Suitable Juvenile Steelhead Habitat
in the Carmel River Lagoon

by Julianne Rhodes, CSUMB Coastal & Watershed Science & Policy, M.S. candidate in partnership with Monterey Peninsula Water Management District

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Table of Contents

ACKNOWLEDGEMENTS ......................................................................................... 2

EXECUTIVE SUMMARY ...................................................................................... 3

PROJECT OBJECTIVES ....................................................................................... 3
  Temperature ........................................................................................................ 3
  Dissolved Oxygen ................................................................................................. 3
  Salinity .................................................................................................................. 4
  Estuarine Macroinvertebrates .............................................................................. 4
  Lagoon Processes ................................................................................................. 4
  Study Area ........................................................................................................... 5

PROJECT APPROACH ............................................................................................ 6
  Monitoring Sites .................................................................................................. 6

PROJECT OUTCOMES ............................................................................................ 7

CONCLUSIONS ...................................................................................................... 35

REFERENCES ......................................................................................................... 36

APPENDIX – YSI METER SPECIFICATIONS ......................................................... 37

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Executive Summary

The Carmel River Lagoon (CRL) provides key rearing habitat for the federally endangered juvenile steelhead (*Oncorhynchus mykiss*) prior to its migration into marine waters. Juvenile steelhead living in coastal lagoons have been found to have faster growth rates and larger size at ocean entry when compared to juveniles reared further upstream within the freshwater reaches (Hayes et al. 2008). Several studies have attributed the success of lagoon–reared salmon to abundant food in the form of a diverse macroinvertebrate prey community and the longer duration spent in the transition zone where fish can adjust to increasing salinity prior to migrating out to sea (Hayes et al., 2008). Additionally, there is a greater return rate of lagoon–reared steelhead: 95.5% of the returning adults in Scott Creek Lagoon in adjacent Santa Cruz County were lagoon–reared, though only 8 to 48% of the steelhead population smolt in the lagoon (Bond, 2006). However, if steelhead inhabiting Central Coast estuaries are to benefit from the lagoon environment, good water quality habitat (GWQH) must be manifest.

Project Objectives

Suitable lagoon habitat for juvenile steelhead consists of cool, well-oxygenated fresh or brackish waters, and abundant food (Smith, 1990). This memorandum evaluates the suitability of the CRL for steelhead rearing using water quality parameter values collected monthly at five sites between January 2007 and April 2013. GWQH for steelhead rearing was determined based upon specific tolerances of temperature, dissolved oxygen (DO), and salinity. Project outcomes from the analysis of these data can be used by the Monterey Peninsula Water Management District (MPWMD) to implement management practices likely to help foster steelhead recovery.

Temperature

Lagoon habitat provides heterogeneous thermal zones, where steelhead can move between cooler and warmer water. While optimal temperatures for juvenile steelhead growth range between 6 and 10 °C, if food resources are abundant, steelhead can grow and survive in the slightly warmer temperatures found in Central Coast lagoons (Smith, 1990). Juvenile steelhead live in streams that regularly exceed 20°C for a few hours each day with high food availability and temperatures that lower nocturnally (Moyle, 2008). In this report, temperatures greater than 19 °C (66 °F) were defined as poor, temperatures between 15 and 19 °C to be fair, and temperatures less than 15 °C (59 °F) as good habitat for juvenile steelhead survival and growth rate. (K. Urquhart, MPWMD, pers. com).

Dissolved Oxygen

The lack of mechanical mixing due to low or no flow in the lagoon environment together with salinity stratification in the lower part of water column can result in low dissolved oxygen levels. The presence of rooted aquatic plants and algae can also contribute to lowered dissolved oxygen overnight due to plant respiration. Smith (2003) observed that lagoons where freshwater inflows are sufficient to create an unlayered freshwater system rarely have major or
persistent dissolved oxygen problems, even if aquatic plants abundant. DO lower than 5 mg/L can harm fish and levels lower than 2 mg/L are lethal especially at warmer temperatures (Moyle, 2008). In this report DO levels less than 5 mg/L were considered poor, DO levels between 5 and 7 mg/L to be fair and DO levels greater than 7 mg/L to be good habitat for steelhead survival and growth (K. Urquhart, MPWMD, pers. comm.).

**Salinity**
While direct pumping from the Carmel River ceased in 2003 (MPWMD, Water Supply Summary, 2013), diversions via groundwater extraction in the upper watershed reduce freshwater inflows. This lack of freshwater entering the lagoon increases salinity and stratification during the dry season. In the saline layer at the bottom of the water column, DO concentrations are often substantially depressed and temperatures are often raised in the lagoon environment (Atkinson, 2010). In a typical estuary, the water column near the beach is often less stratified due to wind-driven mixing. In this report, a salinity level greater than 10ppt was considered poor, salinity levels between 3 and 10ppt to be fair, and levels less than 3ppt to be good habitat for steelhead survival and growth rate (K. Urquhart, MPWMD, pers. comm.).

**Estuarine Macroinvertebrates**
A survey of macroinvertebrates conducted by the Watershed Institute at CSUMB (Anderson, 2007), found a total of eight taxa: one brackish and seven freshwater. The importance of sufficient freshwater inflow necessary to convert the stratified lagoon was reported by Smith (1990) who observed, that full–conversion to freshwater substantially increased abundance of macroinvertebrates, as well as contributing to the growth and abundance steelhead in San Mateo and Santa Cruz County streams.

**Lagoon Processes**
The summer and fall are relatively static periods at the lagoon. River inflow has generally ceased by the end of June and the mouth of the lagoon is cut off from the ocean by a berm of sand built by changes in seasonal currents. The final seasonal closure occurs any time when spring flows have dropped below 20 cfs (MPWMD TM–O5–01). Once closed, the water level in the lagoon recedes until it has reached equilibrium with the local water table, typically at an elevation of 2.5 to 3.0 feet (MPWMD TM–O5–01). The final seasonal closure is the last opportunity to store a pool of fresh water in the lagoon that will help to foster mixing of fresh and saline layers, resulting in better water quality habitat during the dry months. With the onset of the wet season in late fall, increased flow from the river fills the lagoon and the sand berm is eroded and eventually breached, usually sometime in December or January, allowing the steelhead smolts to move out to sea.

This seasonal cycle depends upon sufficient fresh water flows and no interruption from artificial breaching of the lagoon, however concerns about localized flooding in the residential area adjacent to the CRL have caused the Monterey County Public Works Department to artificially breach the lagoon when it reaches a level of 8.78 feet (MPWMD TM–O5–01). In recent years, the County has endeavored to delay their breaching effort as long as possible, usually waiting until
lagoon levels are over 10 feet to take action (K. Urquhart, pers. comm.). Artificial breaching of the sand berm for flood control purposes frequently results in low lagoon elevations, elimination of most of the aquatic habitat of the lagoon, a short and steep outflow path to the ocean, and can cause the lagoon to drain too quickly sweeping young-of-the-year steelhead out to sea (Study Plan for Long Term Adaptive Management of the Carmel River State Beach and Lagoon, 2007).

**Study Area**

The Carmel River watershed is 255 square miles (Figure 1) located on California's central coast. The 36-mile river features steep canyons in the upper reaches. The lower 16 miles of river flows through a moderately developed alluvial plain, eventually draining to the lagoon. Much of the CRL is permanently under water, while other areas, including the boundaries of perennial areas, are inundated only occasionally during high tide or river stages. The lagoon is the site of a fluctuating interface between marine and freshwater river systems and is comprised of both fresh water wetlands and open water habitat (Study Plan for Long Term Adaptive Management of the Carmel River State Beach and Lagoon, 2007).

**Figure 1** - Location of the Carmel River Lagoon and the boundaries of the Carmel River Watershed and Monterey Peninsula Water Management District
Project Approach

Temperature, salinity, and DO water quality parameters for the CRL were measured in situ. Measurements were taken monthly from a kayak at five sites (Figure 2) using YSI MPS Model 85 at 0.25 m interval depth profiles. Table 3 in Appendix B shows the instrument specifications for each parameter. The YSI MPS was calibrated monthly. The data, which span from January 2007 to April 2013, were collected by various staff and interns employed by the MPWMD. The water quality profiles (Figures 3 – 27) were generated using the software R 2.15.1 (R Core Team, 2020).

Monitoring Sites

The ‘N’ site is in the north arm zone, the ‘R’ site is in the river zone, the ‘S’ site is in the south arm zone, and the ‘O’ sites refer to the Odello extension, which was excavated in 2006 (Figure 2).

Site N2 (Figure 2) is the in the north arm adjacent to the parking lot. The substrate consists of finer sediments, accumulated organic debris, and smaller amounts of sand. The inland side is covered with tule marsh (Scirpus sp.). Typical depths range from 0.5 m to 1.25 m. The maximum depth achieved during the period of this study was 3.5 m in November 2011 and May 2012 and the minimum was 0 m in May and June of 2010 due to breaching.

Site R2 (Figure 2) in the main lagoon is an area that has little to no vegetative cover. This site is exposed to continuous wind action; it is therefore subject to more mixing than all other areas of the lagoon. When the mouth of the lagoon is connected to the ocean, this is where the river passes through the lagoon (Casagrande, 2006). Typical depths range from .75 m to 1.25 m. The maximum depth achieved during the period of this study was 3.5 m in November 2011 and the minimum was 0 m in May of 2010 due to breaching.

Site S2 (Figure 2) in the south arm of the lagoon is the location of a staff plate maintained by the MPWMD. The site is adjacent to the wastewater treatment plant pipe that crosses the south arm of the lagoon. The banks are covered with tule marsh (Scirpus sp.). It is an historic sampling site and is the deepest with an average depth of more than two meters in dryer months. This site experiences the most stratification with respect to salinity, temperature, and DO (Casagrande, 2006). Typical depths range from 2.25 m to 3.0 m. The maximum depth achieved during the period of this study was 4.75 m in May 2007, June 2009, October and November 2009, October and December 2011, and February 2012. The minimum was 1.5 m in January 2011.

Site O1 (Figure 2) is the northern branch of the Odello extension. At low stages, a fresh water spring can be seen at the top of this site. (Larson et al, 2006). The substrate consists of finer sediments and accumulated organic debris. The banks are covered with seasonal tule marsh (Scirpus sp.). Typical depths range from 1.25 m to 1.75 m. The maximum depth achieved
during the period of this study was 3.75 m in December 2011 and the minimum was .25 m in March 2012.

**Site O4** (Figure 2) is farthest from the lagoon mouth and located in the Odello extension, which was excavated 2006. The substrate consists of finer sediments and accumulated organic debris and the banks are covered with seasonal tule marsh (*Scirpus* sp.). Depth at Site O4 is typically less than 1 m. The maximum depth achieved during the period of this study was 3.25 m in October and December 2011 and the minimum was .25 m in August 2008, April 2009, February 2010, January 2011 and October 2012, and January 2013.

![Figure 2](image.png)

**Figure 2** – Carmel River Lagoon water quality sampling sites

**Project Outcomes**

Figures 3 – 27 show water quality profiles for each site from January 2007 to April 2013. Table 1 shows the parameters for good, fair, and poor water quality habitat. Table 2 shows the percent of time from January 2007 to April 2013, that water quality was good, fair, or poor for each site.
Table 1. Parameters for good, fair, and poor water quality in the CRL

<table>
<thead>
<tr>
<th>Water Quality</th>
<th>Temperature</th>
<th>Dissolved Oxygen</th>
<th>Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>≤ 15 °C</td>
<td>≥ 7</td>
<td>≤ 3 ppt</td>
</tr>
<tr>
<td>Fair</td>
<td>≤ 19 °C</td>
<td>≥ 5</td>
<td>≤ 10 ppt</td>
</tr>
<tr>
<td>Poor</td>
<td>&gt; 19 °C</td>
<td>&lt; 5</td>
<td>&gt; 10 ppt</td>
</tr>
</tbody>
</table>

**Site N2:** Overall GWQH, where temperature, DO, and salinity were all within tolerances determined to be good for juvenile steelhead rearing, occurred 17% of the time in the period from January 2007 to April 2013 (Table 2 and Fig.3). Figures 8 – 11 show good, fair, and poor water quality overall and for each parameter distributed through the water column over time at Site N2.

**Site R2:** Overall GWQH, where temperature, DO, and salinity were all within tolerances determined to be good for juvenile steelhead rearing, occurred 21% of the time in the period from January 2007 to April 2013 (Table 2 and Fig.4). Figures 12 – 15 show good, fair, and poor water quality overall and for each parameter distributed through the water column over time at Site R2.

**Site S2:** Overall GWQH, where temperature, DO, and salinity were all within tolerances determined to be good for juvenile steelhead rearing, occurred 13% of the time in the period from January 2007 to April 2013 (Table 2 and Fig. 5). Figures 16 – 19 show good, fair, and poor water quality overall and for each parameter distributed through the water column over time at Site S2.

**Site O1:** Overall GWQH, where temperature, DO, and salinity were all within tolerances determined to be good for juvenile steelhead rearing, occurred 12.5% of the time in the period from January 2007 to April 2013 (Table 2 and Fig. 6). Figures 20 – 23 show good, fair, and poor water quality overall and for each parameter distributed through the water column over time at Site O1.

**Site O4:** Overall GWQH, where temperature, DO, and salinity were all within tolerances determined to be good for juvenile steelhead rearing, occurred 11.5% of the time in the period from January 2007 to April 2013 (Table 2 and Fig. 7). Figures 24 – 27 show good, fair, and poor water quality overall and for each parameter distributed through the water column over time at Site O4.
Table 2. Percent of time between Jan 2006 and Apr 2013, that there was good, fair, and poor water quality in the CRL at each site.

<table>
<thead>
<tr>
<th>Site</th>
<th>Water Quality</th>
<th>Overall %</th>
<th>Temperature %</th>
<th>DO %</th>
<th>Salinity %</th>
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<tbody>
<tr>
<td>N2</td>
<td></td>
<td>17</td>
<td>53</td>
<td>59</td>
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<tr>
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<td>13</td>
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<td>37.5</td>
<td>73.5</td>
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<td>30.5</td>
<td>13.5</td>
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<td></td>
<td></td>
<td>11.5</td>
<td>37</td>
<td>64</td>
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</tr>
<tr>
<td>O4</td>
<td></td>
<td>36.5</td>
<td>32</td>
<td>21.5</td>
<td>21.5</td>
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<td>52</td>
<td>31</td>
<td>14.5</td>
<td>14</td>
</tr>
</tbody>
</table>
Figure 3. Percent of time that overall water quality, temperature, DO, and salinity are poor, fair and good at Site N2 from January 2007 to April 2013.
Figure 4. Percent of time that overall water quality, temperature, DO, and salinity are poor, fair and good at Site R2 from January 2007 to April 2013.
Figure 5. Percent of time that overall water quality, temperature, DO, and salinity are poor, fair and good at Site S2 from January 2007 to April 2013
Figure 6. Percent of time that overall water quality, temperature, DO, and salinity are poor, fair and good at Site O1 from January 2007 to April 2013.
Figure 7. Percent of time that overall water quality, temperature, DO, and salinity are poor, fair and good at Site O4 from January 2007 to April 2013.
Figure 8. Water quality at Site N2 from January 2007 to April 2013

Poor: Salinity < 10 ppt, DO > 5 mg/l, Temperature > 19 C
Fail: Salinity >= 10 ppt, DO >= 5 mg/l, Temperature >= 19 C
Good: Salinity >= 3 ppt, DO < 7 mg/l, Temperature >= 15 C

Site N2 Water Quality in Carmel River Lagoon
Figure 9. Water temperature at Site N2 from January 2007 to April 2013
Figure 10. DO concentration in water column at Site N2 January 2007 to April 2013
Figure 11. Salinity of water at Site N2 from January 2007 to April 2013
Figure 12. Water quality at Site R2 from January 2007 to April 2013.
Figure 13. Temperature of water at Site R2 from January 2007 to April 2013
Figure 14. DO concentration in water column at Site R2 from January 2007 to April 2013.

Site R2 Dissolved Oxygen Concentration in Carmel River Lagoon Water Column
Figure 15. Salinity of water at Site R2 from January 2007 to April 2013
Figure 16. Water quality at Site S2 from January 2007 to April 2013
Figure 17. Temperature of water at Site S2 from January 2007 to April 2013
Figure 18. DO concentration in water column at Site S2 from January 2007 to April 2013
**Figure 19.** Salinity of water at Site S2 from January 2007 to April 2013
Figure 20. Water quality at Site O1 from January 2007 to April 2013

Poor: Salinity > 10 ppt, DO > 5 mg/l, Temperature > 19°C
Fair: Salinity <= 10 ppt, DO >= 5 mg/l, Temperature <= 19°C
Good: Salinity <= 3 ppt, DO >= 7 mg/l, Temperature <= 15°C

Site O1 Water Quality in Carmel River Lagoon
Figure 21. Temperature of water at Site O1 from January 2007 to April 2013
Figure 22. DO concentration of water column at Site O1 from January 2007 to April 2013
Figure 23. Salinity of water at Site O1 from January 2007 to April 2013
Figure 24. Water quality at Site O4 from January 2007 to April 2013
Figure 25. Temperature of water at Site O4 from January 2007 to April 2013
Figure 26. DO concentration of water column at Site O4 from January 2007 to April 2013
Figure 27. Salinity of water at Site O4 from January 2007 to April 2013.
Conclusions

GWQH was found in the CRL only 11.5 to 21% of the time during the period evaluated. In order to increase these percentages, current management practices must be improved. Studies done by Smith (1990) and by Cannata (1998) on California estuaries, and more recently by Atkinson (2010) on the San Gregorio Lagoon in San Mateo County found that where insufficient flows existed to mix fresh and saltwater layers, DO concentrations were often very low to anoxic, and temperatures were often elevated in the lower saltwater layer of the lagoon. Under these conditions, steelhead utilized the middle to upper water column (Atkinson, 2010). Studies by Hayes (2011) and Frechette (2012, 2010) have found juvenile steelhead using the upper strata of these typically shallow estuaries are vulnerable to predation by piscivorous sea birds, especially the western gull. An evaluation of the CRL to determine the volume of fresh water flows required to prevent saltwater stratification, thus promoting GWQH throughout the water column would likely benefit ongoing efforts to foster steelhead recovery.

The results presented in this report are a survey of conditions and various limitations inherent in the dataset prevent definitive conclusions from being drawn about GWQH in the CRL. The measurements were collected monthly during the middle part of the day and, thus diurnal and nocturnal fluctuations, particularly in temperature and DO are not known. From March 15th, 2010 to March 1st, 2011, the California State Department of Parks and Recreation operated a Sonde at Site S2, which collected readings of temperature, salinity, and DO continuously every six minutes. These data could be compared to YSI readings collected during that period to gain a better understanding of daily changes in lagoon conditions. However, there is some doubt as to the accuracy of the parameter values collected by the Sonde as they differed from both YSI meter readings and HACH test results taken at the same time and location (C. Hamilton, MPWMD, pers comm.).

In 1995, the State Water Resources Control Board imposed Order 95–10 requiring California America Water Company (Cal Am) to reduce its usage of the Carmel River by 75% in an effort to protect the steelhead, riparian vegetation, and other wildlife, which depend on the river for survival. A Low Flow Memorandum of Agreement between Cal Am, the California Dept. of Fish and Wildlife, and the MPWMD manages water releases from San Clemente Reservoir as a means of maintaining GWQH sufficient to support steelhead and other sensitive species (MPWMD Exhibit 10–A). While efforts have been made by Cal Am and others to find alternative sources of water, flows into the lagoon remain restricted or nonexistent during most of the year. The problems of inadequate flow into the lagoon together with untimely, artificial breaching are the biggest challenges to providing GWQH to young steelhead.
3 | SUITABLE JUVENILE STEELHEAD HABITAT

References


Frechette, D. F. 2010. Impacts of avian predation on juvenile salmonids in Central California watersheds. Master’s Thesis. San Jose State University, San Jose, California.


Mbay_IRWM/IRWM_library/CarmelBay/LongTermStudyPlanFinal2007–04–17.pdf

Appendix – YSI meter specifications

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SENSOR</th>
<th>ACCURACY</th>
<th>RANGE</th>
<th>RESOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>YSI Model 85</td>
<td>±0.1 °C</td>
<td>-5 to +65 °C</td>
<td>0.1 °C</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>YSI Model 85</td>
<td>± 0.3 mg/L</td>
<td>0 to 20 mg/L</td>
<td>0.01 mg/L</td>
</tr>
<tr>
<td>Salinity</td>
<td>YSI Model 85</td>
<td>±0.1 ppt</td>
<td>0 to 80 ppt</td>
<td>.1 ppt</td>
</tr>
</tbody>
</table>