High Ocean Biomass of Salmon and
Trends in Alaska Salmon in a Changing
Climate

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Abundance and Biomass of Salmon in the North Pacific Ocean 1925-2015

(A) abundance (millions of fish)

(B) adult biomass (thousands of metric tons)

(C) adult and immature biomass (thousands of metric tons)

From Ruggerone and Irvine (2018).
Average Percentage Hatchery and Wild 1990-2015

Data from Ruggerone and Irvine (2018)
Trends in Alaska Commercial Salmon Harvest: Wild Stock Harvest from 1900-2017

- Statehood 1959
- PNP Hatchery Program 1974
Trends in Alaska Commercial Salmon Harvest: Hatchery and Wild Stock Harvest from 1900-2017

- Hatchery Harvest
- Wild Stock Harvest

Statehood 1959
PNP Hatchery Program 1974
Factors Affecting the Renaissance of Alaska Salmon

• Large expanses of relatively pristine and undeveloped habitats

• Improved salmon management policies and practices since statehood, including limited entry and sustainable escapement based management

• The elimination of high-seas drift net fisheries

• Production from large scale hatchery programs designed and managed to supplement wild stock production

• Favorable environmental conditions associated with the 1977 “regime shift” affecting the ecosystem dynamics of the North Pacific Ocean
Pacific Decadal Oscillation (PDO): Index of Temperature Patterns in Pacific Ocean
The 1977 “Regime Shift”

• Large increases in primary and secondary productivity (Brodeur and Ware 1992)

• Changes in Gulf of Alaska ecosystem structure, e.g., declines in shrimp, crab, capelin and increases in gaddids, pleuronectids, and jellyfish (Anderson and Piatt 1999)

• Increased abundance of salmon

• Changes have persisted even with warm/cold interannual variation in PDO
"Trying to define ocean carrying capacity is like trying to catch a moonbeam in a jar".
O. Gritsenko, VINRO, Moscow. NPAFC Committee on Scientific Research and Statistics

- Carry capacity is the ability of an ecosystem to sustain reproduction and normal functioning of a set of organisms (Farley et al. 2018)

- Over the past few decades, “carrying capacity” conditions in the North Pacific Ocean have been generally favorable to Pacific salmon as reflected by the sustained high abundances and catches

- Responses of stocks of Pacific salmon have not been uniform during this period, and extremes in survival and production have occurred both temporally and geographically.

- Survival and year-class strength of salmon is the result of responses to local, regional, and basin scale conditions, and not a result of a homogeneous ocean carrying capacity (Heard and Wertheimer 2012).
Pink Salmon Harvests In Southeast Alaska and Prince William Sound 1960-2018
Recent North Pacific “Heat Waves”: Summer 2005

NOAA/NESDIS 50 KM GLOBAL ANALYSIS: SST - Climatology (C), 7/12/2005
(white regions indicate sea-ice)
Southeast Alaska Pink Salmon Harvests 1960-2018

SEAK Pink Salmon Harvest (millions of fish)

- Even
- Odd

Data points from 1960 to 2018 showing fluctuations in pink salmon harvests.
The Blob September 2014. NOAA/NCDC
The BLOB

From Tsing et al. (2017)
Density Dependent Interactions and Carrying Capacity

• Various authors over the past 20 years have posited that high abundance of pink, sockeye, and hatchery chum salmon may have exceeded carrying capacity and be negatively affecting or constraining salmon production (e.g., Peterman et al. 1998, Ruggerone et al. 2018)

• Intra- and interspecific interactions have been associated with reduced feeding efficacy, growth, and survival of populations of Pacific salmon (e.g. Davis 2003, Ruggerone et al. 2003, 2018)

• Competition for prey resources by pink salmon has been proposed as a controlling mechanism for epipelagic zooplankton abundance (Batten et al. 2019)
Density Independent Production and Carrying Capacity

• Rather than indicate that carrying capacity has been exceeded, the trends of the past 25 years show that the North Pacific Ocean has had the capacity for the recovery and sustained production of wild stocks while supporting the expansion of large-scale enhancement production from Japan (chum salmon) and Alaska (chum and pink salmon)
Density Independent Production and Carrying Capacity

Prince William Sound Wild Pink Salmon Production
1960-2013

From Gaudet et al. (2017)
Density Independent Production and Carrying Capacity

While studies have linked size and age of maturity shifts in particular populations to density-dependent interactions, trends in average sizes of pink, chum, and sockeye salmon are more consistent with responses to ocean conditions.

Average weight of salmon in commercial fisheries, 1925-2015 (Ruggerone and Irvine (2018))
Trophic Position of Salmon in the North Pacific Ecosystem

• Salmon make up a small proportion of the nekton in the epipelagic North Pacific
  Western North Pacific and Bering Sea: 4-8% (Shuntov 2017)
  Alaska gyre, Gulf of Alaska: 3-5% (Pauley et al. 1996)

• Recent review of decades of intensive field studies in the Western North Pacific showed
  “as a rule, no significant correlations occur among pink salmon growth rate, stock
  abundance, or zooplankton standing crop.” (Radchenko et al. 2018)

• Rather than shaping the ocean food web, pink salmon appear to be most sensitive to
  interannual changes in oceanic conditions, resulting in high variability in their
  numbers, both temporally and geographically.
What About Coho and Chinook Salmon?

• Relatively small proportion of ocean biomass

• Much more piscivorous than the pink/chum/sockeye guild in their diets, with some overlap

• Concern that high abundance of other salmon, particularly pink salmon, may be negatively affecting size and survival (Shaul and Geiger 2017; Ruggerone et al. 2018)
Coho Salmon Interspecific Interactions

- Complex relationships with pink salmon, including predation of coho juveniles and adults on pink salmon juveniles in nearshore and coastal waters, prey competition in coastal and epipelagic habitats, and “predator sheltering” for coho by abundant pink and chum juveniles.

- As a result, both positive and negative associations have been found for marine survival of particular coho salmon stocks in SEAK with the abundance of juvenile pink and chum salmon (Mallick et al. 2014).

- Negative effect of ocean pink salmon abundance on size of coho salmon in SEAK (Shaul and Geiger 2017) but not in British Columbia (Jeffrey et al. 2017).

- Coho salmon and pink salmon harvests in SEAK correlate positively over time, indicating shared ocean conditions and most affecting ocean survival rather than density-dependent interactions.
Coho and Pink Salmon Harvests in Southeast Alaska, 1960-2017

Data from ADF&G harvest statistics
Chinook salmon demonstrate distinct differences in ocean ecology relative to other Pacific salmon, associated with colder temperatures and deeper depths, and utilizing shelf and slope waters during their ocean residency.

- Marine diets different from pink/chum/sockeye guild, more similar to coho salmon
- Differences in depth and ocean distribution reduces potential for competition.
- However, recent declines in Chinook salmon returns throughout Alaska, and declines in size at age and age at maturity, have raised concerns that the high abundance of other salmon species may be a causative factor in the declines.
Timing of declines in abundance/survival of Chinook does not indicate that high abundance is driving the decline.

From CTC (2018)
Size and Age Declines in Alaska Chinook Salmon Populations

From Lewis et al. (2017)
Size and Age Declines in Alaska Chinook Salmon Populations

- Changes in size and age consistent with top-down effects removing larger, older fish

- Size-selective fishing can affect size and age structure of Chinook salmon (Ricker 1981; Hard et al. 2009), but does not explain the changes across the geographic range because exposure to selective fishing varies considerably among populations.

- Killer whales have been shown to preferentially feed on large Chinook salmon (Hanson et al. 2010)

- Resident killer whales in the Gulf of Alaska have been increasing at an annual rate of 2.9-3.5%, more than doubling in abundance since the 1970’s.
Alaska salmon have been at unprecedented high levels for the past three decades. High abundance of Pacific salmon in ocean has not constrained productivity. The trends in Alaska salmon have reflected the general trends in North Pacific salmon abundance.

Density-independent conditions in the ocean, rather than density-dependent interactions, seem to be driving both the high abundance at the basin-scale and the high variability in salmon populations at local and regional scales.

Warming of the North Pacific in 1977 has been associated with higher productivity, but continued warming and marine heat waves may cause increased variability and changes in geographic distribution of high and low salmon production.
Moving Up the Mountain with Climate Change?

- Warming temperatures in GOA and Bering Sea
- Evidence of structural changes occurring in North Pacific ecosystem, e.g., Pacific cod decline
- Poor returns of pink salmon, sockeye salmon to GOA stocks in 2018
- Record runs of pink salmon in Russia, sockeye salmon to Bristol Bay, high abundance of pinks in Norton Sound in 2018
The BLOB may be back!