Bulletin of the Southern California Academy of Sciences

Volume 116 | Issue 3 Article 2

2017

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Bull. Southern California Acad. Sci.
116(3), 2017, pp. 162–173

The Effects of a Prolonged Drought on Southern Steelhead Trout (*Oncorhynchus mykiss*) in a Coastal Creek, Los Angeles, California

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Abstract.—Long-term lifecycle monitoring of federally endangered southern steelhead trout (*Oncorhynchus mykiss*) in Topanga Creek provides a unique opportunity to examine the health and abundance of a steelhead population before (2008–2011) and during (2012–2016) a prolonged drought. We found that the five-year drought resulted in a substantial and significant decline in available wetted habitat suitable for rearing and upstream migratory access for anadromous adults. The response of the steelhead population has been a significant reduction in anadromous spawning, distribution of rearing, and abundance of all life stages of anadromous and resident steelhead. After five years of drought a population that exceeded 325 individuals in 2008, now numbers fewer than 50 fish, and appears to be at extremely high risk of extirpation. Acknowledging the possibility of increased drought regionally and globally, the need to bolster southern steelhead resiliency to additional disturbance is paramount.

Southern steelhead trout (*Oncorhynchus mykiss*) are an endangered species, with an estimated population of less than 500 anadromous adults in California watersheds from Santa Barbara County south to the Mexican Border (NMFS 2012). Adapted to an intrinsically high disturbance environment, the life history trajectory of southern steelhead trout is extremely variable, and includes both resident and anadromous fish (NMFS 2012). The two genetically indistinguishable behavioral forms occur in the same watersheds in southern California, so this study refers to both forms as *O. mykiss*, unless otherwise noted. Threats in this region are high from both anthropogenic (fish passage barriers, habitat loss, water quality, etc.) and natural factors, like drought and wildfires (NMFS 2012). In prolonged periods of drought, flows may become insufficient to support upstream migration of adults from the ocean to freshwater spawning habitat during winter, and to support downstream migration of juveniles during spring. Drought conditions can impact juvenile rearing by preventing or restricting access to preferred habitats, and direct mortality at all life stages can occur when low flows isolate fish in disconnected or dewatered habitats, subjecting them to predation or stranding. Lower flows may also decrease invertebrate production and drift, thus reducing available food supply and negatively affecting growth (Harvey et al. 2006, Hakala and Hartman 2004, Canton et al. 1984). Despite the clear mechanism by which drought can impact salmonid populations, there are few long-term studies documenting the population level responses of salmonids to either direct or indirect effects of prolonged drought (Matthews and Marsh-Matthews 2003).

Topanga Creek has been a focal creek for lifecycle monitoring of *O. mykiss* since 2008. The small population occupying the creek was extirpated for almost 20 years between the drought of the late 1970's and re-establishment in 1998 (Bell et al. 2011a). The nine years of comprehensive

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monitoring and analysis of abundance, distribution, habitat suitability, and growth since 2008 provides a unique opportunity to closely examine the changes in this population in response to the recent California drought. In the Mediterranean winter-wet and summer-dry climate characteristic of southern California, seasonal drying of stream reaches is common, particularly when rainfall during the previous winter was normal or less than normal (Meixner and Wohlgemuth 2001, Dallas 2013). However, the recent five-year drought evolved from classification as 'abnormally dry' in 2012, to 'severe' in 2013, 'extreme' in 2014, and increased to 'exceptional drought' for all of 2015–2016 in the Santa Monica Bay (US Drought Monitor 2016). For the purposes of this study, "before drought" is classified as the period from 2008 through 2011, and the period of "drought" is classified as 2012 through 2016. Here we examine how this multi-year drought affected habitat conditions, abundance, and distribution for the Topanga Creek population of *O. mykiss*.

Materials and Methods

Topanga Creek drains a 50 km^2 coastal watershed into the Santa Monica Bay, entirely within Los Angeles County. Approximately 37 km^2 of the watershed is dedicated public open space, and the remaining area is privately held land. Distances upstream from the ocean within Topanga Creek are referred to as river kilometers (rkm). The study area (Fig. 1) extends from the ocean at Topanga Beach (0 rkm) upstream to the natural limit of anadromy (5.3 rkm). This represents both the current and documented range of *O. mykiss* from initial records in the 1930's to present in Topanga Creek. The study area is divided into two reaches. The lower reach (0–3.6 rkm) has a gradient between 0–3% and is characterized by alluvial floodplain and mixed riffle, runs and step pools, with 14 mid-channel pools that remained watered and with stable depth through multiple years of drought up to 2016, when much of the reach dried down to subsurface flows uninhabitable by *O. mykiss*. The upper reach (3.6–5.3 rkm) gradient ranges from 3–6%, with 16 boulder-dominated step pools, bedrock pools and mid-channel pools that remained wetted throughout the study period. There are no tributaries in the watershed that can support *O. mykiss*.

Long-term monitoring methods conducted in Topanga Creek have been previously described in Bell et al. (2011b) and Dagit et al. (2015).[1] Below we provide a summary of the key methods applied in analysis of the observed effects of the recent drought on steelhead habitat quality and population.

To characterize rainfall during the pre-drought and drought period, precipitation was measured by Los Angeles County Department of Public Works (LACDPW) gauge #318 located at the Topanga Fire Station in the center of the watershed (Fig. 1). Data is summarized annually as a water year (October 1 through September 30). Flow in Topanga Creek was recorded by a Los Angeles County stream gauge (LACDPW F54C) located in the lower main stem at 3.6 rkm (Fig. 1). This gauge was intermittently functional during the study period due to low flows and sediment buildup that isolated the gauge from the thalweg but was functional during high flows. Therefore, flow monitoring in Topanga Creek was used to assess anadromous steelhead migration opportunities that occur during high flows, but was not considered a reliable metric for characterizing average or low flows.

To describe stream habitat within Topanga Creek before and during the drought, habitat characteristic data including habitat type and river kilometer were measured and recorded

[1] Dagit, R., K. Adamek, S. Albers, E. Montgomery, and A. Sanchez. 2015. Topanga Creek Steelhead Monitoring March 2011–December 2014. Prepared for CDFW Contract No. P1050009. Available from: info@rcdsmm.org, RCD of the Santa Monica Mountains, 540 S. Topanga Canyon Blvd., Topanga, CA.

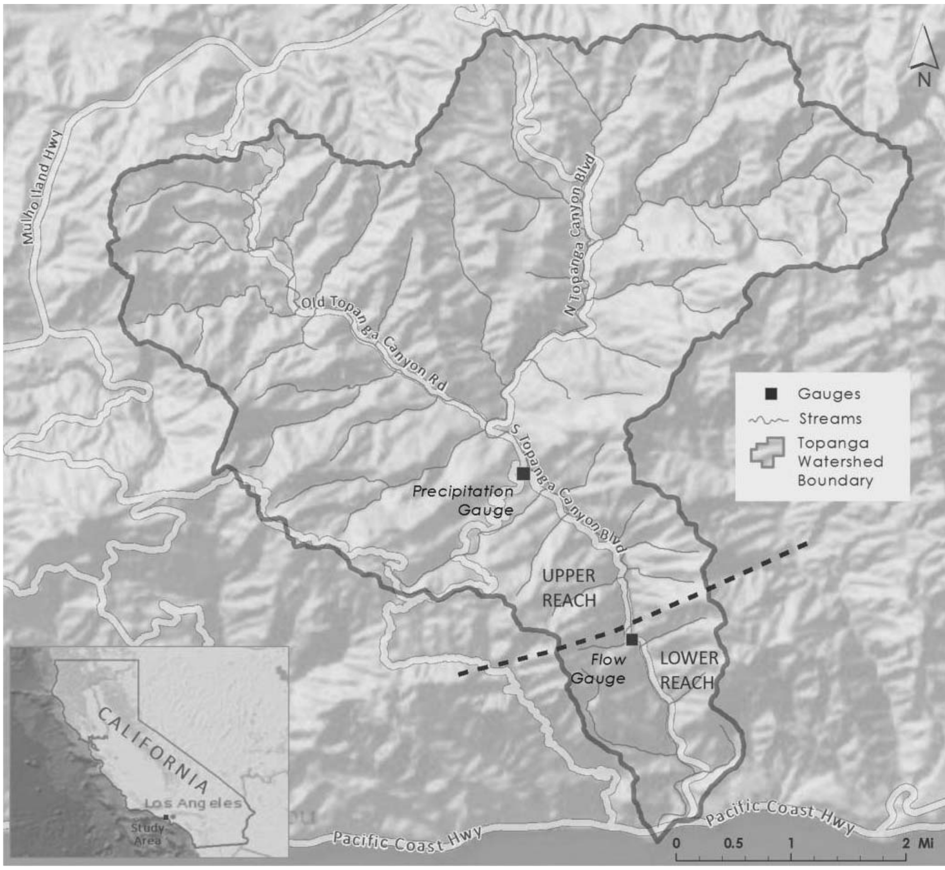

Fig. 1. Map of study reaches within the Topanga Creek study area (0–5.3 rkm)

during monthly surveys following the methods of Flosi and Reynolds (updated 2010). Pool habitat unit area and volume were estimated based on pool length, width, and average water depth measurements. Assessment of pool area and pool volume was conducted within 30 refuge pools (described below) to assess trends. Habitat characterization also included documentation of the proportion of dry habitat units. For analysis, data from the driest period of the year (July through September) was assessed to represent the most critical conditions for rearing and recruitment of young of the year *O. mykiss*.

To assess the abundance of *O. mykiss* within Topanga Creek before and during the drought, snorkel surveys were conducted monthly within all wetted habitat in the study area. Numbers of observed *O. mykiss* within individual habitat units were recorded for three size classes: young-of-year (<10 cm fork length [FL]), juvenile (10–25 cm FL), and adult (>25 cm FL). Data on redd location and size (length, width, depth, and substrate size) were recorded according to the redd survey protocol developed by NMFS (2010).

Conditions during the snorkel surveys were highly variable, and the amount of wetted habitat varied substantially as dry down occurred during the drought. To assess trends in observed abundance independent of shifts in wetted habitat, a subset of 30 pools (14 in the lower reach, 16 in the upper reach) were selected for targeted monitoring. These pools were continuously wetted even during the driest conditions observed, with the exception of four pools in the lower reach which experienced dry down in 2016. These 30 "refuge" pools were surveyed monthly for *O. mykiss* observed abundance, and analyzed separately from the comprehensive snorkels surveys (which included the entire study reach), to assess trends in observed abundance independent of wetted habitat.

To assess growth rates and migration patterns of *O. mykiss* before and during drought, a total of twelve Passive Integrated Transponders (PIT) tag mark-recapture events were held in November of 2008–2016, and March of 2011–2013. During each event, all wetted habitat units were sampled with one pass using two backpack electrofishers. Captured fish were anesthetized with MS-222, scanned with a hand-held PIT tag reader, and fork length was measured to the nearest millimeter with a wetted fish measuring board. New captures were also tagged before being released upon recovery in their pool of capture. A more detailed description of these methods is found in Dagit and Krug (2016).

Analysis consisted of exploring relationships between environmental descriptions of the drought (rainfall, fraction of dry habitat units, pool volume, pool area), and population metrics (observed abundance, spatial distribution) of *O. mykiss* before (2008–2011) and during drought (2012–2016). Conditions were further assessed based on annual precipitation as well as precipitation during the lowest-flow period of the year (average of the July, August, and September) for each year. Abundance of *O. mykiss* of was based on redd counts, number of *O. mykiss* observed in all units surveyed during monthly snorkel surveys, and by the subset of the population within the 30 refuge pool units. Analyses were made using the average values of abundance across all months of the calendar year, and average values for the lowest-flow period of the year (averaging July, August, and September).

Results

Precipitation before drought averaged 54.56 cm (21.48″), and was substantially higher than the 25.12 cm (9.89″) annual average during the drought (t-test; $p < 0.01$; Table 1). Consequently, average pool area of the 30 refuge pools declined substantially in the drought period (t-test; $p < 0.01$; Fig. 2), as did average pool volume (t-test; $p < 0.05$; Fig. 3). With the decline in precipitation, the percentage of the study area that was dry July-September before drought (32%) increased significantly (t-test; $p < 0.05$) during the drought 46%. The lower reach of Topanga Creek (with corresponding lower gradient, 0–3.6 rkm) experienced seasonal dryness to some extent in all years, but the drought increased the length (both spatially and temporally) of low flow or sub-surface flow conditions (Fig. 4). The upper creek (upstream of 3.6 rkm) did not have dry sections, but did experience lower pool volume and flow conditions in drought.

Drought and creek condition metrics were strongly correlated. Rainfall was a good predictor of how long the seasonally dry sections would remain dry ($R^2 = 0.75$, $p = 0.006$) as well as how much of the reach would have dry patches ($R^2 = 0.76$, $p = 0.006$) (Fig. 4). Some of the areas that remained wetted were likely sustained by groundwater input from a variety of seeps and springs located throughout that reach (Tobias[2] 2006). The frequency and magnitude of high-flow events declined during 2012–2016 (Fig. 5). From 2008–2016, the longest period of potential anadromous migration (adults or smolts) was for two days in February 2010 and March 2011. Between 2013 and 2016 there were fewer than five days total with sufficient flows (greater than

[2] Tobias, V.D. 2006. Groundwater sources and their influence on the distribution of steelhead in Topanga Creek, Topanga, California. Master's thesis. University of Michigan, Ann Arbor.

Table 1. Summary of environmental conditions and response of *O. mykiss* before drought (2008–2011) and during drought (2012–2016) in Topanga Creek, California.

	t-test (one-tailed, homoscedastic)		
	Before drought 2008–2011	Drought 2012–2016	p-value
Drought metrics			
Jul-Sep dry (% of study area)	32	46	0.022*
Rainfall (inches)	21.48	9.89	0.007**
Jul-Sep pool area (m^2)	5739.83	3973.01	0.008**
Jul -Sep pool volume (m^3)	372185.08	278057.09	0.028*
Spawning activity			
Redd counts	4.00	1.60	0.044*
Jul-Sep average abundance: study area			
Young of the year (length ≤10 cm)	155.00	37.60	0.031*
Juvenile (length 10–25 cm	91.08	26.20	0.019*
Adult (length ≥25 cm)	17.58	8.40	0.006**
All	263.67	72.20	0.010*
Jul - Sep average abundance: thirty pools			
Young of the year (length ≤10 cm)	52.63	12.60	0.038*
Juvenile (length 10–25 cm	45.04	14.33	0.012*
Adult (length ≥25 cm)	10.04	4.80	0.009**
All	107.71	31.73	0.006**

*$p < 0.05$.
**$p < 0.01$.

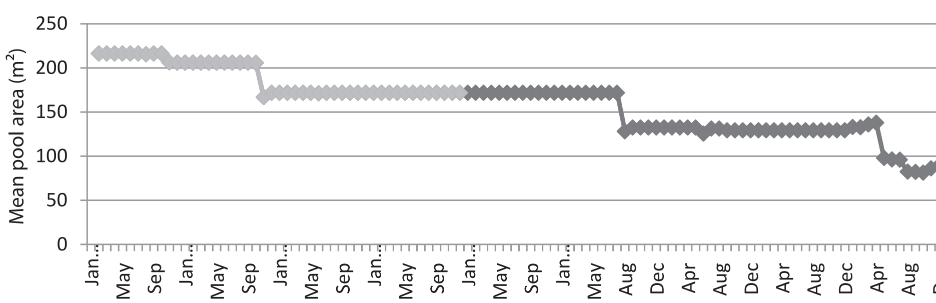

Fig. 2. Mean pool area within study area before (2008–2011) and during (2012–2016) drought in Topanga Creek.

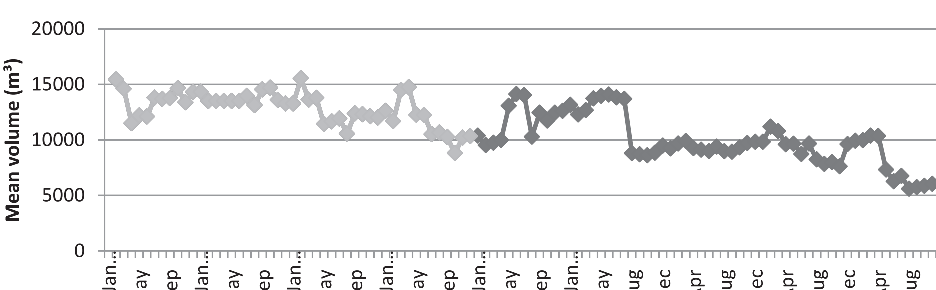

Fig. 3. Mean pool volume within study area before (2008–2011) and during (2012–2016) drought in Topanga Creek.

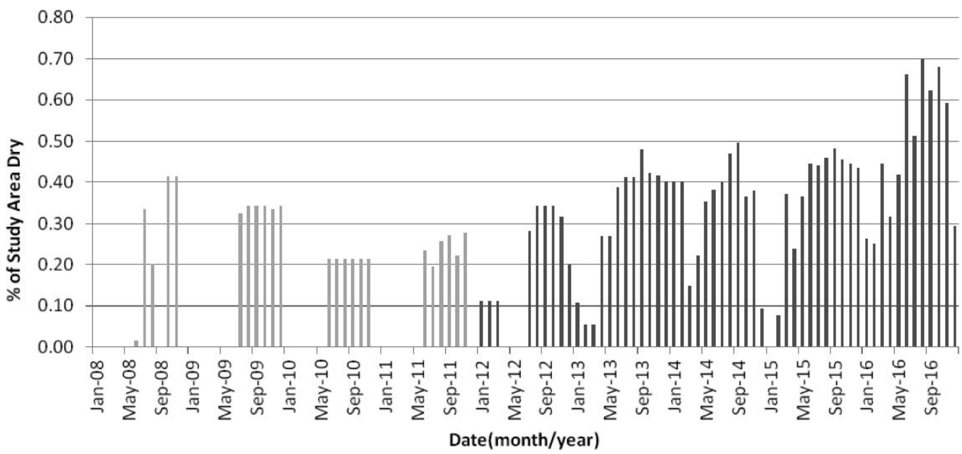

Fig. 4. Percentage of study area that was dry before (2008–2011) and during (2012–2016) drought in Topanga Creek.

100 cfs mean daily flow) to connect habitat and provide anadromous fish passage for adults or smolts (RCDSMM unpublished data).

The average number of observed *O. mykiss* in July through September significantly declined from before drought (263 individuals) to drought years (72 individuals, t-test; $p < 0.01$) throughout the study area (Table 1). Declines were significant for all age classes, most substantially for adults, which declined from an average of 18 adults before drought, to eight adults on average during the drought (t-test; $p < 0.01$). Fewer observations of *O. mykiss* during drought was also apparent when analysis focused on the 30 refugia pools. There was a significant decline in

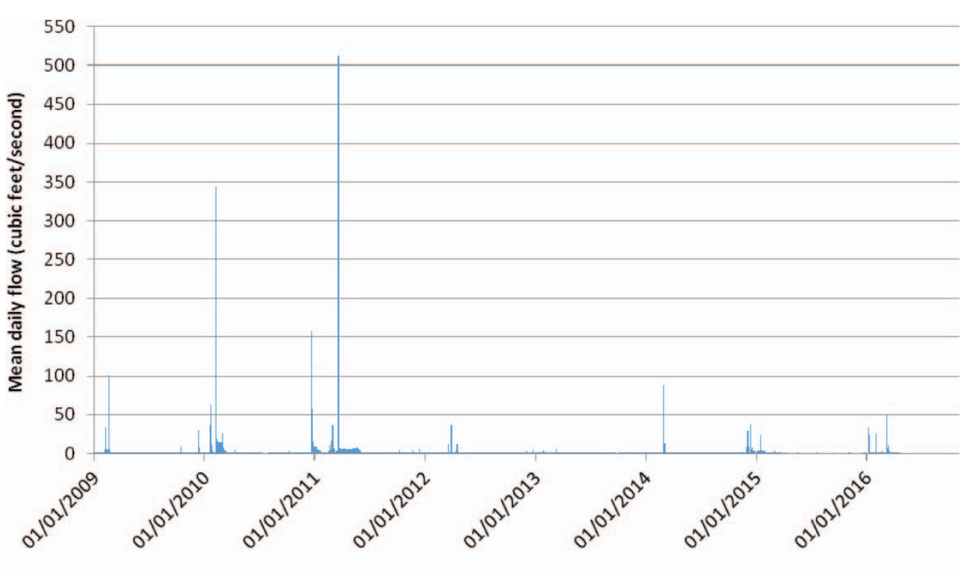

Fig. 5. Flow measurements in Topanga Creek during high flow events (cfs) at F54C-R. Provided by Los Angeles County Department of Public Works.

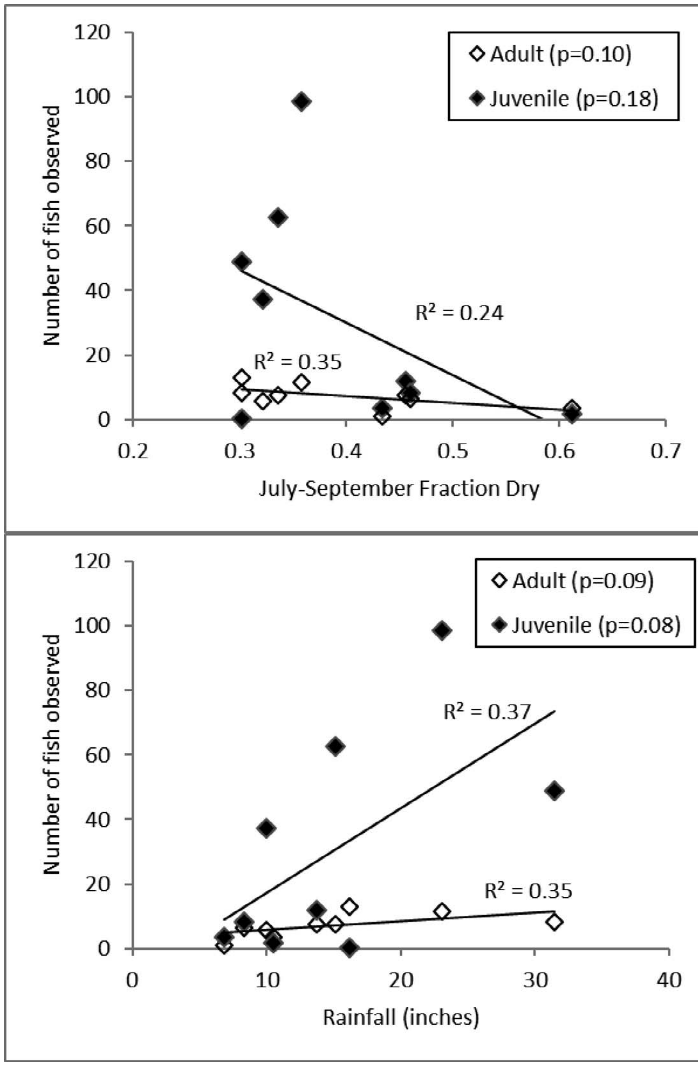

Fig. 6. Observed *O. mykiss* abundance in 30 refuge pools during July, August, and September surveys compared to creek drying and annual rainfall.

observed abundance for all three age classes of trout combined (t-test; $p < 0.01$). Observed abundance was negatively correlated with the fraction of dry units, and positively correlated with annual rainfall, though neither correlation was statistically significant (Fig. 6). Overall, the abundance of young-of-year *O. mykiss* was significantly lower during the drought (t-test; $p < 0.038$; Table 1). The total number of observed *O. mykiss* redds was low prior to the drought (<5), and declined significantly during the drought (t-test, $p < 0.05$), with no redds observed during 2015 or 2016. A single anadromous adult was observed each year of 2008, 2010, and 2012; but based on redd size and presence of few anadromous adults, the majority of redds were produced by resident *O. mykiss*.

Distribution of *O. mykiss* in Topanga Creek was normally seasonally affected by low flow barriers and impediments to migration before drought, but loss of surface flow measured during snorkel surveys expanded during the drought. From 2008–2011 many of the passage impediments were still passable by fish moving downstream even under low flow conditions, however as the drought continued, flows decreased and wetted habitat contracted making movement difficult either up or downstream except during rain events. Overall, the remaining fish re-distributed to the remaining available habitat as portions of the stream dried up. Thus, the number of habitat units observed to be occupied by *O. mykiss* decreased substantially during the drought from an average of 55 habitat locations before the drought to 33 habitat locations during the drought (t-test; $p < 0.01$; Table 1). The distribution of redds also shifted upstream of 3.6 rkm as the dry downs below 3.6 rkm expanded, concentrating them into remaining wetted habitat upstream.

Discussion

Seasonal droughts are a recurrent and defining feature of Mediterranean climate streams, with predictable reductions in flows during the dry summer and fall months (Lake 2011). *Oncorhynchus mykiss* populations are adapted to regular reductions in stream flows, and have historically persisted and thrived within their southern range (NMFS 2012). However, the results of this study indicate that a prolonged drought severely limited available habitat for *O. mykiss*, with a subsequent negative impact on anadromous spawning, opportunity for smolt migration, and total observed abundance of all life stages.

While the significant loss of surface flows and wetted available habitat reported in this study have a direct impact on *O. mykiss* abundance, the synergistic ripple effects of other elements associated with drought such as habitat type conversion, decreased water quality, potential changes to stream thermodynamics, reduced abundance of benthic macro-invertebrate food sources (Garcia et al. 2015, Matthews and Marsh-Matthews 2003, Montgomery et al. 2015) also likely contributed to the significant decline in numbers of observed *O. mykiss*. Habitat type conversion from runs to riffles, and riffles to patches of emergent vegetation, reduced available suitable spawning, rearing and holding refugia (Resource Conservation District of the Santa Monica Mountains (RCDSMM) unpublished data). Habitat quality was compromised by reduced volume in the refugia pools. By August 2016, it was necessary for the California Department of Fish and Wildlife (operating under a permit from National Marine Fisheries Service) to relocate three individuals ranging in size from 10 – 30 cm FL due to stranding in evaporating pools with dissolved oxygen levels below 2 mg/l (RCDSMM unpublished data). It appeared that groundwater sources ameliorated the effect of reduced surface flows on water temperature to some extent, such that maximum and average summer temperatures did not increase during the drought (Montgomery et al. unpublished). However, the minimum temperatures steadily rose during April and May over the drought years and eventually exceeded 15°C, the critical threshold identified by Myrick and Cech (2005) for *O. mykiss* egg incubation and emergence. Our results were not able to discern if this increase in minimum temperatures impacted egg viability or spawning success, but few redds were observed, and fry production was severely limited during the drought.

Previous research on the population of *O. mykiss* in Topanga Creek by Bell et al. (2011a) focused on population factors that supported their long-term persistence in this small creek with high disturbance regime. The conceptual model that resulted from this research suggested that the most significant limiting factors for the population were associated with limited migration opportunities for smolts to reach the ocean, and anadromous adults to return to the creek to spawn (Bell et al. 2011a); both factors which are strongly affected by drought. In Topanga Creek, rate of reproduction does not appear sufficient to seed available rearing habitat. Analysis of age class response using July – September average values highlight the loss of young of the year and low recruitment as the drought intensified (Table 1). The lack of young of the year in 2011 appeared to be related to a strong storm event in March of that year when snorkel surveys revealed that the numbers of smolt size *O. mykiss* dropped abruptly (RCDSMM unpublished data). The small increase observed in 2015 reflects successful recruitment from three resident redds found in 2014.

Because adult anadromous steelhead fecundity (usually >3,000 eggs per female) is much greater than that of resident female *O. mykiss* (usually <1,000 eggs) (Moyle 2002), population dynamics are potentially very different in years when anadromous individuals spawn versus years in which only resident *O. mykiss* spawn. Therefore, one of the most significant effects of the drought was likely the dramatic reduction in days when the lower reach of the study area received sufficient flows to support anadromous migration. Consequently, during the drought there was no anadromous spawning, as well as limited resident spawning, and thus very low levels of fry production.

Lagoon conditions were not analyzed in this paper, but would have a strong influence on the potential opportunities for anadromy as well. Topanga lagoon is currently 0.72 hectares of wetted area constrained by fill banks on the east and west, with only a 24 m opening under the Pacific Coast Highway bridge. There is little wetland vegetation and extremely limited instream cover for fish. Lagoon rearing habitat for juvenile *O. mykiss* migrants preparing to smolt has been demonstrated to be critically important for California coast steelhead populations. Significantly higher growth rates and ocean survival by steelhead that reared in lagoons has been documented, even with lagoon water temperatures as high as 24°C (75°F) (Smith 1990[3], Hayes et al. 2008, Bond et al. 2008). Depending partly on growing conditions in their rearing habitat, steelhead may migrate downstream to estuaries as age 0+ juveniles or may rear in streams for up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Ocean connectivity, as well as up and downstream movement were severely limited between the lagoon and the creek, reducing the life history diversity to resident only individuals.

Food for *O. mykiss* in Topanga Creek documented before the drought by gastric lavage was dominated by dipterans, tricoperans and baetids (Krug et al. 2012). There are numerous studies that document the response of BMI communities to drought (Hall et al. 2016, Stillwater 2007). In Topanga Creek Montgomery et al. (2015) found a significant shift from a baetid dominated community to a chironomid dominated community in low rainfall years, with extremely low numbers overall. Therefore, we expected to see a reduction in growth rates for the Topanga Creek population during the drought. We observed that growth rates declined slightly during the drought, but were not significantly different than those observed prior to drought conditions. This suggests that even with more restricted habitat available, and a potentially different suite of food organisms available, the fewer number of fish (and thus lower density) were still able to find sufficient food and continue to grow.

Following the drought, the population in 2016 numbered fewer than 50 individuals, with approximately 10 resident adults, and no anadromous spawning. These low numbers paired with spatial isolation could potentially cause a severe genetic bottleneck in the population. A severe reduction in, or extirpation of the Topanga Creek population has substantial implications for the entire Southern California steelhead meta-population as well. Analysis indicates that the *O. mykiss* in Topanga Creek are genetically distinct from other populations and have little

[3] Smith, J. J. 1990. The effects of sandbar formation and inflows on aquatic habitat and fish utilization in Pescadero, San Gregorio, Waddell and Pornponio Creek Estuary/Lagoon systems, 1985–1989. Dept. Bio. Sci., San Jose State University, San Jose, California.

influence from historical hatchery introductions (RCDSMM unpublished data). The long-term recovery of the southern California steelhead trout throughout their range relies on genetic intermixing that is only possible with sufficient smolt production, and migration opportunities in source watersheds (Boughton et al. 2006), especially since increased resiliency to climate change may require specific genetic adaptations that could occur in independent populations like Topanga Creek (NMFS 2016, Clemento et al. 2009). However, the loss of migratory opportunity documented here in the 2012 to 2016 Topanga Creek *O. mykiss* because of drought induced loss of habitat connectivity and population abundance prevents genetic mixing with the meta-population.

Although it is challenging to assign the decline of *O. mykiss* relative abundance in Topanga Creek solely to drought (i.e., overall numbers of individuals were low before the drought), it is evident that the increased loss of habitat connectivity and migration opportunities poses a substantial threat. This genetically distinct population segment possesses a unique diversity of adaptations that has permitted them to survive the erratic and unpredictable climate conditions in southern California for millennia, but the cumulative impact of both anthropogenic and natural stressors has brought the population to the brink of extinction (NMFS 2012). The most recent five-year drought highlights the tenuous condition of these small populations in coastal creeks, with the decline in relative abundance observed in Topanga Creek being just one example. This population blinked out in response to drought in the 1980's (Bell et al. 2011b), but at that time there were more straying anadromous adults to re-establish the population when habitat connectivity was available. NMFS (2016) concluded that the drought has increased the threat level to the already endangered population, and recommends the prevention of local extirpations of steelhead populations. Restoring wetland function and habitat quality of the degraded lagoon habitat in Topanga Creek watershed could potentially support *O. mykiss* recovery and resiliency both locally and regionally by facilitating smolting and providing greater opportunity for fish passage and anadromous recruitment.

Conclusions

Long-term monitoring of the Topanga Creek population of *O. mykiss* presented a unique opportunity to assess the impacts of a prolonged five-year drought in a southern California coastal stream. We found that below average rainfall during five years of drought resulted in too few substantial flow events to provide habitat connectivity and support anadromy. The proportion of wetted habitat significantly declined, as did the total number of habitat units available to support *O. mykiss*. No anadromous spawning occurred and resident spawning also significantly decreased during the drought period. Abundance of all life-stages of *O. mykiss* in Topanga Creek significantly declined throughout the study reach and within monitored refuge pools, but growth rates of individuals in those pools declined only slightly. Continued monitoring of the Topanga Creek population is highly recommended to further clarify the long term impacts of the drought, and/or to monitor the recovery of the population from this chronic disturbance.

Acknowledgements

Funding for this effort was provided though contracts with the California Department of Fish and Wildlife Fisheries Restoration Grants Programs numbers P105009, P1350010, P1450013 and P1550012. The Los Angeles County Fish and Game Commission, and Los Angeles County District 3 provided additional equipment. Additional thanks to California State Parks for providing access and their work to conserve and protect Topanga State Park. Field work was conducted by RCDSMM Stream Team members including: S. Albers, A. Balcerzack, H. Block,

B. Chubak, P. Essig, J. Krug, D. Lathers, C. Menegin, J. Shuman, S. Severyn, K. Wheeland, K. Widen, and S. Williams. Many local Watershed Steward Project members also contributed their efforts including A. Blue, A. Esperza-Camacho, B. Chandler, K. Christionason, C. Fong, K. Gangle, C. Garcia, L. Gonzalez, D. Gottsman, D, Hofflander, A. Krist, S. Mueller, T. Reeder, A. Sanchez, and Yi-Jiun Tsai. We greatly appreciate the assistance of Salvador Contreras Robledo for the map, and Danielle Alvarez for help with Figures. This paper benefitted from review and input by Dana McCanne, Kate McLaughlin, Mary Larson, Dr. Camm Swift and two anonymous reviewers.

Literature Cited

Bell, E., R. Dagit, and F. Ligon. 2011a. Colonization and persistence of a southern California steelhead (*Oncorhynchus mykiss)* population. Bull. So. Calif. Acad. Sci. 110:1–16.

Bell, E., S.M. Albers, J.M. Krug, and R. Dagit. 2011b. Juvenile growth in a population of southern California steelhead (*Oncorhynchus mykiss)*. Calif. Fish Game 97(1):25–35.

Bond, M.H., S.A. Hayes, C.V. Hanson, and R.B. MacFarlane. 2008. Marine survival of steelhead (*Oncorhynchus mykiss*) enhanced by a seasonally closed estuary. Can. J. Fish. Aq. Sci. 65:2242–2252.

Boughton, D.A., P.B. Adams, E. Anderson, C. Fusaro, E. Keller, E. Kelley, L. Lentsch, J. Nielson, K. Perry, H. Regan, J. Smith, C. Swift, L. Thompson, and F. Watson. 2006. Steelhead of the south-central/southern California coast: Population characterization for recovery planning. NOAA-TM-NMFS-SWFSC- 394. NOAA Tech. Mem. October 2006.

Canton, S.P., L.D. Cline, R. Short, and J.V. Ward. 1984. The macroinvertebrates and fish of a Colorado stream during a period of fluctuating discharge. Fresh. Bio. 14:311–316

Clemento, A.J., E.C. Anderson, D. Boughton, D. Girman, and J.C. Garza. 2009. Population genetic structure and ancestry of *Oncorhynchus mykiss* populations above and below dams in south-central California. Conserv. Gen. 10:1321–1336.

Dagit, R., and J. Krug. 2016. Rates and effects of branding due to electroshock observed in southern California steelhead (*Oncorhynchus mykiss*) in Topanga Creek, California. Management Brief. N. Am. J. Fish. Man. 36(4). http://dx.doi.org/10.1080/02755947.2016.1173136

Dallas, H.F. 2013. Ecological status assessment in Mediterranean rivers: Complexities and challenges in developing tools for assessing ecological status and defining reference conditions. Hydrobiologia 719: 483–508.

Flosi, G., and F. L. Reynolds. 2010. California salmonid stream habitat restoration manual. Second edition. California Department of Fish and Game, Sacramento.

Garcia, C., E. Montgomery, J. Krug and R. Dagit. 2015. Removal efforts and ecosystem effects of invasive red swamp crayfish (*Procambarus clarkii*) in Topanga Creek, California. Bull. So. Calif. Acad. Sci. 114(1): 12–21.

Hakala, J.P., and K.J. Hartman. 2004. Drought effect on stream morphology and brook trout (*Salvelinus fontinalis*) populations in forested headwater streams. Hydrobiologia 515:203–213.

Hall, L. W. Jr., R. D. Anderson, and W. K. Killen. 2016. Spatiotemporal trends analysis of benthic communities and physical habitat during non-severe drought and severe-drought years in a residential creek in California. Calif. Fish Game 102(2):55–70

Harvey, B.C., R.J. Nakamoto, and J.L. White. 2006. Reduced streamflow lowers dry-season growth of rainbow trout in a small stream. Trans. Am. Fish. 135:998–1005.

Hayes, S.A., M.H. Bond, C.V. Hanson, E.V. Freund, J.J. Smith, E.C. Anderson, A.J. Ammann, and R.B. MacFarlane. 2008. Steelhead growth in a small central California watershed: upstream and estuarine rearing patterns. Trans. Am. Fish. 137:114–128.

Krug, J., E. Bell, and R. Dagit. 2012. Growing up fast: diet and growth of a population of *Oncorhynchus mykiss* in Topanga Creek, California. Calif. Fish Game 98(1):38–46.

Lake, P.S. 2011. Drought and aquatic ecosystems: effects and responses. Wiley and Blackwell, Wiley Online Library 9781444341812; ePub 9781444341799.

Matthews, W.J. and E. Marsh-Matthews. 2003. Effects of drought on fish across axes of space, time and ecological complexity. Fresh. Bio. 48:1232–1253

Meixner T., and P. M. Wohlgemuth. 2001. The San Dimas Experimental Forest: long term study of fire, water and vegetation. American Geophysical Union, Fall Meeting 2001, abstract #H41A-0268 http://adsabs.harvard.edu/abs/2001AGUFM.H41A0268M.

Montgomery, E., C. Garcia, K. Krug, and R. Dagit. 2015. Evidence for negative effects of drought on benthic macroinvertebrate community of a southern California Stream. Bull. So. Calif. Acad. Sci. 114(3):129–140.

Moyle, P.B. 2002. Inland fishes of California. Revised edition. Univ. of Calif. Press, Berkeley.

Myrick, C.A., and J.J. Cech. 2005. Effects of temperature on the growth, food consumption, and thermal tolerance of age-0 Nimbus-strain steelhead. N. Am. J. Aqua. 67:324–330.

NMFS. 2010. Southern California Redd Survey Protocol. (updated in 2015). Southwest Regional Office, Long Beach, CA. 10 pp.

NMFS. 2012. Southern California Steelhead Recovery Plan. Southwest Regional Office, Long Beach, CA. 430 pp.

NMFS. 2016. 5-Year review: summary and evaluation of southern California Coast Steelhead Distinct Population Segment. National Marine Fisheries Service. West Coast Region, California Coastal Office, Long Beach, CA. 8 pp.

Shapovalov, L., and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special referenceto Waddell Creek, California, and recommendations regarding their management. Calif. Fish Game. Fish Bulletin 98. 373 pp.

US Drought Monitor. 2016. National Drought Mitigation Center (NDMC), the U.S. Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA). Available at droughtmonitor.unl.edu