Impact of a marine heatwave on Pacific salmon habitat

Steve Lindley, Nate Mantua, Steve Munch, and Tanya Rogers
Southwest Fisheries Science Center, National Marine Fisheries Service

Steve.Lindley@noaa.gov

Background

Recently (2014-16), the northeast Pacific was struck by a marine heatwave that garnered much attention at the time because of its unusual magnitude, extent, duration, and anecdotal observations of marine organisms suggesting a significant reorganization of marine ecosystems.

From the perspective of a fisheries scientist in the continental USA, severe marine heatwaves such as the 2014-16 event in the northeast Pacific are viewed with apprehension because historically, anomalously warm periods are associated with poor performance of fish populations, especially Pacific salmon.

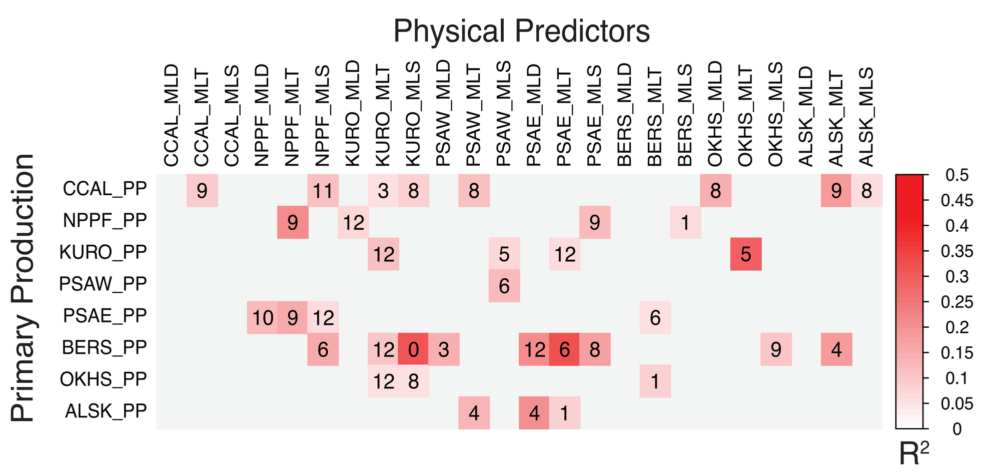
Marine heatwaves may impact salmon in at least three ways: 1) altering distribution of thermally suitable habitat, 2) altering lower trophic level productivity, and 3) altering the distribution and activity level of salmon predators (predation not addressed here).

SST anomalies are a limited indicator of ecosystem state, since they may arise from a variety of physical phenomena, different ecosystems of the North Pacific are driven by different phenomena, and the important drivers vary seasonally. We should therefore expect the ecological response to differ among heatwaves, seasons, and ecosystems. Here, we attempt to look deeper (literally and figuratively) into how the marine heatwave of 2014-16 impacted ecosystems and salmon of the north Pacific.

What drives changes in productivity?

We used convergent cross mapping (CCM) to evaluate whether physical variable anomalies (mixed layer depth, temperature, and salinity) cause anomalies in primary production. To address the causal relationship between two time series, CCM reconstructs system states from the two time series variables and then quantifies the correspondence between them using nearest neighbor forecasting (Ye et al 2015). If variable *X* drives variable *Y*, then information about *X* can be obtained from *Y*, establishing causality (Sugihara et al 2012).

Primary production anomalies were weakly to moderately coupled to anomalies in physical variables, with linkages most typically to adjacent regions at lags of several months. The California Current and North Pacific Transition Zone are exceptions: productivity is related to temperature in those areas 9 months previously.



Color intensity indicates strength of relationship; number is the lag (in months) with the strongest relationship. Abbreviations: CCAL = California Current; NPPF = North Pacific Transition Zone; KURO= Kurushio Current; PSAW = Pacific Subarctic Gyre (west); PSAE = Pacific Subarctic Gyre (east); BERS = Bering Sea; OKHS = Okhotsk Sea; ALSK = Alaskan Coastal Downwelling; PP = primary production; MLD = mixed layer depth; MLT = mixed layer temperature; MLS = mixed layer salinity. Ecoregion boundaries as defined by Longhurst (1998), but splitting his BERS region into the Bering and Okhotsk seas. The map in the "Ocean Response" panel shows the ecoregion boundaries.

References

Abdul-Aziz, O.I., N.J. Mantua, and K.W. Myers. 2011. Potential climate change impacts on thermal habitats of Pacific salmon (*Oncorhynchus* spp.) in the North Pacific Ocean and adjacent seas. Can J Fish Aquat Sci 68(9): 1660–1680.

Behrenfeld, M.J., and P.G. Falkowski. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol Oceanogr 42(1): 1–20.

Longhurst, A.R. 1998. Ecological Geography of the Sea. Academic Press. 398p.

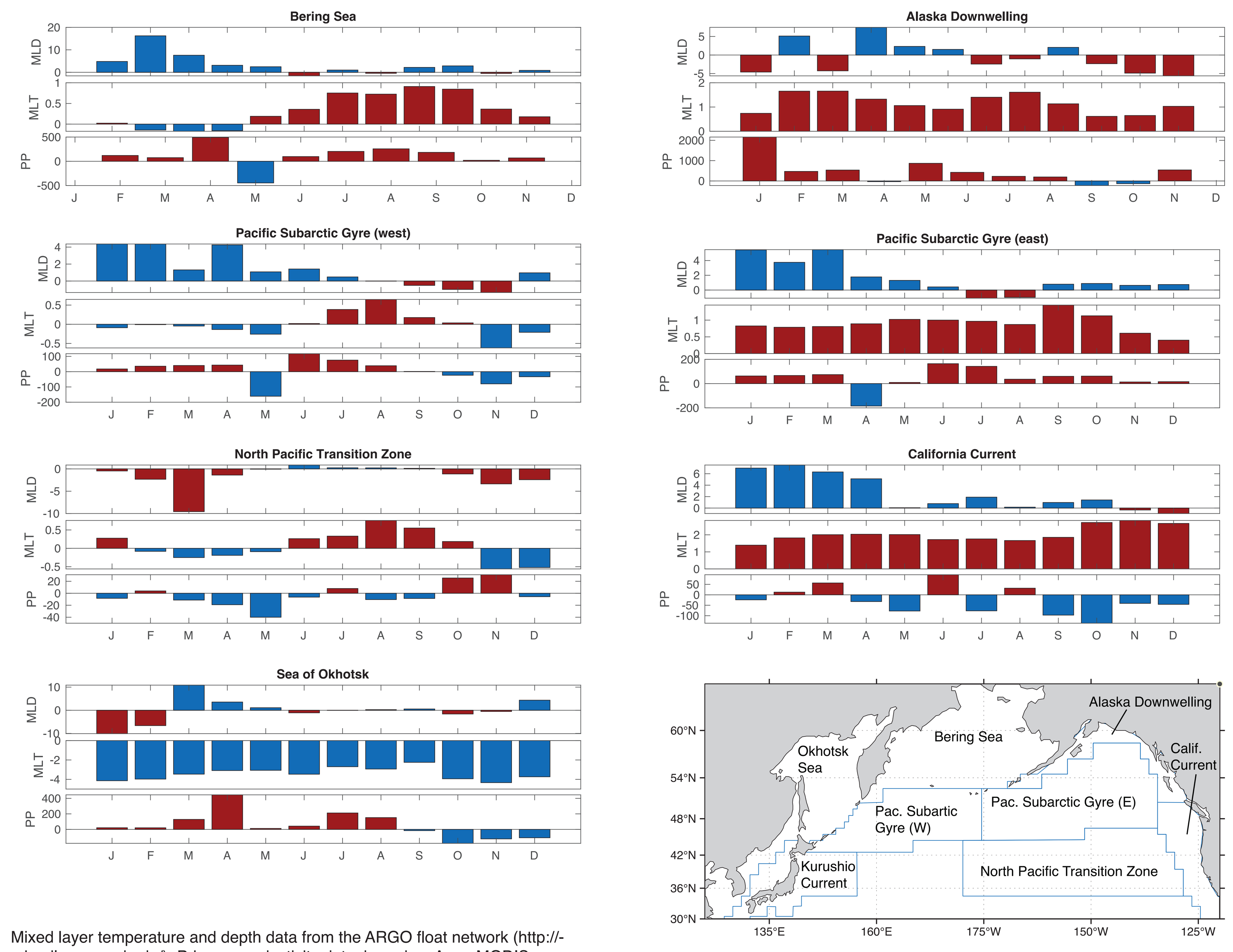
Rayner, N. A., D.E. Parker, E.B. Horton, C.K. Folland, L.V. Alexander, D.P. Rowell, E.C. Kent, and A. Kaplan. 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. J Geophys ResVol. 108, No. D14.

Sugihara, G., R. May, H. Ye, C.H. Hsieh, E. Deyle, M. Fogarty, and S. Munch. 2012. Detecting causality in complex ecosystems. Science 338(6106): 496–500.

Ye, H., Deyle, E.R., Gilarranz, L.J., and Sugihara, G. 2015. Distinguishing time-delayed causal interactions using convergent cross mapping. Sci Rep: 1–9.

Ocean response

Changes in mixed layer depth, temperature, and primary production during the 2014-16 heatwave relative to 2002-2018 averages. Year-round warming was evident in the eastern Pacific, and increased primary production in northern areas.



Mixed layer temperature and depth data from the ARGO float network (http://mixedlayer.ucsd.edu/). Primary productivity data, based on Aqua MODIS ocean color data and the Behrenfeld-Falkowski (1997) model , were obtained from https://coastwatch.pfeg.noaa.gov/erddap/griddap.

Salmon population response

Bristol Bay sockeye and Russian pink salmon run-sizes and fisheries had strong performance for year classes entering the ocean from 2014-2016.

There were multiple Federal Fishery Disaster Declarations for salmon fisheries targeting salmon stocks that enter the Gulf of Alaska directly, or migrate there shortly after entry.

Because background SSTs in the Gulf of Alaska are warm relative to those at similar latitudes farther west, the same amount of SST anomaly can bring the total SST above thermal preferences for salmon on the high seas.

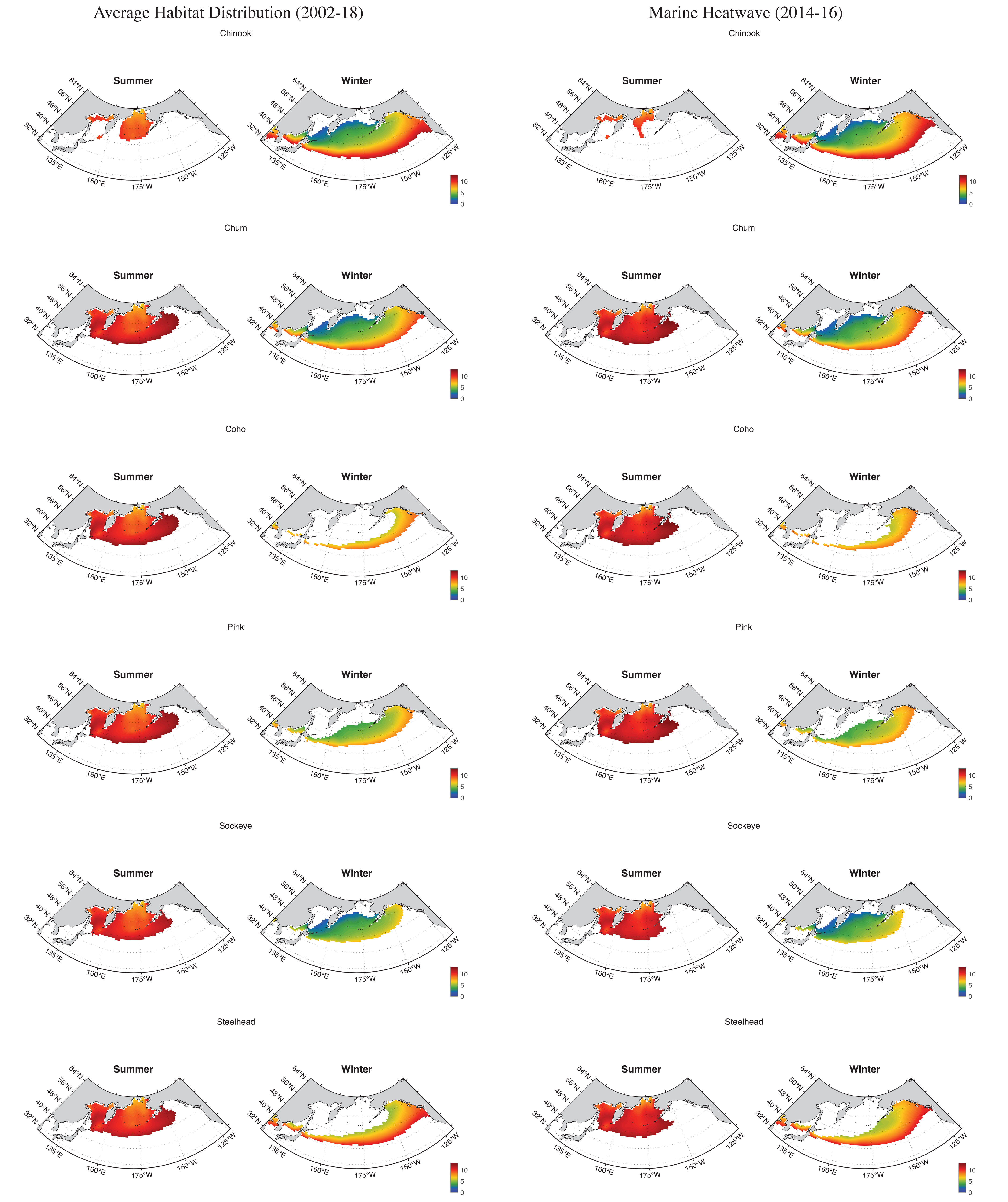
Table 1: Ocean temperatures and observations of unusual salmon fishery conditions aligned by ocean entry year for the dominant year classes of the affected species for all entries except *2014 US Fraser River Sockeye Fishery Disaster Determination. In that case, return year 2014 is aligned with marine heatwave year 2014 to reflect the impact of warm SSTs on the adult migration route.

Russian pink salmon harvest data from npafc.org; Chignik harvest and escapement from adfg.alaska.gov; US Federal Fishery Disaster Determinations (FDDs) from https://www.fisheries.noaa.gov/national/funding-and-financial-services/fishery-disaster-determinations; BC fishery information from Pacific Salmon Commission Reports (psc.org)

2014-MHW Year 1 **Extreme warm SSTs in the Bering Sea and Gulf of Alaska, warm in the subarctic western North Pacific**	**2015-MHW Year 2** **Extreme warm SSTs in the Gulf of Alaska, warm in the Bering Sea, about average in the subarctic western North Pacific**	**2016-MHW Year 3** **Extreme warm SSTs in the Bering Sea, warm in the Gulf of Alaska and western Subarctic North Pacific**	**2017** **Near normal SSTs in the Gulf of Alaska, warm in the Bering Sea**
2015 pink salmon harvest in Russia - 368.7 million	2016 pink salmon harvest in Russia - 439 million	2017 pink salmon harvest in Russia - 353 million	2018 record high pink salmon harvest in Russia - 676 million!
2016 near-historical high Bristol Bay sockeye harvest and returns (> 50 million); 2015: record high Prince William Sound pink salmon harvest (98 million!)	2017 near-historical high Bristol Bay sockeye harvest and returns (> 50 million)	2018 near-historical high Bristol Bay sockeye harvest and returns (> 50 million)	2019 near-historical high Bristol Bay sockeye harvest and returns (56.5 million wild sockeye!)
2015 Washington State coho and pink salmon, tribal fishery FDD	2016 Gulf of Alaska pink salmon FDD (13.3 million harvest in Prince William Sound)	2018 Chignik sockeye FDD; many GoA sockeye stocks had poor returns	2019 Chignik sockeye harvest below average, barely met escapement goals
2016 lowest Fraser River sockeye return on record	2017 extreme low harvest for Fraser River Sockeye	2018 Fraser River "cycle-year" sockeye harvest and returns well below average	2019 Fraser River sockeye fishery closed; record-low in-season run-size of 500,000 adopted

Salmon habitat distribution

Distribution of thermally-suitable habitat in summer and winter during the 2014-16 heatwave and more typical conditions. Note declines in summer habitat area in the eastern Pacific subarctic gyre.



SST data: Had1SST from the Hadley Center (Rayner et al 2003). Thermal limits from Abdul-Aziz et al (2011), summarized in the table at right.

	Frequently observed range (°C)	
Species	Summer	Winter
Sockeye (*O. nerka*)	1–12	1.5–7
Chum (*O. keta*)	1–13	1.5–10
Pink (*O. gorbuscha*)	3–13	3.5–8.5
Coho (*O. kisutch*)	6–13	5.5–9
Chinook (*O. tshawytscha*)	1–10	1.5–12
Steelhead (*O. mykiss*)	6–12.5	5–11