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

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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-km² 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, 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>
<thead>
<tr>
<th>Age class</th>
<th>Cohort</th>
<th>n</th>
<th>Size range</th>
<th>Median</th>
<th>Mean</th>
<th>SD</th>
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<tr>
<td>0</td>
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<td>60</td>
<td>55–125</td>
<td>110</td>
<td>106</td>
<td>15</td>
</tr>
<tr>
<td>1</td>
<td>2007</td>
<td>28</td>
<td>110–226</td>
<td>125</td>
<td>144</td>
<td>33</td>
</tr>
<tr>
<td>2</td>
<td>2006</td>
<td>7</td>
<td>187–291</td>
<td>219</td>
<td>236</td>
<td>43</td>
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<tr>
<td>3</td>
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<td>278–309</td>
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<tr>
<td>0</td>
<td>2009</td>
<td>29</td>
<td>75–125</td>
<td>95</td>
<td>98</td>
<td>13</td>
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<td>1</td>
<td>2008</td>
<td>51</td>
<td>125–215</td>
<td>165</td>
<td>163</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
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<td>12</td>
<td>170–235</td>
<td>203</td>
<td>200</td>
<td>21</td>
</tr>
<tr>
<td>3</td>
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<td>2</td>
<td>240–240</td>
<td>248</td>
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<td>11</td>
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<td>January 2010</td>
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<tr>
<td>1</td>
<td>2009</td>
<td>11</td>
<td>85–155</td>
<td>118</td>
<td>124</td>
<td>20</td>
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</table>
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 15°C in winter and 20°C during summer, although temperature regularly exceeded 22°C during late July. Daily maximum water temperatures were generally less than 22°C during most of the fall, winter, and spring, but usually exceeded 23°C 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>
<thead>
<tr>
<th>Capture Size (FL mm)</th>
<th>Age</th>
<th>Recapture Size (FL mm)</th>
<th>Age</th>
<th>Annual growth (mm/year)</th>
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<td>110</td>
<td>0</td>
<td>180(^a)</td>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>120</td>
<td>0</td>
<td>224(^a)</td>
<td>2</td>
<td>52</td>
</tr>
<tr>
<td>140</td>
<td>1</td>
<td>195</td>
<td>2</td>
<td>55</td>
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<td>125</td>
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<td>82</td>
</tr>
<tr>
<td>150</td>
<td>1</td>
<td>231</td>
<td>2</td>
<td>81</td>
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<td>246</td>
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<td>86</td>
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<td>1</td>
<td>206</td>
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<td>51</td>
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<td>180</td>
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<td>32</td>
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<td>235</td>
<td>2</td>
<td>274</td>
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<td>39</td>
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<tr>
<td>220</td>
<td>2</td>
<td>252</td>
<td>3</td>
<td>32</td>
</tr>
</tbody>
</table>

\(^a\) recaptured two years after tagging
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.

<table>
<thead>
<tr>
<th>Date of capture</th>
<th>Time of capture</th>
<th>Fork length (mm)</th>
<th>Age based on scale analysis</th>
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<tr>
<td>15 Feb 2003</td>
<td>1215</td>
<td>116</td>
<td>--</td>
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<tr>
<td></td>
<td>0415</td>
<td>230</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>0515</td>
<td>164</td>
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<tr>
<td></td>
<td>1815</td>
<td>255</td>
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<tr>
<td></td>
<td>1815</td>
<td>225</td>
<td>--</td>
</tr>
<tr>
<td>25 Feb 2003</td>
<td>1815</td>
<td>188</td>
<td>--</td>
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<tr>
<td></td>
<td>2015</td>
<td>170</td>
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<tr>
<td></td>
<td>2015</td>
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<td>--</td>
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<tr>
<td>26 Feb 2003</td>
<td>0615</td>
<td>195</td>
<td>--</td>
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<tr>
<td></td>
<td>0220</td>
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<td>--</td>
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<tr>
<td>16 Mar 2003</td>
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<tr>
<td>17 Mar 2003</td>
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<td>175</td>
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<td>175</td>
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<tr>
<td>4 Jan 2006</td>
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<td>180</td>
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<td>0700</td>
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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

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

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