The Origins of Life History Variation in Steelhead/Rainbow Trout from Coastal California

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Life History Variation

Age- 2.0
Sex- M
Length- 12 cm

Age- 4.0 estuarine
Sex- F
Length- 32 cm

Age- 5.0
Sex- M
Length- 27 cm

Age- 1.1?
Sex- M
Length- 41 cm

Age- 2.1
Sex- M
Length- 53 cm

Age- 3.4 estuarine?
Sex- F
Length- 42 cm

Age- 1.3?
Sex- F
Length- 42 cm

Age- 2.2
Sex- M
Length- 71 cm

Age- 1.3
Sex- M
Length- 88 cm
Coastal CA Steelhead Population Structure

- “Snapshot” of population structure from 60 sites, 40 basins in all five CA Coastal steelhead ESUs
- ~4500 juvenile fish non-lethally sampled from 5 sections/location
- Samples collected June-Oct. 2001
- Avg. of 66 fish/site analyzed
- Data from 18 microsatellite loci
- ~132,000 allele copies, 540 unique alleles sampled.
Steelhead Bootstrap Consensus Tree

ESU Assignment
- Klamath Mountain
- Northern California
- Central California
- South Central California

Strict consensus of 1000 neighbor-joining trees
- 100 replicates
Isolation by distance

Regression of genetic distance on geographic distance for 59 steelhead populations in coastal California.

Geographic distance explains about 30% of the variation in genetic distance.

\[ r^2 = 0.31 \] for (a) Full siblings excluded

\[ r^2 = 0.18 \] for (b) All data

\[ F_{st} = 0.036 + 8.34 \times 10^{-5} \times \text{Dist (km)} \]

\[ F_{st} = 0.053 + 7.30 \times 10^{-5} \times \text{Dist (km)} \]
Coastal CA Steelhead Population Structure

Model Based Clustering Assignment Tests

Results for K = 3
Coastal CA Steelhead Population Structure

Model Based Clustering Assignment Tests

(a) $k = 2$ $44/44$

$44/44$

$31/44$

$13/44$

$43/44$

$1/44$

$18/20$

$2/20$

$9/20$

$8/20$

$2/20$

$1/20$

(b) $k = 5$

coastal dist. $43/44$ $55/55$
Coastal CA Steelhead Population Structure

DPS/ESU vs. Genetic Group Boundaries

- Humboldt Bay
- Lost Coast
- Russian Gulch
- San Francisco Bay
Southern California Trout Population Structure

- Extension of population structure study to South-Central & Southern California
- Five basins with population sampling above and below dams
- Small numbers from further south
- All strains of rainbow trout used in stocking also sampled
- ~1900 juvenile fish non-lethally sampled w/ standardized protocol
- Data from same 18 microsatellite loci as previous study.
Consensus chord distance tree with bootstrap support (10,000 replicates)
Factorial Correspondence Analysis
Expeditions of John Otterbein Snyder

-Prominent early California ichthyologist-Student of David Starr Jordan

-Zoology professor at Stanford. Organized the National Museum fish collections.

-Published “The Fishes of the Streams Tributary to Monterey Bay, California”-1912

-Population collections of steelhead in Central California from 1897 & 1909 described.
### Sampling for Historical Steelhead Study

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Location</th>
<th>Historical</th>
<th>Modern</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Year</td>
<td>N</td>
</tr>
<tr>
<td>Eel River</td>
<td>South Fork</td>
<td>1897</td>
<td>30</td>
</tr>
<tr>
<td>Lagunitas Creek</td>
<td></td>
<td>1909</td>
<td>10</td>
</tr>
<tr>
<td>Coyote Creek</td>
<td></td>
<td>1909</td>
<td>15</td>
</tr>
<tr>
<td>San Lorenzo River</td>
<td></td>
<td>1897, 1909</td>
<td>41</td>
</tr>
<tr>
<td>Pajaro River</td>
<td>Uvas Creek</td>
<td>1909</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Llagas Creek</td>
<td>1897</td>
<td>13</td>
</tr>
<tr>
<td>Salinas River</td>
<td>Arroyo Seco</td>
<td>1897, 1909</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>San Antonio River</td>
<td>1909</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Nacimiento River</td>
<td>1909</td>
<td>24</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td></td>
<td></td>
<td>212</td>
</tr>
<tr>
<td>American River</td>
<td>Hatchery-Mt. Shasta</td>
<td>-</td>
<td>2002</td>
</tr>
<tr>
<td>Santa Clara River</td>
<td>Hatchery-Virginia</td>
<td>-</td>
<td>2003</td>
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</tbody>
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Results

Mitochondrial DNA - ~200bp section of control region
- Lagunitas population coho!
- No significant difference in number of alleles/diversity
- Four new alleles detected: 3 historically, 1 contemporary
- Differences range from very minor to dramatic
- No major replacement with hatchery stocks, although poorly sampled
Results

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Modern samples, River distances

Modern

\[ r^2 = 0.0673 \]
Historical samples, River distances

Historical

$r^2 = 0.9038$
The Deep South
The Deeper South
Big Creek Falls

• *O. Mykiss* introduced above Big Creek Falls c. 1910

• Genetic analysis supports within-basin origin of the above-falls population (Pearse et al. 2009)

• 1.8% emigration rate over the falls, based on PIT tag data. (Hayes et al. 2012)

>> Strong, continuing selection on above-falls fish not to move downstream.
24 individuals each from above and below falls.

298 microsatellite loci genotyped, many mapped. (Martinez et al. 2011)

96 un-mapped SNP loci. (Abadía-Cardoso et al. 2011)

~400 loci distributed over all 29 linkage groups with ~10 cM coverage of the genome.
Fst Histogram Micros and SNPS

Fst\(_{(298)}\) = 0.034

(Martinez et al. 2011; Pearse et al. 2014)
Hatchery
Hatchery
Hatchery
Goose Lake
Upper Klamath
McCloud
Eel
Bauers
Buckboard
Butcherknife
Cutfinger
Summer SH
Willow
Winter SH
Scott
Above
Below
San Lorenzo
Carmel
Salinas
Tassajera
Nacimiento
Santa Ynez
Hilton
NF Juncal
Salsipuedes
Santa Cruz
Lion Canyon
Frenchmen
Santa Paula
Gold Hill

Pearse et al. 2014
Populations

- ARHEagle
- FHMTWhitney
- Kamloops
- GLBauers
- UKBuckboard
- McCloudBk
- EelCutfinger
- EelSummerSH
- EelWillow
- EelWinterSH
- ScottAbove
- ScottWeir
- SanLorenzo
- Carmel
- Tassajera
- Nacimiento
- SYHilton
- SYNFJuncal
- SYSaisipuedes
- SYSantaCruz
- SCLionCan
- SCFrenchmen
- SCSantaPaula
- SCGoldHill

SNP loci

Pearse et al. 2014

Frequency of the allele most common in anadromous adults
Conclusions

- Historical population structure relatively “intact” north of Pt. Conception: mostly concordant with geography, no detectable hatchery impact

- **Migration** and drift represents natural state: corridors important

- Between Pt. Conception and the Los Angeles basin, above and below dam populations recently derived from coastal steelhead

- Deep south populations (LA, Orange and San Diego counties) highly variable, many with a strong signal of hatchery ancestry

- Little support for current DPS boundaries. Primary structuring: Local (~90%) -> Drainage -> Region

- A chromosomal region on Omy5 is strongly associated with life history variation in O. mykiss throughout its range.
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