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C.H. HUCKELBERRY
County Administrator

November 6, 2017

Mr. William James, National Mining Expert
U. S. Army Corps of Engineers
3701 Bell Road
Nashville, Tennessee 37214-2660

Re: **New information on the Intermittent Status of Barrel and Davidson Canyons**

Dear Mr. James,

We understand that a decision from the Corps regarding the Clean Water Act and the Rosemont Mine is imminent. We appreciate your consideration of past correspondence from Pima County and request that you consider the new information contained in this letter, which responds to the continued assertions by Rosemont and its contractors that the wetland conditions of Barrel and downstream Davidson canyons are ephemeral[1].

In this letter we will present information that shows that such a claim is clearly false and that *intermittent* wetland conditions persist in these systems in spite of the extreme and persistent drought that we are currently experiencing.

An Overview of Regional Drought

Southern Arizona and the Cienega Valley has been in an extreme drought for almost 20 years[2], a fact that is "well known" and especially for the area's rivers, streams, and springs, which continue to be "degraded or lost entirely"[3]. Furthermore, "the effect of decreased streamflow is that streams become smaller, intermittent or dry, and thereby reduce the amount of habitat available for aquatic species".

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[1] Westland Resources Inc, and Water and Earth Technologies. 2017. Final Habitat mitigation and monitoring plan, Permit No. SPL-2008-00816-MB, Rosemont Copper Project

[2] Woodhouse, C. A., D. M. Meko, G. M. MacDonald, D. W. Stahle, and E. R. Cook. 2010. A 1,200-year perspective of 21st century drought in southwestern North America. Proc Natl Acad Sci U S A 107:21283-21288.

[3] U. S. Fish and Wildlife Service. 2013. Final biological and conference opinion for the Rosemont Copper Mine, Pima County, Arizona. Appendix F of the Final environmental impact statement for the Rosemont Copper project: A proposed mining operation, Coronado National Forest, Pima County, Arizona. U.S. Department of Agriculture, Forest Service, Southwestern Region. Document number MB-R3-05-6a

To understand the extent and severity of the current drought on streamflow, we used the Evaporative Demand Drought Index[4], a drought index that can serve as an indicator

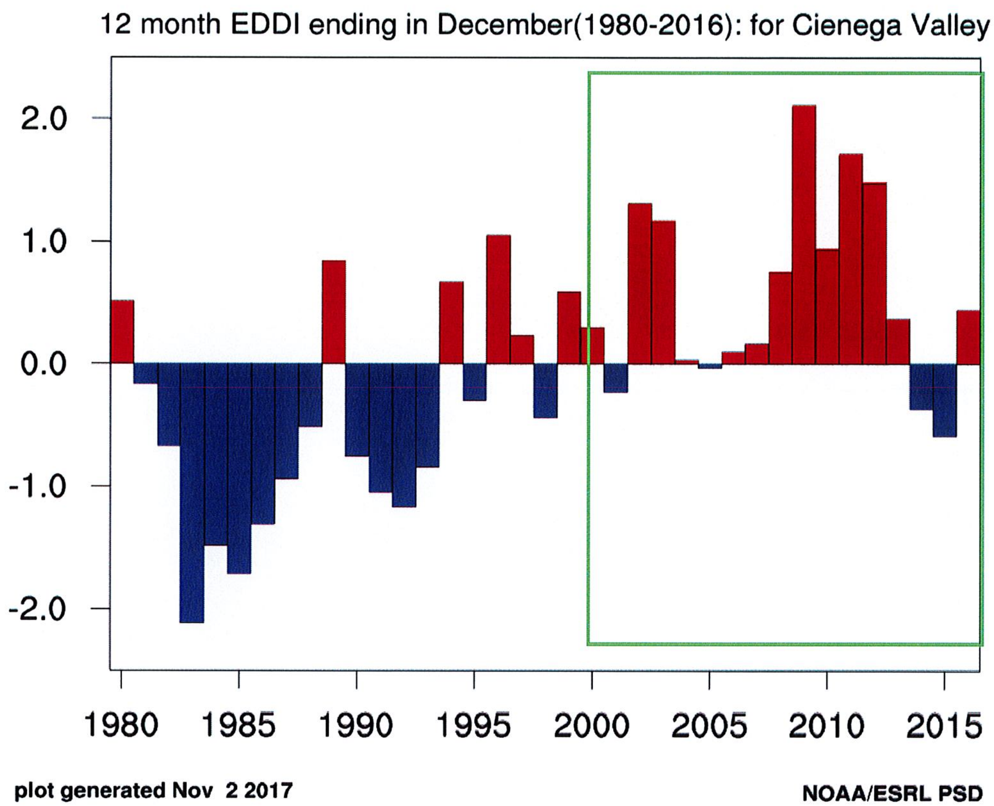
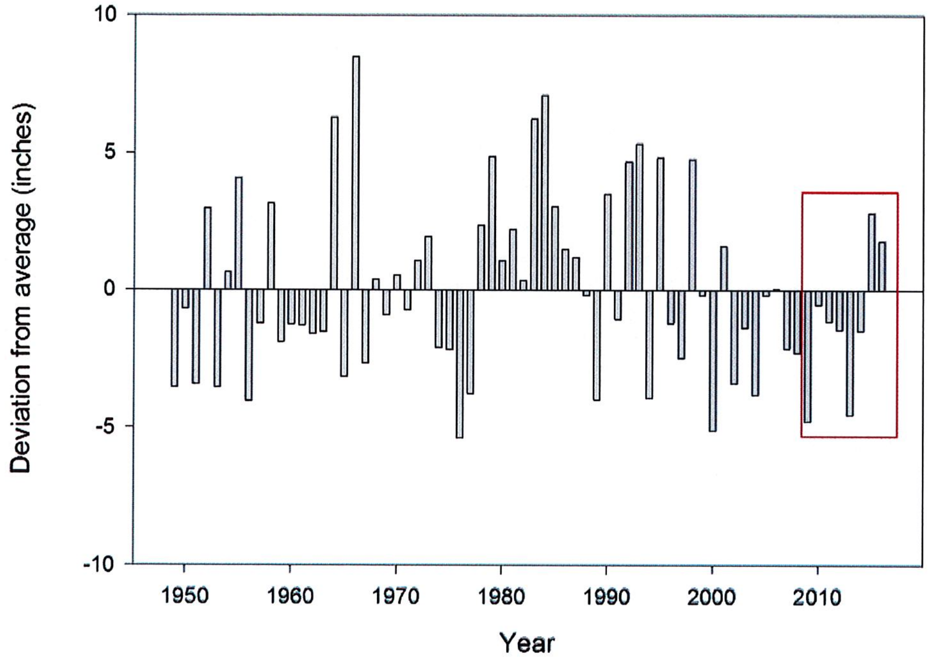


Figure 1. Evaporative Demand Drought Index (EDDI) graph showing the drought conditions (in red), especially since 2000 (green box). Higher positive values on the Y axis indicate more extreme drought. EDDI values for each year are averaged across months and compared to a 30-year average.

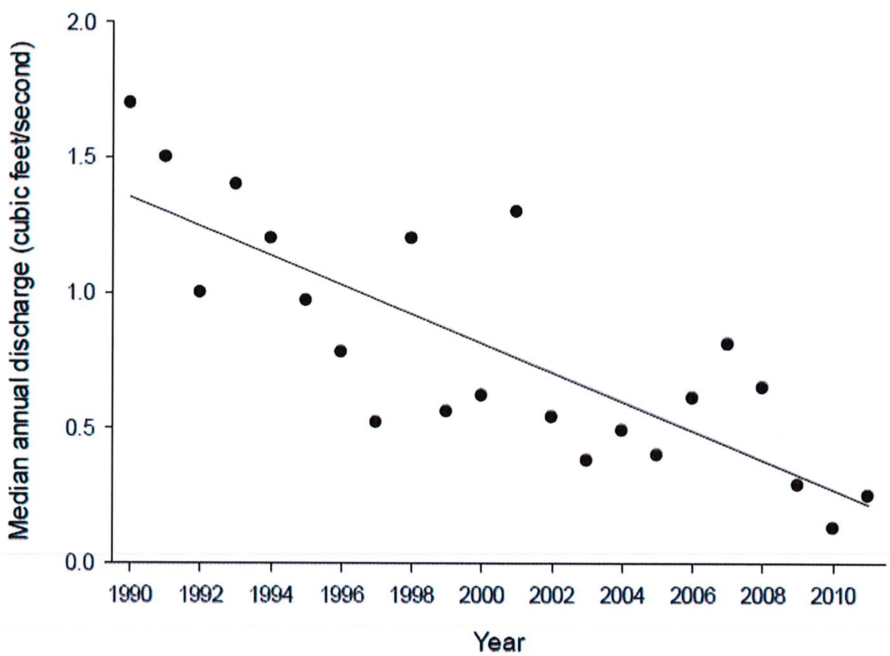
of both rapidly evolving "flash" droughts (developing over a few weeks) and sustained droughts (developing over months but lasting up to years). We centered the web-based index window over the northern portion of the Cienega Valley where the proposed mine would be located. Since 2000, there have been drought conditions in all but four years (Figure 1). When looked over a longer time period, the drought over the last decades is considered significant (Figure 2) and anomalous when looking at deviations from average annual rainfall since 1947.

It is also important to note that HudBay continues to assert that modeled streamflow and stormwater discharge from Barrel Canyon are overestimates. However, their modeling efforts focus on a very narrow period of time (2009-present) that clearly does not reflect the breadth of precipitation conditions in the last 60 or so years (Figure 2), nor even discharge

[4] Hobbins, M., A. Wood, D. McEvoy, J. Huntington, C. Morton, M. Anderson, and C. Hain. 2016. The Evaporative Demand Drought index: Part I – Linking Drought Evolution to Variations in Evaporative Demand. Journal of Hydrometeorology 17:1745-1761.



measurements of the last 27 years (Figure 3). By relying on an extremely dry period for estimating Barrel Canyon stormflow and baseflow, HudBay appears to be hoping to minimize their needs for mitigating impacts on Waters of the United States. **Figure 2. Deviations from annual precipitation totals for Tucson, 1947-2016. Red box indicates the period of record for the Barrel Canyon gage (09484580), which HudBay uses to assert the stream status of**



Barrel and Davidson canyons. This graph clearly shows that drought conditions have persisted during this period. Yet despite this extreme drought—and contrary to HudBay's assertions—intermittent surface water conditions have persisted in Barrel and Davidson canyons.

Figure 3. Median annual discharge at the Pantano gage, Cienega Creek, 1990-2011. The gage is downstream of Barrel gage, but was chosen here because of its longer period of record. Note that 2009 and 2010 were extremely dry years. Despite this, a species stonefly—which requires intermittent water—was found in Barrel canyon in 2010.

Despite the extreme drought of the last years 20 year or so, an overwhelming body of evidence shows that Barrel and Davidson canyon continue to maintain intermittent surface water conditions during this period.

In a letter dated September 28, 2017, I provided a clear set of metrics and data showing that Barrel Canyon has intermittent streamflow. Since that time, a new piece of information has come to my staff's attention that provides additional evidence that Barrel Canyon has intermittent streamflow. Bogan (2017, attached)[5] documented the life cycle and distribution of a winter stonefly species (*Mesocapnia arizonensis*), one specimen of which was collected at Barrel Canyon[6] in April 2010. The specimen collection occurred during an extremely dry period for the region and following one of the driest years on record for the Cienega basin (see Figure 3 for drought conditions present). For this species, Bogan (2017) noted "Nymphs were abundant within days of flow resumption, grew rapidly as a single cohort, and started emerging as adults 42 days after flow resumed". In other words, for this species to mature, it needs at least 42 consecutive days with water. This is clearly a species that relies on intermittent surface water conditions for survival.

In conclusion, Pima County and the Regional Flood Control District appreciate the Corps' thorough analysis of Rosemont's impacts to the Waters of the U.S. This latest set of evidence should leave little doubt that Barrel and Davidson canyons must be considered intermittent and not be repeatedly referred to as "ephemeral" water bodies (Westland Resources Inc and Water and Earth Technologies 2017). Water quality standards, impact analysis and mitigation must take into consideration these aquatic resources, and the long-term impacts of the mine on the resources during operation, as well as closure.

If you require any additional information, my staff are available to answer any questions you may have.

Respectfully,

C. Huckelberry

C. H. Huckelberry
County Administrator

c: Deanna Cummings, U.S. Army Corps of Engineers
Elizabeth Goldmann, U. S. Environmental Protection Agency

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[5] Bogan, M. T. 2017. Hurry up and wait: life cycle and distribution of an intermittent stream specialist (Mesocapnia arizonensis). Freshwater Science:000-000

[6] According to Dr. Bogan, the specimen reported as being collected from "Davidson Canyon" was actually collected in Barrel Canyon near the Barrel Canyon USGS gage (Michael Bogan, personal communication).

Hurry up and wait: life cycle and distribution of an intermittent stream specialist (*Mesocapnia arizonensis*)

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Abstract: Species inhabiting intermittent streams must have life-history traits that confer resistance or resilience to flow cessation or drying. However, we lack basic life-history information for most aquatic invertebrate species, especially those from intermittent streams. I documented the life cycle and distribution of an unusual winter stonefly species, *Mesocapnia arizonensis* (Capniidae). The species was first described from 6 localities in 1969, but its natural history remained enigmatic. I surveyed >90 streams across the southwestern USA, documented the life cycle of *M. arizonensis* at 1 locality, and experimentally rehydrated dry streambed sediment in search of dormant stoneflies at another locality. Field surveys expanded the number of localities from 22 to 98, most of which were intermittent with flow durations as brief as 3 mo/y, and extended the known range of the species by 800 km. Nymphs were abundant within days of flow resumption, grew rapidly as a single cohort, and started emerging as adults 42 d after flow resumed. The brief appearance of a 2nd cohort of tiny nymphs 1 mo before the stream dried indicates direct hatching of at least some eggs. I failed to find dormant stoneflies in the top 30 cm of dry stream sediment, suggesting that *M. arizonensis* undergoes dormancy deep in the substrate, putting it safely out of reach of scouring summer floods that occur between favorable winter seasons. The remarkable ability of *M. arizonensis* to survive in short-flow duration streams and to endure multiple consecutive dry years, suggests that the species is well prepared for the drier climatic conditions predicted to occur across its range.
Key words: drought, drying, dormancy, disturbance, intermittent, Plecoptera

Species inhabiting intermittent streams must have life-history traits that confer resistance or resilience to flow cessation or drying (Lytle and Poff 2004, Datry et al. 2014). Despite this recognition of the importance of traits in shaping species distributions, basic natural-history information often is limited for aquatic invertebrate species (Poff et al. 2006, Robson et al. 2011, Strachan et al. 2015; but see Williams 2006). Furthermore, until recent years, aquatic invertebrate species inhabiting intermittent streams had received little scientific attention (Larned et al. 2010, Datry et al. 2011, Leigh et al. 2016). This lack of information hampers our ability to predict how species will respond to more intense drying regimes caused by climate change and water abstraction (Carlisle et al. 2011, Seager et al. 2012, Deitch et al. 2016).

Many species found in intermittent streams also occur in perennial streams (Arscott et al. 2010, Datry et al. 2014, Mazor et al. 2014), but some intermittent streams support unique invertebrate taxa (e.g., Dieterich and Anderson 2000, Schriever et al. 2015). These intermittent stream specialist species often have traits that confer resistance to drying, such as dormant stages that are synchronized with dry periods (Williams 1996, Lytle and Poff 2004, Strachan et al. 2015). Drought resistance traits are especially well documented among stonefly (Plecoptera) species. For example, several species in the Capniidae and Perlodidae families have dormant egg or nymph stages that survive dry periods lasting weeks or months (e.g., Harper and Hynes 1970, Snellen and Stewart 1979, Jacobi and Cary 1996, López-Rodríguez et al. 2009b).

The winter stonefly *Mesocapnia arizonensis* (Fig. 1A–H) was first described nearly 50 y ago from 4 intermittent and 2 perennial streams in central Arizona (Baumann and Gaufin 1969). Males are brachypterous, but females are fully winged and can fly at least short distances. In his study of aquatic insect life histories at Sycamore Creek, Gray (1981) hypothesized that *M. arizonensis* had an egg diapause stage that persisted through dry periods in that system. In subsequent years, the known distribution of *M. arizonensis* was

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expanded to include several streams in New Mexico, USA (Jacobi and Baumann 1983, Jacobi and Cary 1996), and Sonora, Mexico (Sargent et al. 1991). The species appeared to be relatively rare (~20 localities), but Bogan et al. (2013) found *M. arizonensis* in several Arizona streams with flow durations as short as 3 mo/y. These findings suggested that the species may be more common than previously thought, but primarily inhabit stream systems that are infrequently surveyed. Indeed, Jacobi and Cary (1996) observed that *M. arizonensis* in New Mexico were found in lowland streams where water tables can fall far below the streambed during the dry season.

The goal of my study was to document the distribution and life cycle of *M. arizonensis*, including understanding how the species persists in intermittent streams. I hypothesized that *M. arizonensis*: 1) is primarily a species of short flow-duration (i.e. <6 mo/y) streams, 2) has a univoltine fast life cycle, and 3) has a dormant stage capable of surviving long dry periods (>9 mo). To address these hypotheses, I compiled existing localities and surveyed >90 additional sites, documented the life cycle of *M. arizonensis* at 1 short flow-duration locality, and experimentally rehydrated dry streambed sediment in search of dormant stoneflies at another short flow-duration locality.

METHODS

Historical records

I sought published collection records for *M. arizonensis* via searches of Google Scholar® (Google, Mountain View, California) and Web of Science® (Thomson Reuters, New York) for "*Capnia arizonensis*" and "*Mesocapnia arizonensis*". I also checked the literature-cited sections of identified publications to look for additional records. Last, I gathered unpublished records by examining specimens at the University of Arizona Insect Collection.

Regional stonefly surveys

In April 2005, I collected *M. arizonensis* from a short flow-duration (~3 mo/y) intermittent stream in southeastern Arizona (West Stronghold Canyon; Appendix S1). I planned to survey similar short flow-duration habitats over next 3 y (Fig. 2A–D), but drought dominated the region from 2006–2009, and most intermittent streams in the region remained dry for that entire period (Bogan et al. 2013). El Niño conditions marked the return of winter rainfall and stream flow in early 2010, so I searched for *M. arizonensis* at 45 intermittent stream reaches across southeastern Arizona between February and April 2010. I failed to find *M. arizo-*

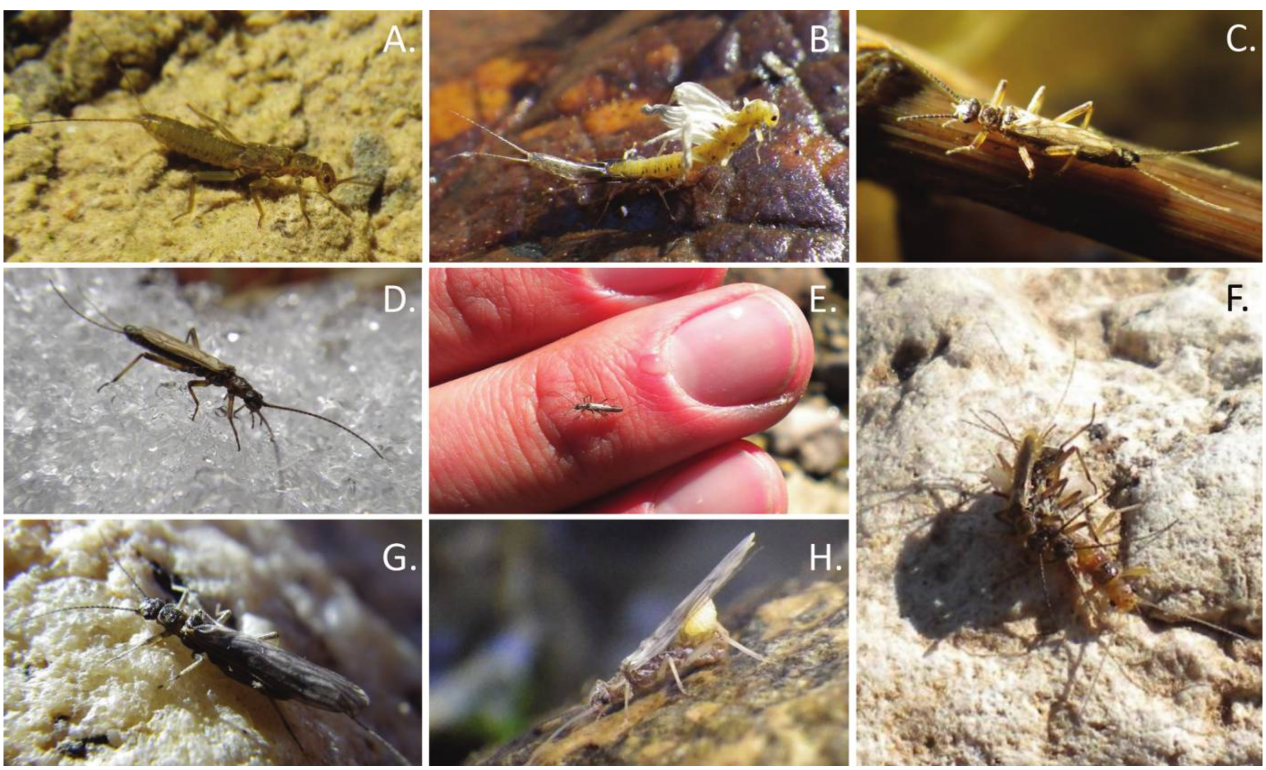

Figure 1. Examples of different life stages and behaviors of *Mesocapnia arizonensis* from several Arizona streams. A.—Nymph. B.—Emerging adult. C.—Adult male. D.—Adult male on snow. E.—Relative size of adult male on a human hand. F.—Two adult males attempting to mate with teneral adult female. G.—Adult female. H.—Adult female with egg mass.

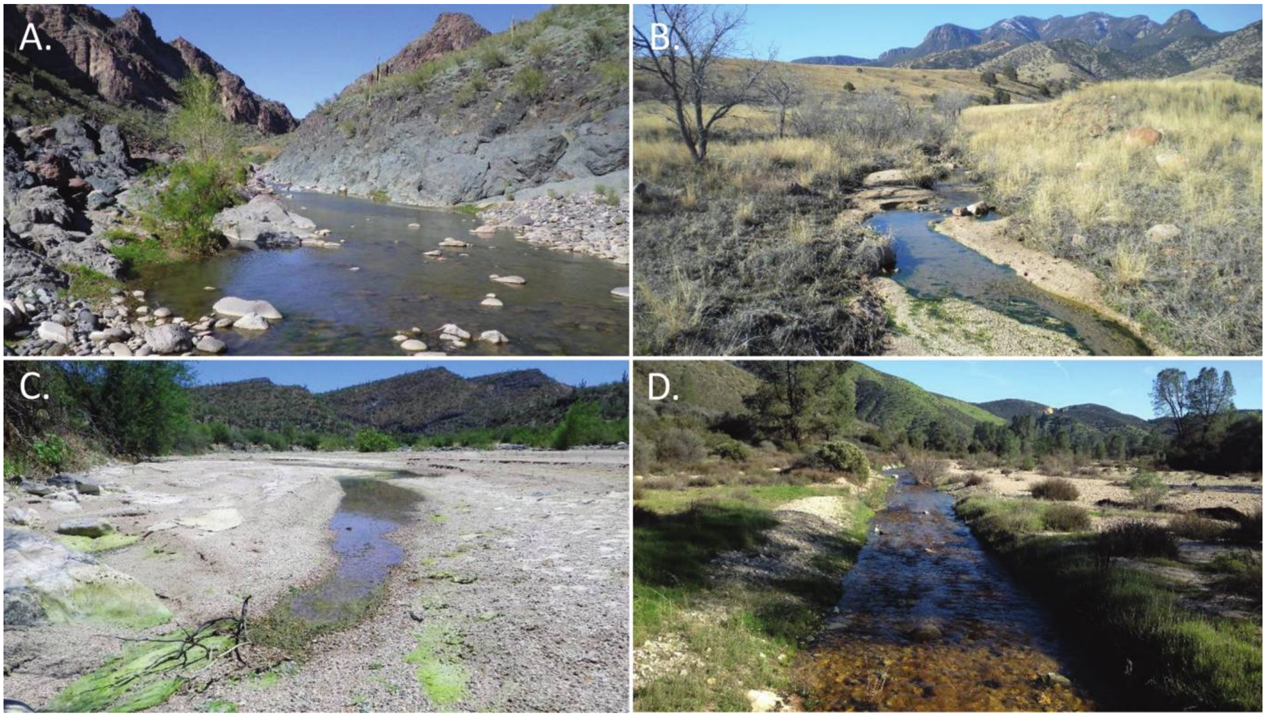

Figure 2. Typical stream habitat of *Mesocapnia arizonensis*. A.—Burro Creek (Arizona). B.—Soldier Creek (Arizona). C.—Sycamore Creek (Arizona). D.—Chalone Creek (California).

nensis at 2 intermittent stream sites (Mendoza Wash and Browns Canyon, listed in Appendix S2). Colleagues (D. A. Lytle [Oregon State University], K. S. Boersma [University of San Diego], and E. Wallace [independent naturalist]) surveyed an additional 8 streams during that time period. When possible, I surveyed multiple reaches within a given drainage to determine the upper and lower elevational limits of *M. arizonensis*. In addition, between 2011 and 2016, I opportunistically surveyed for *M. arizonensis* at 45 other intermittent streams across Arizona and California (Appendix S1). Furthermore, I had previously surveyed for stoneflies at 27 perennial streams across Arizona (Bogan and Lytle 2007, Bogan 2012, Bogan et al. 2013; Appendix S2). All sites were visited at least once during the dry season (May to July) to confirm whether they were perennial or intermittent.

Life-history observations at Bear Canyon

Field surveys in 2010–2012 revealed that *M. arizonensis* was one of the most abundant aquatic invertebrate species at Bear Canyon, Arizona (lat 32.3131, long 110.7962). This stream typically flows for 4 to 5 mo/y in response to winter precipitation (December–April) and is dry the rest of the year except for short periods during the monsoon season (July–September). On 19 December 2012, flow resumed at Bear Canyon after an ~120-d period with 0 flow. Beginning 12 d after flow resumption, and continuing every 2 wk thereafter, I collected 3 replicate kick samples with a D-frame net (0.5-mm mesh, total sampled area = 0.33 m^2) in a 100-m reach, until the stream dried on 3 May 2013. I used these benthic samples to estimate the density of *M. arizonensis* nymphs in the study reach. In addition, I measured intraocular widths (to nearest 0.01 mm) to quantify nymph cohort structure. I measured all individuals when nymphs were uncommon in samples (i.e., <100 collected), and I randomly selected 100 individuals for measurement when nymphs were abundant.

I surveyed weekly for *M. arizonensis* adults from the day flow resumed until the last pool dried, searching stream banks and emergent rocks and grasses for a 30-min period each week. Previous observations indicated that *M. arizonensis* adults are found primarily on emergent rocks and grasses, rather than on riparian bushes and trees (Bogan 2012). Last, I measured water temperature (°C), conductivity (μS/cm), pH, dissolved O_2 (mg/L), and flow volume (L/s) weekly at Bear Canyon.

Rehydration experiment

To search for dormant individuals of *M. arizonensis* in dry stream sediment, I extracted and experimentally rehydrated sediments from West Stronghold Canyon, where I first collected the species in 2005. On 4 November 2009, I extracted fifteen 1-L samples of sediment from a 100-m reach of the dry stream. I used a trowel to collect the sediment samples from ~0- to 30-cm depth. I retained all sand, gravel, and organic material but discarded rocks >10 cm in diameter. Large cobbles and boulders made it impractical to dig deeper into the stream bed. Also, previous studies suggested that dormant aquatic invertebrates are most abundant in the top 20 cm of dry sediment (Harper and Hynes 1970, Larned et al. 2007, Datry et al. 2012). At the time of sediment extraction, the reach had been completely dry for 13 mo, and the sediment was dusty dry to 30-cm depth. Furthermore, winter flow periods lasting longer than 30 d and emergences of adult stoneflies had not occurred since April 2005 (Bogan 2012).

I transported sediment samples to the laboratory and divided them into 3 rehydration groups of 5 samples each. I rehydrated the first five 1-L samples with room-temperature dechlorinated tap water (conductivity = 70 μS/cm) and immediately examined them under a dissecting microscope (40× magnification) to look for dormant eggs or nymphs. I placed the remaining 10 samples into individual 4-L trays, inundated them with 1.2 L of dechlorinated tap water, and aerated them with an aquarium aeration stone. I put 5 of these samples in a cold room (10°C) with a 10 : 14 h light: dark cycle and 5 in a warm room (20°C) with a 14 : 10 hr light: dark cycle. These treatments were meant to simulate winter and summer flow events, respectively. I inspected each tray daily for 32 d and removed any active invertebrates for identification. On day 32, I preserved all sediment and invertebrates in 70% ethanol and examined preserved samples under the microscope.

Last, to compare invertebrate communities from rehydrated sediments in the laboratory vs naturally rewetted sediments in the stream, I collected benthic samples from West Stronghold Canyon on 10 March 2010, 8 wk after flow resumed (Bogan et al. 2013).

RESULTS

Historical records

Baumann and Gaufin (1969) first described *M. arizonensis* from specimens collected at 6 Arizona streams, and 3 more localities were added in later publications by Baumann and Gaufin (1970), Gray (1981), and Masteller (1994). Sargent et al. (1991) extended the species' range to Mexico, reporting it from 3 streams in northern Sonora, within 60 km of the international border. Jacobi and Baumann (1983) and Jacobi and Cary (1996) documented the species from 7 intermittent streams in western New Mexico. Last, 3 additional localities in southern Arizona were found by Carl Olson and colleagues in 1984 (Appendix S1); those specimens reside in the University of Arizona Insect Collection. Thus, the species was collected from 22 scattered locations in central and southern Arizona, western New Mexico, and northern Sonora in the first 35 y after it was described (Fig. 3).

Range-wide stonefly surveys I collected *M. arizonensis* from 34 new locations in southeastern Arizona in March and April 2010, and colleagues added 7 localities during that same period (Appendix S1). In subsequent years, I found *M. arizonensis* at 32 more sites across Arizona and 1 in northern Sonora. I also found the species at 2 streams in California: Caruthers Canyon in southeastern California and Chalone Creek in northern California (Appendix S1). These 2 California records extend the known range of the species by 270 and 800 km, respectively (Fig. 3). All 76 new localities are intermittent streams, most of which dry for >6 mo/y, and many of which experience consecutive years without significant periods of flow (i.e. <1 mo/y). I failed to find *M. arizonensis* at 2 intermittent streams, and it was absent from all 27 perennial streams that I had surveyed previously (Appendix S2).

These new collections increased the number of known *M. arizonensis* localities from 22 to 98. The mean elevation of these localities was 1281 m asl (range: 299–1950 m). Data were available regarding the presence or absence of co-occurring stonefly species for 76 of the 98 localities. At 71% of these sites, *M. arizonensis* was the only stonefly species found. At the remaining 29% of sites, co-occurring species included *Mesocapnia frisoni*, *Mesocapnia werneri*, *Capnia californica*, and *Taenionema jacobii*. *Mesocapnia arizonensis* was most abundant in the lower-elevation portions of drainages (800–1300 m) and reached peak dominance in alluvial reaches near the mouths of arid montane canyons (Table 1, Fig. 2A–D). In these alluvial reaches, *M. arizonensis* occasionally co-occurred with *M. frisoni* and *M. werneri*. At higher elevations (1300–1800 m asl), relative abundances of *M. arizonensis* declined, and relative abundances of *C. californica* and *T. jacobii* increased. *Mesocapnia arizonensis* was not found at the highest elevations (>1950 m) or in perennial streams at any elevation (564–2835 m). Other stoneflies, including *Capnia decepta*, nemourids (e.g., *Malenka coloradensis*), and chloroperlids (e.g., *Sweltsa coloradensis*), were present at these sites (Appendix S2).

Life-history observations

At Bear Canyon, *M. arizonensis* nymphs were present in benthic samples 12 d after flow resumed, and the density of nymphs increased dramatically in subsequent weeks (Fig. 4). Peak nymphal density (1186 individuals [ind]/m^2) was reached 47 d after flow resumed and began to decline thereafter. Nymphs were nearly absent from samples 13 wk after flow resumed, rebounded slightly at 15 wk, but were absent in the final 4 wk before flow ceased and the study reach dried. When nymphs were present, water temperatures ranged from 5 to 18°C, conductivity from 43 to 106 μS/cm, pH from 6 to 6.75, dissolved O_2 from 7 to 11 mg/L, and discharge from 14 to 113 L/s (Appendix S3). A rain-on-snow flood event occurred on 26 January 2013, as evident from disturbed substrate in the study reach and records from the flow gage in neighboring Sabino Canyon (US Geological Survey 09484000). Regressing weekly measured flows at

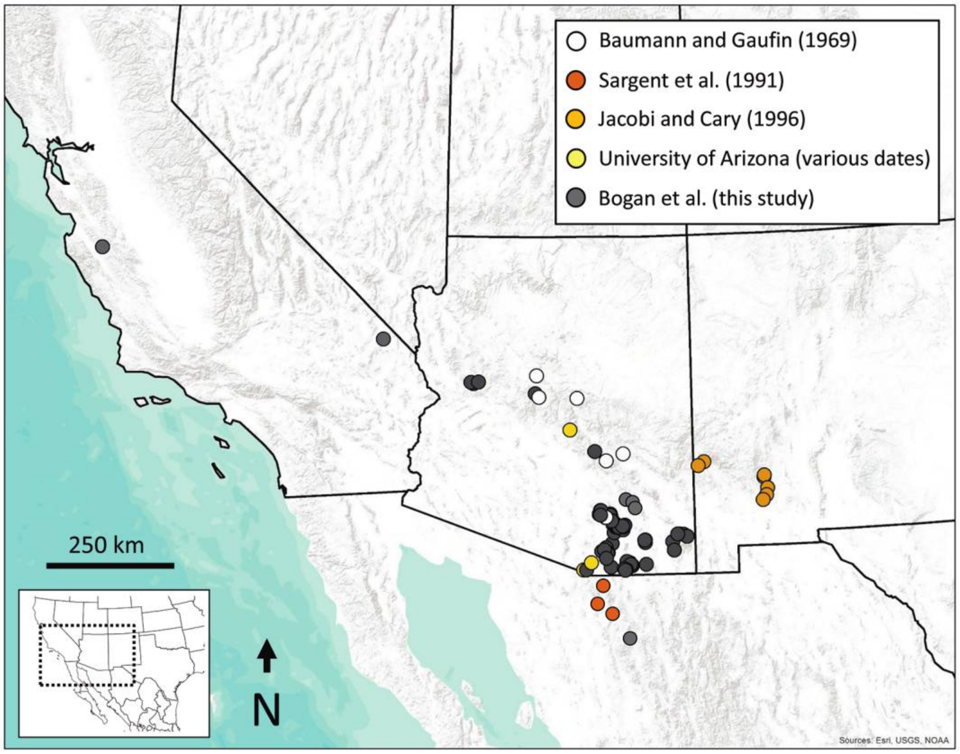

Figure 3. Existing and newly reported localities for *Mesocapnia arizonensis*. The species was described from 6 streams in Baumann and Gaufin (1969), and an additional 16 localities were found between 1969 and 1996. New collections reported in my study increase the total number of localities to 98.

Bear Canyon on continuous flow measurements from the Sabino Canyon gage ($R^2 = 0.91$) yielded a peak flood estimate of 3540 L/s for Bear Canyon on 26 January 2013. Nymph density temporarily diminished after the flood, but rebounded quickly (Fig. 4).

I collected 594 *M. arizonensis* adults over a 56-d period. Emergence began 43 d after flow resumed, and peak abundances occurred at 72 d (Fig. 5). Males emerged earlier than females, and overall abundances were heavily male-biased (80.4% male, 19.6% female). The final adults of the season were observed 99 d after flow resumed, just 36 d before the reach dried.

Most nymphs appeared to form a single cohort (Fig. 6). Individuals found 12 d after flow resumed were small (mean intraocular distance = 0.3 mm). Nymphs grew larger in subsequent weeks until adults began to emerge. Approximately 4 wk after adult emergence began, small nymphs (mean intraocular distance = 0.1 mm) were found in benthic samples. This new cohort was the dominant cohort 12 and 14 wk after flow resumed, but was absent from benthic samples in the final weeks before flow ceased (Fig. 6).

Rehydration experiment

I found no dormant stonefly eggs or nymphs in the 5 dry sediment samples examined immediately after rehydration. Furthermore, I found no active invertebrates during daily visual inspection of the 10 sediment trays rehydrated for 32 d. After terminating the experiment and examining preserved samples under the microscope, I found only 1 individual of the mite *Hydrozetes* (Sarcoptiformes:Hydrozetidae) and 3 ostracods (Ostracoda) from the 5 trays in the 10°C treatment. From the five 20°C treatment trays, I found 7 *Hydrozetes* individuals and 1 specimen of the beetle *Hydraena* (Coleoptera:Hydraenidae) in poor condition. I found no *M. arizonensis* during the experiment. In contrast, I found 19 aquatic invertebrate taxa in benthic samples collected from West Stronghold Canyon 8 wk after flow resumed (and 20 wk after dry sediment samples were collected). *Mesocapnia arizonensis* was abundant in West Stronghold Canyon after flow resumption (mean density = 183 ind/m^2), with only midges (Chironomidae) and blackflies (Simuliidae) exhibiting higher densities.

DISCUSSION

Perennial streams are sampled regularly during basic research studies and biomonitoring but short flow-duration intermittent streams are rarely sampled because they flow infrequently and may remain dry for >1 y (Bogan et al. 2013, Mazor et al. 2014). *Mesocapnia arizonensis* was previously thought to be uncommon, but I found it at >75 intermittent

Table 1. Relative abundances of *Mesocapnia arizonensis* and co-occurring stonefly taxa in reaches at different elevations in 5 stream basins in southeastern Arizona

		Relative abundance (%) of all stonefly taxa			
Stream basin	Elevation (m)	*M. arizonensis*	*Mesocapnia* spp.	Other Capniidae	Taeniopterygidae
Bear Canyon	811	100	0	0	0
	841	94	6	0	0
	953	88	12	0	0
	1207	25	75	0	0
	1338	85	4	11	0
	1677	2	0	98	0
	1829	0	0	100	0
Ash Creek	1220	100	0	0	0
	1521	0	0	33	67
	1799	0	0	100	0
Paige Creek	1159	75	24	0	1
	1220	60	13	0	27
	1738	90	0	10	0
	2134	0	0	100	0
Chimenea Canyon	1009	100	0	0	0
	1067	92	0	8	0
	1585	27	0	73	0
	2287	0	0	100	0
East Turkey Creek	1524	100	0	0	0
	1829	0	0	100	0
	1951	0	0	100	0

streams from northwestern Mexico to northern California. Similar distributions across this wide band of dryland intermittent streams have been noted for other species, including a dobsonfly (Cover et al. 2015), 2 hydroptilid caddisflies (Ruiter 2011), and 2 winter stoneflies (*M. werneri* and *C. californica:* Baumann and Gaufin 1970). *Mesocapnia arizonensis* was not found in perennial streams and was the only stonefly species present in streams that flowed <4 mo/y. I even found *M. arizonensis* in Rillito River, an ephemeral river that runs through the desert city of Tucson, Arizona (Appendix S1). I failed to find *M. arizonensis* at only 2 intermittent streams, both of which flow quite infrequently (<2 mo/y) and are situated in isolated mountain ranges (Appendix S2).

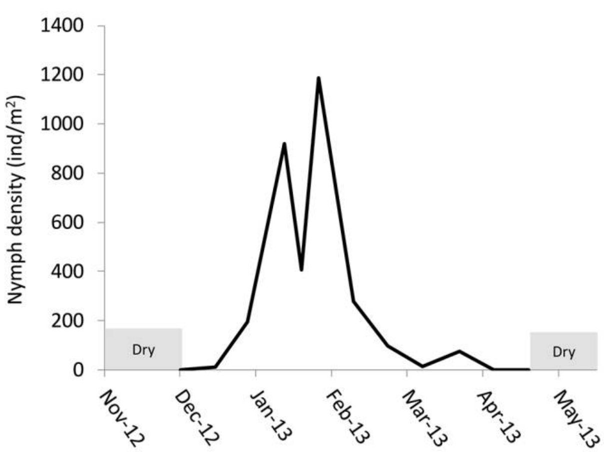

Figure 4. Average density of *Mesocapnia arizonensis* nymphs in 3 replicate D-net kick samples collected biweekly from Bear Canyon across the 2012–2013 winter flow period. Ind = individuals.

Traits that facilitate persistence in short flow-duration streams include fast seasonal life cycles, in which individuals complete their development and reproduce during brief periods of flow and have desiccation-resistant dormant stages. Fast life cycles have been reported for numerous stoneflies inhabiting intermittent streams, including species of Capniidae, Leuctridae, Taeniopterygidae, and Perlodidae (e.g., Grubbs et al. 2006, Navarro-Martinez et al. 2007, López-Rodríguez et al. 2009a, b). At Bear Canyon, *M. arizonensis* nymphs appeared to grow rapidly once flow resumed (Fig. 5), with adults emerging after 6 to 12 wk. While the nymphs of many stonefly species can mature in 5 to 6 mo (e.g., Snellen and Stewart 1979, Grubbs et al. 2005, 2006), only *Rhabdiopteryx christinae* is known to complete nymphal development in ≤4 mo (López-Rodríguez and Tierno de Figueroa 2006).

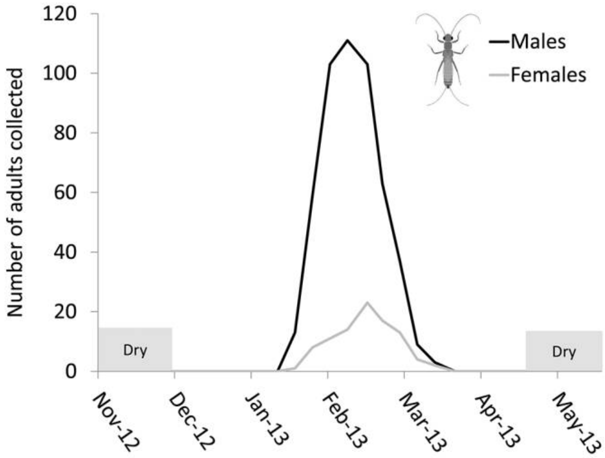

Figure 5. Number of adult *Mesocapnia arizonensis* collected during weekly 30-min surveys at Bear Canyon across the 2012–2013 winter flow period. Adult illustration by I. C. Phillipsen.

Rhabdiopteryx christinae has tightly synchronized nymphal cohorts and inhabits streams that are dry for >6 mo/y, similar to the patterns documented in this study. I quantified *M. arizonensis* nymphal development only at Bear Canyon, but many other localities have even shorter flow durations. Thus, the rapid development time reported here is likely to be observed in other populations.

Egg diapause is commonly used by stoneflies to survive unfavorably warm or dry seasons (Harper 1973, Pugsley and Hynes 1985, Stewart and Anderson 2009). In fact, Zwick (1996) proposed that dormant stonefly eggs form a 'seed-bank' in streambed sediments. Gray (1981) hypothesized that *M. arizonensis* had an egg diapause stage to persist through the hot, dry summers at Sycamore Creek, Arizona. He brought a cluster of 250 eggs into the laboratory and observed that some eggs hatched within days, but most remained unhatched (Gray 1981). However, most *M. arizonensis* localities experience extreme floods during summer monsoon storms. For example, discharge at Sycamore Creek can increase 100-fold in an instant and scour stream substrate to depths >1 m (Fisher et al. 1982). Dormant stonefly eggs probably would be damaged or destroyed during these events. Gray (1981) suggested that egg diapause occurred primarily in higher-elevation tributaries of Sycamore Creek, which are less likely to be scoured, and that hatchlings drifted downstream to repopulate the mainstem when winter flow resumed. That process may be feasible at Sycamore Creek, but many other localities are intermittent streams with ephemeral headwaters that do not support stonefly populations. These patterns suggest that most dormant individuals must survive in situ.

Nymphal dormancy is also widespread among stoneflies, but appears to be less common than egg diapause (e.g., Khoo 1968, Williams and Hynes 1976, López-Rodríguez et al. 2009a, b). In frequently disturbed habitats, nymphal dormancy may be advantageous because, unlike passively dispersed eggs, nymphs can actively seek a suitable place to spend their dormant periods (Harper and Hynes 1970). In flood-prone streams, this strategy would allow nymphs to crawl deep into the substrate, below the scour zone, before entering dormancy. Such refuge-seeking behavior could explain why hatchling *M. arizonensis* were present for such a brief time at Bear Canyon, despite the appropriate habitat conditions that occurred after their disappearance (Fig. 6). Furthermore, I failed to find resting stages of *M. arizonensis* in the top 30 cm of streambed sediment at West Stronghold Canyon, despite this being the zone in which dormant stoneflies are found in other streams (e.g., Harper and Hynes 1970, Williams and Hynes 1976). Together, these observations suggest that at least some *M. arizonensis* eggs hatch directly, allowing 1st instars to seek refuge deep in the streambed before entering dormancy.

In addition to univoltine fast life cycles with a seasonal diapause, more complex semivoltine life cycles have been documented from species in intermittent streams. For example, the dobsonfly *Neohermes filicornis* enters and emerges from dormancy as many as 5 times during its larval stage (Cover et al. 2015). The stonefly *Zwicknia bifrons* can be induced to enter nymphal diapause more than once (Khoo

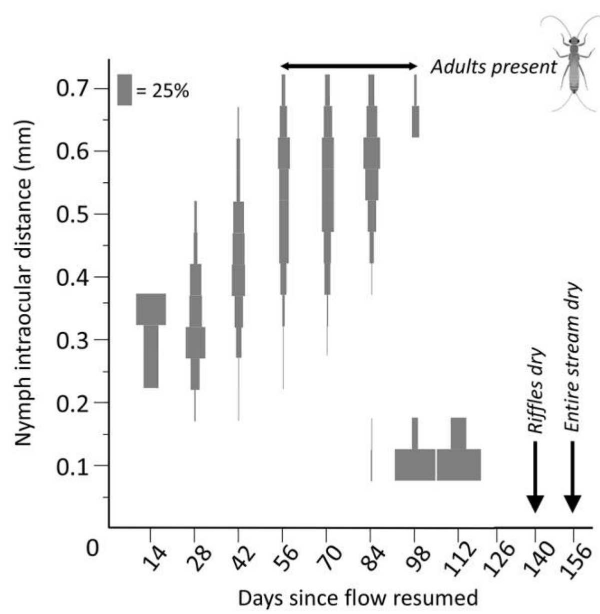

Figure 6. Size classes of *Mesocapnia arizonensis* nymphs from biweekly benthic samples collected from Bear Canyon across the 2012–2013 winter flow period. Width of gray bars indicate the relative abundance of size classes when binned at 0.05-mm intervals. Black arrows indicate when adult *M. arizonensis* were present, when riffles dried, and when the entire stream dried. Adult illustration by I. C. Phillipsen.

1968), and *Guadalgenus franzi* may exhibit both egg and larval dormancy (Agüero-Pelegrín and Ferreras-Romero 2002). Thus, *M. arizonensis* might exhibit a more complex life cycle within and across populations including both egg and nymphal dormancy, but this pattern was not documented with the limited geographic scope of my study.

Dormancy in *M. arizonensis* can last significantly >1 y in at least 1 population, as documented at West Stronghold Canyon. Multiyear climatic cycles (e.g., El Niño-Southern Oscillation) regularly leave short-flow duration intermittent streams in the region dry for periods of 2 to 5 y (Bogan et al. 2013). Jacobi and Cary (1996, p. 696) noted that species "with multiyear diapause would have an additional advantage in southwestern streams with unpredictable winter flow from year to year". A few stonefly species are known or assumed to be capable of dormancy lasting >1 y, including chloroperlids (Stewart and Anderson 2009) and perlodids (Snellen and Stewart 1979). Sandberg and Stewart (2004, 2005) reported that egg clutches of *Isogenoides zionensis* hatched slowly over a 4-y period in an artificial stream, with some eggs hatching immediately and others waiting years to hatch. This pattern could be a bet-hedging strategy (Philippi and Segar 1989) in streams with highly variable flow regimes, with eggs programmed to hatch in different years so that at least some offspring experienced favorable flow conditions. At least the studied population of *M. arizonensis* clearly has a similar capacity for long dormant periods, but other populations must be assessed to determine if this ability is widespread within the species. Furthermore, laboratory rearing of *M. arizonensis* eggs and dormant nymphs is needed. Such experiments could be used to test whether the species uses a bet-hedging strategy, with variable timing in emergence from dormancy to avoid catastrophic population losses in years when flow ceases before nymphs can mature.

In addition to drought-resistant diapause strategies, populations in short-flow duration streams could be 'rescued' periodically by populations from nearby streams with less-harsh flow regimes. Genetic analyses suggest that females of *M. arizonensis* can fly among hydrologically isolated populations (Phillipsen et al. 2015), so female dispersal and oviposition may enhance the resiliency of some populations. However, nymphs were abundant at West Stronghold Canyon within days of flow resumption, nearly 2 mo before adults emerged from nearby populations (Bogan 2012). These observations suggest that emergence from dormancy, not ovi-

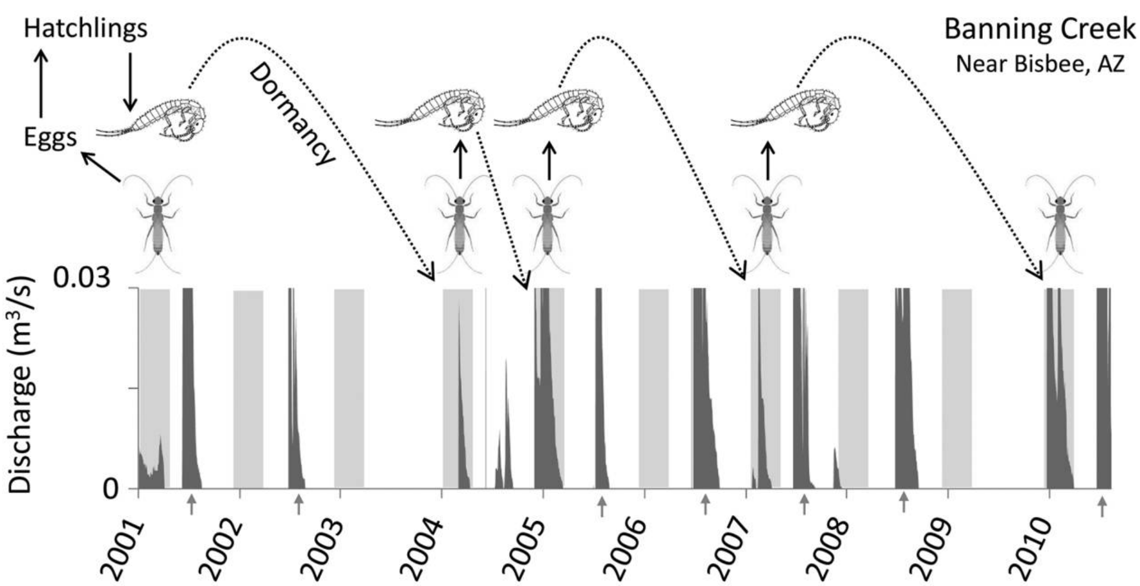

Figure 7. Hypothetical multiyear life cycle of *Mesocapnia arizonensis* at a typical intermittent stream habitat, Banning Creek, Arizona (US Geological Survey gage 09470700), from 2001–2010. Lightly shaded areas highlight the suitable season (December–April) for *M. arizonensis*. Small grey arrows indicate where summer monsoon storms cause scouring floods and high-flow periods. Discharge (*y*-axis) is truncated to maximize display of baseflow periods because large monsoon flood events (>10 m^3/s) render baseflow difficult to see. Successful nymphal development occurs when flow periods (dark grey) coincide with the winter flow period. Proposed life cycle: 1) nymphs emerge from dormancy when winter flow resumes, 2) nymphs rapidly grow and emerge into the adult stage, 3) adults mate and lay eggs, 4) eggs hatch, 5) hatchlings are in benthos for a brief time before crawling deep into the substrate, 6) hatchlings enter dormant stage deep enough in substrate to avoid monsoon flood scour, 7) at least some nymphs break dormancy during next winter flow period (1–5 y later). Adult illustration by I. C. Phillipsen and dormant nymph redrawn from Harper and Hynes (1970). AZ = Arizona.

position, was the primary source of stonefly nymphs at West Stronghold Canyon when flow returned.

A combination of rapid nymphal development, refuge-seeking behavior prior to dormancy, and the capacity for long-term dormancy may facilitate persistence in intermittent streams with highly variable flow regimes. In any given decade, streams in the study region may be dry for long periods of time, flow or not flow in winter, and flood or not flood in summer (Bogan et al. 2013). Based on the 2 populations in my study, *M. arizonensis* appears to be able to grow rapidly during brief winter flow periods, find deep refuges that are safe from summer floods, and remain dormant for several years (Fig. 7). Furthermore, bet-hedging strategies, such as staggered emergence from dormancy, would help buffer populations from 'false starts', when winter flow does not last the 6 wk needed by nymphs to reach adulthood (e.g., 2008 in Fig. 7). This 'hurry up and wait' life cycle enables *M. arizonensis* to thrive in intermittent streams that may have only 3 mo of winter flow once every few years.

Mesocapnia arizonensis may be one of a small number of aquatic insect species adapted to meet the challenges of the 21st century. In the coming decades, much of western North America is predicted to experience longer and more severe droughts than those of the historical record (Seager et al. 2007), which will reduce flow duration in many streams (Seager et al. 2012). Although unprecedented drying events are already causing local extinctions of several aquatic insect species in the region (Bogan and Lytle 2011), *M. arizonensis* seems particularly well adapted to long dry spells. Future studies should resolve the mechanisms that *M. arizonensis* uses to survive drying (e.g., egg vs nymphal dormancy), test the limits of the species to withstand long-term drought (i.e., >5 y), and understand how these factors vary across populations in streams with different flow regimes.

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