The saga continues:
recent ocean conditions and biological response in the NE Pacific Ocean

Laurie Weitkamp
NOAA Fisheries
Northwest Fisheries Science Center
Laurie.weitkamp@noaa.gov
Today’s talk

Latest stoplight table

Physical conditions across the North Pacific
  – The blob, El Niños, La Niñas, recent SSTs

Salmon marine distributions

Biological response to physical conditions

Forecasts
  – El Niño-Southern Oscillation (ENSO)
    – Sea surface temperatures (SSTs)

Summary
## Bill Peterson’s stoplight table

### Salmon ocean entry year

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PDO (Sum Dec-March)</td>
<td>19</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>7</td>
<td>21</td>
<td>12</td>
<td>17</td>
<td>14</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>16</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>22</td>
<td>20</td>
<td>18</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>PDO (Sum May-Sept)</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>12</td>
<td>14</td>
<td>2</td>
<td>9</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td>15</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td>ONI (Average Jan-Jun)</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>14</td>
<td>16</td>
<td>15</td>
<td>17</td>
<td>9</td>
<td>12</td>
<td>3</td>
<td>11</td>
<td>18</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>19</td>
<td>22</td>
<td>13</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SST NDBC buoys</td>
<td>17</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>11</td>
<td>22</td>
<td>12</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>16</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>13</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Upper 20 m T</td>
<td>21</td>
<td>11</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>15</td>
<td>16</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>9</td>
<td>18</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>22</td>
<td>20</td>
<td>19</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Upper 20 m T</td>
<td>16</td>
<td>11</td>
<td>13</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>17</td>
<td>7</td>
<td>6</td>
<td>18</td>
<td>20</td>
<td>9</td>
<td>14</td>
<td>12</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Deep temperature</td>
<td>22</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>12</td>
<td>16</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>14</td>
<td>9</td>
<td>3</td>
<td>15</td>
<td>21</td>
<td>19</td>
<td>13</td>
<td>18</td>
<td>20</td>
<td>17</td>
</tr>
<tr>
<td>Deep salinity</td>
<td>21</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>19</td>
<td>12</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>20</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>22</td>
<td>17</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copepod richness anom. (no. species; May-Sept)</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>19</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>N copepod biomass anom. (mg C m^-3; May-Sept)</td>
<td>20</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>17</td>
<td>21</td>
<td>16</td>
<td>13</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>S copepod biomass anom. (mg C m^-3; May-Sept)</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>15</td>
<td>16</td>
<td>21</td>
<td>14</td>
<td>10</td>
<td>1</td>
<td>7</td>
<td>17</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>11</td>
<td>19</td>
<td>20</td>
<td>8</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Biological transition (day of year)</td>
<td>19</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>15</td>
<td>12</td>
<td>20</td>
<td>14</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>17</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>10</td>
<td>21</td>
<td>21</td>
<td>18</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Nearshore Ichthyoplankton (mg C 1,000 m^-3; Jan-Mar)</td>
<td>17</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>1</td>
<td>21</td>
<td>22</td>
<td>15</td>
<td>8</td>
<td>17</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>19</td>
<td>14</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Nearshore &amp; offshore Ichthyoplankton community index (PCO axis 1 scores; Jan-Mar)</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>20</td>
<td>1</td>
<td>14</td>
<td>3</td>
<td>12</td>
<td>15</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>10</td>
<td>18</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Chinook salmon juvenile catches (no. km^-1; June)</td>
<td>20</td>
<td>4</td>
<td>5</td>
<td>17</td>
<td>8</td>
<td>12</td>
<td>18</td>
<td>21</td>
<td>13</td>
<td>11</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>16</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Coho salmon juvenile catches (no. km^-1; June)</td>
<td>20</td>
<td>8</td>
<td>14</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>17</td>
<td>21</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>19</td>
<td>1</td>
<td>13</td>
<td>9</td>
<td>15</td>
<td>22</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Mean of ranks</td>
<td>18.5</td>
<td>6.2</td>
<td>7.3</td>
<td>7.4</td>
<td>5.9</td>
<td>13.9</td>
<td>16.4</td>
<td>17.6</td>
<td>10.9</td>
<td>9.5</td>
<td>2.9</td>
<td>8.6</td>
<td>13.1</td>
<td>7.1</td>
<td>6.1</td>
<td>8.3</td>
<td>13.4</td>
<td>17.7</td>
<td>18.3</td>
<td>16.6</td>
<td>11.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Rank of the mean rank</td>
<td>22</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>9</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>20</td>
<td>21</td>
<td>18</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

[www.nwfwsc.noaa.gov/research/hottopics/salmon_forecasts.cfm](www.nwfwsc.noaa.gov/research/hottopics/salmon_forecasts.cfm)
What promotes rapid growth & survival?

### Indicators

<table>
<thead>
<tr>
<th>Ecosystem indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDO (Sum Dec–March)</td>
</tr>
<tr>
<td>ONI (Average Jan–Jun)</td>
</tr>
</tbody>
</table>

**Ocean-basin scale**

<table>
<thead>
<tr>
<th>Seasonal PDO</th>
</tr>
</thead>
<tbody>
<tr>
<td>= NE Pacific SST El Niño index</td>
</tr>
</tbody>
</table>

**Physical indicators**

<table>
<thead>
<tr>
<th>Seasonal sea surface temp Deep temps &amp; salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep temp (°C; May–Sept)</td>
</tr>
<tr>
<td>Deep salinity (May–Sept)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biological indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copepod richness (no. species; May–Sept)</td>
</tr>
<tr>
<td>N. copepod biomass (mg C m(^{-3}); May–Sept)</td>
</tr>
<tr>
<td>S. copepod biomass (mg C m(^{-3}); May–Sept)</td>
</tr>
<tr>
<td>Biological production (day of year)</td>
</tr>
<tr>
<td>Ichthyoplankton biomass (mg L(^{-1}); Jan–Mar)</td>
</tr>
<tr>
<td>Ichthyoplankton community index (PCD with 1 score; Jan–Mar)</td>
</tr>
<tr>
<td>Chinook salmon juvenile catches (no. km(^{-1}); June)</td>
</tr>
<tr>
<td>Coho salmon juvenile catches (no. km(^{-1}); June)</td>
</tr>
<tr>
<td>Mean of ranks</td>
</tr>
<tr>
<td>Rank of the mean rank</td>
</tr>
</tbody>
</table>

### “Good” conditions

- **Cold** water along West Coast before/after spring outmigration, no El Niño

- **Cold** & salty water off Newport, OR

- Lots of lipid-rich copepods & good salmon prey, early onset of upwelling, lots of juvenile salmon in June
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(Sum Dec-March) PDO</td>
<td>19</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>7</td>
<td>21</td>
<td>12</td>
<td>17</td>
<td>14</td>
<td>19</td>
<td>16</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>22</td>
<td>20</td>
<td>18</td>
<td>11</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>(Sum May-Sept) PDO</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>12</td>
<td>14</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td>15</td>
<td>13</td>
<td>19</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>ONI (Average Jan-June)</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>14</td>
<td>16</td>
<td>15</td>
<td>17</td>
<td>9</td>
<td>12</td>
<td>3</td>
<td>8</td>
<td>10</td>
<td>19</td>
<td>22</td>
<td>13</td>
<td>5</td>
<td>20</td>
<td>18</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>SST NDBC buoys (°C; May-Sept)</td>
<td>17</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>11</td>
<td>22</td>
<td>12</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>10</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>16</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Upper 20 m T (°C; Nov-Mar)</td>
<td>21</td>
<td>11</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>15</td>
<td>16</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>9</td>
<td>18</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>22</td>
<td>20</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>Upper 20 m T (°C; May-Sept)</td>
<td>16</td>
<td>11</td>
<td>13</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>17</td>
<td>7</td>
<td>6</td>
<td>18</td>
<td>20</td>
<td>9</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Deep temperature (°C; May-Sept)</td>
<td>22</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>12</td>
<td>16</td>
<td>11</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>14</td>
<td>9</td>
<td>3</td>
<td>15</td>
<td>21</td>
<td>19</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep salinity (May-Sept)</td>
<td>21</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>19</td>
<td>12</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>20</td>
<td>15</td>
<td>14</td>
<td>13</td>
<td>22</td>
<td>17</td>
<td>9</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Copepod richness anom.</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>19</td>
<td>16</td>
<td>10</td>
<td>8</td>
<td>9</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>N. copepod biomass anom.</td>
<td>20</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>17</td>
<td>14</td>
<td>21</td>
<td>16</td>
<td>13</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>S. copepod biomass anom.</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>15</td>
<td>16</td>
<td>21</td>
<td>14</td>
<td>10</td>
<td>1</td>
<td>7</td>
<td>17</td>
<td>9</td>
<td>8</td>
<td>6</td>
<td>11</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Biological transition</td>
<td>19</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>15</td>
<td>12</td>
<td>20</td>
<td>14</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>17</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>10</td>
<td>21</td>
<td>21</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Nearshore ichthyoplankton (mg C 1,000 m⁻³; Jan-Mar)</td>
<td>17</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>1</td>
<td>21</td>
<td>22</td>
<td>15</td>
<td>8</td>
<td>17</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td>10</td>
<td>19</td>
<td>14</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearshore &amp; offshore ichthyoplankton community index (PCO axis 1 scores; Jan-Mar)</td>
<td>11</td>
<td>6</td>
<td>5</td>
<td>9</td>
<td>8</td>
<td>13</td>
<td>16</td>
<td>20</td>
<td>1</td>
<td>14</td>
<td>3</td>
<td>12</td>
<td>15</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td>10</td>
<td>18</td>
<td>21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinook salmon juvenile catches (no. km⁻¹; June)</td>
<td>20</td>
<td>4</td>
<td>5</td>
<td>17</td>
<td>8</td>
<td>12</td>
<td>18</td>
<td>21</td>
<td>13</td>
<td>11</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>16</td>
<td>2</td>
<td>3</td>
<td>10</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Coho salmon juvenile catches (no. km⁻¹; June)</td>
<td>20</td>
<td>8</td>
<td>14</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>17</td>
<td>21</td>
<td>18</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>19</td>
<td>1</td>
<td>13</td>
<td>9</td>
<td>15</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Mean of ranks</td>
<td>18.5</td>
<td>6.2</td>
<td>7.3</td>
<td>7.4</td>
<td>5.9</td>
<td>13.9</td>
<td>16.4</td>
<td>17.6</td>
<td>10.9</td>
<td>9.5</td>
<td>2.9</td>
<td>8.6</td>
<td>13.1</td>
<td>7.1</td>
<td>6.1</td>
<td>8.3</td>
<td>13.4</td>
<td>17.7</td>
<td>18.3</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>Rank of the mean rank</td>
<td>22</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>9</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>20</td>
<td>21</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

Bill Peterson’s stoplight table
Salmon ocean entry year

1997/98 El Niño

Good Bad Good

www.nwfs.noaa.gov/research/hottopics/salmon_forecasts.cfm
## Bill Peterson’s stoplight table
### Salmon ocean entry year

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PDO (Sum Dec-March)</td>
<td>19</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>7</td>
<td>21</td>
<td>12</td>
<td>17</td>
<td>14</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>16</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>10</td>
<td>22</td>
<td>20</td>
<td>18</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>PDO (Sum May-Sept)</td>
<td>10</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>17</td>
<td>16</td>
<td>18</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>8</td>
<td>20</td>
<td>22</td>
<td>21</td>
<td>15</td>
<td>13</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ONI (Average Jan-June)</td>
<td>21</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>14</td>
<td>16</td>
<td>15</td>
<td>17</td>
<td>12</td>
<td>8</td>
<td>7</td>
<td>10</td>
<td>19</td>
<td>22</td>
<td>13</td>
<td>6</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SST NDBC buoys (°C; May-Sept)</td>
<td>17</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>5</td>
<td>11</td>
<td>22</td>
<td>12</td>
<td>3</td>
<td>7</td>
<td>9</td>
<td>16</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>13</td>
<td>15</td>
<td>14</td>
<td>7</td>
<td>17</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Upper 20 m T (°C; Nov-Mar)</td>
<td>21</td>
<td>11</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>15</td>
<td>16</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>9</td>
<td>18</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>22</td>
<td>20</td>
<td>19</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Upper 20 m T (°C; May-Sept)</td>
<td>16</td>
<td>11</td>
<td>13</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>17</td>
<td>7</td>
<td>6</td>
<td>18</td>
<td>20</td>
<td>9</td>
<td>14</td>
<td>12</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Deep temperature (°C; May-Sept)</td>
<td>22</td>
<td>6</td>
<td>8</td>
<td>4</td>
<td>1</td>
<td>10</td>
<td>12</td>
<td>16</td>
<td>11</td>
<td>8</td>
<td>9</td>
<td>15</td>
<td>21</td>
<td>19</td>
<td>13</td>
<td>18</td>
<td>20</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deep salinity (May-Sept)</td>
<td>21</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>5</td>
<td>18</td>
<td>19</td>
<td>12</td>
<td>7</td>
<td>10</td>
<td>6</td>
<td>18</td>
<td>20</td>
<td>13</td>
<td>8</td>
<td>7</td>
<td>15</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copepod richness anom. (no. species; May-Sept)</td>
<td>20</td>
<td>2</td>
<td>1</td>
<td>7</td>
<td>6</td>
<td>15</td>
<td>14</td>
<td>19</td>
<td>16</td>
<td>5</td>
<td>3</td>
<td>11</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>13</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N. copepod biomass anom. (mg C m⁻³; May-Sept)</td>
<td>20</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>17</td>
<td>14</td>
<td>21</td>
<td>16</td>
<td>13</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>S. copepod biomass anom. (mg C m⁻³; May-Sept)</td>
<td>20</td>
<td>15</td>
<td>11</td>
<td>12</td>
<td>4</td>
<td>17</td>
<td>14</td>
<td>21</td>
<td>16</td>
<td>13</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>19</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Biological transition (day of year)</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>12</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>12</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>12</td>
<td>19</td>
<td>20</td>
<td>18</td>
<td>13</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearshore ichthyoplankton (mg C 1,000 m⁻³; Jan-Mar)</td>
<td>17</td>
<td>14</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>20</td>
<td>17</td>
<td>19</td>
<td>18</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nearshore &amp; offshore Ichthyoplankton community index (PCO axis 1 scores; Jan-Mar)</td>
<td>13</td>
<td>18</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td>22</td>
<td>17</td>
<td>19</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinook salmon juvenile catches (no. km⁻¹; June)</td>
<td>20</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td>15</td>
<td>9</td>
<td>12</td>
<td>19</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td>15</td>
<td>9</td>
<td>12</td>
<td>19</td>
<td>14</td>
<td>19</td>
<td>22</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coho salmon juvenile catches (no. km⁻¹; June)</td>
<td>20</td>
<td>8</td>
<td>14</td>
<td>6</td>
<td>7</td>
<td>3</td>
<td>17</td>
<td>21</td>
<td>18</td>
<td>10</td>
<td>4</td>
<td>5</td>
<td>10</td>
<td>11</td>
<td>16</td>
<td>19</td>
<td>13</td>
<td>9</td>
<td>15</td>
<td>22</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Mean of ranks</td>
<td>18.5</td>
<td>6.2</td>
<td>7.3</td>
<td>7.4</td>
<td>5.9</td>
<td>13.9</td>
<td>16.4</td>
<td>17.6</td>
<td>10.9</td>
<td>9.5</td>
<td>2.9</td>
<td>8.6</td>
<td>13.1</td>
<td>7.1</td>
<td>6.1</td>
<td>8.3</td>
<td>13.4</td>
<td>17.7</td>
<td>18.3</td>
<td>16.6</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td>Rank of the mean rank</td>
<td>22</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>19</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>9</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>14</td>
<td>20</td>
<td>21</td>
<td>18</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

Bottom line: 5+ years of unfavorable ocean conditions, no obvious end in sight

**Blob and after effects**

**Marine heat wave**

www.nwfsc.noaa.gov/research/hottopics/salmon_forecasts.cfm
Physical conditions across the North Pacific

Drivers of physical conditions
• Formation of the blob
• El Niño and La Niñas

Recent sea surface temperature (SST) anomalies
How the blob formed (Winter 2013/14)
Unusually stationary high pressure over the North Pacific blocked storms, which limited vertical mixing

Ridiculously resilient ridge

Warm, low-nutrient surface waters = “the blob”

Heat transferred to depth

Heat transferred to atmosphere

Atmospheric pressure anomalies, Nov 1, 2013-Jan 9, 2014

STRONG WIND

How the blob formed (Winter 2013/14)
Unusually stationary high pressure over the North Pacific blocked storms, which limited vertical mixing

Ridiculously resilient ridge

Warm, low-nutrient surface waters = “the blob”

Heat transferred to depth

Heat transferred to atmosphere

Atmospheric pressure anomalies, Nov 1, 2013-Jan 9, 2014

STRONG WIND

How the blob formed (Winter 2013/14)
Unusually stationary high pressure over the North Pacific blocked storms, which limited vertical mixing

Ridiculously resilient ridge

Warm, low-nutrient surface waters = “the blob”

Heat transferred to depth

Heat transferred to atmosphere

Atmospheric pressure anomalies, Nov 1, 2013-Jan 9, 2014

STRONG WIND
How the blob formed (Winter 2013/14)
Unusually stationary high pressure over the North Pacific blocked storms, which limited vertical mixing

Don’t know what mechanism caused the 2019 marine heat wave (yet), but likely different than blob
El Niños and La Niñas: Tropical phenomena that impact global weather

Measured as 5 consecutive 3-month SST anomalies in the Niño 3.4 area:
- El Niños > +0.5°C
- La Niñas < -0.5°C

Current conditions: neutral (neither El Niño nor La Niña present at equator)
North Pacific surface temperature anomalies

The blob

El Niño

La Niña

http://polar.ncep.noaa.gov/sst/ophi/
North Pacific surface temperature anomalies

Jul '17  Oct '17  Jan '18  Apr '18

Jul '18  Oct '18  Jan '19  Apr '19

May '19  June '19  July '19  August '19

El Niño

La Niña

Blobish

El Niño

El Niño

El Niño

El Niño

Marine heat wave

http://polar.ncep.noaa.gov/sst/ophi/
North Pacific surface temperature anomalies

Sept '19  Oct '19  Nov '19

http://polar.ncep.noaa.gov/sst/ophi/
Salmon marine distributions

Where salmon go in the ocean determines the conditions they encounter:

- Physical condition (temp, salinity)
- Prey, competitor, and predator abundances which influences
  - Growth potential
  - Decisions to mature
  - Ultimately survival

Knowing where salmon are at any time is the 1st step to understanding their marine ecology
First summer in the ocean: 3 patterns for NW salmon

Pattern 1: Rapid northwards movement on shelf to Gulf of Alaska
\textit{Which:} Spring Chinook, chum, sockeye, some coho

Pattern 2: Remain in local waters
\textit{Which:} Fall Chinook, some coho

Pattern 3: Move rapidly offshore
\textit{Which:} Steelhead
First summer in the ocean: 3 patterns for NW salmon

Pattern 1: Rapid northwards movement on shelf to Gulf of Alaska
Which: Spring Chinook, chum, sockeye, some coho

Pattern 2: Remain in local waters
Which: Fall Chinook, some coho

Pattern 3: Move rapidly offshore
Which: Steelhead

This early period is when most marine mortality occurs
Initial ocean migrations of Northwest salmon in recent Julys

(shading = monthly sea surface temperature anomalies)

July 2015  July 2016  July 2017

July 2018  July 2019

Spring Chinook, sockeye
Steelhead
Fall Chinook, coho
NW high seas distributions

- Chinook
- Sockeye & chum
- Coho
- Steelhead
Winter 2019 expedition to Gulf of Alaska
Winter 2019 Salmon distributions

- Clear north-south and east-west differences between species
Winter 2019 Salmon distributions

**Chum**
- Originated from:
  - Japan
  - Russia
  - Alaska
  - BC
  - Wash Coast

**Coho**
- Originated from:
  - Alaska
  - BC
  - Wash Coast
  - Columbia
  - Ore Coast

**Sockeye**
- Originated from:
  - Alaska
  - BC

**Pink**
- Originated from:
  - Alaska
  - BC

**Chinook**
- Originated from:
  - Alaska
  - BC
  - Columbia
  - (Snake fall)

- Clear north-south and east-west differences between species
1. Adults returning to the NW: 3 general migration patterns

**Pattern 1:** Southwards movement along shelf

Which: Fall Chinook, Chum (?), sockeye (?)

**Pattern 2:** Northwards along CA & OR Coasts (CR-S); southward off BC coast (WA cst-N)

Which: Coho

**Pattern 3:** Move rapidly onshore (or unknown)

Which: Steelhead, Spring Chinook
Biological response to physical conditions

**Highlights**
- Extremes across the N Pacific
- Observations from juvenile salmon surveys (JSOES study)
- Adult salmon returns, AK to CA

Pyrosomes caught in a 5 minute tow off the Washington coast, May 2018
Extreme biological response to warm oceans

2015

Tropicals in Oregon

Species range extensions from CA to AK

Dramatic changes to food webs

Domoic acid closes crab and clam fisheries AK-CA

Young Chinook & coho in ocean very skinny

2016

Squid fishery in Oregon!

Anchovies invade the Salish Sea

Changes to food webs continue

Red pelagic crabs in Newport!

2017

High Pacific lamprey counts at Bonneville Dam

Pyrosomes explode AK-CA

Swordfish off Vancouver Is.

Extremely low Pacific cod abundance in Gulf of Alaska

Crab and clam fishery closures

Crab and clam fishery closures
Continuing crab and/or razor clam fisheries closures due to domoic acid

Zooplankton returning to “normal”

Pyrosomes thick in spring, gone by fall

Big hypoxia event caused crab die-offs

Huge squid fishery in Oregon!

Some warm water fish still around

Continuing crab and/or razor clam fisheries closures due to domoic acid

Extremes across the N Pacific

2018

2019

Squid boats in Newport, big squid fishery

They’re back! Invasion of subtropical fishes on West Coast

Pacific mackerel

Dorado

Striped marlin

Yellowtail Jack

Zooplankton “normal”

Domoic acid still present in Oregon & N California
Juvenile Salmon Surveys

- Document distribution and condition of juvenile salmon off OR/WA coasts
- 1998 – present (also 1981 – 85)
- Sampling fish community, hydrography, plankton
- Funded by BPA
Juvenile salmon catches in 2018 and 2019 suggested a large coho return in 2019, “normal” in 2020 for both Yearling Chinook salmon and Yearling coho salmon.
Unusual adult salmon observations

2015
- 3rd largest Bristol Bay sockeye ever
- Huge kills of sockeye in Fraser and Columbia due to hot river temps
- Record low coho returns to Fraser, Puget Sound, Columbia, WA & OR coasts

2016
- Lowest AK pinks in memory
- Fraser sockeye lowest on record
- Fraser chum highest in 20 years

2017
- Highest AK Chum, lowest Chinook ever
- Fraser River 2nd lowest sockeye & pinks, lowest steelhead
- Lowest CR steelhead since 1990s
- Lowest OR coast steelhead ever
- Fishery closures for Chinook in SEAK, S OR

2018
- Huge Bristol Bay sockeye return (60 mill)
- Even lower CR steelhead, lowest Fall Chinook 10 yrs
- Highest shad count over BON ever
- Ocean closure for poor coho
Unusual adult salmon observations

2019

- Salmon kills in Alaska due to hot river temps
- Offspring of fish killed in 2015 due to high river temps
- S. BC closed to Chinook fishing to protect expected extremely low Fraser returns. Lowest Fraser River sockeye return ever
- Extremely low Columbia sockeye, Spring Chinook
- Even higher shad count across Bonneville Dam (7.5 million)
- Lots of big Chinook off CA

4th largest Bristol Bay sockeye return ever (56 mill)

Juv. Chinook salmon

Log (CPUE + 1)

0.0
0.1
0.2
0.3
0.4
0.5

Year

98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17

Bristol Bay sockeye return

Even higher shad count across Bonneville Dam (7.5 million)
Forecasts

- El Niño
- SST forecasts
13 January 2020

ENSO-neutral conditions are present

A majority of models favor ENSO-neutral through the Northern Hemisphere summer 2020.
Forecast SST anomalies
NOAA Climate prediction Center coupled forecast model 2

Mar-Apr-May 2020
May-Jun-Jul 2020
Jul-Aug-Sep 2020

Summary

• Warm ocean waters present since 2014 still continue across large parts of the North Pacific Ocean

• Biological response to warm ocean has been huge
  – Effects observed at all levels of marine ecosystem
  – Expect biological effects of warm ocean conditions will continue for several years (e.g., salmon returns, hake increase)

• Last summer’s marine heat wave and predicted above average N Pacific waters this spring/summer are unlikely to be favorable for cold water species (e.g., salmon, crab).

• What’s next?!
Questions?