# High Aquatic Biodiversity in an Intermittent Coastal Headwater Stream at Golden Gate National Recreation Area, California

**ARTICLE** *in* NORTHWEST SCIENCE · MAY 2015

Impact Factor: 0.97 · DOI: 10.3955/046.089.0211



Michael Bogan
University of California, Berkeley



Jason L Hwan
University of California, Berkeley

# Northwest Science Notes

*The purpose of Notes is to publish papers typically five to eight pages long. No specific format or content is required for articles published as Notes, but all will be peer-reviewed and must be scientifically credible. Authors may contact the Editor about the suitability of manuscripts for this section.*

**Michael T. Bogan**[1], **Jason L. Hwan**, and **Stephanie M. Carlson,** Department of Environmental Science, Policy, and Management, 130 Mulford Hall #3114, University of California, Berkeley, California 94720-3114

## High Aquatic Biodiversity in an Intermittent Coastal Headwater Stream at Golden Gate National Recreation Area, California

### Abstract

Headwater and intermittent streams have traditionally been considered less biologically diverse than downstream perennial reaches. However, recent studies have highlighted the significant role that headwaters play in supporting regional aquatic biodiversity. Additionally, intermittent streams in the Pacific Northwest may be more diverse than similar streams in other regions. Here, we present a four-year biodiversity study of the John West Fork, an intermittent coastal headwater stream in northern California. It only flows for 5-7 months each year, but supports residual perennial pools during the summer dry season. Our goals are to describe the physical and biological settings of the John West Fork, document its aquatic biodiversity, and promote the use of it and similar streams as study systems. From 2009 to 2012, we sampled fish and invertebrates in riffles and pools during early summer (June) and in residual pools during late summer (late September/early October). We documented four vertebrate species (steelhead trout, coho salmon, California giant salamander, and Pacific chorus frog) and 159 aquatic invertebrate taxa. Steelhead trout were common each year, but coho salmon were present only in 2010 and 2011. Most invertebrate taxa were tolerant of stagnant pool conditions; only nine taxa were exclusive to flowing riffle habitats. Intermittent headwater streams similar to John West Fork are numerous along the west coast of North America. This great number of replicate systems and their tractability make them ideal for ecological studies, and their high biodiversity makes them deserving of consideration in local and regional conservation planning.

**Keywords**: temporary flow, salmon, aquatic invertebrates, drought, drying disturbance

### Introduction

First-order headwater streams have traditionally been considered less biologically diverse than larger downstream reaches (e.g., Vannote et al. 1980). However, in recent years researchers have highlighted the significant role headwaters can play in supporting regional aquatic biodiversity (Meyer et al. 2007, Clarke et al. 2008, Finn et al. 2011). Similarly, intermittent streams (i.e., those that cease flowing during some portion of the year) were understudied and underappreciated until recent years, despite making up a large percentage of total stream length worldwide (Larned et al. 2010, Datry et al. 2014). While many of the recent studies of intermittent streams have focused on higher-order reaches (e.g., 3rd or 4th order intermittent streams), intermittent headwaters have received less attention.

Intermittent headwater streams are numerous along the west coast of North America. While some regional studies suggest that seasonal flow cessation in these streams reduces the diversity of aquatic invertebrates (del Rosario and Resh 2000), others

[1] Author to whom correspondence should be addressed.
Email: michaelthomasbogan@gmail.com

have reported similar levels of aquatic invertebrate diversity, productivity, and/or biomass between intermittent and perennial headwaters (Progar and Moldenke 2002, Price et al. 2003, Banks et al. 2007). Intermittent headwaters across the region may also provide important habitat for endangered coho salmon (*Oncorhynchus kisutch*) and other salmonid fishes, especially when residual stream pools persist after flow ceases (Wigington et al. 2006). Understanding the roles that intermittent coastal headwaters play in supporting regional biodiversity and salmonid stocks is especially important given the looming threats of climate change and increased anthropogenic water withdrawals (Grantham et al. 2012, Katz et al. 2013, Wainwright and Weitkamp 2013).

We conducted a four-year study of invertebrate and fish community dynamics in one intermittent coastal headwater stream, the John West Fork, located in the Golden Gate National Recreation Area, California. The John West Fork is one of hundreds of similarly-sized intermittent headwater streams (drainage area < 5 $km^2$) along the coast of western North America. Our goals here are to (1) describe the physical and biological settings of the John West Fork, (2) document the aquatic biodiversity we recorded over the study period, and (3) promote the use of coastal intermittent headwater streams like the John West Fork as study systems.

## Study Area

John West Fork (37.99° N, 122.75° W) is a small (3.1 $km^2$ drainage area), short (3 km in length) first-order stream in Golden Gate National Recreation Area, Marin County, California (Figure 1). It is a headwater tributary to Olema Creek, which flows through Point Reyes National Seashore for approximately 16 km before joining Lagunitas Creek just before its entry into the Pacific Ocean at Tomales Bay. The lower 1.5 km of John West Fork, where most of the biological sampling occurred, is relatively low gradient (average slope: 2.5%) and has a riffle-pool sequence channel morphology. In contrast, the upper half of the stream is much steeper (average slope: 11.6%), has a cascade-pool channel, and consists of two forks draining the Bolinas Ridge.

Average annual rainfall at the nearest long-term NOAA/NWS rainfall gauge (18 km away: Kentfield #044500) is 94 cm, but varies greatly among seasons and years. More than 83% of average annual rainfall occurs between November and March, and yearly rainfall totals range from 48 cm to 233 cm. Annual rainfall totals during our four study years were 68 cm (2009), 89 cm (2010), 113 cm (2011), and 72 cm (2012). This rainfall variability produces similar variability in flow at John West Fork. During high flow periods, the entire 3 km of stream can be connected and flowing. In general, however, John West Fork flows only between late November and late May or early June, and supports isolated pools the rest of the year. Some pools persist through dry years (perennial pools), while others begin to dry when flow ceases in May or June and dry completely before the end of the summer (seasonal pools). The exact timing of wet season flow and number of remnant pools during the dry season, however, depends on antecedent winter precipitation. For example, due to extreme drought conditions in 2013-2014, flow did not resume at the John West Fork until 8 Feb 2014, prior to which wetted habitat in the entire basin had contracted to less than 150 small stream pools and seeps in scattered isolated reaches (Figure 1). The nearest perennially-flowing stream reach is 1.4 km downstream of the junction of John West Fork and Olema Creek, where a spring-fed tributary enters Olema Creek.

Though its flow is intermittent, John West Fork has a dense riparian forest (spherical densiometer mean in stream channel: 93%; range: 76-100%). Canopy tree species include, in descending order of dominance, California bay (*Umbellularia californica*), willow (*Salix* spp.), big-leaf maple (*Acer macrophyllum*), Douglas-fir (*Pseudotsuga menziesii*), coast live oak (*Quercus agrifolia*), and red alder (*Alnus rubra*). The understory is composed of a mix of shrubs and herbaceous plants, including California hazelnut (*Corylus cornuta* var. *californica*), bitter cherry (*Prunus emarginata*), poison oak (*Toxicodendron diversilobum*), stinging nettle (*Urtica* sp.), horsetail (*Equisetum* sp.), and ferns. In part due to this dense riparian cover, water temperatures in the perennial pools that persist after flow ceases remain relatively cool

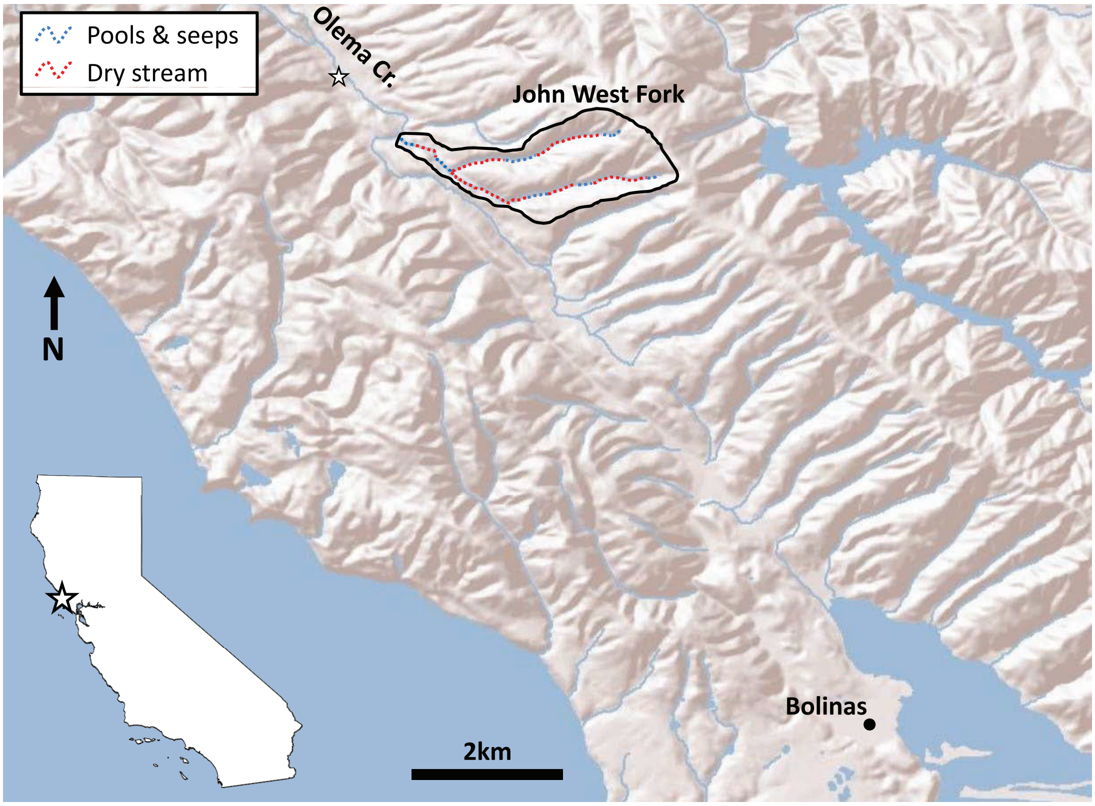


Figure 1. Map of the John West Fork and surrounding area. The extent of the John West Fork drainage basin is marked by the solid black line. The dashed lines within the basin show the distribution of dry reaches (red dashed lines) and reaches with pools or seeps (blue dashed lines) during drought (mapped on 26 Jan 2014). The white star marks the nearest perennial flow, 1.4 km downstream of the junction of John West Fork and Olema Creek, where a spring-fed tributary enters Olema Creek. The San Andreas Fault runs northwest-southeast through the area, creating a number of similar-sized replicate headwater streams.

during the summer dry season. Water temperature loggers (HOBO Pendant UA-002-64, Onset Computer Corporation, Bourne, MA) placed in 28 study pools during the dry season (June to October, from 2009 to 2012) reported an overall mean water temperature of 14.3 °C, with little variability through time except in seasonal pools immediately preceding drying. The maximum water temperature recorded in any stream pool over the study period was 22.8 °C.

## Methods

Biological sampling was confined to the lowest 1 km of John West Fork, between the confluence of its two headwater forks and its confluence with Olema Creek (Figure 1). We studied 12 riffle-pool sequences in 2009, and then expanded our study to include 28 riffle-pool sequences from 2010 to 2012. Each year, we surveyed for fishes during the early and late summer (June and late September/early October, respectively) using three-pass depletion electrofishing in each of our study pools and riffles. In 2012, we also captured fish using seining techniques every three weeks between our two electrofishing samples. We walked the entire study reach during each visit and conducted visual surveys for other aquatic vertebrates (e.g., salamanders) that were not detected during electrofishing. We sampled aquatic invertebrates by collecting a single, randomly-located, Surber sample (area: 900 $cm^2$; mesh size: 500 μm) in each of the study pools and riffles present in early and late summer each year. While Surber samples may underestimate the diversity of taxa that swim in open water (e.g., Dytiscidae, Notonectidae), supplemental sampling of these habitats with a D-frame net suggested that free swimming taxa were uncommon at John West Fork. In 2012, additional Surber samples were collected from each pool every three weeks between the early summer sampling event in June and the late summer sampling event in early October. Samples were preserved in 95% ethanol and transported to UC Berkeley for identification. A random subset of samples from five perennial pools, five seasonal pools (wetted in June, dry by September), and the ten intermittent riffles adjacent to these pools (flowing in June, dry in September) were selected for invertebrate identification and enumeration. Our goals here are to document species occurrences in the study system and discuss their temporal trends over the study period.

## Results

Four species of aquatic or semi-aquatic vertebrates were recorded from John West Fork over the study period. The vertebrate taxa included steelhead trout, (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), California giant salamander (*Dicamptodon ensatus*), and Pacific chorus frog (*Pseudacris regilla*). Steelhead were present in moderate numbers in the 12 study pools in 2009, but were abundant across the study pools in 2010, 2011, and 2012. Coho salmon were absent in 2009, rare in 2010 (4 individuals detected), abundant in 2011, and absent in 2012. One California giant salamander neonate was found each year between 2009 and 2011, and 2 neonates were found on each of two sampling dates in 2012 (4 found in total). Pacific chorus frogs were seen infrequently over the entire study period, and one male was heard making a territorial call in 2012, but no breeding was documented in John West Fork pools.

One hundred and fifty-nine taxa of aquatic invertebrates were recorded from the subsample of five perennial pools, five seasonal pools, and 10 associated riffles over the study period (Table 1). The total number of invertebrate taxa recorded from early and late summer samples was similar in each year (99 in 2009, 105 in 2010, 103 in 2011, and 114 in 2012), though the extra sampling effort in 2012 yielded 16 additional taxa not found in early and late summer samples (130 taxa total detected in 2012). The ten most abundant taxa across all samples were the mayflies *Paraleptophlebia*, *Leucrocuta*, and *Centroptilum*, the caddisfly *Lepidostoma*, the midges *Paramerina*, *Micropsectra*, and *Tanytarsus*, the stonefly *Malenka californica*, Copepoda, and Oligochaeta. Nearly all invertebrate taxa were encountered in perennial and seasonal pools at some point during the study period. Only 9 of the 159 taxa were exclusive to riffles, and each of these taxa was represented by only one or two individuals across all years (the mayflies *Epeorus* and *Ironodes*, the caddisflies *Helicopsyche* and *Neothremma*, the stoneflies *Hesperoperla* and *Yoraperla*, the beetles *Helichus* and *Optioservus divergens*, and the midge *Eukiefferiella brehmi* group). Though signal crayfish (*Pacifastacus leniusculus*) were not collected in Surber samples in any year, three individuals were observed during visual surveys of the study reach in 2011 (2) and 2012 (1).

## Discussion

Intermittent and first-order headwater streams are often thought to support relatively low diversity aquatic communities (e.g., Vannote et al. 1980, Datry et al. 2014). However, we found that John West Fork, an intermittent headwater stream, supported a rich aquatic invertebrate community and robust populations of imperiled salmonids. These observations, along with those from several other studies along the west coast of North America (e.g., Progar and Moldenke 2002, Price et al. 2003, Banks et al. 2007), indicate that intermittent headwater streams in the region are indeed important sources of biodiversity. In fact, Dieterich and Anderson (2000) reported higher aquatic invertebrate diversity in "summer-dry" headwater streams of Oregon than in neighboring perennial headwaters.

Relatively long periods of continuous flow (4-7 months/year) and dense forest cover, with resultant cooler water temperatures in residual pools during the dry season, may partially explain

TABLE 1. Aquatic invertebrate taxa detected across the four sampling years at John West Fork.

| CLASS | ORDER | FAMILY | GENUS/SPECIES | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| Insecta | Coleoptera | Dryopidae | *Helichus* | | | | x |
| | | Dytiscidae | *Agabus* | x | x | x | x |
| | | | *Oreodytes picturatus* | x | | | |
| | | | *Sanfilippodytes* | x | x | | |
| | | | Hydroporinae (undet.) | x | x | x | x |
| | | Elmidae | *Narpus* | x | x | x | x |
| | | | *Optioservus divergens* | | | | x |
| | | | *Optioservus quadrimaculatus* | x | x | x | x |
| | | | *Optioservus* (undet.) | | x | x | x |
| | | | *Zaitzevia* | | | x | x |
| | | Gyrinidae | *Gyrinus* | | | | x |
| | | Hydraenidae | *Hydraena* | | | | x |
| | | Hydrophilidae | *Cymbiodyta* | | | | x |
| | | | Hydrophilidae (undet.) | | x | | |
| | | Psephenidae | *Eubrianax* | x | x | x | x |
| | | Scirtidae | Scirtidae (undet.) | | | x | x |
| | Diptera | Ceratopogonidae | *Atrichopogon* | | x | x | x |
| | | | *Bezzia* | x | x | x | x |
| | | Chaoboridae | *Chaoborus* | | x | | |
| | | Chironomidae | *Apedilum* | | | | x |
| | | | *Apsectrotanypus* | x | x | x | x |
| | | | *Boreochlus* | | | x | x |
| | | | *Brillia* | x | x | x | x |
| | | | *Chironomus* | x | | x | x |
| | | | *Corynoneura* | x | x | x | x |
| | | | *Cricotopus* | | x | x | |
| | | | *Eukiefferiella brehmi* grp. | | | x | |
| | | | *Eukiefferiella claripennis* grp. | x | x | x | x |
| | | | *Heleniella* | x | x | x | x |
| | | | *Heterotrissocladius marcidus* grp. | x | x | x | x |
| | | | *Krenopelopia* | | | | x |
| | | | *Krenosmittia* | x | x | x | x |
| | | | *Larsia* | | x | | |
| | | | *Limnophyes* | | | x | x |
| | | | *Micropsectra* | x | x | x | x |
| | | | *Microtendipes rydalensis* grp. | x | x | x | x |
| | | | *Nanocladius balticus* grp. | x | x | x | x |
| | | | *Parachaetocladius* | | x | x | |
| | | | *Paracladopelma* | x | | | x |
| | | | *Paramerina* | x | x | x | x |
| | | | *Parametriocnemus* | | x | x | x |
| | | | *Paratanytarsus* | x | | x | x |
| | | | *Phaenopsectra* | x | x | x | x |
| | | | *Polypedilum laetum* grp. | x | x | x | x |
| | | | *Polypedilum scalaenum* grp. | x | x | x | x |

TABLE 1, Continued.

| CLASS | ORDER | FAMILY | GENUS/SPECIES | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| | | | *Psectrocladius* | x | | | x |
| | | | *Pseudosmittia* | x | | x | |
| | | | *Rheocricotopus* | x | x | x | x |
| | | | *Rheotanytarsus* | x | x | x | x |
| | | | *Smittia* | | | | x |
| | | | *Stempellinella* | x | x | x | x |
| | | | *Synorthocladius* | x | x | x | x |
| | | | *Tanytarsus* | x | x | x | x |
| | | | *Thienemanniella xena* grp. | | x | | x |
| | | | *Thienemannimyia* grp. | | x | x | x |
| | | | *Tvetenia bavarica* grp. | x | x | x | x |
| | | | *Zavrelia* | | | | x |
| | | Culicidae | *Culex* | x | | | |
| | | | *Culiseta* | | | | x |
| | | Dixidae | *Dixa* | x | x | x | x |
| | | | *Dixella* | x | x | x | x |
| | | | *Meringodixa* | x | | | x |
| | | Dolichopodidae | Dolichopodidae (undet.) | x | | | |
| | | Empididae | *Clinocera* | x | x | | |
| | | | *Neoplasta* | x | x | x | x |
| | | | *Trichoclinocera* | x | x | x | x |
| | | | Empididae (undet.) | | x | | |
| | | Ephydridae | Ephydridae (undet.) | x | | | x |
| | | Pelecorhynchidae | *Glutops* | | | | x |
| | | Psychodidae | *Maurina* | | | x | x |
| | | | *Pericoma* | | | | x |
| | | Simuliidae | *Simulium* | | x | x | |
| | | Stratiomyidae | *Caloparyphus* | x | | | x |
| | | Tipulidae | *Dicranota* | x | x | x | x |
| | | | *Hexatoma* | x | x | x | x |
| | | | *Limnophila* | | | x | x |
| | | | *Rhabdomastix* | x | x | x | x |
| | | | *Tipula* | | x | | |
| | Ephemeroptera | Ameletidae | *Ameletus* | | x | | |
| | | Baetidae | *Baetis* | x | x | x | x |
| | | | *Callibaetis* | | | | x |
| | | | *Centroptilum* | x | x | x | x |
| | | | *Diphetor* | x | x | x | x |
| | | Ephemerellidae | *Drunella flavilinea* | x | x | x | x |
| | | Heptageniidae | *Epeorus* | | x | | |
| | | | *Ironodes* | | x | | |
| | | | *Leucrocuta* | x | x | x | x |
| | | Leptohyphidae | *Tricorythodes* | x | | | x |
| | | Leptophlebiidae | *Paraleptophlebia* | x | x | x | x |

TABLE 1, Continued.

| CLASS | ORDER | FAMILY | GENUS/SPECIES | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| | Hemiptera | Gerridae | *Aquarius remigis* | x | x | x | x |
| | | Macroveliidae | *Macrovelia horni* | x | | | |
| | | Notonectidae | *Notonecta kirbyi* | | | x | x |
| | | Veliidae | *Microvelia* | x | x | x | x |
| | Megaloptera | Sialidae | *Sialis* | x | x | x | x |
| | Odonata | Aeshnidae | Aeshnidae (undet.) | | | | x |
| | | Coenagrionidae | *Argia* | x | | | |
| | | Cordulegastridae | *Cordulegaster dorsalis* | x | | | x |
| | | Gomphidae | *Octogomphus specularis* | | x | | x |
| | Plecoptera | Capniidae | *Mesocapnia projecta* | x | x | x | x |
| | | Chloroperlidae | *Suwallia* | x | x | x | x |
| | | | *Sweltsa* | x | x | x | x |
| | | Leuctridae | *Despaxia* | | x | x | x |
| | | Nemouridae | *Malenka californica* | x | x | x | x |
| | | | *Soyedina* | | | | x |
| | | | *Zapada* | x | | | |
| | | Peltoperlidae | *Yoraperla* | | x | | |
| | | Perlidae | *Calineuria* | x | x | x | x |
| | | | *Hesperoperla* | | | | x |
| | | Perlodidae | *Isoperla* | | x | x | |
| | Trichoptera | Apataniidae | *Apatania* | x | x | x | x |
| | | Brachycentridae | *Micrasema* | | x | x | x |
| | | Calamoceratidae | *Heteroplectron californicum* | x | x | x | x |
| | | Glossosomatidae | *Agapetus* | | | x | |
| | | | *Glossosoma* | x | x | x | x |
| | | Helicopsychidae | *Helicopsyche* | | | | x |
| | | Hydropsychidae | Hydropsychinae | | x | x | x |
| | | Lepidostomatidae | *Lepidostoma* sp. | x | x | x | x |
| | | | *Lepidostoma unicolor* grp. | x | x | x | x |
| | | Limnephilidae | *Ecclisomyia* | | | x | x |
| | | | *Hydatophylax hesperus* | | | | x |
| | | | *Onocosmoecus* | | x | x | x |
| | | | *Psychoglypha* | x | x | x | x |
| | | Odontoceridae | *Parthinia* | | | | x |
| | | Polycentropodidae | *Polycentropus* | x | x | x | x |
| | | Rhyacophilidae | *Rhyacophila betteni* grp. | | x | x | x |
| | | | *Rhyacophila grandis* grp. | | x | x | |
| | | | *Rhyacophila siberica* grp. | x | x | x | x |
| | | Sericostomatidae | *Gumaga* | x | x | x | x |
| | | Uenoidae | *Neophylax rickeri* | x | x | x | x |
| | | | *Neothremma* | | | x | x |
| Acari | Hydrachnidia | Arrenuridae | *Arrenurus* | x | | | x |
| | | Aturidae | *Aturus* | x | | | |
| | | Axonopsidae | *Ljania* | x | x | x | x |

TABLE 1, Continued.

| CLASS | ORDER | FAMILY | GENUS/SPECIES | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|
| | | Hydrozetidae | *Hydrozetes* | x | x | x | x |
| | | Hygrobatidae | *Hygrobates* | x | x | x | x |
| | | | *Mesobates* | x | x | x | x |
| | | Lebertiidae | *Estelloxus* | x | x | | x |
| | | | *Lebertia* | x | x | x | x |
| | | Mideopsidae | *Mideopsis* | x | x | x | x |
| | | Sperchonidae | *Sperchon* | x | x | | x |
| | | Stygothrombiidae | *Stygothrombium* | | x | x | x |
| | | Torrenticolidae | *Torrenticola* | x | x | x | x |
| | | Trhypochthoniidae | *Mucronothrus* | x | x | x | x |
| Bivalva | Veneroida | Sphaeriidae | *Pisidium* | x | x | x | x |
| Branchiopoda | Cladocera | Cladocera | Cladocera (undet.) | x | | | |
| Entognatha | Collembola | Collembola | Collembola (undet.) | x | x | x | x |
| Gastropoda | Basommatophora | Physidae | Physidae (undet.) | x | x | x | x |
| | | Planorbidae | *Ferrissia* | | x | | |
| | | | Planorbidae (undet.) | x | | x | x |
| Hydrozoa | Anthoathecata | Hydridae | *Hydra* | x | x | | x |
| Malacostraca | Amphipoda | Gammaridae | *Gammarus* | x | | x | x |
| | Decapoda | Astacidae | *Pacifastacus leniusculus* | | | x | x |
| | Isopoda | | Isopoda (undet.) | | | | x |
| Maxillopoda | Copepoda | | Copepoda (undet.) | x | x | x | x |
| Nematoda | | | Nematoda (undet.) | | x | | x |
| Nematomorpha | | | Nematomorpha (undet.) | x | | | x |
| Oligochaeta | | Lumbricidae | Lumbricidae (undet.) | x | x | x | x |
| | | Lumbriculidae | Lumbriculidae (undet.) | x | x | x | x |
| Ostracoda | | | Ostracoda (undet.) | x | x | x | x |

this surprisingly high diversity (Dieterich and Anderson 2000, Banks et al. 2007). In contrast, intermittent first-order desert streams of Arizona, which experience much harsher dry seasons (e.g., scarce shade, high water temperatures in residual pools), generally support 50-60% less invertebrate taxa than we observed at John West Fork (Bogan 2012). However, we also found that John West Fork supported 2.5x the number of invertebrate taxa than were found by del Rosario and Resh (2000) from two similar sized coastal headwater streams only a few kilometers away. This difference can partly be explained by taxonomic effort. del Rosario and Resh (2000) identified midges (Chironomidae) at the family-level, while we identified 38 separate midge genera and/or species groups from John West Fork. Though it requires additional effort to identify midges to finer taxonomic levels, they are often dominant taxa in intermittent streams and they can serve as indicators of local flow permanence in ungauged streams (Bogan et al. 2013).

Seasonal drought can play a stronger role in shaping aquatic communities than catastrophic disturbances like wildfire (Verkaik et al. 2013). However, if seasonal drought is predictable, then many aquatic species will develop life history adaptations to drought (Gasith and Resh 1999, Lake 2003). Most aquatic invertebrate taxa at John West Fork appear to be adapted to survive flow cessation during the lengthy (5-7 month) dry season. Although annual rainfall, and thus the intensity of seasonal drought, varied greatly across the study period, similar total numbers of invertebrate taxa were found in each year. Additionally, nearly all invertebrate taxa present at John West Fork occupied residual pool habitats during the dry season. Thus, these pools that persist after flow ceases serve as essential refuge habitats and may facilitate higher diversity than would be found in a stream that dries completely. The nine taxa that were exclusive to intermittent riffle habitats were mainly larger stonefly, mayfly, and caddisfly taxa that require perennial flow (Poff et al. 2006). Their low abundances in our samples (< 2 individuals/taxon over 4 years) suggest that they may occasionally colonize John West Fork from perennially-flowing refuges in nearby Olema Creek, but that flow cessation each year prohibits the establishment of large, stable populations.

Intermittent streams are not traditionally thought of as important habitats for salmonid fishes. However, Wigington et al. (2006) reported that coho salmon may not only use intermittent streams for breeding, but also that juvenile salmon may grow faster in these systems. Though we only found endangered juvenile coho to be abundant at John West Fork during 2011, this pattern reflects their regional cycles of abundance, where currently only every third year supports a consistently strong cohort (Carlisle et al. 2011). Unfortunately, this 3-year pattern also makes them highly vulnerable to stochastic extreme drought events. In contrast, threatened steelhead trout were common to abundant in all four years, suggesting that they are well-adapted to shady coastal headwater streams that cease flowing for as much as seven months per year.

Understanding the distribution of salmonids in intermittent streams is important because regional climate models predict increased temperatures and decreased precipitation in late spring, summer, and early fall (March-October) for northern California and the Pacific Northwest (Mote and Salathé 2010, Pierce et al. 2013). These climatic changes will likely increase the extent and duration of dry season flow cessation in streams and the water temperature in remnant stream pools, thus heightening the extinction risk of many salmonid populations across the region (Katz et al. 2013, Wainwright and Weitkamp 2013). Understanding current salmonid use of intermittent streams will facilitate more realistic modeling of future salmonid distributions under various climate change scenarios.

In addition to documenting the high biodiversity of our focal intermittent headwater stream, our goal here is to promote the use of similar streams as model study systems. Within a 10 km radius of John West Fork, there are over 30 similarly-sized intermittent headwater streams (Figure 1). Similar intermittent coastal headwater streams occur all the way up the western coast of North America, at least as far as British Columbia (Price et al. 2003). This great number of replicate stream systems, their high biotic diversity, and their tractability (wadable in high flow, isolated pools in low flow) make them ideal for ecological studies. Finally, given the high biodiversity that coastal intermittent headwater streams support, they should be included in local and regional conservation planning efforts.

## Acknowledgments

The project described in this publication was supported by the UC California Institute for Water Resources through a Grant/Cooperative Agreement from the United States Geological Survey. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the UC CIWR or the USGS. JLH was supported by a National Science Foundation Graduate Research Fellowship and the UC Berkeley Wildlife Fund. MTB was also supported by a David H. Smith Conservation Research Fellowship, administered by the Society for Conservation Biology and funded by the Cedar Tree Foundation. This manuscript was improved by the insightful comments of three anonymous reviewers.

## Literature Cited


Banks, J. L., J. Li, and A. T. Herlihy. 2007. Influence of clearcut logging, flow duration, and season on emergent aquatic insects in headwater streams of the Central Oregon Coast Range. Journal of the North American Benthological Society 26:620-632.

Bogan, M. T. 2012. Drought, dispersal, and community dynamics in arid-land streams. Ph.D. Dissertation, Oregon State University, Corvallis.

Bogan, M. T., K. S. Boersma, and D. A. Lytle. 2013. Flow intermittency alters longitudinal patterns of invertebrate diversity and assemblage composition in an arid-land stream network. Freshwater Biology 58:1016-1028.

Carlisle, S. J., M. Reichmuth, A. Dedrick, C. Brown, and B. J. Ketcham. 2011. Long-term coho salmon and steelhead trout monitoring in coastal Marin County: 2008 annual monitoring progress report. Natural Resource Technical Report NPS/SFAN/NRTR-2011460. National Park Service, Fort Collins, CO.

Clarke, A., R. Mac Nally, N. Bond, and P. S. Lake. 2008. Macroinvertebrate diversity in headwater streams: a review. Freshwater Biology 53:1707-1721.

Datry, T., S. T. Larned, K. M. Fritz, M. T. Bogan, P. J. Wood, E. I. Meyer, and A. N. Santos. 2014. Broad-scale patterns of invertebrate richness and community composition in temporary rivers: effects of flow intermittence. Ecography 37:94-104.

del Rosario, R. B., and Resh, V. H. (2000) Invertebrates in intermittent and perennial streams: is the hyporheic zone a refuge from drying? Journal of the North American Benthological Society 19:680-696.

Dieterich, M., and N. H. Anderson. 2000. The invertebrate fauna of summer-dry streams in western Oregon. Archiv fur Hydrobiologie 147:273-295.

Finn, D. S., and N. L. Poff. 2011. Examining spatial concordance of genetic and species diversity patterns to evaluate the role of dispersal limitation in structuring headwater metacommunities. Journal of the North American Benthological Society 30:273-283.

Gasith, A., and V. H. Resh. 1999. Streams in Mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics 30:51-81.

Grantham, T. E., D. A. Newburn, M. A. McCarthy, and A. M. Merenlender. 2012. The role of streamflow and land use in limiting oversummer survival of juvenile steelhead in California streams. Transactions of the American Fisheries Society 141:585-598.

Katz, J., P. B. Moyle, R. M. Quiñones, J. Israel, and S. Purdy. 2013. Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes 96:1169-1186.

Lake, P. S. 2003. Ecological effects of perturbation by drought in flowing waters. Freshwater Biology 48:1161-1172.

Larned, S. T., T. Datry, D. B. Arscott, and K. Tockner. 2010. Emerging concepts in temporary-river ecology. Freshwater Biology 55:717-738.

Meyer, J. L., D. L. Strayer, J. B. Wallace, S. L. Eggert, G. S. Helfman, and N. E. Leonard. 2007. The contribution of headwater streams to biodiversity in stream networks. Journal of the American Water Resources Association 43:86-103.

Mote, P. W., and E. P. Salathé Jr. 2010. Future climate in the Pacific Northwest. Climatic Change 102:29-50.

Pierce, D. W., T. Das, D. R. Cayan, E. P. Maurer, N. L. Miller, Y. Bao, M. Kanamitsu, K. Yoshimura, M. A. Snyder, L. C. Sloan, G. Franco, and M. Tyree. 2013. Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. Climate Dynamics 40:839-856.

Poff, N. L., J. D. Olden, N. K. M. Vieira, D. S. Finn, M. P. Simmons, and B. C. Kondratieff. 2006. Functional trait niches of North American lotic insects: trait-based ecological applications in light of phylogenetic relationships. Journal of the North American Benthological Society 25:730-755.

Price, K., A. Suski, J. McGarvie, B. Beasley, and J. S. Richardson. 2003. Communities of aquatic insects of old-growth and clearcut coastal headwater streams of varying flow persistence. Canadian Journal of Forestry Research 33:416-1432.

Progar, R. A., and A. R. Moldenke. 2002. Insect production from temporary and perennially flowing headwater streams in western Oregon. Journal of Freshwater Ecology 17:391-407.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Verkaik, I., M. Vila-Escale, M. Rieradevall, and N. Prat. 2013. Seasonal drought plays a stronger role than wildfire in shaping macroinvertebrate communities of Mediterranean streams. International Review of Hydrobiology 98:1-13.

Wainwright, T. C., and L. A. Weitkamp. 2013. Effects of climate change on Oregon Coast Coho salmon: habitat and life-cycle interactions. Northwest Science 87:219-235.

Wigington Jr, P. J., J. L. Ebersole, M. E. Colvin, S. G. Leibowitz, B. Miller, B. Hansen, H. R. Lavigne, D. White, J. P. Baker, M. R. B. Church, J. R Brooks, M. Cairns, and J. E. Compton. 2006. Coho salmon dependence on intermittent streams. Frontiers in Ecology and the Environment 4:513-518.



*Received 30 January 2014*

*Accepted for publication 03 November 2014*