PROGRESS REPORT
ON
OCEANOGRAPHY

by
Felix Favorite

Pacific Salmon Investigations
U. S. Fish and Wildlife Service
Seattle, Washington
September, 1957
The contract with the Department of Oceanography, University of Washington, was terminated and an oceanographic section has been established in the High Seas Project of the Pacific Salmon Investigations.

The cessation of the contract resulted in the absence of a supporting research vessel in this year's area of investigation and necessitated an increase in the oceanographic observations taken by personnel on the exploratory vessels. The following changes from the previous year were instigated on this year's exploratory boats.

1. Sampling depths were changed from 0, 25, 50, 75, 100, 200, 300, 600 and 1,000 meters to 0, 10, 20, 30, 50, 75, 100, 125, 150, 175, 200, 300, 500, 800, and 1,100 meters in order to define more clearly the properties of the surface layer.

2. The 450' BT's which were too shallow to penetrate through the surface layer were replaced by 900' BT's.

3. Instead of one vertical plankton haul from 150 meters to the surface, three ½ meter net hauls were made as follows:
   a. From the bottom of surface layer (temperature minimum) to the surface.
   b. From 300 meters to bottom of surface layer.
   c. From 300 meters to the surface.

These hauls were made to determine the existence of a discrete population in the surface layer, to observe the types of organisms existing below this layer, to compare the validity of the discontinuous and continuous hauls, and to compare the contents of salmon stomachs with the plankton.

4. Phosphate-P analyses were made on board from water samples at depths of 10, 30, 75, 125, 150, 200, 500, and 1,100 meters. and oxygen samples were drawn from the same sample depths.
5. A total of 480 drift bottles was released at various points in the Aleutian Island area to aid in the determination of surface water movements.

The locations of oceanographic stations were dependent upon pre-determined fishing stations; however, occasional shallow casts were made at the 1,000 fathom curve north and south of the Aleutian passages. BT's were taken at approximately 20 mile intervals.

Activities at the Seattle laboratory included equipping the exploratory vessels, instructing inexperienced personnel, and establishing the oceanographic section. In addition to processing the data forwarded by mail from the vessels, an analysis of North Pacific oceanographic data, collected in previous years by other agencies, was commenced.

Application of Oceanography to Salmon

A preliminary analysis of 1956 salmon catch data from U. S. exploratory vessels indicates two interesting conditions — the absence of salmon throughout the summer in the central part of the Pacific Ocean south of approximately 48° N latitude, and the large numbers of red salmon caught in June in the Bering Sea just off the Bristol Bay Shelf. Both of these conditions are believed to be related to temperature distributions in the ocean, although, of course, many other factors are involved.
The southern salmon boundary at approximately 48°N is the region where Subarctic water is separated from Subtropic water by the Polar Front. These water masses are identified by Tully and Dodimead (1957). South of this boundary along 157°W longitude, the sub-surface isotherms drop sharply downward, horizontally isolating from the warmer southern water a stratum of water which is cold, has a high oxygen content, and is formed locally by winter turnover. North of the boundary, the vertical intrusion at depth of cold, saline, intermediate water greatly reduces the vertical extent of the surface layer, thus permitting the existence of the cold, oxygen-rich water at a shallow depth of approximately 75-100 meters.

The latitudinal extent of this region in 1955 at 157° 30'W longitude is shown in Figure 1 in which the stratum is indicated by stippling. The 4°C isotherm generally represents the depth of the top of the intermediate layer and shows the plateauing effect under the cold stratum north of 48°N.

The boundary of this cold stratum (which is the bottom of the surface layer) and the intermediate layer is clearly marked by a small increase in temperature, a sharp increase in salinity, and a sharp decrease in oxygen content. In addition to permitting a biological population requiring these cold temperatures to exist near the surface in the summer, it may be significant that the values of temperature, salinity, and existing oxygen in this stratum during the summer are equivalent to those existing in the winter months at the sea surface as shown in Table 2, which is a comparison of winter and summer data of two water columns at approximately 53°N and 158°W.
Figure 1. Vertical Profile Along 157°30'W August 17 - September 3, 1955, Showing Stratum of Cold Water at 100 Meters. (U. of W. Sta. No's. 47, 56, 57; FOG Sta. No. 10; POFT Sta. No's. 86-96)
TABLE 1

COMPARISON OF WATER PROPERTIES AT FOG STA. 21
(52° 58' N, 150° 25' W.), FEBRUARY 4, 1957, AND
FOG STA. 21 (53° 28' N, 157° 48' W.), AUGUST 5, 1957

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Winter Temp. (°C)</th>
<th>Summer Temp. (°C)</th>
<th>Salinity (°/oo) Winter</th>
<th>Summer</th>
<th>O2 (mg at/l) Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3.90</td>
<td>11.90</td>
<td>32.91</td>
<td>32.88</td>
<td>.648</td>
<td>.564</td>
</tr>
<tr>
<td>10</td>
<td>3.65</td>
<td>11.61</td>
<td>32.89</td>
<td>32.82</td>
<td>.641</td>
<td>.597</td>
</tr>
<tr>
<td>20</td>
<td>3.65</td>
<td>11.77</td>
<td>32.88</td>
<td>32.83</td>
<td>.644</td>
<td>.599</td>
</tr>
<tr>
<td>30</td>
<td>3.64</td>
<td>10.13</td>
<td>32.86</td>
<td>32.91</td>
<td>.649</td>
<td>.615</td>
</tr>
<tr>
<td>50</td>
<td>3.65</td>
<td>5.17</td>
<td>32.91</td>
<td>32.91</td>
<td>.643</td>
<td>.658</td>
</tr>
<tr>
<td>75</td>
<td>3.51</td>
<td>3.63</td>
<td>32.98</td>
<td>33.06</td>
<td>.620</td>
<td>.595</td>
</tr>
<tr>
<td>100</td>
<td>3.93</td>
<td>3.66</td>
<td>33.65</td>
<td>33.45</td>
<td>.248</td>
<td>.400</td>
</tr>
<tr>
<td>150</td>
<td>4.13</td>
<td>4.10</td>
<td>33.94</td>
<td>33.92</td>
<td>.144</td>
<td>.093</td>
</tr>
<tr>
<td>200</td>
<td>4.06</td>
<td>4.03</td>
<td>34.03</td>
<td>34.01</td>
<td>.065</td>
<td>.050</td>
</tr>
<tr>
<td>250</td>
<td>3.97</td>
<td>3.93</td>
<td>34.07</td>
<td>34.06</td>
<td>.035</td>
<td>.036</td>
</tr>
<tr>
<td>300</td>
<td>3.90</td>
<td>3.86</td>
<td>34.08</td>
<td>34.11</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>400</td>
<td>3.72</td>
<td>3.71</td>
<td>34.20</td>
<td>34.18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>500</td>
<td>3.52</td>
<td>3.50</td>
<td>34.25</td>
<td>34.21</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 2 indicates a possible relationship of the cold stratum with salmon gill net catch at 155° W longitude in August 1956. The region south of 49°N latitude where no salmon were caught cannot be identified by surface temperatures but is clearly marked by the southward limit of the cold stratum indicated by the vertical isotherms.

The summer minimum temperature in this stratum is dependent on the winter surface temperature and in this region it will vary from 2°C to 4°C. Thus, the sharpness of the north-south boundary will depend on the severity of local winter conditions.

The region in which this shallow, cold, oxygen-rich stratum exists north of the polar front (coastal waters discounted) can be divided into four areas. The area in the Gulf of Alaska has been discussed.
Figure 2. Vertical Section Along 155° W.
(M/V Celtic 16-27 August 1956)
The second lies between 170°W longitude and 170°E, in which for a given year the temperature in the stratum is slightly warmer than that to the eastward due to a reduced salinity gradient which permits greater vertical mixing. Insufficient data prevents a complete analysis of this area, but the conditions existing are believed to be the result of a divergence or mixing of the Oyashio, Kuroshio, and Aleutian Currents. In this area both salmon and albacore have been caught in the same gill net.

Westward from 170°E to the continent the third area exists and has properties similar to those described in the Gulf of Alaska, cold, oxygen-rich stratum existing at 75 - 100 meters and a sharp discontinuity at the Polar front, although the stratum is considerably colder with temperatures between 0° and 2°C.

The fourth area is the Bering Sea where, although the surface waters are generally more saline than south of the Aleutians, the cold stratum exists. However, the extensive shallow continental shelf makes this area more complex.

Since these areas may provide environments for different species of salmon, and annual differences in temperature may effect the concentrations of salmon, the isotherms of minimum temperatures existing at depths of 75 - 100 meters (which Table 1 has indicated to be relatively permanent) were drawn from Japanese data collected in the spring and summer of 1936 and 1953 (Figures 3 and 4). These are not extreme variations but are years in which some oceanographic data are available. The crowding of the 3°C isotherm near the Aleutian Islands in 1953 as compared to the expanded region in 1936 shows a considerable geographical variation in water properties. If these minimum isotherms reflect winter surface conditions, this would imply that 1936 was milder than 1953.
Figure 3. Minimum Temperatures in Surface Layer 1936 (spring-summer).
Figure 6. Minimum Temperatures in Surface Layer 1953 (spring - summer)
However, the absence of winter oceanographic data in these years necessitates referring to air temperatures reported from shore stations to investigate differences in these years. Figure 5, a graph of the deviation from long term monthly mean air temperatures, indicates air temperatures in this area considerably warmer in 1936 than in 1953. It is particularly noteworthy that the February temperatures in 1936 are warmer because this is the month of greatest winter turnover, and surface air temperatures would have the greatest effect on a water column.

The significance of the isotherms at the depth of minimum temperature is difficult to evaluate because fishing operations are not conducted during the months these temperatures exist at the surface. However, a possible effect of the annual variations in geographical extent of the 3°C isotherm is indicated in Figure 6 which is a comparison of red salmon catch with a vertical temperature profile in the Bering Sea along 170°W. In June 1956 (Figure 6a) when the water temperatures over the shelf were 3°C or less, large numbers of red salmon were caught in the warmer water off the shelf. However, in 1957 (Figure 6b) the surface water over the shelf was much warmer and considerably fewer were caught at the surface off the shelf. It is believed that the cold surface water temperatures in 1956 could impose a barrier which would contribute to the concentration of red salmon off the shelf.
Figure 5. Deviation of °F from normal mean monthly air temperatures at St. Paul Island.
Figure 5a.
M/V TORDENSKJOLD
15-24 June 1956

Figure 5b.
M/V ATTU
17-19 June 1957

Figure 6. Vertical Sections Along 170° W.
Figure 7 is a comparison of two vertical sections in the Bering Sea along 175°E, in June 1956 and 1957, which also shows the increase in temperature of the surface water in the Bering Sea in 1957, indicating an earlier westward extension of the red salmon environment than in 1956. It should be noted that the minimum temperature at 100 meters is approximately the same for the two years. Advection neglected, this may imply that the winter surface temperatures were equivalent, but that the rate of spring heating was considerably greater in 1957. Thus, if it is true that the commencement of a shoreward migration of red salmon is dependent on surface waters warmer than 3°C, any prediction of movement would have to be based on both of these factors — the heat required to raise the winter temperatures to above 3°C and the rate at which this heat is available in the spring months. Of course, the minimum surface temperatures and amount of insolation would vary geographically.

An attempt has been made to show the general thermal characteristics of the waters in which salmon are caught on the high seas, and that these characteristics are unique in this region. Annual temperature variations as a result of warm or cold years are significant and may effect the geographical extent and regional abundance of red salmon particularly. Air temperatures at local coastal shore stations may provide a key to predicting local effects of these warm and cold years. The relationships of salinity, other chemical constituents, and plankton to this salmon environment, as well as monthly and annual changes of these water properties, are being investigated.
Figure 7. Vertical Sections Along 175° E.
References


Physical, Chemical and Plankton Data Record: Project Norpac: July 26 to September 1, 1955. Pacific Oceanographic Group, Nanaimo, British Columbia.

Physical, Chemical and Plankton Data Record: North Pacific Survey: January 23 to March 4, 1957. Pacific Oceanographic Group, Nanaimo, B. C.

Physical, Chemical and Plankton Data Record: North Pacific Survey: July 23 to August 30, 1957. Pacific Oceanographic Group, Nanaimo, B. C.