California Fish and Game 97(1):25-35; 2011

Juvenile growth in a population of southern California steelhead (*Oncorhynchus mykiss*)

ETHAN BELL*, SANDRA M. ALBERS, JENNA M. KRUG, AND ROSI DAGIT

Stillwater Sciences, 850 G Street, Arcata, CA 95521, USA (EB)

Resource Conservation District of the Santa Monica Mountains, P.O. Box 638, Agoura Hills, CA 91376-0638, USA (SMA, JMK, RD)

**Correspondent: ethan@stillwatersci.com*

The life histories of *Oncorhynchus mykiss* populations in the southern portion of their range have received less attention than in the Pacific Northwest, and have only recently been the subject of focused studies. Here we examine size-at-age data collected from *O. mykiss* in Topanga Creek, Los Angeles County, California, where research has been conducted for nearly a decade. Our results suggest that all age classes of resident and anadromous *O. mykiss* in Topanga Creek grow year-round despite high summer water temperatures. In addition, age 2 steelhead smolts attain a size that has been associated with high (>10%) marine survival in other studies.

Key words: steelhead, *Oncorhynchus mykiss*, southern California, Topanga Creek, water temperature, bioenergetics, growth, size, survival

---

Steelhead trout (*Oncorhynchus mykiss*) in Topanga Creek, southern California, belong to the federally endangered Southern California Steelhead Evolutionarily Significant Unit (now Distinct Population Segment), as modified in July 2002. Steelhead refers to the anadromous life-history form of rainbow trout (*O. mykiss*); because both anadromous and resident *O. mykiss* are found within the watershed, the term *O. mykiss* is used in situations where distinguishing juvenile steelhead from resident rainbow trout would be problematic. Although the anadromous life-history was the basis for listing (NMFS 2006), preservation of both life-history forms is considered a high priority (NMFS 2009).

Despite their perilous condition, little is known about basic life-history of steelhead in southern California. For example, the growth rate of juvenile steelhead during freshwater rearing can have important consequences on their survival during outmigration and entry into the ocean (Kabel and German 1967, Hume and Parkinson 1988, Ward and Slaney 1988, Ward et al.1989, Bond et al. 2008). Therefore, as recommended by Boughton (2010), measuring juvenile growth rates and factors that may affect these rates in freshwater is likely crucial for maintaining or restoring steelhead populations in southern California streams.

Growth of fish is highly dependent on their metabolic rate as affected by water temperature, as well as food availability. Water temperature in turn is affected by several key environmental parameters, including instream flows, riparian condition, groundwater influence, and channel morphology— all of which have drastically different characteristics in southern California than in the more northern streams. However, until recently, all available information on steelhead growth has been based on populations found in larger watersheds further north (e.g., Shapovalov and Taft 1954, Sogard et al. 2009). Based on the work of Spina (2007), there is reason to believe that steelhead in southern California, such as those in Topanga Creek, have life history characteristics that are adapted to their specific environmental conditions, suggesting the importance of avoiding reliance on data from northern conspecifics, and the strong need to develop regional data specific to southern California steelhead (Boughton 2010). This study focuses on an *O. mykiss* population in the small, southern California coastal stream of Topanga Creek. The objective of this study was primarily to describe the size-at-age structure of the *O. mykiss* population in Topanga Creek as an assessment of age-specific growth. In addition, we attempted to assess a key environmental parameter, water temperature, that affects growth and evaluate whether juvenile steelhead are growing enough to achieve sizes that have been associated with high rates of ocean survival.

Materials and Methods

Study area.—Topanga Creek drains a 47-km^2 watershed, is the third largest watershed within the Santa Monica Bay, Los Angeles County, and is adjacent to the City of Los Angeles (Figure 1). Although believed to be extirpated in the 1980s, a self-sustaining population of *O. mykiss* is now documented to occur within the study reach from the ocean upstream to the town at river kilometer (rkm) 6 (Bell et al. *in press*). Characterized by steep sided canyons, a narrow mainstem channel, numerous faults, and a well-established riparian corridor, the study reach includes the documented historic and present distribution of *O. mykiss*, and is located entirely within Topanga State Park. Despite flashy hydrologic conditions common to steep gradient creeks, Topanga Creek provides suitable spawning, summer and winter rearing habitat, and persistent refugia habitat. The reach of Topanga Creek (rkm 0.5-1.5) downstream of the antenna-trap location (Figure 1) is typically intermittently dewatered from May through November. Other native fish species found in Topanga Creek include Arroyo chub (*Gila orcuttii*) and tidewater goby (*Eucyclogobius newberryi*). A population of invasive red-swamp crayfish (*Procambarus clarkii*) became established in 2004, but there are no other invasive aquatic species present. Despite a population of approximately 12,000 people, and a main state highway following the creek channel from north to south, water quality remains suitable to support *O. mykiss.*

Fish collections and growth analysis.—Fish were collected between October 2008 and November 2010 using electrofishing, baited hoop-nets, and downstream migrant trapping. A total of 551 *O. mykiss* was captured during sampling efforts in November 2008, 2009, and 2010. An additional 11 fish were captured in the downstream migrant trap in January 2010. Electrofishing began at rkm 1.7 (below which point flow intermittently dropped beneath the bed surface) and continued upstream to rkm 4.4 in 2008, rkm 4.2 in 2009, and rkm 5.3 in 2010. Hoop-net traps were set and baited for up to

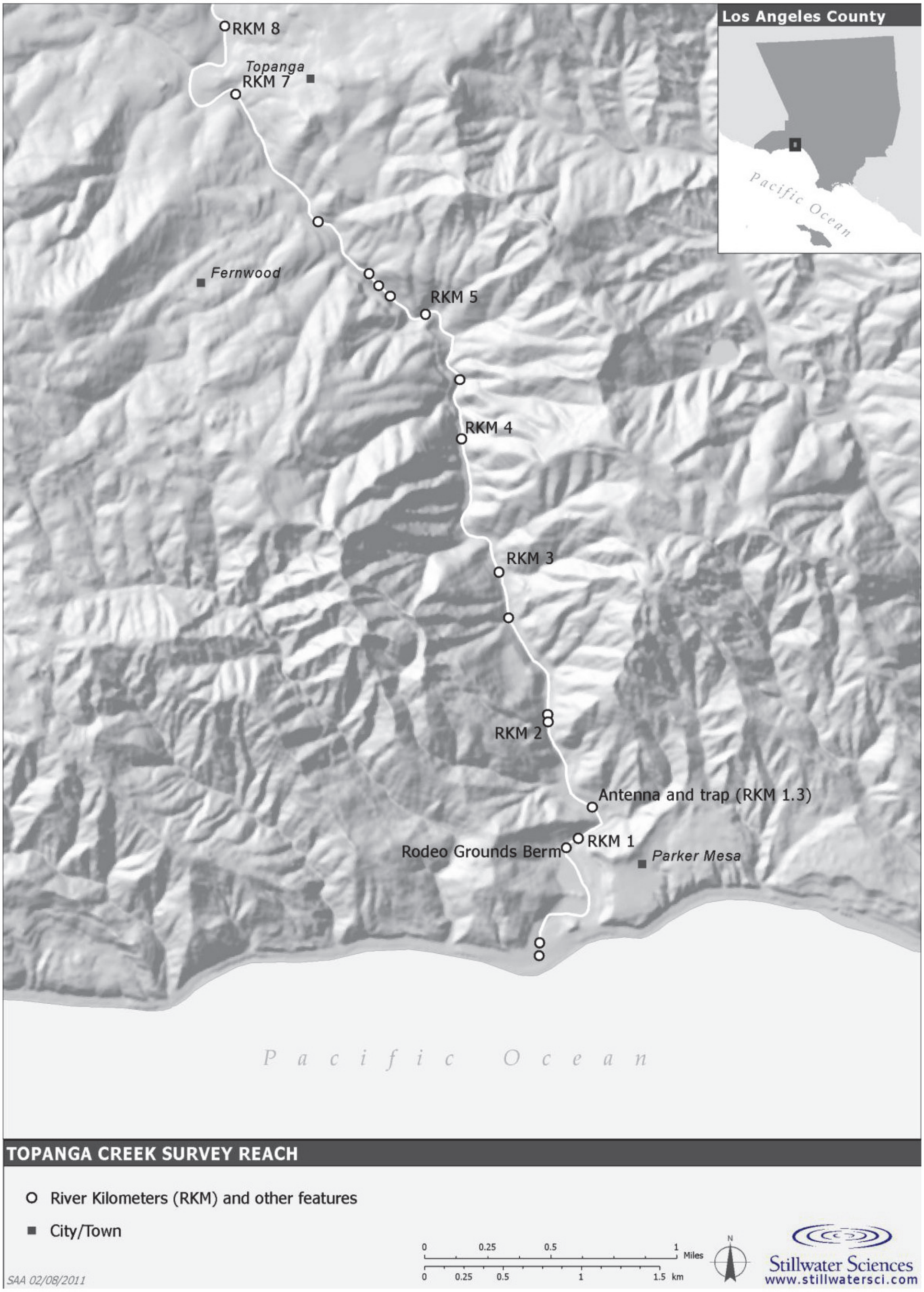

Figure 1.—Study Area in Topanga Creek, Los Angeles County, California, 2008-2010.

twelve hours in larger, deep pools where electrofishing was not effective. All *O. mykiss* captured were anesthetized and fork lengths (FL) measured to the nearest millimeter. Depending on size, fish were tagged with either a full-duplex (110-125 mm FL) or half-duplex (>125 mm FL) passive integrated transponder tags (PIT tags). Half-duplex tags are detected by the PIT-tag antennae (see Stillwater et al. 2010), and both tag types could be detected using a hand-held PIT-tag reader on subsequent captures. Overall, 59 fish were tagged with full-duplex PIT tags, and 288 with half-duplex PIT tags.

Ages were assigned to the population during each sampling event by summarizing the length frequency distribution of all captured fish. Groupings by size generally indicate age grouping, which were validated by scale analysis and otolith readings. Scales were collected and analyzed from 101 *O. mykiss* in 2008, 95 in 2009, and 14 recaptured *O. mykiss* in 2010. Scales were prepared following procedures described in Drummond (1966) and independently analyzed by Resource Conservation District of the Santa Monica Mountains (RCDSMM), California Department of Fish and Game (CDFG), and National Marine Fisheries Service (NMFS) staff. Age of fish was determined using the methods of DeVries and Frie (1996), and established a range of sizes for each age grouping. In addition, following three unintentional mortalities of sampled fish, otoliths were extracted, cleaned, photographed, and used to independently validate age groupings.

Annual growth rates were estimated for the period from November 2008 to November 2009, and from November 2009 to November 2010. For each recaptured PIT tagged fish, annual growth (mm/year) was calculated as the change in fork length between the time of tagging and the time of recapture. One PIT tagged fish was recaptured in fall 2009 and 14 were recaptured in fall 2010. In addition, average annual growth rates (mm/year) were calculated based on the change in average length for each cohort between sampling events for over 400 captured fish. Average growth rates were also estimated for the summer, fall, and winter periods based on a smaller sample (<50) of fish captured in each season. Scale and otolith analysis was also used to assess patterns in growth. Tight spacing between circuli on the scales or otolith typically form during periods of reduced growth, whereas wide spacing between circuli indicate periods of higher growth (DeVries and Frie 1996).

Size during downstream migration.—Fish were collected using a fyke net (for downstream migrants) and a weir (for upstream migrants) deployed at the same location each year, approximately 1.3 rkm upstream from the lagoon. Traps were set on the tail end of storm-related runoff events when the water depth was sufficient to allow the fyke net to function properly for 14-96 hours. Traps were checked each hour. Captured fish were carefully removed from the trap, placed into a bucket with water, assessed for smolting status, and treated according to a capture-tag-release protocol described above.

Temperature monitoring.—Because fish are poikilothermic, their metabolic rate is determined by the water temperature. High water temperatures increase energy allocated to catabolic processes, and thus less energy remains to allocate to growth. To assess the potential influence of water temperature on growth of *O. mykiss* in Topanga Creek, temperature data loggers (Stowaway® Tidbits or Onset® data loggers, recording at 30-minute interval) were deployed during the summers of 2005 through 2010 in seven thermally mixed pools where *O. mykiss* have been observed during snorkel surveys. These pools were selected to represent a range of conditions with regard to habitat type, canopy cover, proximity to seeps or springs, and depth.

Results

Growth analysis.—Grouping by fork length and scale analysis were used to definitively distinguish five age classes in the fall of 2008, and four in fall 2009 (Table 1). Based on growth analysis of individually tagged fish, annual growth ranged from 32 to 86 mm/year (Table 2), and smaller fish generally grew at higher rates than larger fish. This pattern of younger smaller fish growing at higher rates was further corroborated by the recapture of an individual in both 2009, after it had grown 70 mm from age 0 to age 1, and again in 2010 after it had grown 33 mm from age 1 to age 2. Growth rates for individually tagged fish were also consistent with analysis of average annual growth rates. Average annual growth rates ranged from 12 mm/year for age 2 to age 3 fish, to 57 mm/year for age 0 to age 1 fish. Similar to individually tagged fish, in general growth rates were highest for age 0 and 1 fish, and declined after age 2. No sampling was conducted during the spring; however, based on a single observation of a 36-mm age 0 fish in April 2002, and on the growth of the smallest age 0 fish measured in November 2009, we estimated that spring growth of age 0 fish in Topanga Creek generally exceeded 24 mm,

Table 1.—Size and age summary based on scale analysis of 206 *O. mykiss* in Topanga Creek, Los Angeles County, California, 2008–2010.

Age class	Cohort	n	Size range	Median	Mean	SD
November 2008						
0	2008	60	55–125	110	106	15
1	2007	28	110–226	125	144	33
2	2006	7	187–291	219	236	43
3	2005	4	278–309	293	293	13
4	2004	2	?310	316	316	8
November 2009						
0	2009	29	75–125	95	98	13
1	2008	51	125–215	165	163	20
2	2007	12	170–235	203	200	21
3	2006	2	?240	248	248	11
January 2010						
1	2009	11	85–155	118	124	20

and summer (April to November) growth was around 70 mm. This is most likely an underestimate, since *O. mykiss* fry tend to emerge at a size smaller than 30 mm FL. Based on eleven *O. mykiss* captured while migrating downstream at the fyke net in January 2010, the change in average size was 26 mm during winter (November to January).

Based on scale and otolith analysis, we found that circuli became compressed into annual "growth checks" during the fall, when decreasing water temperature and photoperiod likely reduced growth (Figure 2). However, based on generally wide spacing of circuli, it appeared that growth occurred year-round.

Table 2.—Annual growth (mm/year) based on 15 individually PIT-tagged *O. mykiss* recaptured in Topanga Creek, Los Angeles County, California, 2008–2010.

Capture Size (FL mm)	Age	Recapture Size (FL mm)	Age	Annual growth (mm/year)
110	0	180	1	70
120	0	224[a]	2	52
140	1	195	2	55
125	1	207	2	82
150	1	231	2	81
160	1	246	2	86
180	1	236	2	56
195	1	244	2	49
155	1	218	2	63
155	1	206	2	51
180	1	213	2	33
155	1	225	2	70
196	1	260	2	32
235	2	274	3	39
220	2	252	3	32

[a] recaptured two years after tagging

Size during downstream migration.—Downstream-migrating *O. mykiss* have been captured during opportunistic downstream migrant trapping efforts since 2002. Based on morphological characteristics indicative of smolting, we presumed that these fish were outmigrating to the ocean. However, many of the fish captured and tagged at the fyke net in winter and spring 2010 were detected by the PIT-tag antenna as moving up and downstream repeatedly before finally departing downstream. Overall, captured downstream migrating *O. mykiss* ranged in size from 85 mm to 320 mm FL, and averaged 184 (n=36) (Table 3). Fish migrating downstream in January (age 1) were typically smaller than 150 mm FL (n=14), whereas those captured February-April were typically larger than about 170 mm FL (n=18). A few (n=4) presumably age 2 (>250 mm) *O. mykiss* were captured at the fyke net as early as January.

Water temperature.—Daily average water temperatures were generally less than 15ºC in winter and 20ºC during summer, although temperature regularly exceeded 22ºC during late July. Daily maximum water temperatures were generally less than 22ºC during most of the fall, winter, and spring, but usually exceeded 23ºC for nearly a week each summer in late July and early August.

Discussion

Summer water temperatures in Topanga Creek regularly exceed those documented as being stressful to *O. mykiss*. However, we found that *O. mykiss* continue to grow in the summer at relatively high rates. There may be several factors contributing to this

Table 3.—Size and age during downstream migration based on 36 *O. mykiss* captured in a fyke trap in Topanga Creek, Los Angeles County, California, 2003–2010. Scales were not collected before 2010.

Date of capture	Time of capture	Fork length (mm)	Age based on scale analysis
15 Feb 2003	1215	116	--
	0415	230	--
	0515	164	--
25 Feb 2003	1815	255	--
	1815	225	--
	1815	188	--
	2015	170	--
	2015	155	--
26 Feb 2003	0615	195	--
16 Mar 2003	0220	192	--
	0200	172	--
	0515	182	--
17 Mar 2003	0915	183	--
18 Mar 2003	0200	280	--
1 Jan 2006	1800	190	--
	1800	305	--
	1800	320	--
3 Jan 2006	2000	175	--
	2200	250	--
4 Jan 2006	0100	180	--
5 Apr 2006	1900	255	--
	2000	260	--
6 Apr 2006	0000	215	--
7 Jan 2008	0500	300	--
17 Feb 2009	0600	120	--
23 Jan 2010	1900	85	1
	1900	145	1
	1900	135	1
	1900	140	1
	1900	115	1
	1900	110	1
	1900	115	1
	1900	115	1
	2200	130	1
24 Jan 2010	0700	155	1
	0700	118	1

Figure 2.—Scale from a 213 mm age 2 *O. mykiss* in Topanga Creek, Los Angeles County, California, collected in November 2010.

phenomenon. Upper lethal temperatures for salmonids tend to be much higher when fish have been gradually acclimated to warmer temperatures (Cherry et al. 1977, Threader and Houston 1983), as would occur in a stream such as Topanga Creek where stream temperatures are warm most of the year. Summer growth at higher temperatures may also be supported by food availability that is more than sufficient to maintain the bioenergetic demands of the fish during a time when their metabolic rates may be very high. Boughton et al. (2007) experimentally increased food supply for juvenile *O. mykiss* in a southern California stream to see if there was a growth response related to temperature and found that the variation (fluctuation) in water temperature was as important as the mean water temperature in allowing fish to convert food into growth. It has also been suggested that some *O. mykiss* populations may be better adapted to higher water temperatures and may have a higher temperature range within which growth is optimal (Spina 2007).

Despite high summer water temperatures, *O. mykiss* in Topanga Creek appeared to grow quickly and adults over 270 mm FL were not uncommon. This raises questions about how these fish meet their bioenergetic demands. Preliminary diet analysis from three stomach contents, and from gastric lavage, has documented that *O. mykiss* in Topanga

Creek are at least occasionally consuming non-native red swamp crayfish, native arroyo chub, and a wide variety of terrestrial and aquatic macroinvertebrates. Further investigation of the diet of *O. mykiss* in Topanga Creek is ongoing.

The size distribution of fish observed in Topanga Creek is consistent with, and in most case, larger than, that reported from comparable streams (Shapovalov and Taft 1954; Capelli 1997; Stillwater Sciences 2006; Stillwater Sciences 2007a, 2007b), indicating that temperature conditions and food availability are sufficient to counteract any negative effects of occasional high temperatures. In other California coastal streams, it seems that a period of rapid growth during spring is sufficient to compensate for high-temperature-related growth limitations during summer and low-temperature-related growth rates during fall and winter (Hayes et al. 2008, Sogard et al. 2009). If Topanga Creek *O. mykiss* grow throughout the year, as our study indicates, this could explain the large size of fish when compared with those from other streams.

The rate of growth of *O. mykiss* in fresh water has been shown to have a direct effect on whether juvenile fish outmigrate and become steelhead, or remain as year-round residents, as well as whether or not they reach a size large enough to undergo smoltification and survive in the marine environment (Ward et al. 1989, Bond 2008, Satterthwaite et al. 2009). Despite high water temperatures, juvenile growth rates in Topanga Creek appear sufficient to produce smolts that are similar in size to those observed in other streams within the Southern California DPS region (Capelli 1997, Kelley 2008), and are large enough (typically greater than 170 mm) to expect relatively high (>10%) marine survival (Ward et al. 1989).

We believe the results of this study demonstrate that despite their perilous status, *O. mykiss* in southern California can obtain the resources to grow and reach sizes large enough to smolt successfully from small streams, and contribute to the anadromous metapopulation. We hope this work will aid the development of regional specific-data to compare with other watersheds within the DPS, and lead to future research on the mechanism that regulates juvenile growth in small southern California streams.

Acknowledgments

This work was funded by a grant from California Department of Fish and Game (Contract No. P0750021). We extend special thanks to M. Larson, C. Lima, J. O'Brien, and C. McKibbin of the California Department of Fish and Game for their continued support of and assistance with our work in Topanga Creek, and to K. Robledo of Filmore Fish Hatchery for providing critical training opportunities. S. Goode, N. Cox, and K. Birney were among the many California State Parks employees who supported our efforts. S. Glowacki and M. Larson generously analyzed over two hundred scales collected during this study. S. Williams, J. Shuman, D. Lathers, T. Lucas, and M. Wade provided essential field support. Much of the information used in this report is a result of the efforts of the volunteer members of the Topanga Creek Stream Team (in alphabetical order): C. Driscoll, S. Engelman, N. Moffatt, K. Tchakerian, K. Wheeland, K. Widen, and B. Yin. Their commitment and assistance were invaluable. This article benefited greatly from the careful review and edit from A.Percival, J. Nelson, K. Shaffer, V. Bleich and an anonymous reviewer. Finally, we are grateful to the staff and directors of the Resource Conservation District of the Santa Monica Mountains who provided continuous logistical and administrative support.

Literature Cited

Bell, E., R. Dagit, and F. Ligon. *in press*. Colonization and persistence of a southern California steelhead (*Oncorhynchus mykiss*) population. Bulletin of the Southern California Academy of Sciences.

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. Canadian Journal of Fisheries and Aquatic Sciences 65:2242-2252.

Boughton, D. A. 2010. Some research questions on recovery of steelhead on the south-central and southern California coast. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-467. National Marine Fisheries Service, La Jolla, California, USA.

Boughton, D. A., M. Gibson, R. Yedor, and E. Kelley. 2007. Stream temperature and the potential growth and survival of juvenile *Oncorhynchus mykiss* in a southern California creek. Freshwater Biology 52:1353-1364.

Capelli, M. H. 1997. Ventura River steelhead survey, Ventura County, California. Prepared for California Department of Fish and Game, Region 5. UC Santa Barbara Library: Special Collections, University of California, Santa Barbara, USA.

Cherry, D. S., K. L. Dickson, J. Cairns, Jr., and J. R. Stauffer. 1977. Preferred, avoided, and lethal temperatures of fish during rising temperature conditions. Journal of the Fisheries Research Board of Canada 34:239-246.

DeVries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland, USA.

Drummond, R. A. 1966. Techniques in the collection and mounting of trout scales. Progressive Fish Culturist 28:113-116.

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. Transactions of the American Fisheries Society 137:114-128.

Hume, J. M. B., and E. A. Parkinson. 1988. Effects of size at and time of release on the survival and growth of steelhead fry stocked in streams. North American Journal of Fisheries Management 8:50-57.

Kabel, C. S., and E. R. German. 1967. Some aspects of stocking hatchery-reared steelhead and silver salmon. Marine Resources Administrative Report No. 67-3. California Department of Fish and Game, Sacramento, USA.

Kelley, E. 2008. Steelhead trout smolt survival in the Santa Clara and Santa Ynez River estuaries. Prepared for California Department of Fish and Game, Fisheries Restoration Grant Program. University of California, Santa Barbara, USA.

NMFS (National Marine Fisheries Service). 2006. Endangered and threatened species: final listing determinations for 10 distinct population segments of West Coast steelhead. Federal Register 71:834-859.

NMFS (National Marine Fisheries Service). 2009. Southern California steelhead recovery plan. Public review draft. Southwest Regional Office, Long Beach, California, USA.

Satterthwaite, W. H., M. P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard, and M. Mangel. 2009. Steelhead life history on California's central coast: insights from a state-dependent model. Transactions of the American Fisheries Society 138:532-548.

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 reference to Waddell Creek, California, and recommendations regarding their management. California Department of Fish and Game, Fish Bulletin 98:1-375.

Smith, J. J. 1990. The effects of sandbar formation and inflows on aquatic habitat and fish utilization in Pescadero, San Gregorio, Waddell and Pomponio Creek estuary/lagoon systems, 1985-1989. Report to the California Department of Parks and Recreation. San Jose State University, Department of Biological Sciences, San Jose, California, USA.

Sogard, S. M., T. H. Williams, and H. Fish. 2009. Seasonal patterns of abundance, growth, and site fidelity of juvenile steelhead in a small coastal California stream. Transactions of the American Fisheries Society 138:549-563.

Spina, A. P. 2007. Thermal ecology of juvenile steelhead in a warm-water environment. Environmental Biology of Fishes 80:23-24.

Stillwater Sciences. 2006. Upper Penitencia Creek limiting factors analysis. Final technical report. Prepared for the Santa Clara Valley Urban Runoff Pollution Protection Program, San Jose, California. Stillwater Sciences, Berkeley, California, USA.

Stillwater Sciences. 2007a. Lagunitas limiting factors analysis phase II: limiting factors for coho salmon and steelhead. Prepared for Marin Municipal Water District, Point Reyes Station, California. Stillwater Sciences, Berkeley, California, USA.

Stillwater Sciences. 2007b. Napa River tributary steelhead growth analysis. Final report. Prepared for U. S. Army Corps of Engineers, San Francisco, California. Stillwater Sciences, Berkeley, California, USA.

Stillwater Sciences, R. Dagit, and J. C. Garza. 2010. Lifecycle monitoring of *O. mykiss* in Topanga Creek, California. Final report. California Department of Fish and Game Contract No. P0750021. Stillwater Sciences, Berkeley; Resource Conservation District of the Santa Monica Mountains, Agoura Hills; and National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, California, USA.

Threader, R. W., and A. H. Houston. 1983. Heat tolerance and resistance in juvenile rainbow trout acclimated to diurnally cycling temperatures. Comparative Biochemistry and Physiology 75A:153-155.

Ward, B. R., and P. A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relation to smolt size. Canadian Journal of Fisheries and Aquatic Sciences 45:1110-1122.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:1853-1858.

Submitted 27 September 2010
Accepted 10 January 2011
Associate Editor was K. Shaffer