fauna, a surprisingly large number of species considering the creek's small size, low elevation, immediate proximity to the ocean, and single location. Of the 9 families of North American stoneflies, 7 occurred in Irish Gulch Creek. No representatives of Perlodidae and Taeniopterygidae were found, even though both are known to occur in the region (Jewett 1960). Five stonefly species found at Irish Gulch Creek are uncommonly collected in California – *Hesperoperla hoguei, Kathroperla takhoma, Paraleuctra divisa, Suwallia dubia,* and *Sweltsa pisteri*. This is the first time that *Suwallia dubia* has been reported from California; previously it was known from Alaska, British Columbia, Washington, Idaho, Montana, and Oregon (Alexander & Stewart 1999).

Table 1. Stoneflies of lower Irish Gulch Creek

Capniidae
- *Capnia excavata* Claassen
- *Mesocapnia projecta* (Frison)

Leuctridae
- *Despaxia augusta* (Banks)
- *Moselia infuscata* (Claassen)
- *Paraleuctra divisa* (Hitchcock)
- *Paraleuctra occidentalis* (Banks)
- *Paralecutra vershina* Gaufin & Ricker

Nemouridae
- *Malenka californica* (Claassen)
- *Malenka cornuta* (Claassen)
- *Malenka depressa* (Banks)
- *Soyedina producta* (Claassen)
- *Zapada cinctipes* (Banks)
- *Zapada frigida* (Claassen)

Chloroperlidae
- *Alloperla delicata* Frison
- *Alloperla fraterna* Frison
- *Kathroperla takhoma* Stark & Surdick
- *Suwallia dubia* (Frison)
- *Sweltsa borealis* (Banks)
- *Sweltsa pisteri* Baumann & Bottorff

Peltoperlidae
- *Soliperla thyra* (Needham & Smith)

Perlidae
- *Calineuria californica* (Banks)
- *Hesperoperla hoguei* Baumann & Stark

Pteronarcyidae
- *Pteronarcys princeps* Banks

Typical of most streams in North America, a serial succession of stonefly adults occurred throughout the year in Irish Gulch Creek (Fig. 2). Adult stoneflies were present at all times of the year, but each species had its own seasonal pattern of occurrence as determined by larval growth patterns and environmental factors. Most species were present as adults for 1-3 months, though periods of maximum abundance often lasted only a few weeks. Adult phenology was very similar during the second year, except that most species started to emerge about 2-3 weeks earlier than in the first year. Warm rainstorms on 4-5 January 2006 increased creek temperatures from 8°C to 12°C; the thermal effects of these storms persisted in the runoff for at least the next month. We believe that warmer than normal water temperatures in January and February speeded the growth of stonefly larvae and caused earlier adult emergences.

Unexpectedly, *Malenka depressa* adults were collected year-round in Irish Gulch Creek, including both study years and all 44 sampling dates. They were most common during February-August (April-May peak) and sparse in September-January. Despite these seasonal changes in abundance, both male and female adults were always present and the abdomens of some females contained fully formed eggs during every month. Further, on any date, larval size and development spanned the full range from early to late instars. These observations imply that this species has an unusual pattern of continuous reproduction and oviposition. No previous life history studies of *M. depressa* have been published, and very little is known about any other *Malenka* species, except that adults have been collected in North America over a relatively long period from late-March into early fall (Stewart & Stark 2002). In the Rocky Mountains, most *M. californica* emerge in the autumn, but adults that originate from spring-water populations can be

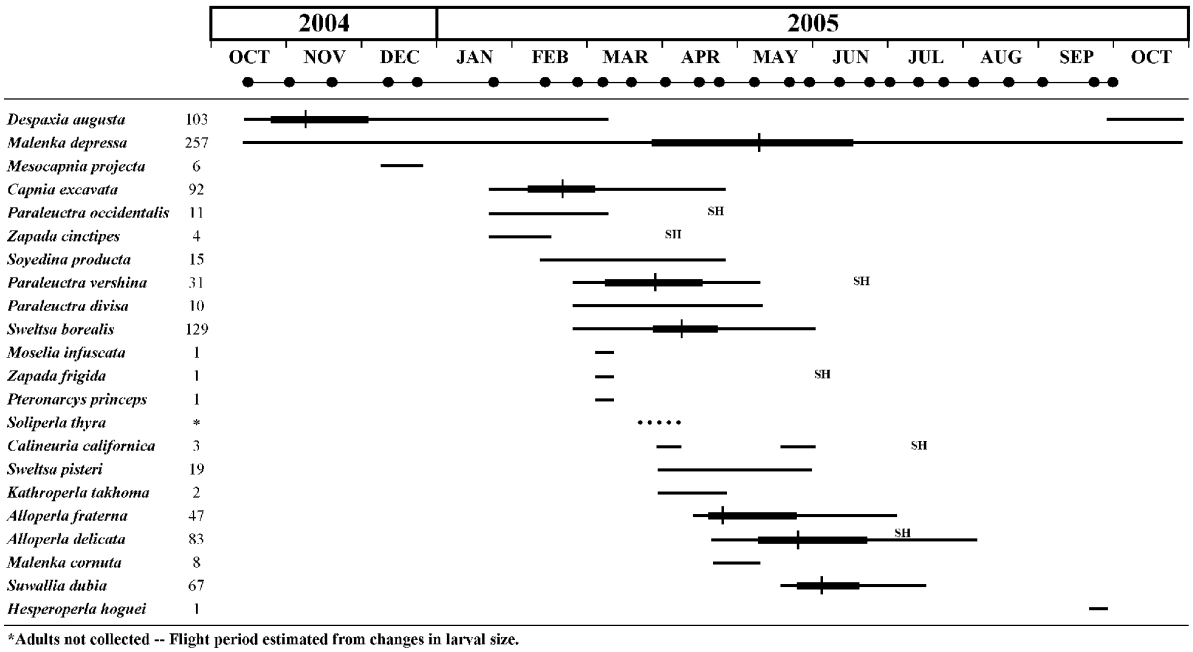

Fig. 2. Seasonal occurrence of adult stoneflies at Irish Gulch Creek, 2004-2005. The thin line shows the full range of occurrence. For more abundant species, the median occurrence (vertical line) and 25-75% range (heavy line) are indicated. Collecting dates are shown by bold dots; total specimens collected are given for each species. The presence of adult stoneflies at Sagehen Creek (SH), California are shown for 6 species (see text).

present from March to December (Baumann et al. 1977). Apparently, the uniform water temperatures found in spring streams and in Irish Gulch Creek lengthen the reproductive season and emergence of *Malenka* and some other stonefly species.

In contrast to the year-round presence of *M. depressa* in Irish Gulch Creek, *M. cornuta* adults occurred for only a brief 3-week period in April-May. The reasons for the vast difference in adult phenology of these two *Malenka* species are unknown. In addition to these two *Malenka* species, a single adult male of *M. californica* was collected at Irish Gulch Creek on 4 August 2006.

Despaxia augusta adults were most abundant during October-December in Irish Gulch Creek, but some individuals were collected for 5.5 months (September-March). Their presence throughout winter differed from previous reports that this is an autumnal species (July-October) in western North America, the exact timing being affected by elevation and latitude (Stewart & Stark 2002). Adults of this species have been collected in September-December from coastal environments in NW Oregon (Jewett 1959) and in July-December in the Rocky Mountains (Baumann et al. 1977).

Five stonefly genera in Irish Gulch Creek were represented by two or more species – *Alloperla, Malenka, Paraleuctra, Sweltsa,* and *Zapada*. These congeneric species displayed both temporal segregation and considerable overlap in their adult flight periods. Of the three *Paraleuctra* species, *P. occidentalis* occurred earliest in the year and was largely separated in time from *P. divisa* and *P. vershina,* both of which overlapped in their flight periods. The flight periods of *Z. cinctipes* and *Z. frigida* were separated by several weeks. In contrast, considerable overlap occurred in the presence of *S. borealis* and *S. pisteri,* and of *M. depressa*, *M. cornuta,* and *M. californica.* Likewise, the flight periods of *A. delicata* and *A. fraterna* coincided, but their peak abundances were separated by about one month.

The adult sex ratios of most stonefly species in Irish Gulch Creek varied similarly throughout their flight period. Typically, males predominated during

the early flight season and reached peak abundance before females, which often persisted for several weeks after the last males were collected. Sheldon & Jewett (1967) reported similar changes in the sex ratios of Sagehen Creek stoneflies.

Adult stonefly richness varied widely over the seasons in Irish Gulch Creek, from 2 species in autumn to 13 species in spring (Fig. 3). Relatively few species (≤ 4) were present from June to December, but species number began to increase in January until the peak was reached in March-April (12-13 species), after which richness rapidly declined in May-June. On any one collection date, from 2 to 11 species were present.

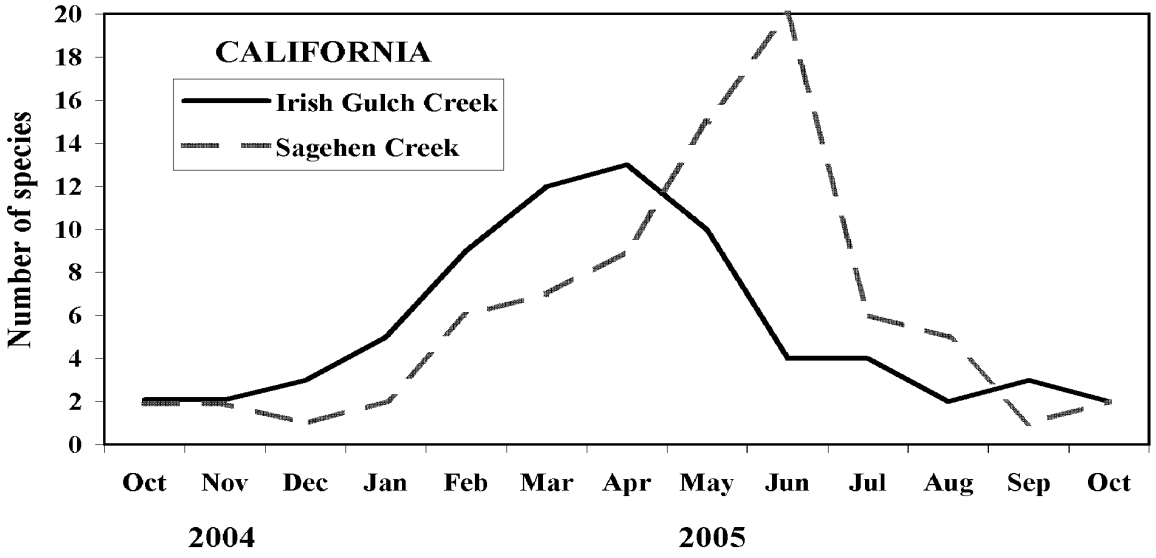

Fig. 3. Number of species of adult stoneflies present during each month in two small streams of California – Irish Gulch Creek (10 m elevation; Coast Range) and Sagehen Creek (1900 m elevation; Sierra Nevada).

We collected 4 stonefly species (*Moselia infuscata, Zapada frigida, Pteronarcys princeps,* and *Hesperoperla hoguei*) on only one date in the first year, but these taxa likely had somewhat longer flight periods than shown. Typically, both *M infuscata* and *Z. frigida* are reported to inhabit small seep habitats or streams higher in a watershed (Stewart & Stark 2002), rather than the downstream reaches. These two species apparently occurred in lower Irish Gulch Creek after spring freshets washed a few mature larvae downstream from higher sources. We checked this assumption by collecting adult stoneflies in the upper basin in April 2006 and found both species much more abundant upstream. We believe this washout phenomenon occurs in most California streams, attenuating the downstream distribution of stonefly species that predominate upstream.

The two large stoneflies, *Pteronarcys princeps* and *Hesperoperla hoguei,* were difficult to collect with a beating net, but larvae of both species were fairly common in the benthos of Irish Gulch Creek. Sheldon and Jewett (1967) also found it difficult to collect the adults of large stonefly species with a sweep net at Sagehen Creek. Emergence of *P. princeps* in Irish Gulch Creek was determined by collecting final instar exuviae in the first year (early March), but a single male adult collected on 7 April 2006 showed that it persists for at least a month. *Hesperoperla hoguei* was the only purely autumnal-emerging species in Irish Gulch Creek, a distinctly different pattern than the usual spring-summer emergence of all other Perlidae species in the state. We collected a single adult male of *H. hoguei* on 22 September 2005 and both sexes on 8-9 September 2006, similar flight times to those previously reported from California (Baumann & Stark 1980). Repeated attempts to collect this uncommon species only met with limited success, possibly because of its short emergence

period or use of microhabitats inefficiently sampled with beating nets.

We failed to collect *Soliperla thyra* adults, even though larvae were present in the creek. Its March-April emergence period was estimated by observing changes in larval size over several months.

Since it seemed unusual that the stonefly fauna of lower Irish Gulch Creek completely lacked Perlodidae and Taeniopterygidae species, we explored upstream for a distance of 3.2 km (to 240m elevation) from the lower collection site on three dates (7 April-13 May 2006). Despite intensive sampling of both adult and larval stoneflies, neither family was found. Yet, unexpectedly, this upstream search revealed three additional stonefly species for the Irish Gulch basin – *Perlomyia utahensis* Needham and Claassen, *Yoraperla siletz* Stark and Nelson, and *Zapada cordillera* (Baumann and Gaufin) – bringing the overall fauna to 26 species. Because the Irish Gulch basin is rather small, with only 4 km separating its ocean discharge on the west and extreme watershed boundary on the east, the stonefly fauna might be expected to be nearly the same throughout the drainage. Instead, the fauna differed over relatively short distances.

DISCUSSION

The stonefly fauna of Irish Gulch Creek clearly demonstrated the rich heritage of biodiversity found in California's streams. We consider it remarkable that 23 stonefly species occurred at one small collecting site, though possibly such richness may be common or exceeded at other California streams and in other bioregions. Unfortunately, with the exception of the research at Sagehen Creek (Sheldon & Jewett 1967), no previous published studies of stonefly diversity exist for California's streams. In fact, the high stonefly diversity of these streams is not well recognized in the state, even though these aquatic environments have been increasingly surveyed during the past decade using rapid bioassessment methods. These bioassessments are based on collections of the benthic macroinvertebrate community, which is largely composed of immature life stages that often cannot be identified to species level. As a result, such surveys do not fully measure the inherent richness of the stonefly fauna. The rapid bioassessment protocol for California streams, for example, would fail to identify more than 50% of the stonefly species in Irish Gulch Creek. Thus, studies of stonefly adults help to place the rapid bioassessments in proper context and reveal the true diversity present in the state's running waters.

Water temperature is an important environmental factor that controls the growth of stonefly nymphs and the seasonal progression of many life history features (Stewart & Stark 2002). Water temperatures in Irish Gulch Creek were remarkably stable on a daily, seasonal, and annual basis. This uniformity was caused by the stable air temperatures moderated by the nearby ocean and summer fog, the entry of groundwater that sustained the creek's base flow during wet and dry seasons, and heavy shading of the creek by dense riparian vegetation, incised stream banks, and the basin's aspect (Fig. 1). Mean monthly air temperatures for the region have a narrow annual range (8.9-14.8°C), and water temperatures in Irish Gulch Creek had a similar annual range (7.5-13.5°C). During the winter-spring rainy period, the creek's water temperature can be anywhere within its annual range depending upon the specific marine sources (polar or subtropical) of eastward moving storms. For example, winter-spring storms that originated in the warm sub-tropical regions of the Pacific Ocean produced warm water temperatures in Irish Gulch Creek in January 2006 that were similar to those of summer and autumn. In many respects, the stable water temperatures of Irish Gulch Creek are similar to those found in freshwater springs or spring streams. This thermal constancy appears to explain the extended presence of *Malenka depressa* and *Despaxia augusta* adults. Protracted flight periods have been reported for other nemourid stoneflies that inhabit thermally stable springs in Sweden (Brink 1949) and spring streams in Germany (Wolf & Zwick 1989).

Many California streams have relatively large and predictable thermal variations each year that directly affect stonefly larval growth and undoubtedly provide strong environmental cues for life cycle development (Bottorff 1990). In contrast, the small thermal variation in Irish Gulch Creek must be an unreliable seasonal indicator for its stoneflies. Nevertheless, the regular seasonal appearance and succession of stonefly adults each year suggests that other environmental signals, possibly photoperiod, are important in Irish Gulch Creek.

Besides stability, the water temperatures of Irish

Gulch Creek were always within, or close to, an optimal growth range for many stonefly species. That is, the growth of stonefly larvae was unlikely to be curtailed by temperatures that approach 0°C in winter or exceed 20-25°C in summer-autumn. Hence, it is doubtful that Irish Gulch stoneflies need egg or larval dormant stages to survive periods of extreme temperature, such as can occur in the small streams of other California bioregions.

The seasonal occurrence of adult stoneflies has been published for only one other California location, Sagehen Creek in the northern Sierra Nevada (Sheldon & Jewett 1967). Both Sagehen and Irish Gulch creeks are located at the same latitude (39°N), but are separated by 300 km and occur in two different bioregions (the Sierra and Klamath/North Coast, respectively). Sagehen Creek lies at high elevation (1900 m) on California's eastern edge; the Irish Gulch study site lies near sea level (10 m) on the state's western edge (Table 2). Both creeks are influenced by the same weather systems that move inland from the Pacific Ocean and receive similar quantities of monthly and annual precipitation. Yet, the Sagehen watershed has a deep winter snow pack (mean snow depths in January-March are about 1m) and winter water temperatures near 0°C for 4 months, whereas Irish Gulch only receives rainfall and maintains winter water temperatures well above 5°C. As a consequence, peak flows in Sagehen Creek occur at spring snowmelt (April-June), followed by low flows in summer, autumn, and winter, while the flow regime of Irish Gulch Creek closely follows the pattern of seasonal precipitation (Fig. 1). The Sagehen region has a continental climate, low mean annual air temperature (5.2°C), and wide annual range of air temperatures (17.6°C); the Irish Gulch region has a maritime climate, higher mean annual air temperature (11.8°C), and narrow annual range of air temperatures (5.9°C). The annual thermal accumulation (degree-days above 0°C) of Sagehen Creek was roughly half that of Irish Gulch Creek (Table 2).

Table 2. Comparison of Irish Gulch and Sagehen creeks, California.

	Irish Gulch Creek	Sagehen Creek
Number of stonefly species	23	31
California Bioregion	Klamath/North Coast	Sierra
Elevation (m)	10	1,900
Stream order	2	3
Study reach (m)	94	800
Drainage basin area (km^2)	5.4	27.2
Precipitation (mm)	1,038	844
Winter snow pack	None	December-April
Mean annual air temperature (°C)	11.8	5.2
Annual range of mean monthly air temperatures (°C)	8.9 - 14.8	-3.1 - 14.5
Annual range of water temperatures (°C)	7.5 - 13.5	0 - 18.0
Annual degree-days (°C - days above 0°C)	4,100	2,100
Mean annual discharge (m^3/s)	0.12	0.35
Peak discharge	January	May
Latitude	39° 01.209′ N	39° 25.900' N
Longitude	123° 41.268′ W	120° 14.217' W

Because of the strikingly different water temperatures and flows of Sagehen and Irish Gulch creeks, the respective stonefly faunas might be expected to be dissimilar. Of the 47 species of stoneflies found at Sagehen and Irish Gulch creeks combined, they shared only 7 species, all being widely distributed in western North America – *Alloperla delicata, Calineuria californica, Malenka californica, Paraleuctra occidentalis, Paraleuctra vershina, Zapada cinctipes,* and *Zapada frigida*. Thus, Sagehen Creek had 24 unique species; Irish Gulch Creek had 16 unique species. Representatives of all 9 North American stonefly families occurred in the Sagehen fauna, but only 7 families occurred in the Irish Gulch fauna. A particularly noticeable difference between the two faunas was the diverse assemblage of Perlodidae (7 species) in Sagehen Creek and the complete absence of this family from Irish Gulch Creek. Despite the different faunas, the total number of stonefly species recorded from each creek was similar, 31 species at Sagehen Creek and 23 species at Irish Gulch Creek (or 26 if the upstream species are included). Sagehen Creek apparently had slightly more stonefly species because it had (1) a higher stream order (3 vs. 2), (2) a larger watershed area (27.2 km^2 vs. 5.4 km^2), (3) larger seasonal variations in water temperature, and (4) a longer collection reach (800 m vs. 94 m).

Adult stoneflies were present at all times of the year at both Sagehen and Irish Gulch creeks, but each species had its own shorter period of occurrence, usually of 3 months or less. No Sagehen species had an extended presence as was recorded for *Malenka depressa* at Irish Gulch. The number of adult stonefly species varied seasonally in both creeks, but peak richness was reached in different months (Fig. 3). In Sagehen Creek, adults of few species (≤ 2) occurred during September-January, but species number began increasing in February and continued through the spring until a peak (20 species) was reached in June, after which adult richness rapidly declined in July-August. Irish Gulch Creek had a similar variation in adult stonefly richness, except that the whole pattern was shifted about 2 months earlier and the peak (13 species) occurred in April (Fig. 3). Adult species richness was low in both creeks during September-December.

Of the 7 species common to both creeks, adults were typically present at Sagehen Creek 2-3 months after they occurred at Irish Gulch Creek (Fig. 2). Because each creek had its own pattern and magnitude of thermal accumulation, substantial differences must exist in the growth and life histories of these 7 common species, with some possibly needing an extra year to complete their life cycle in Sagehen Creek.

In summary, the distinct differences in species occurrences and seasonal changes in adult stonefly diversity between the two creeks appear to be controlled by their unique thermal regimes – variable colder temperatures in Sagehen Creek that delayed stonefly emergence, and uniform warmer temperatures in Irish Gulch Creek that advanced stonefly emergence. Clearly, the stonefly faunas of small streams in the Klamath/North Coast and Sierra bioregions are dissimilar and reflect very different aquatic environments.

ACKNOWLEDGMENTS

We thank Richard W. Baumann and Bill P. Stark for data on California's stonefly distributions and personnel of the museum in Elk, California, for information about the historic logging eras in the Irish Gulch watershed.

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Received 19 Januar 2007, Accepted 19 Februar 2007, Published 9 March 2007