Is the North Pacific Ocean Carrying Capacity for Pacific Salmon Limited?

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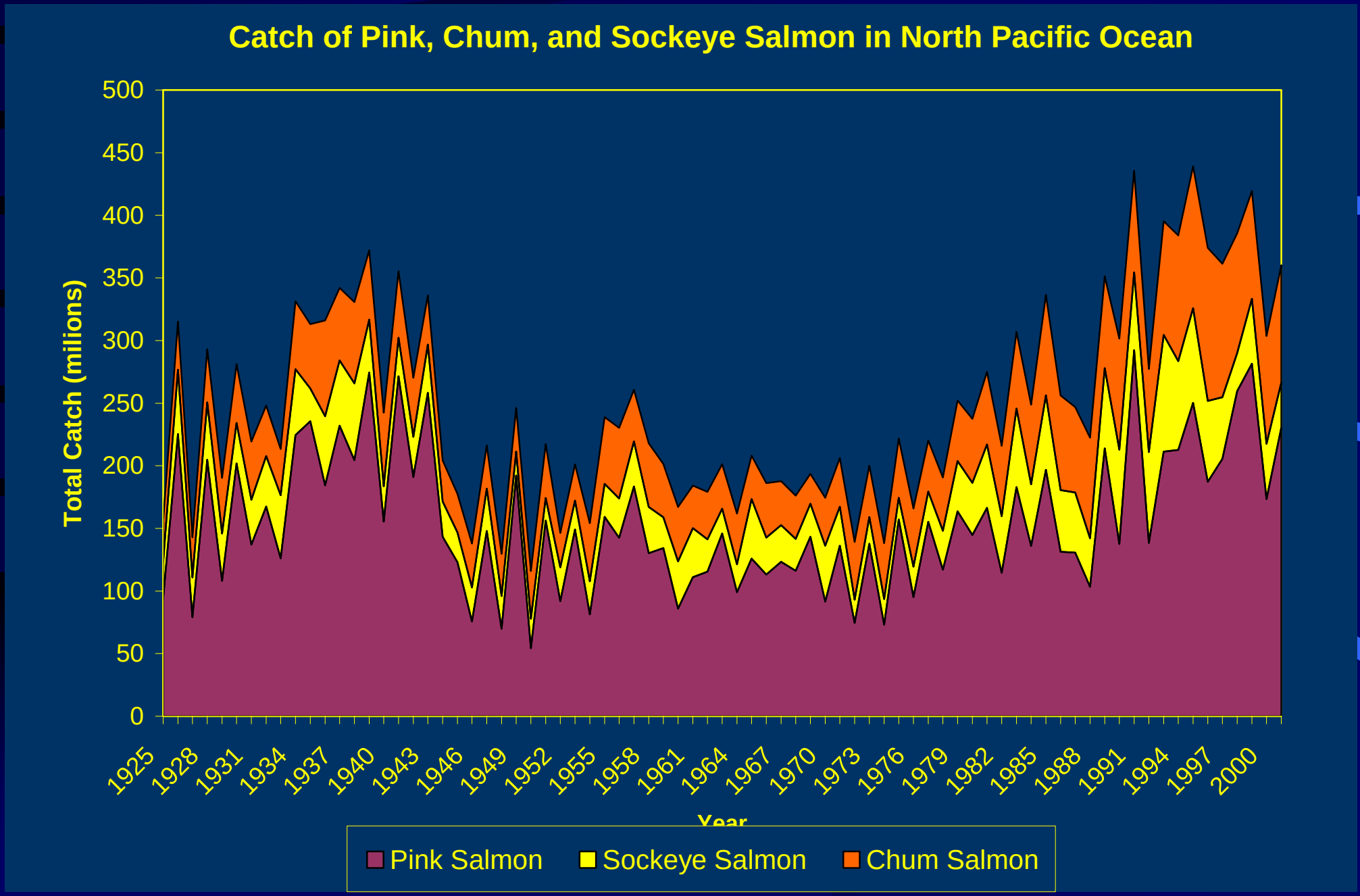

Catch of Pink, Chum, and Sockeye Salmon in North Pacific Ocean
Total Catch (milions)
500
450
400
350
300
250
200
150
100
50
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year
Pink Salmon
Sockeye Salmon
Chum Salmon

Summary of Presentation

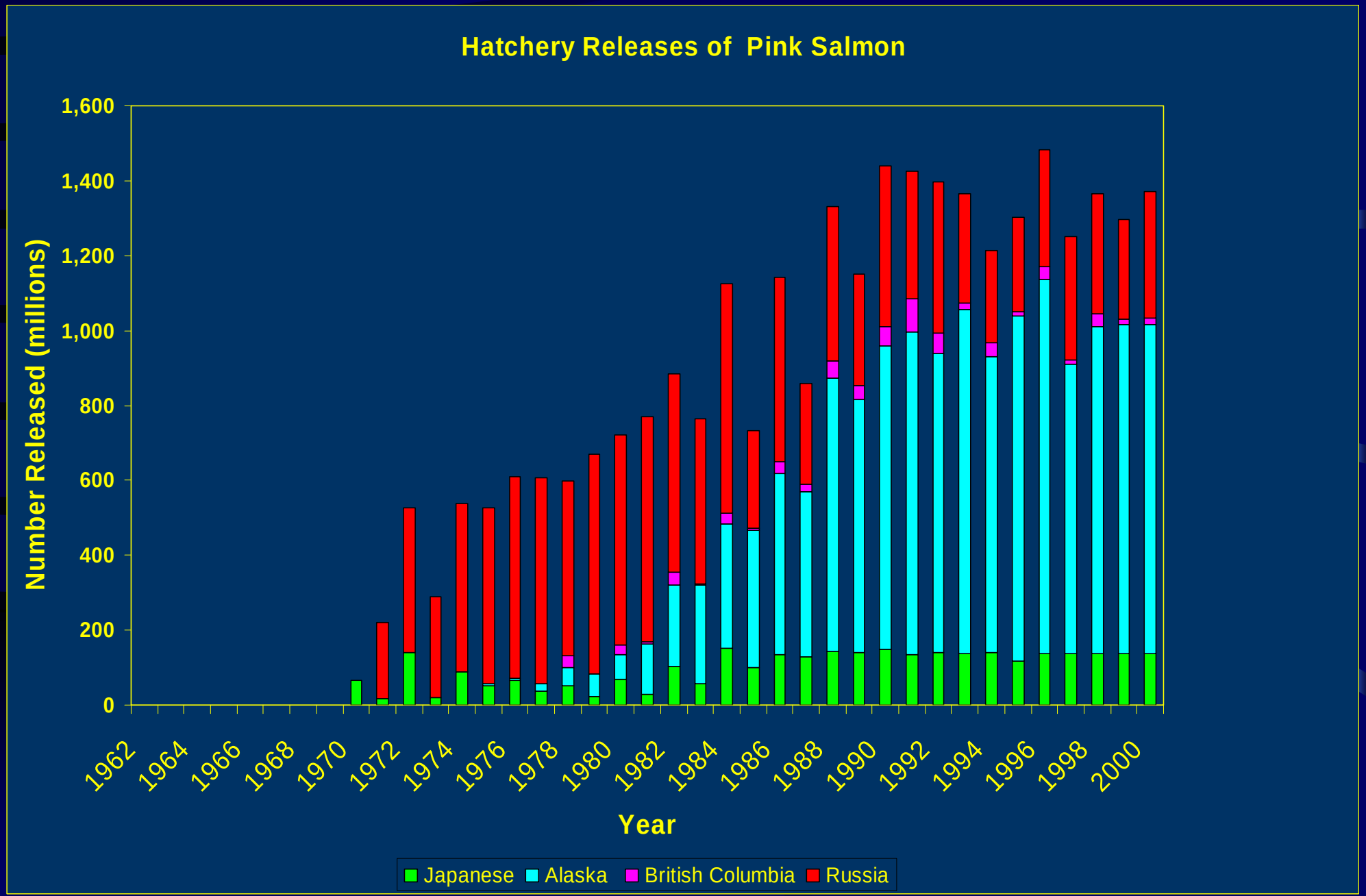
- Questions pertaining to limiting carrying Capacity of North Pacific Ocean make sense in the context of extremely successful ocean ranching operations and massive releases of hatchery smolts have occurred.

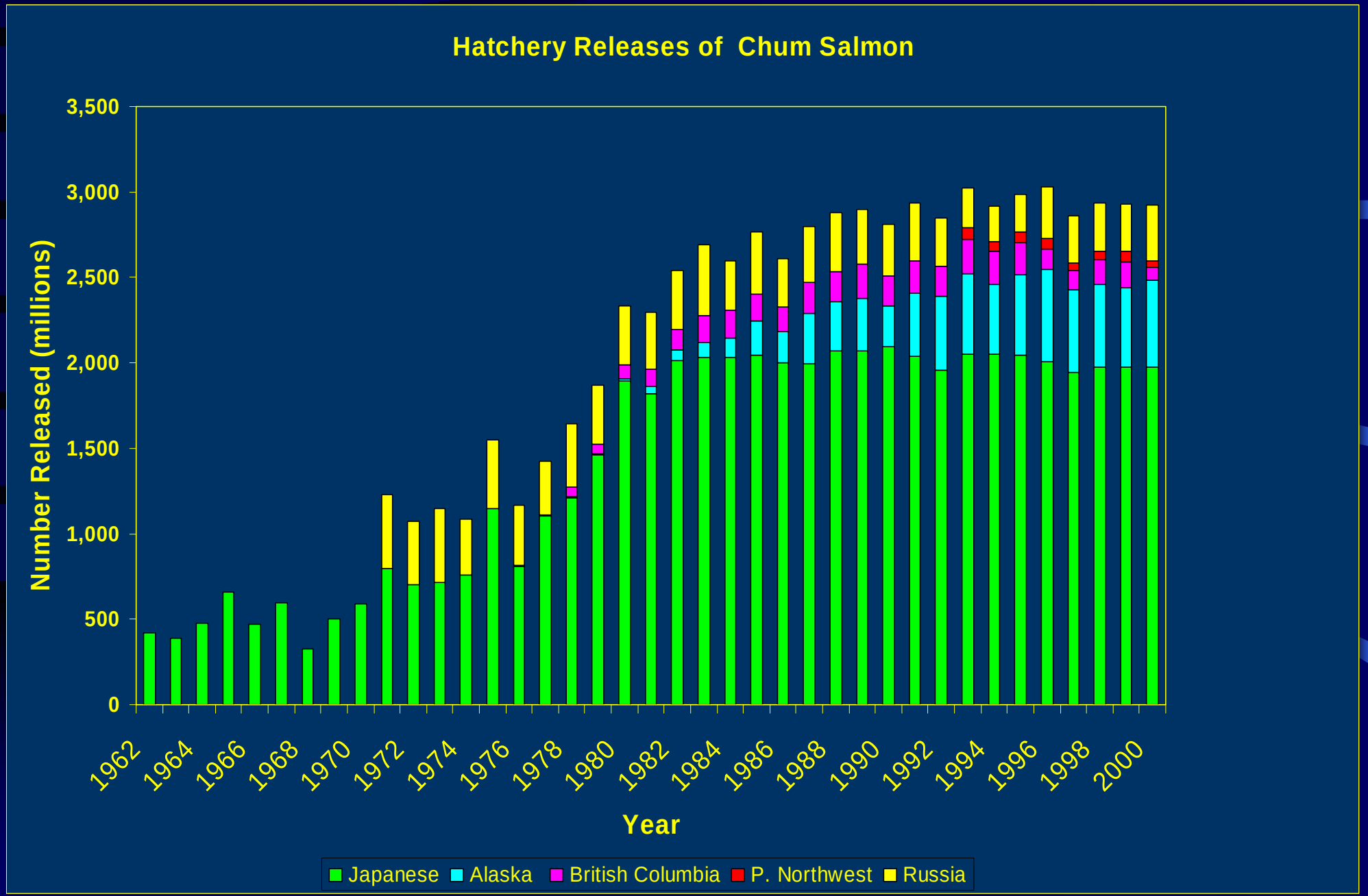
- To put the massive increase in hatchery runs in perspective, I will construct historical biomass of hatchery and wild pink, chum and sockeye salmon in the North Pacific Ocean, 1925 to 2001.

- The total biomass of salmon in the North Pacific at the peak in the late-1990's was 2.5 times that of the minimum in late-1960s. Wild salmon biomass increased roughly 1.6 times during this period. Hatchery runs account for most of this increase in biomass of salmon in the North Pacific Ocean.

- Summarize response of salmon populations to the large increase in biomass of salmon in the North Pacific Ocean.
  - Patterns in size of returning salmon.
  - Patterns in the age at returning salmon.
  - Patterns in recruitment and survival of salmon populations
  - Review response of selected wild salmon populations to establishment of large hatchery runs.

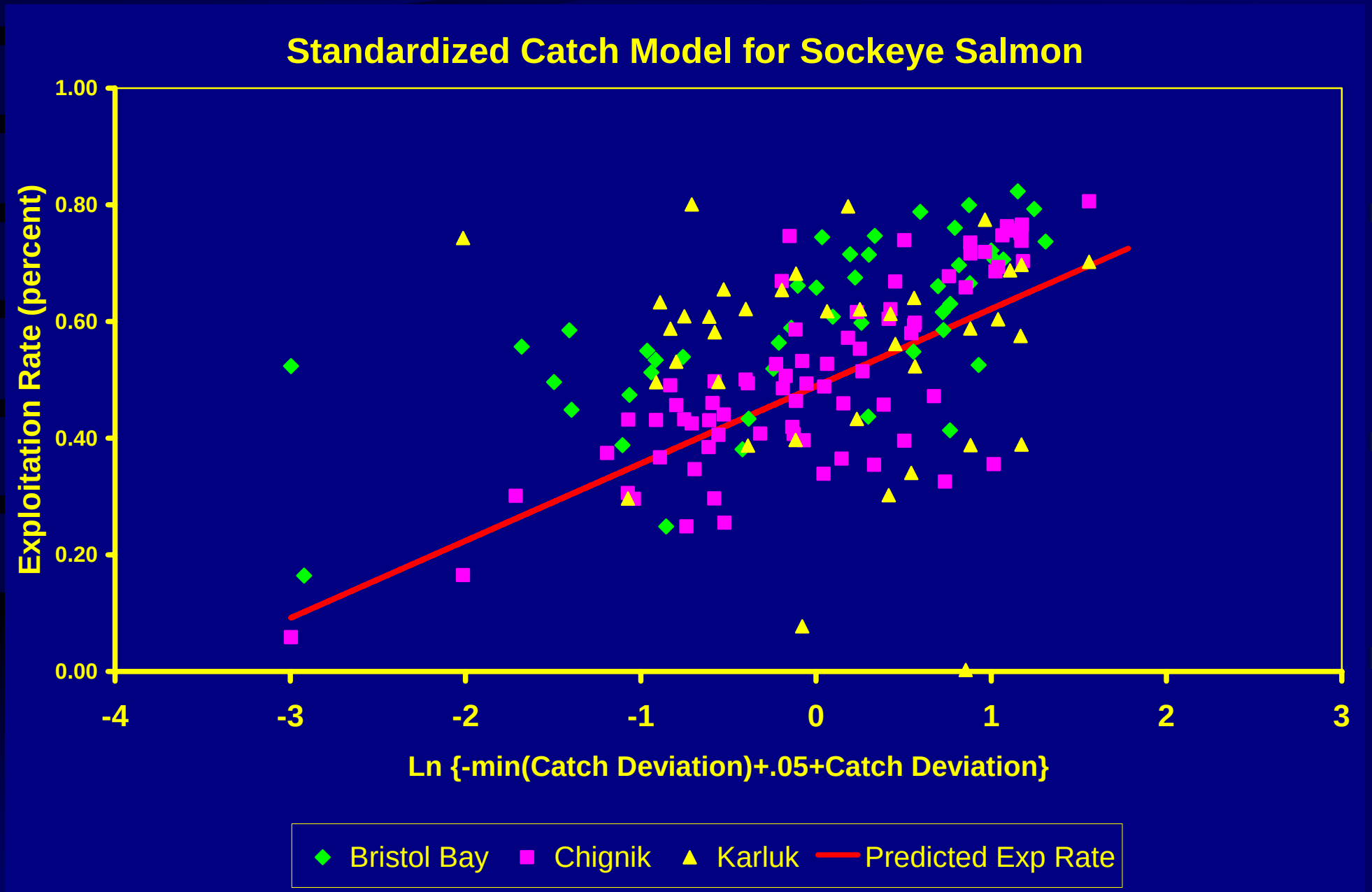
- Conclusions

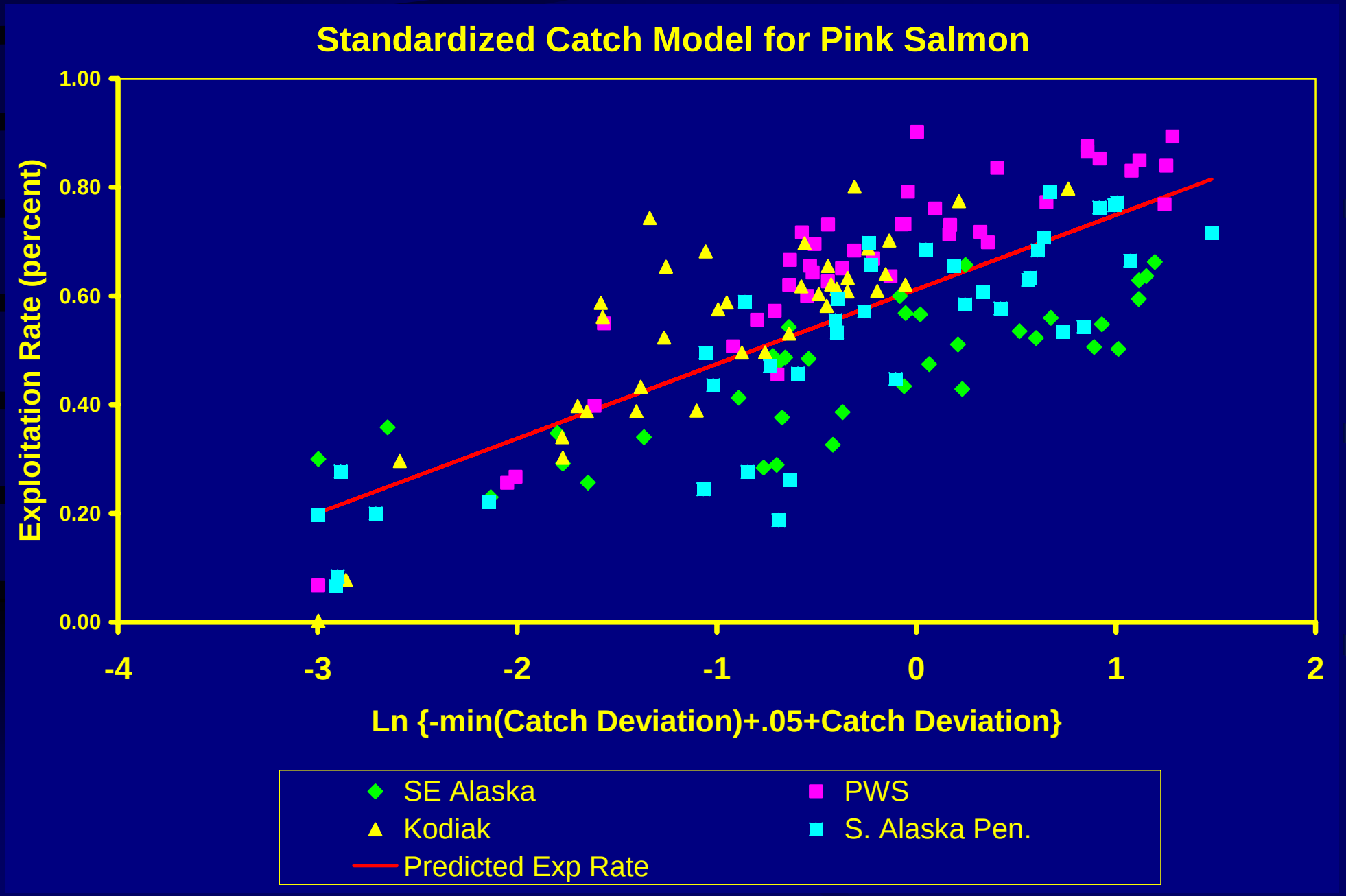

Hatchery Releases of Pink Salmon
Number Released (millions)
1,600
1,400
1,200
1,000
800
600
400
200
0
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Japanese
Alaska
British Columbia
Russia


Hatchery Releases of Chum Salmon
Number Released (millions)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Japanese
Alaska
British Columbia
P. Northwest
Russia

Catch and Total Run Data Sources

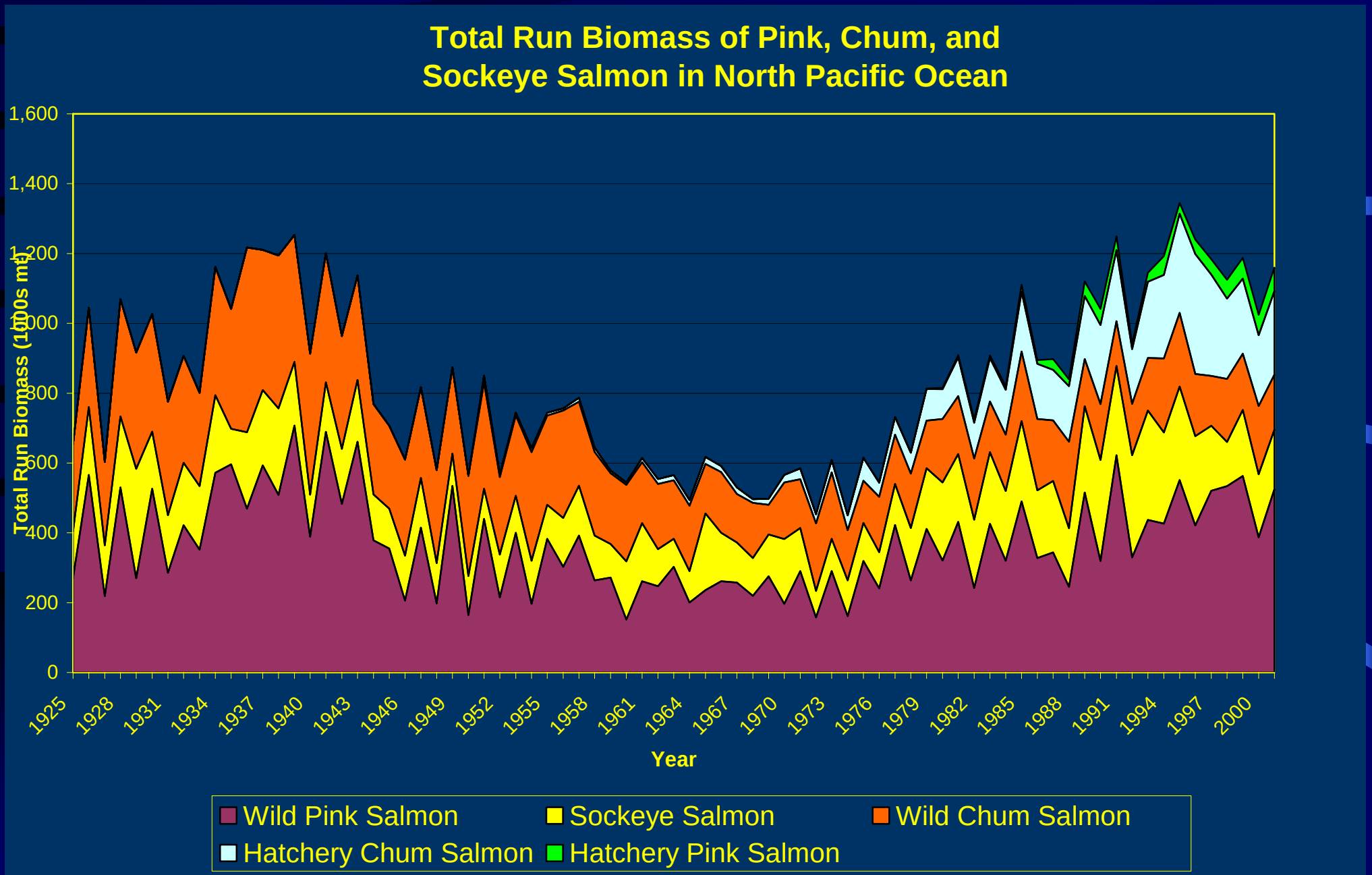
- INPFC (1978)
- INPFC Statistical Yearbooks, 1976 – 1992
- NPAFC Statistical Yearbooks, 1993 – 1998
- Don Rogers, personal communication
- ADF&G Fish Ticket System, average weights
- ADF&G Historical Salmon Catch Data
- Radchenko (1998)
- O. Rassadnikov, TINRO, Unpublished Catch and Escapement Data


Standardized Catch Model for Sockeye Salmon
Exploitation Rate (percent)
1.00
0.80
0.60
0.40
0.20
0.00
-4
-3
-2
-1
0
1
2
3
Ln {-min(Catch Deviation)+.05+Catch Deviation}
Bristol Bay
Chignik
Karluk
Predicted Exp Rate


Standardized Catch Model for Pink Salmon
Exploitation Rate (percent)
1.00
0.80
0.60
0.40
0.20
0.00
-4
-3
-2
-1
0
1
2
Ln {-min(Catch Deviation)+.05+Catch Deviation}
SE Alaska
PWS
Kodiak
S. Alaska Pen.
Predicted Exp Rate

Methods Used for Estimation of Total Run by Area

Total Run Estimates Area	Pink Salmon	Sockeye Salmon	Chum Salmon
Japan: Coastal	Total Run	None	Total Run
Japanese: Sea of Japan	Interception	None	None
Japanese: High Seas Immature	Interception	Interception	Interception
Japanese: High Seas Maturing	Interception	Interception	Interception
Russian: Coastal	60% Exploitation Rate	50% Exploitation Rate	50% Exploitation Rate
Western Alaska	None	Total Run	Rogers
Central Alaska	Exp. Rate/Standardized Catch Model	Exp. Rate/Standardized Catch Model	Exp. Rate/Standardized Catch Model
Kodiak/PWS Hatchery	Total Run	None	None
Southeast Alaska	Total Run	Rogers	90% of Pink Salmon Exploitation Rate
Southeast Alaska Hatchery	None	None	Total Run
B.C./Washington/Oregon	50% Exploitation Rate	Rogers	50% Exploitation Rate

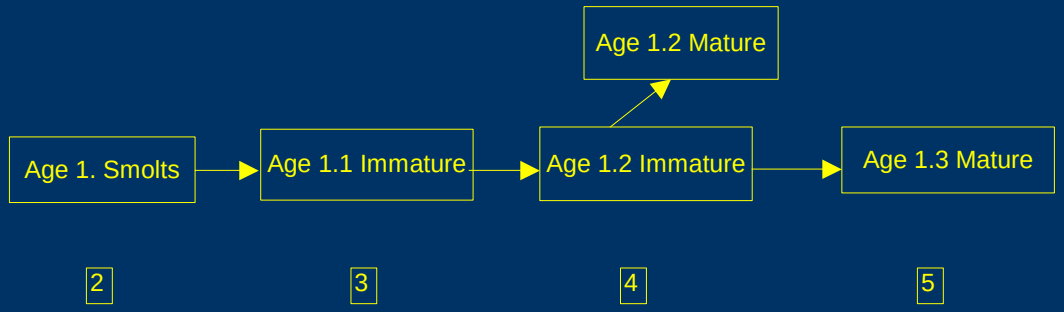

Total Run Biomass of Pink, Chum, and Sockeye Salmon in North Pacific Ocean
Total Run Biomass (1000s mt)
1,600
1,400
1,200
1,000
800
600
400
200
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year
Wild Pink Salmon
Sockeye Salmon
Wild Chum Salmon
Hatchery Chum Salmon
Hatchery Pink Salmon

Data Sources: Smolt Abundance/Releases Returns by Age and Weight

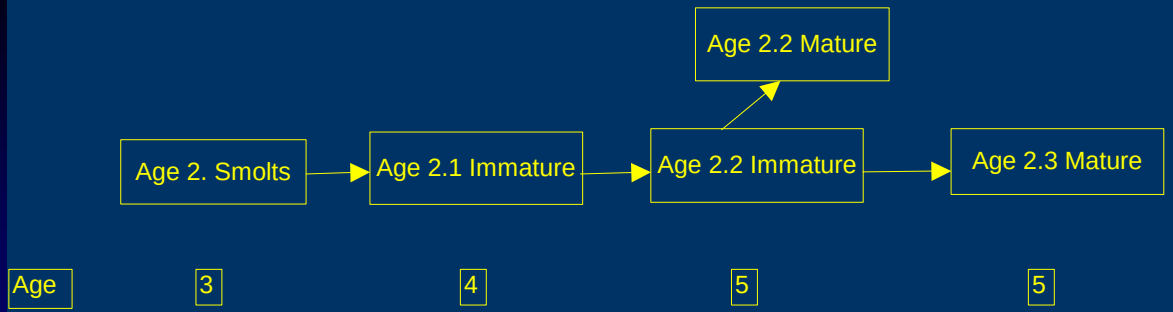
- Hokkaido, Honshu Hatchery Chum Salmon, 61 – 93 Brood Year
  - M. Kaeriyama, Hokkaido Tokai University
- Hokkaido Hatchery Pink Salmon, 61 – 93 Brood Year
  - Hiroo (1998)
- Southeast Alaska Hatchery Chum Salmon
  - Gary Freitag, SSRAA, 79 – 96 Brood Year
  - Chip Blair, NSRAA, 77 – 96 Brood Year
  - Rick Foct, DIPAC, 84 – 96 Brood Year
- PWS(77-99 BY), Kodiak Hatchery(72-95 BY) Pink Salmon
  - ADF&G Area Management Reports, Hilborn and Eggers (1998)
- Ugashik (80-99 BY), Egegik(79-99 BY) Sockeye Salmon
  - ADF&G data

Sockeye Salmon Life History

Age 1. Sockeye Salmon Life History



Age 2. Sockeye Salmon Life History



Sockeye Salmon Forward Projection Model

$$N_{a.1} = S_a e^{-\Delta t_1 \mu_a}$$

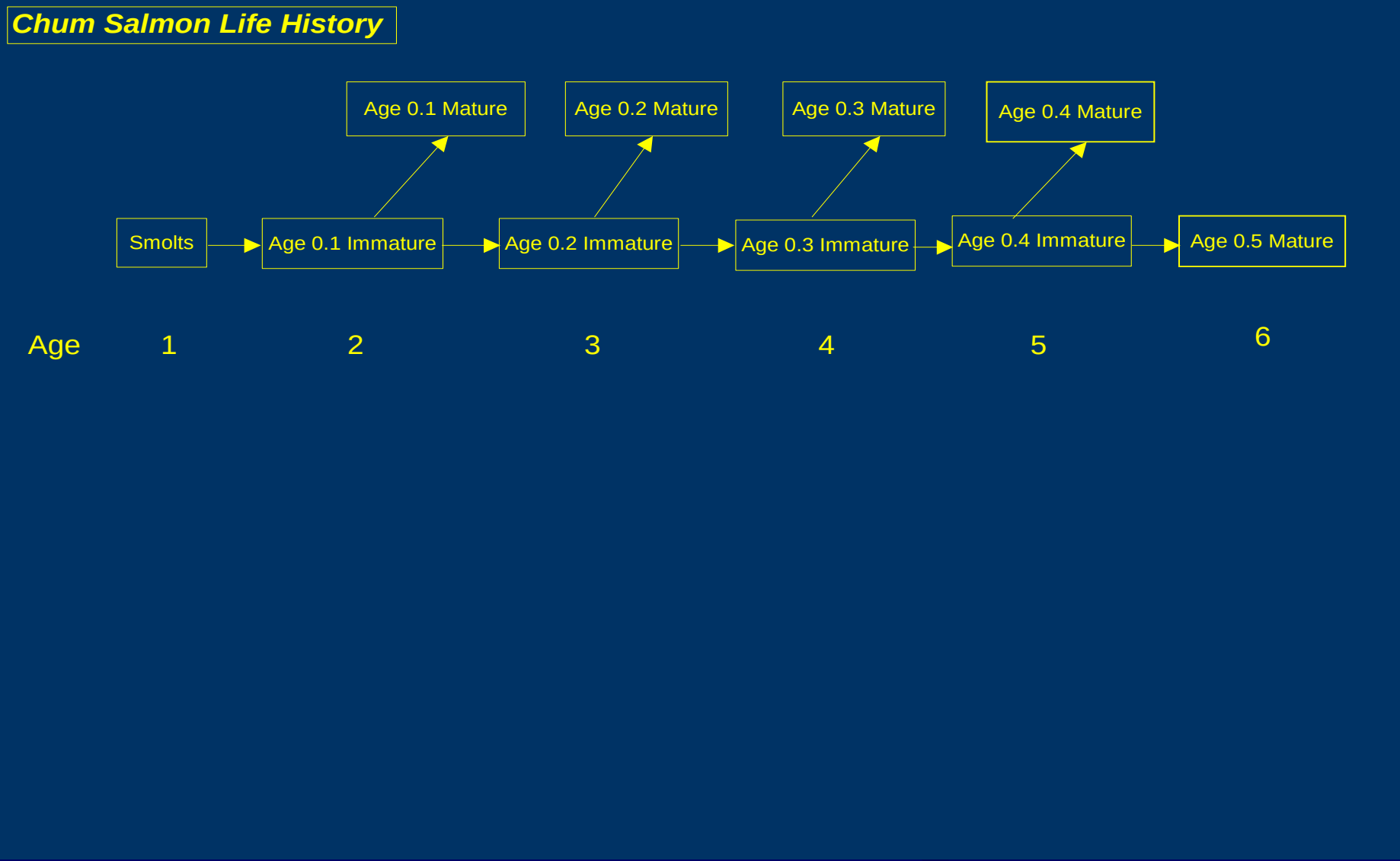
$$N_{a.2} = (1 - m_{a2}) N_{a.1} e^{-\Delta t_2 \mu_a}$$

$$R_{a.2} = m_{a2} N_{a.1} e^{-\Delta t_2 \mu_a}$$

$$R_{a.3} = N_{a.2} e^{-\Delta t_3 \mu_a}$$

a = freshwater age
o = ocean age
Δt_o = length of ocean year in months
$N_{a,o}$ = immature cohort
$R_{a,o}$ = mature cohort
$M_{a,o}$ = maturation rate
μ_a = natural mortality rate (monthly)

Chum Salmon Life History



Chum Salmon Forward Projection Model

$$N_{0.1} = S_0 e^{-\Delta t_1 \mu}$$

$$N_{0.2} = (1 - t_2) N_{0.1} e^{-\Delta t_2 \mu}$$

$$R_{0.2} = m_2 N_{0.1} e^{-\Delta t_2 \mu}$$

$$N_{0.3} = (1 - t_3) N_{0.2} e^{-\Delta t_3 \mu}$$

$$R_{0.3} = m_3 N_{0.2} e^{-\Delta t_3 \mu}$$

$$N_{0.4} = (1 - t_4) N_{0.3} e^{-\Delta t_4 \mu}$$

$$R_{0.4} = m_4 N_{0.3} e^{-\Delta t_4 \mu}$$

$$R_{0.5} = N_{0.4} e^{-\Delta t_5 \mu}$$

o = ocean age

S_0 = smolt abundance

Δt_o = length of ocean year in months

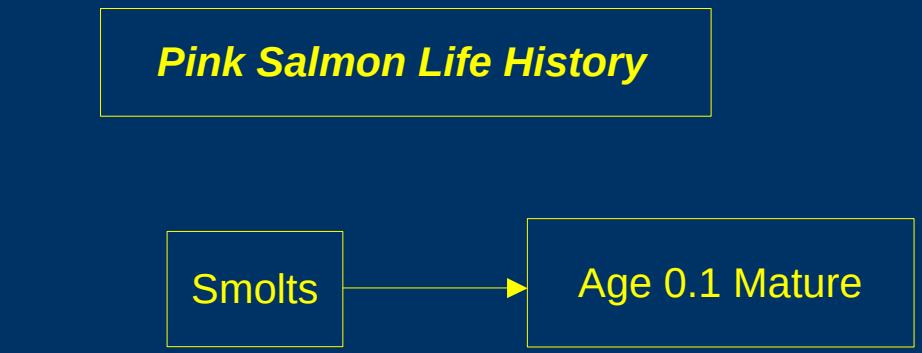
$N_{0,o}$ = immature cohort

$R_{0,o}$ = mature cohort

M_o = maturation rate

μ = natural mortality rate (monthly)

Pink Salmon Life History

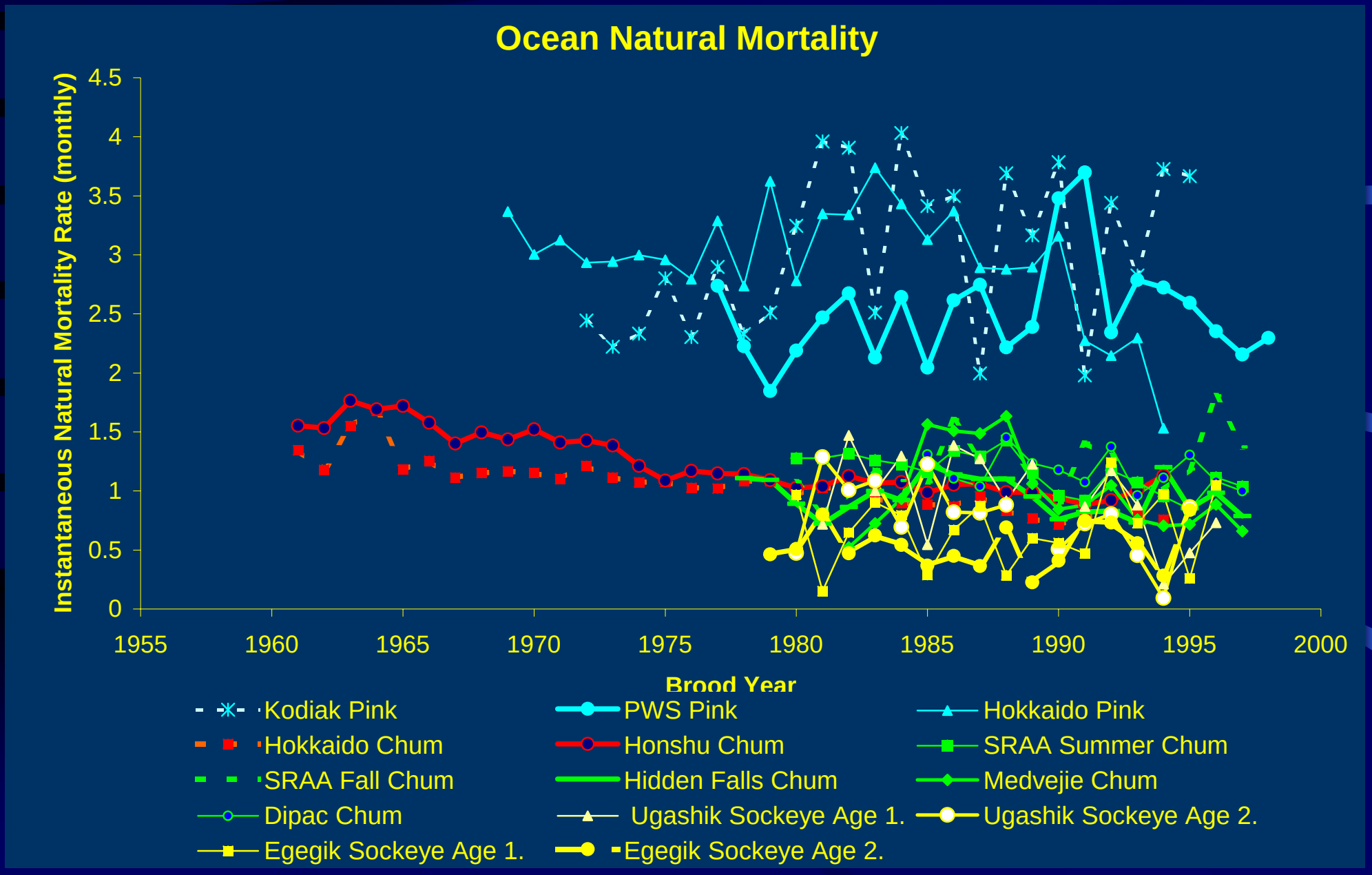


Pink Salmon Forward Projection Model

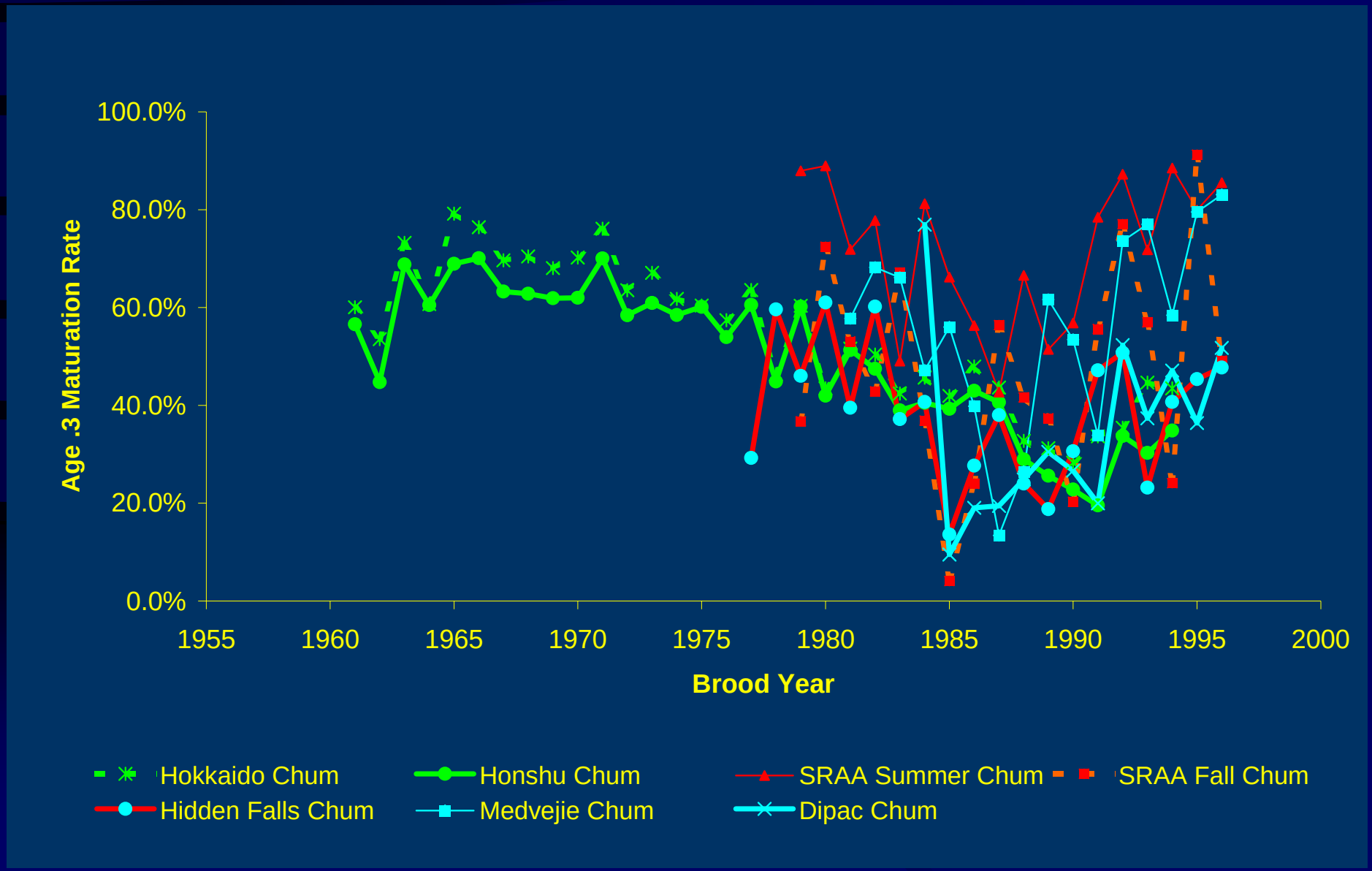
$$N_{0.0} = S_0 e^{-\Delta t_0 \mu}$$

$$R_{0.1} = S_0 e^{-\Delta t_1 \mu}$$

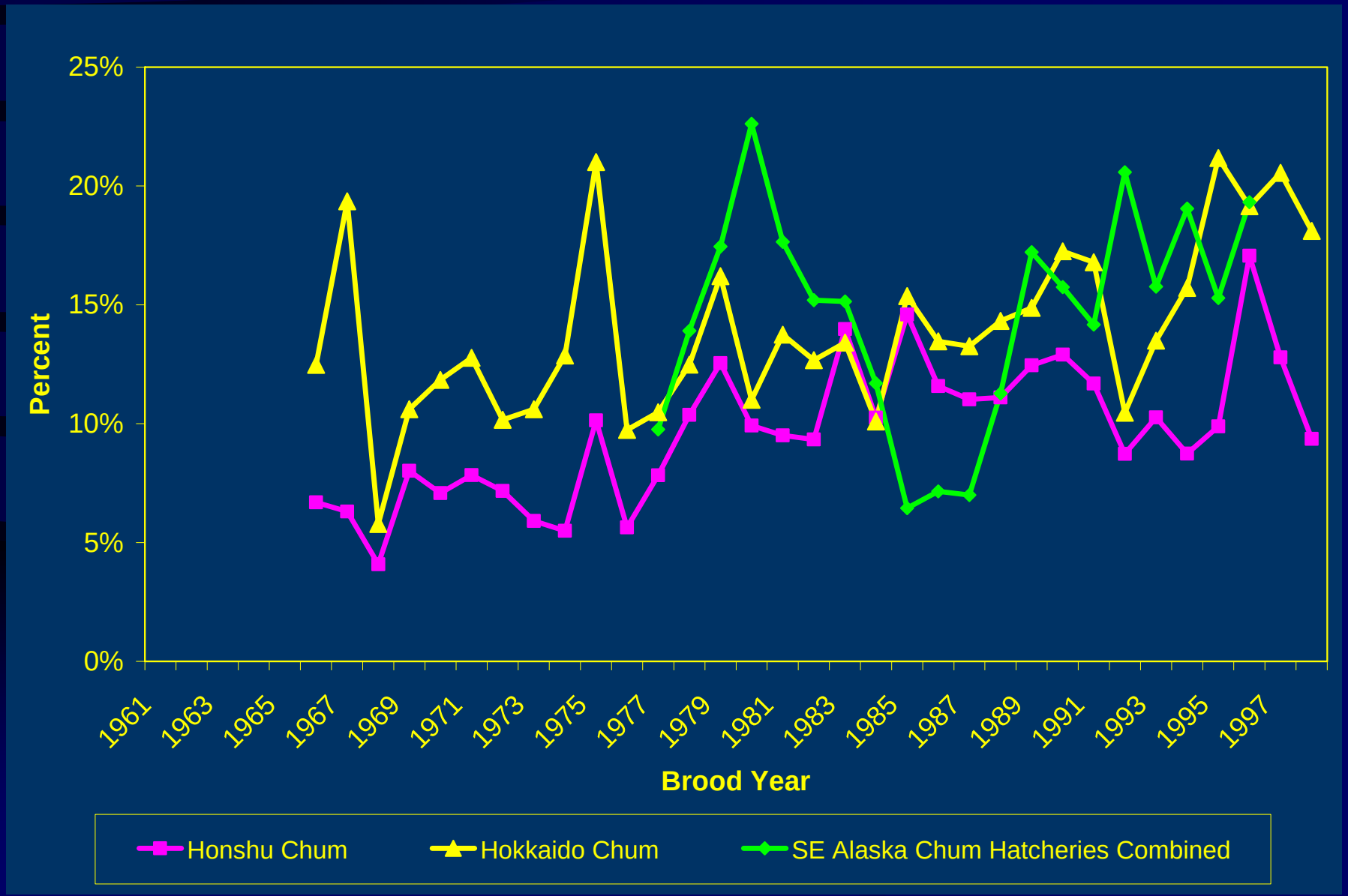
m = natural mortality rate (monthly)
S_0 = smolt abundance
Δt_1 = length of ocean residence in months
$N_{0,0}$ = immature cohort
$R_{0,1}$ = mature cohort
μ = natural mortality rate (monthly)


Ocean Natural Mortality
Instantaneous Natural Mortality Rate (monthly)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Brood Year
Kodiak Pink
PWS Pink
Hokkaido Pink
Hokkaido Chum
Honshu Chum
SRAA Summer Chum
SRAA Fall Chum
Hidden Falls Chum
Medvejie Chum
Dipac Chum
Ugashik Sockeye Age 1.
Ugashik Sockeye Age 2.
Egegik Sockeye Age 1.
Egegik Sockeye Age 2.

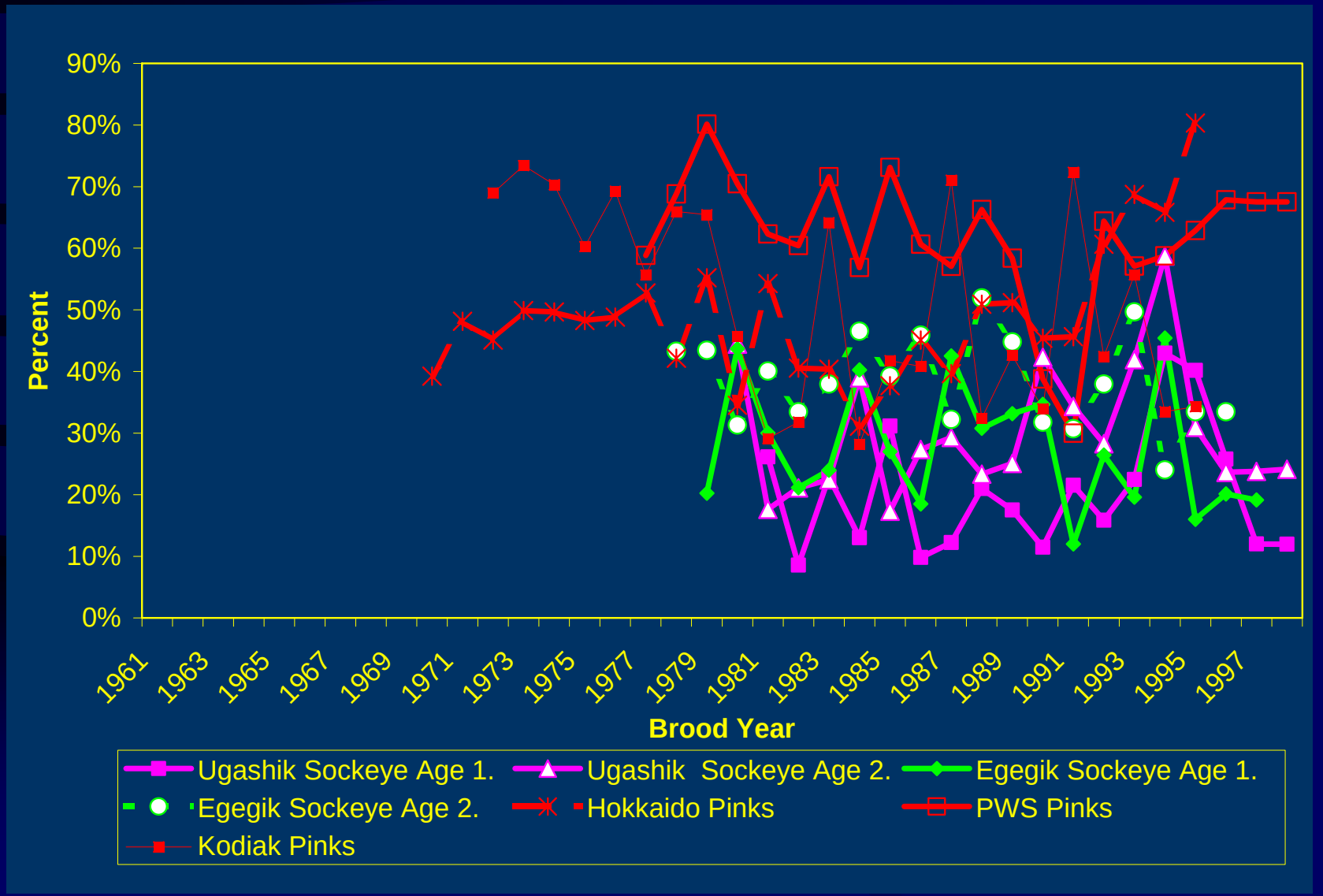
Chum Salmon Age .3 Maturation Rates



Ratio of Terminal Run Biomass To Total Biomass
Chum Salmon

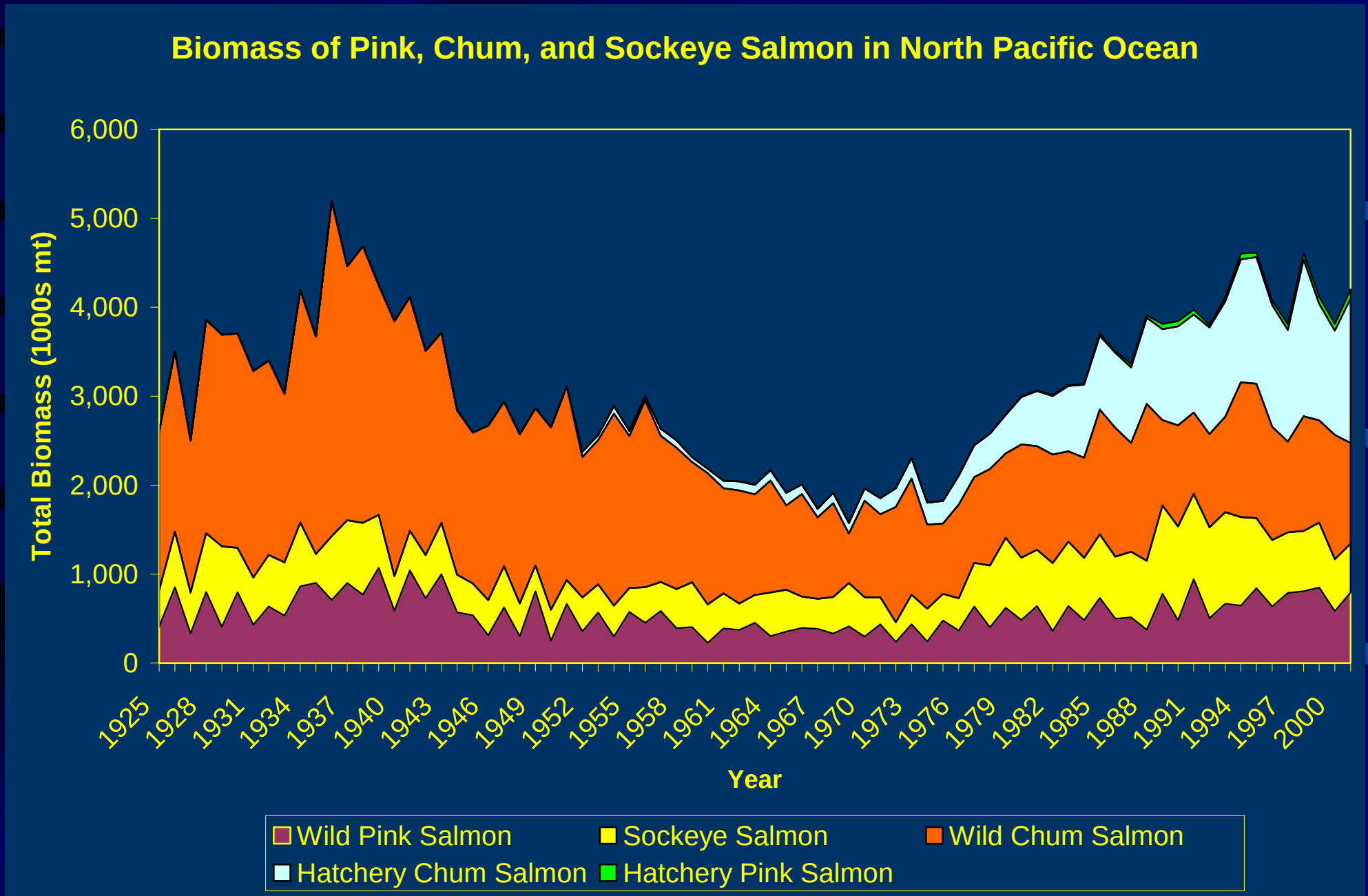


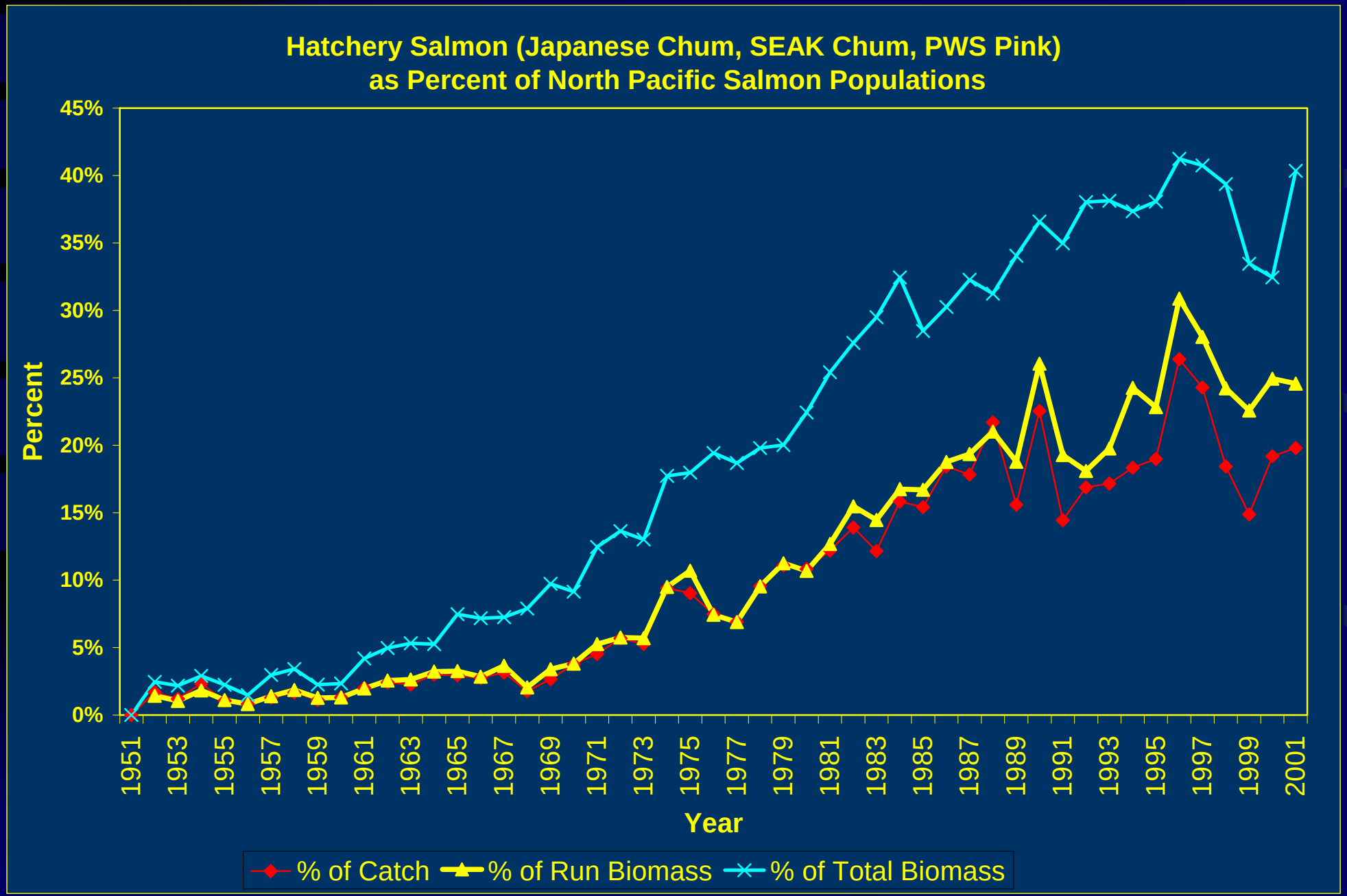
Ratio of Terminal Run To Total Biomass
Sockeye and Pink Salmon



Method of Expansion of Terminal Run to Total Biomass

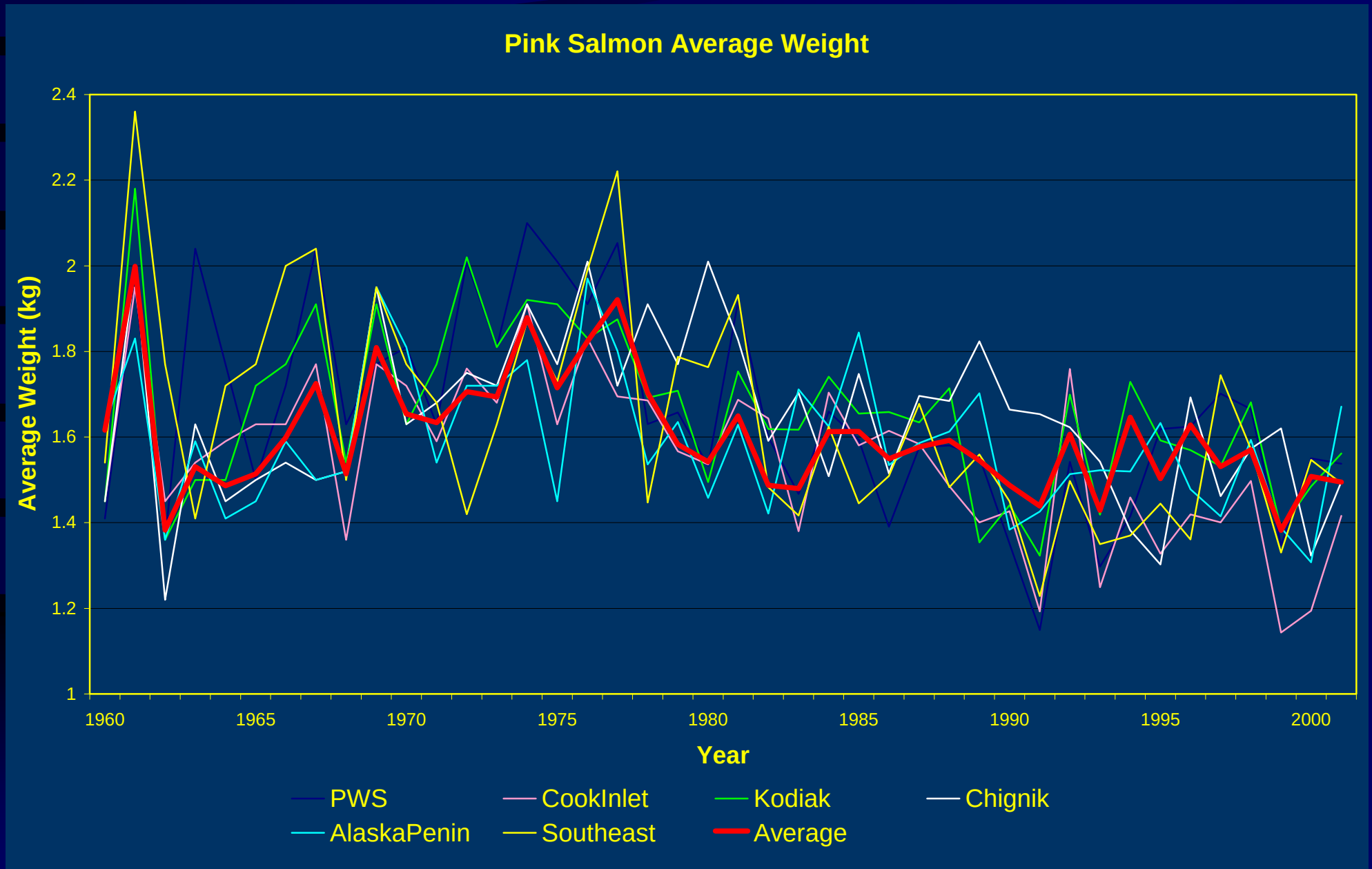
Area	Pink Salmon	Sockeye Salmon	Chum Salmon
Japan: Coastal	62%	None	Forward Construction of Smolt Releases
Japanese: Sea of Japan	70%	None	None
Japanese: High Seas Immature	None	46%	43%
Japanese: High Seas Maturing	70%	32%	17%
Russian: Coastal	66%	30%	14%
Western Alaska	None	Backward Construction of Terminal Run by Age	14%
Central Alaska	65%	30%	14%
PWS Hatchery	Forward Construction of Smolt Releases	None	None
Southeast Alaska	66%	With B.C./Wash./Or.	14%
Southeast Alaska Hatchery	None	None	Forward Construction of Smolt Releases
B.C./Washington/Oregon	66%	40%	14%


Biomass of Pink, Chum, and Sockeye Salmon in North Pacific Ocean
Total Biomass (1000s mt)
6,000
5,000
4,000
3,000
2,000
1,000
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year
Wild Pink Salmon
Sockeye Salmon
Wild Chum Salmon
Hatchery Chum Salmon
Hatchery Pink Salmon


Hatchery Salmon (Japanese Chum, SEAK Chum, PWS Pink)
as Percent of North Pacific Salmon Populations
Percent
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
Year
% of Catch
% of Run Biomass
% of Total Biomass

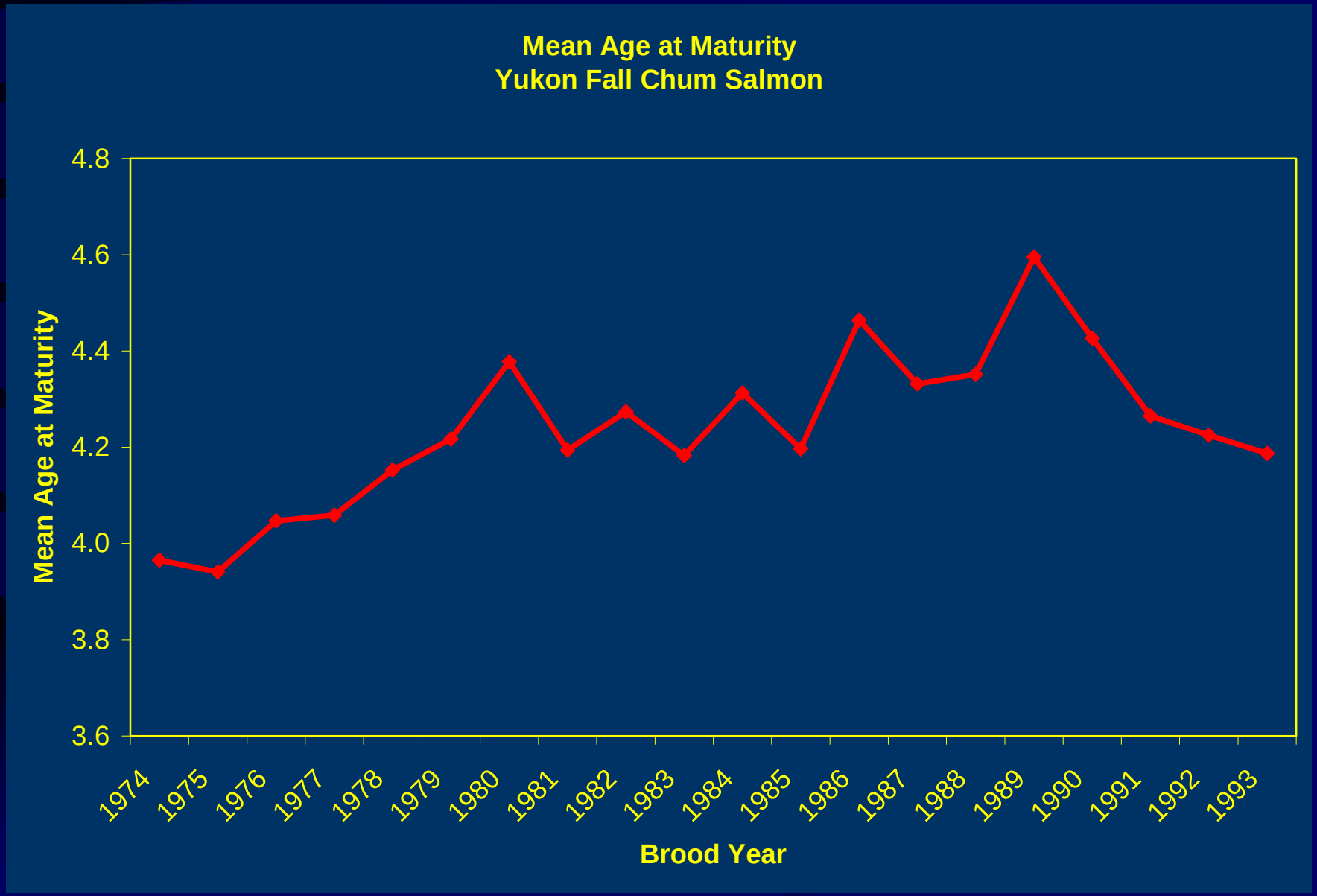
Widely Observed Pattern of Declining Size at Maturity with increasing Biomass of Salmon in the North Pacific Rim

- Review of Size Trends among North Pacific Salmon
  - Bigler et al (1996)
- Yukon River and Anadyr River Chum Scale Growth
  - Smoker and Adkinson
- Hokkaido Chum Salmon Terminal Run
  - Kaeriyama (1998)
- Portland Canal Chum Salmon Escapement
  - Helle (1998)
- High Seas Chum Salmon Scales
  - Walker et al (1998)
- Pink Salmon, High Seas Scales, Alaska Catch
  - Walker et al (1998), Average Weight in Alaska Catch

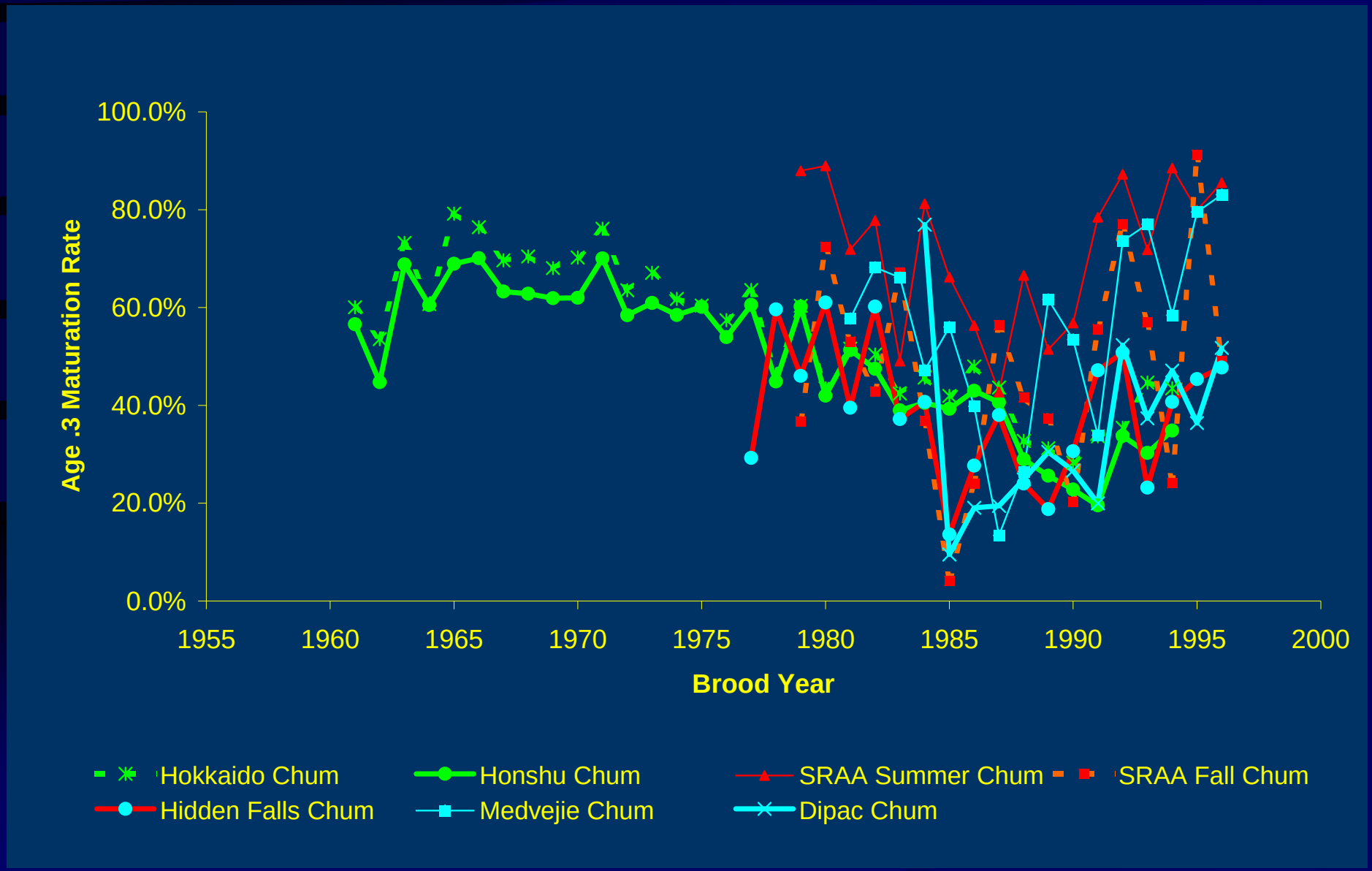

Pink Salmon Average Weight
Average Weight (kg)
2.4
2.2
2
1.8
1.6
1.4
1.2
1
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
PWS
CookInlet
Kodiak
Chignik
AlaskaPenin
Southeast
Average

Widely Observed Pattern of Declining Age at Maturity with increasing Biomass of Salmon in the North Pacific Rim

- Yukon River Chum
  - Lower Yukon River Test Fishery catch
- Hokkaido Chum Salmon
  - Kaeriyama (1998)
- Portland Canal Chum Salmon
  - Helle (1998)

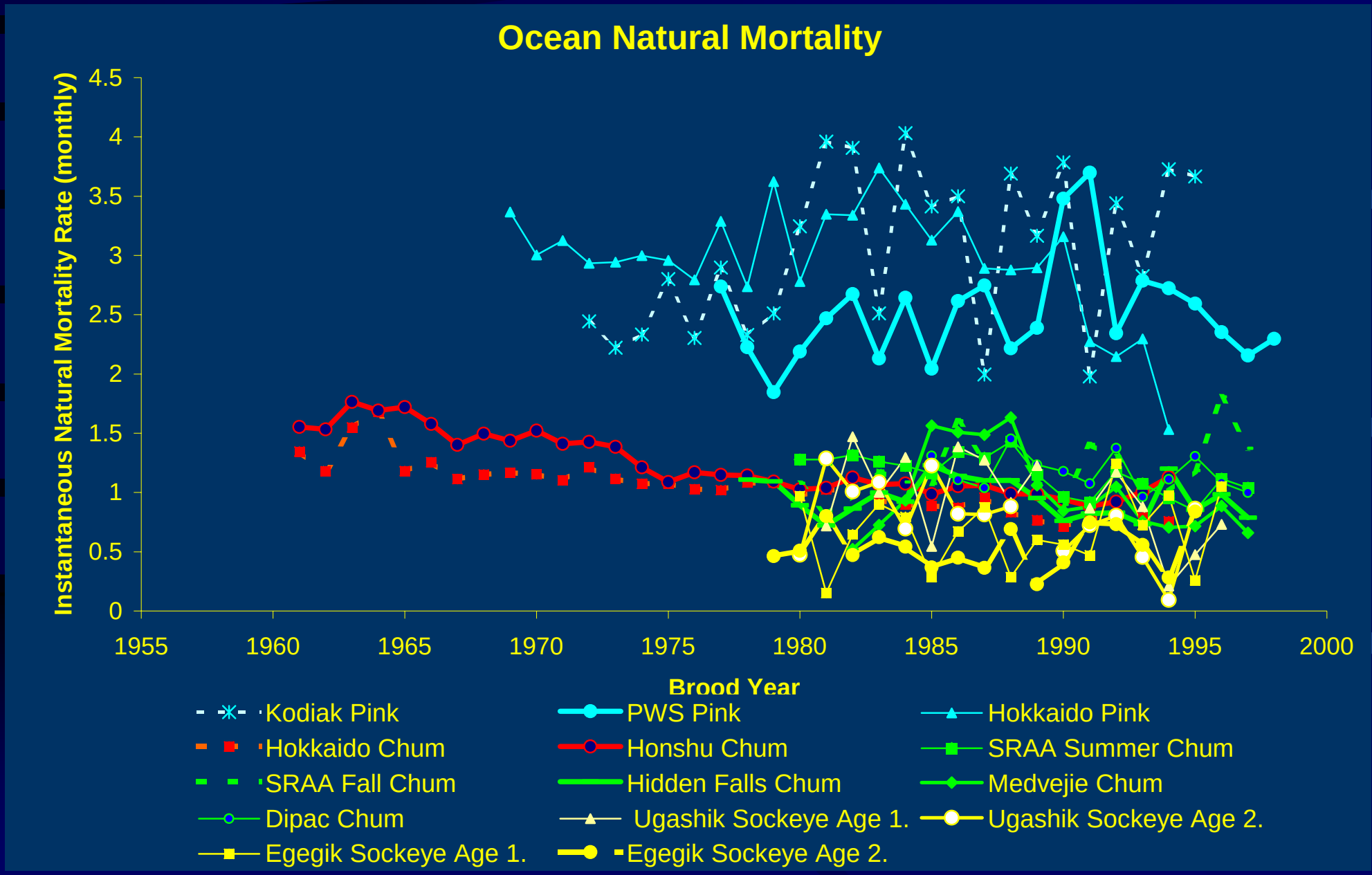

Mean Age at Maturity
Yukon Fall Chum Salmon
Mean Age at Maturity
4.8
4.6
4.4
4.2
4.0
3.8
3.6
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Brood Year

Chum Salmon Age .3 Maturation Rates



Survival Patterns Observed Among Pacific Rim Salmon Populations not Negatively Related to Increasing Biomass of Salmon

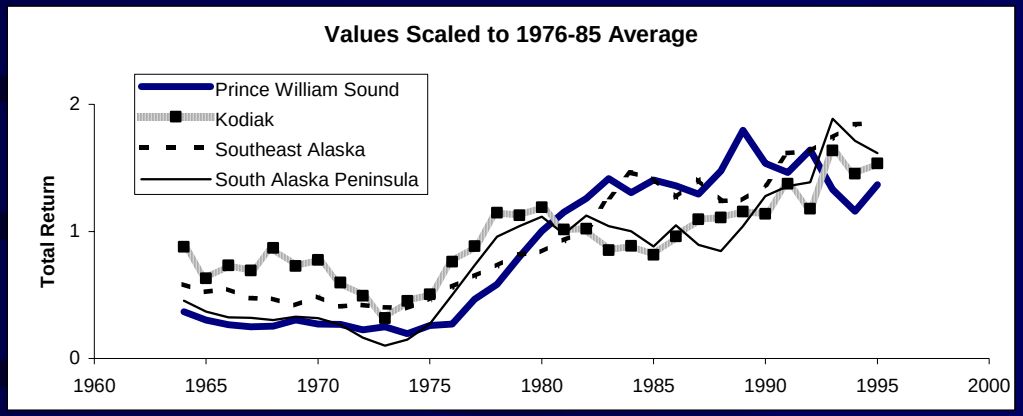
- Hokkaido Hatchery Chum Salmon
  - Kairiyama (1998)
  - SST's and Chum Salmon Survival (Saito 2002)
- Southeast Alaska Hatchery Chum Salmon
  - SSRAA, NSRAA hatchery runs
- Patterns of Co-variation in Salmon Stock Recruitment Data
  - Sockeye Salmon - Peterman et al (1999)
  - Pink Salmon – Pyper et al. (2001)
  - SST's and Salmon Survival - Mueter et al (2002)
- Patterns of Co-variation in Survival CWT Hatchery Releases
  - Coho – Coronodo and Hilborn 1998a
  - Coho and Fall Chinook Salmon – Cororondo and Hilborn 1998b

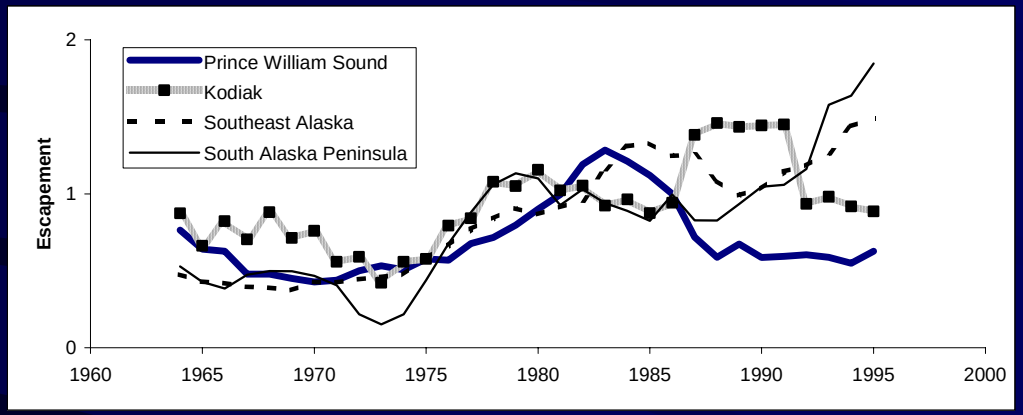

Ocean Natural Mortality
Instantaneous Natural Mortality Rate (monthly)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Brood Year
Kodiak Pink
PWS Pink
Hokkaido Pink
Hokkaido Chum
Honshu Chum
SRAA Summer Chum
SRAA Fall Chum
Hidden Falls Chum
Medvejie Chum
Dipac Chum
Ugashik Sockeye Age 1.
Ugashik Sockeye Age 2.
Egegik Sockeye Age 1.
Egegik Sockeye Age 2.

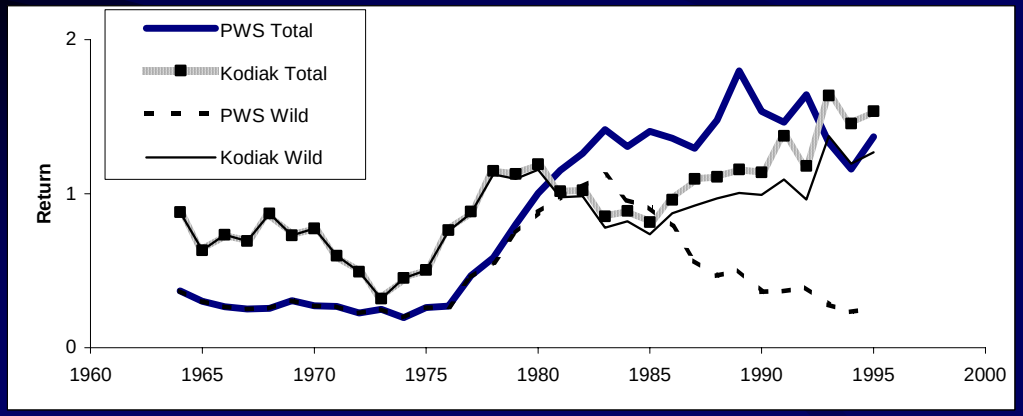
Reduced Survival of Wild Salmon Runs In face of Largescale Hatchery Runs

- Prince William Sound Pink Salmon
  - Hilborn and Eggers (1998)
- Taku River Fall Chum Salmon
  - ADF&G Stock Assessment Data (Leon Shaul, Pers. Comm.)

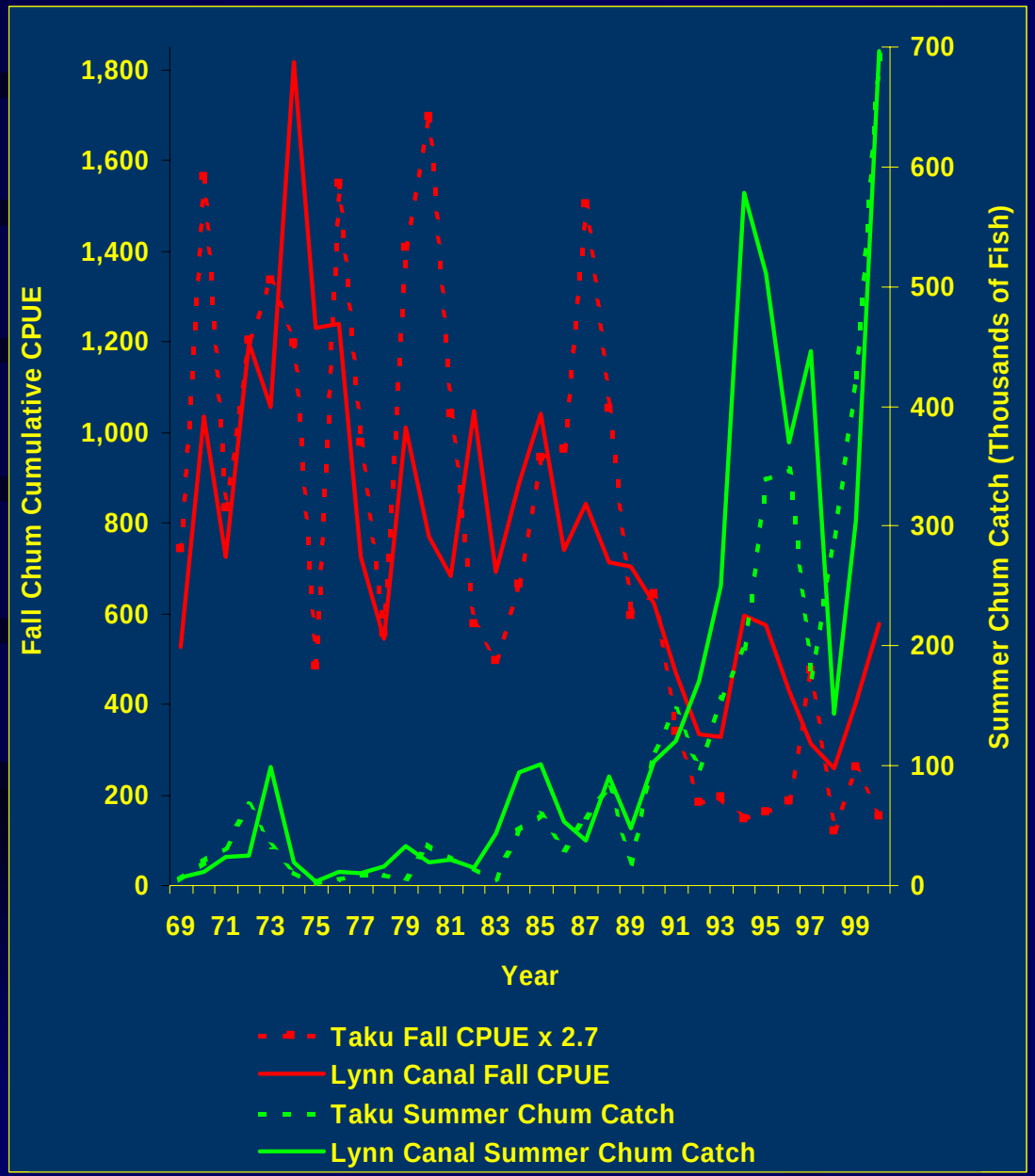
Gulf of Alaska Pink Salmon



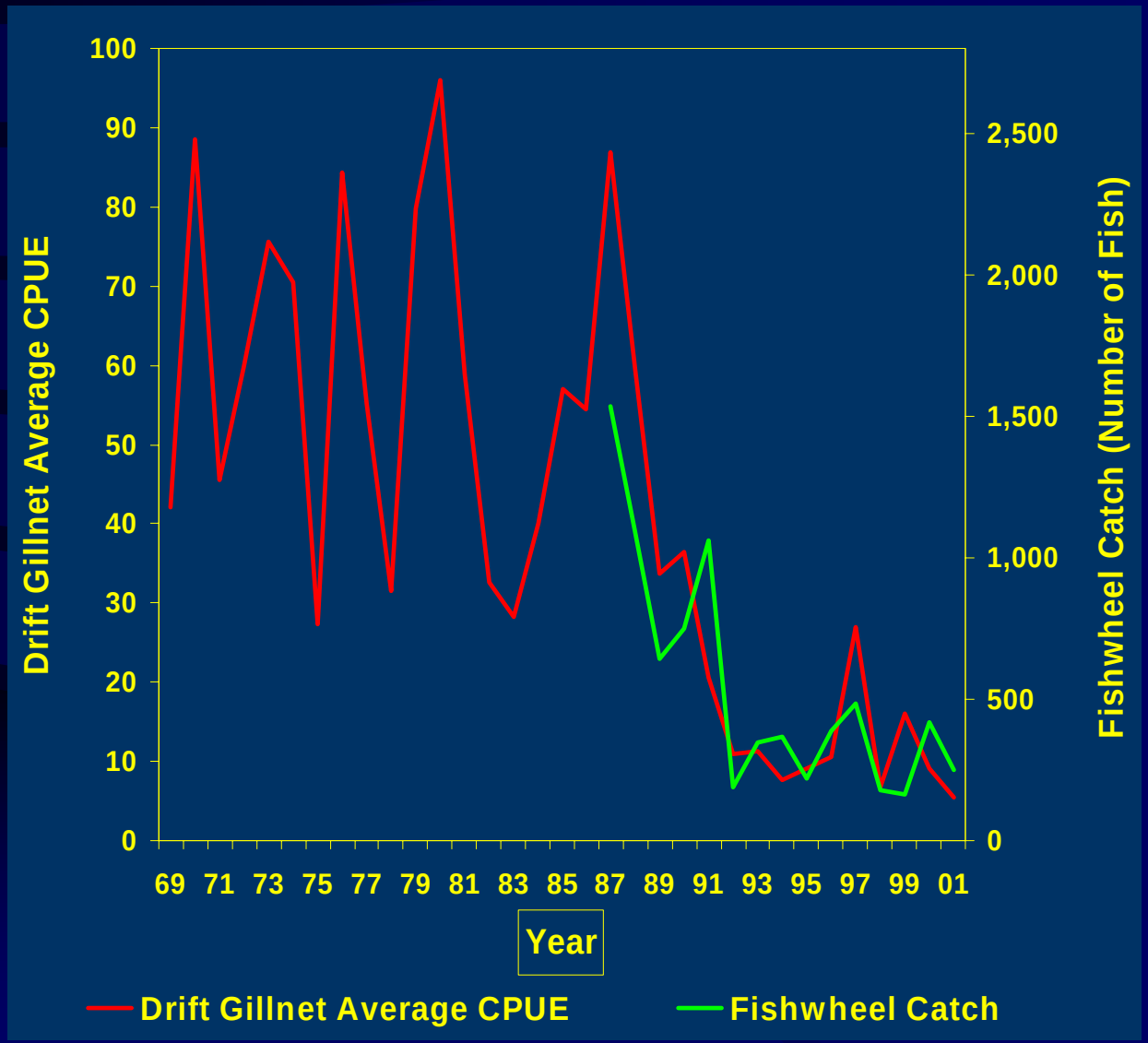




Northern Southeast Chum Salmon

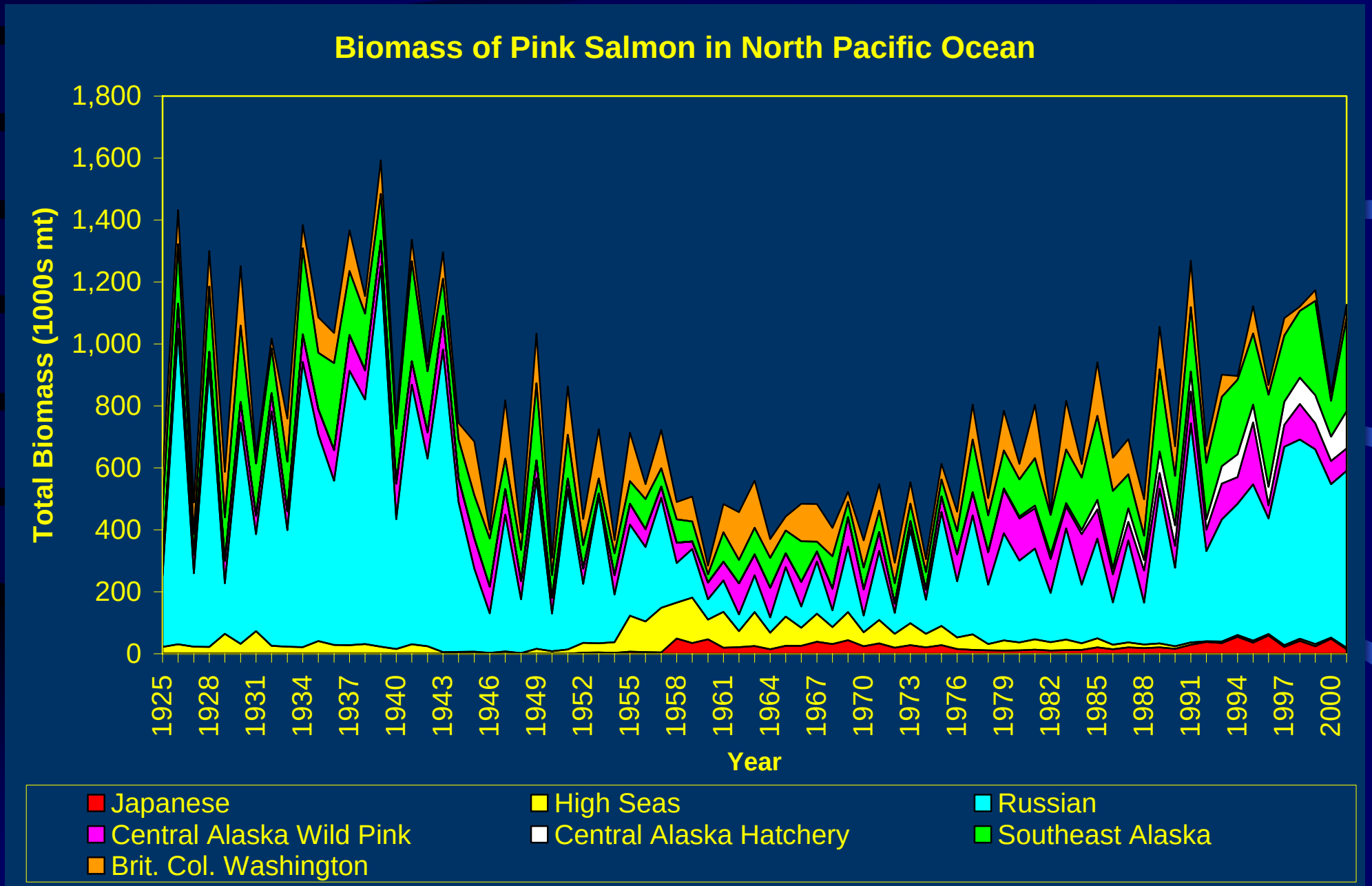


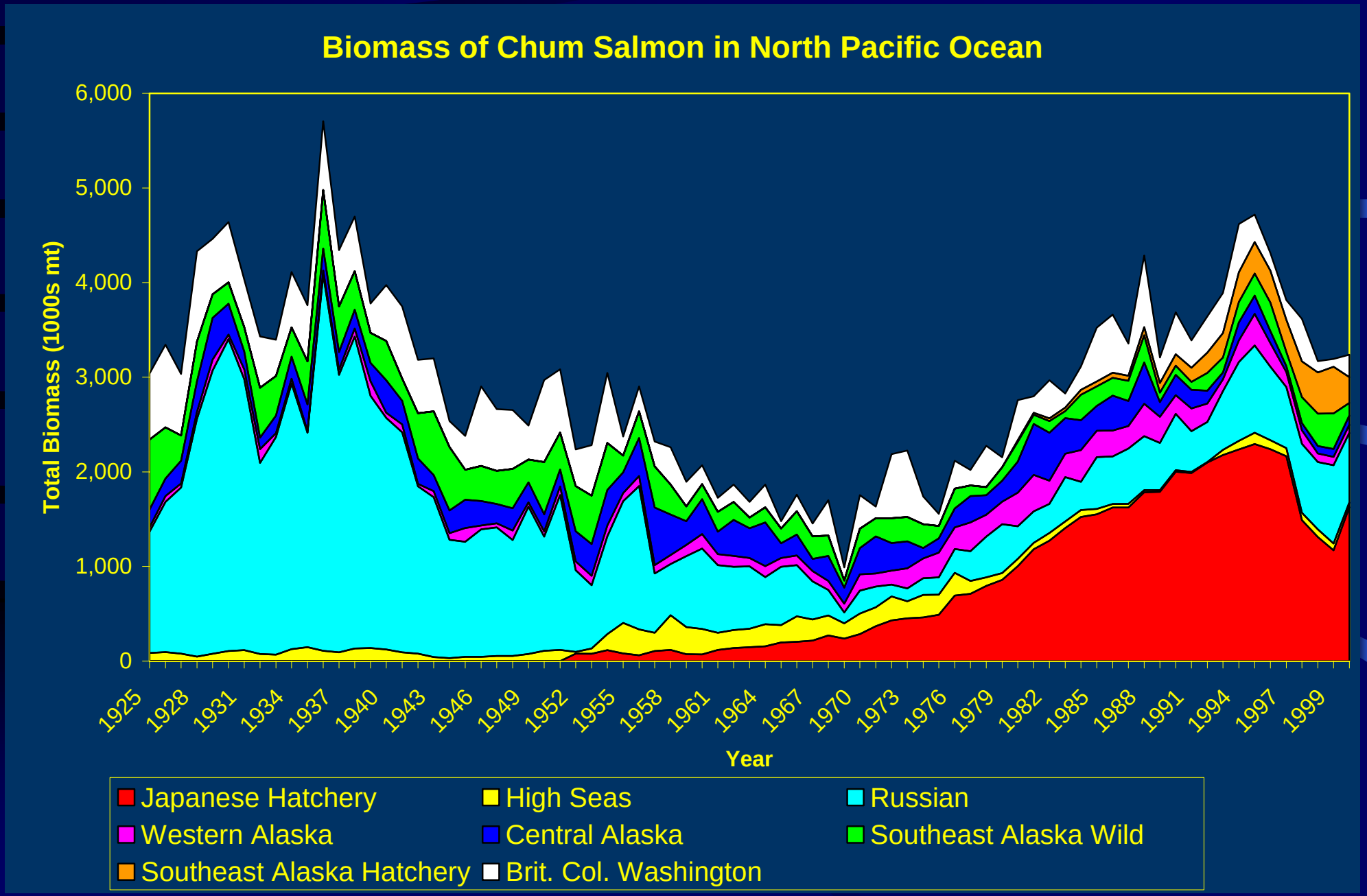
Taku River Fall Chum Salmon

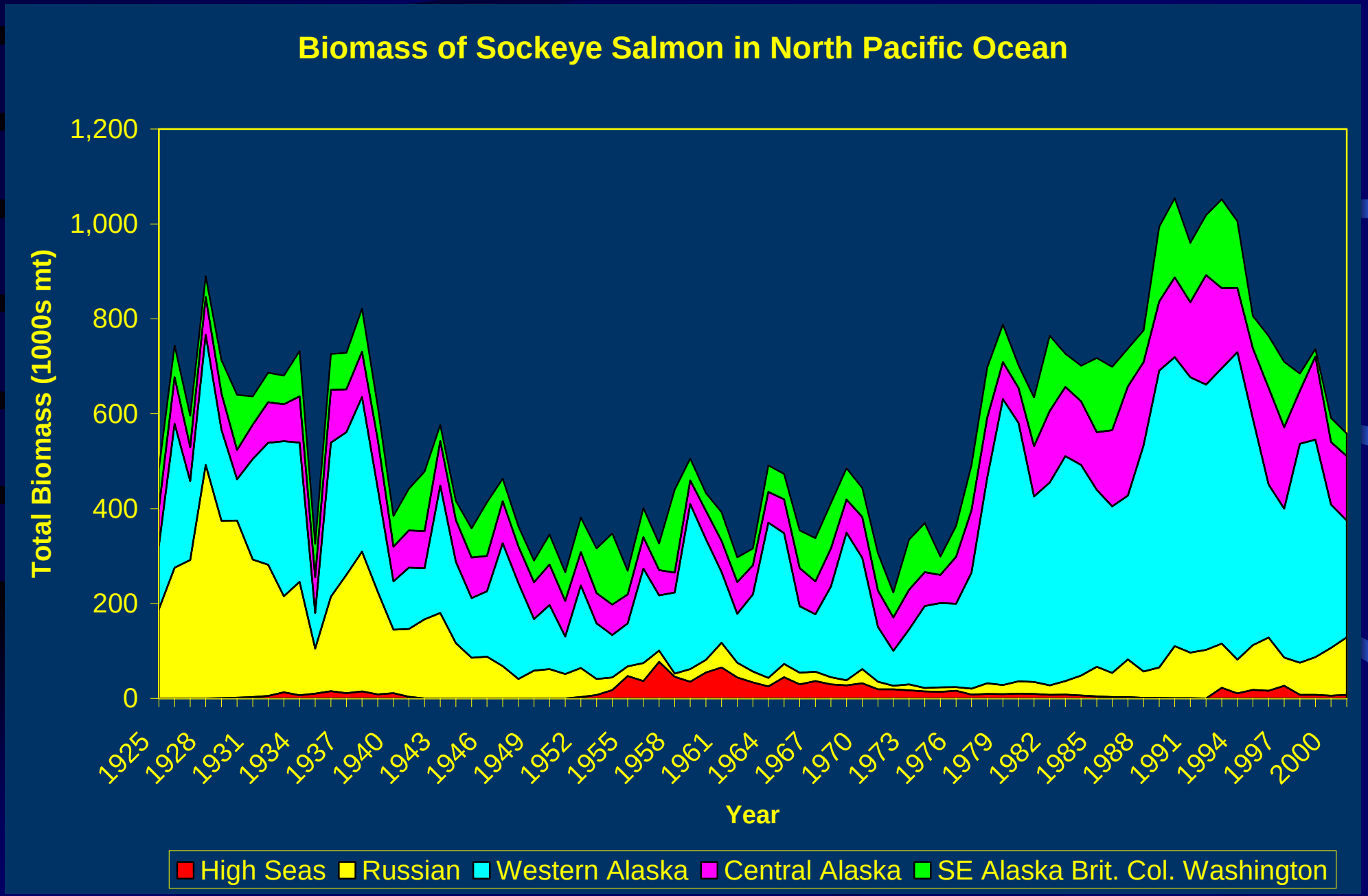


Conclusions

- There appears to be ocean basin scale limits to salmon growth and age at maturity of salmon.
- There is no evidence of ocean basin scale limits to abundance of salmon.
- Survival and year class strength of Pacific Salmon appear to be determined by regional scale variability in environmental conditions in early marine and/or freshwater rearing areas.
- Regional scale depression of wild stock survival by largescale hatchery releases into common rearing areas may be occurring in situations where the magnitude of hatchery runs greatly exceeds historical production.


Biomass of Pink Salmon in North Pacific Ocean
Total Biomass (1000s mt)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year
Japanese
High Seas
Russian
Central Alaska Wild Pink
Central Alaska Hatchery
Southeast Alaska
Brit. Col. Washington


Biomass of Chum Salmon in North Pacific Ocean
Total Biomass (1000s mt)
6,000
5,000
4,000
3,000
2,000
1,000
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
1999
Year
Japanese Hatchery
High Seas
Russian
Western Alaska
Central Alaska
Southeast Alaska Wild
Southeast Alaska Hatchery
Brit. Col. Washington


Biomass of Sockeye Salmon in North Pacific Ocean
Total Biomass (1000s mt)
1,200
1,000
800
600
400
200
0
1925
1928
1931
1934
1937
1940
1943
1946
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
Year
High Seas
Russian
Western Alaska
Central Alaska
SE Alaska Brit. Col. Washington