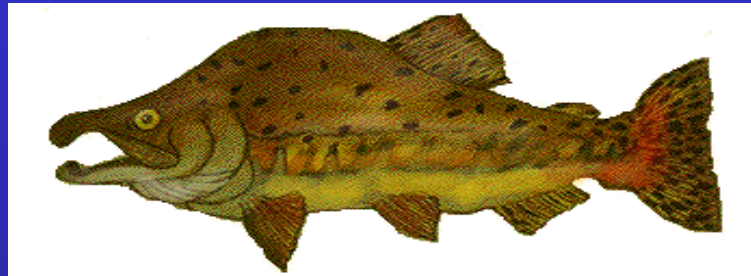




**Relationship of Size at Return  
with Environmental Variation,  
Large-Scale Enhancement, and  
Productivity of Pink Salmon in  
Prince William Sound, Alaska**

# Does Size Matter?

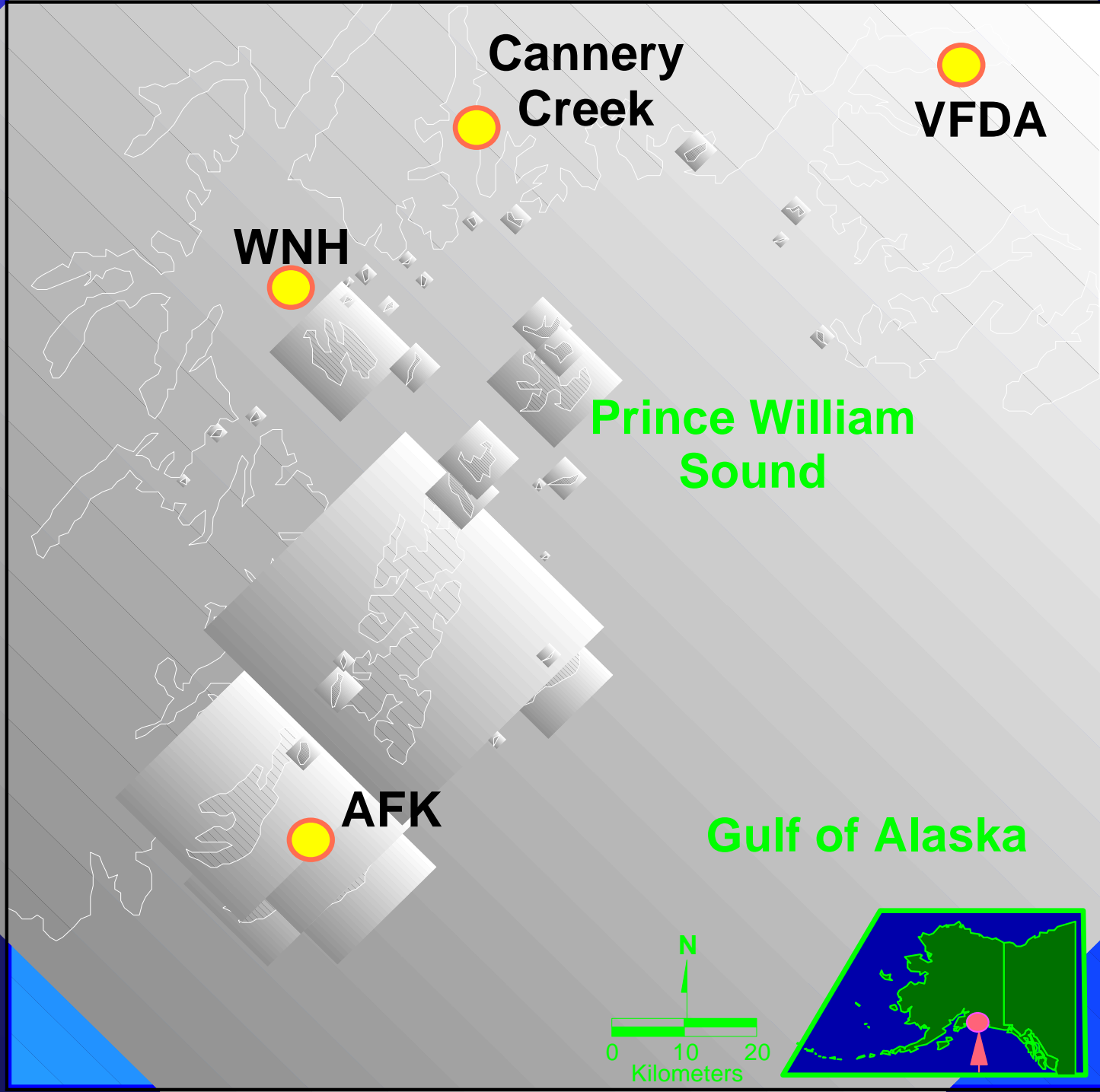


Alex C. Wertheimer, William R. Heard, and J. M. Maselko  
(National Marine Fisheries Service, Auke Bay Laboratory)

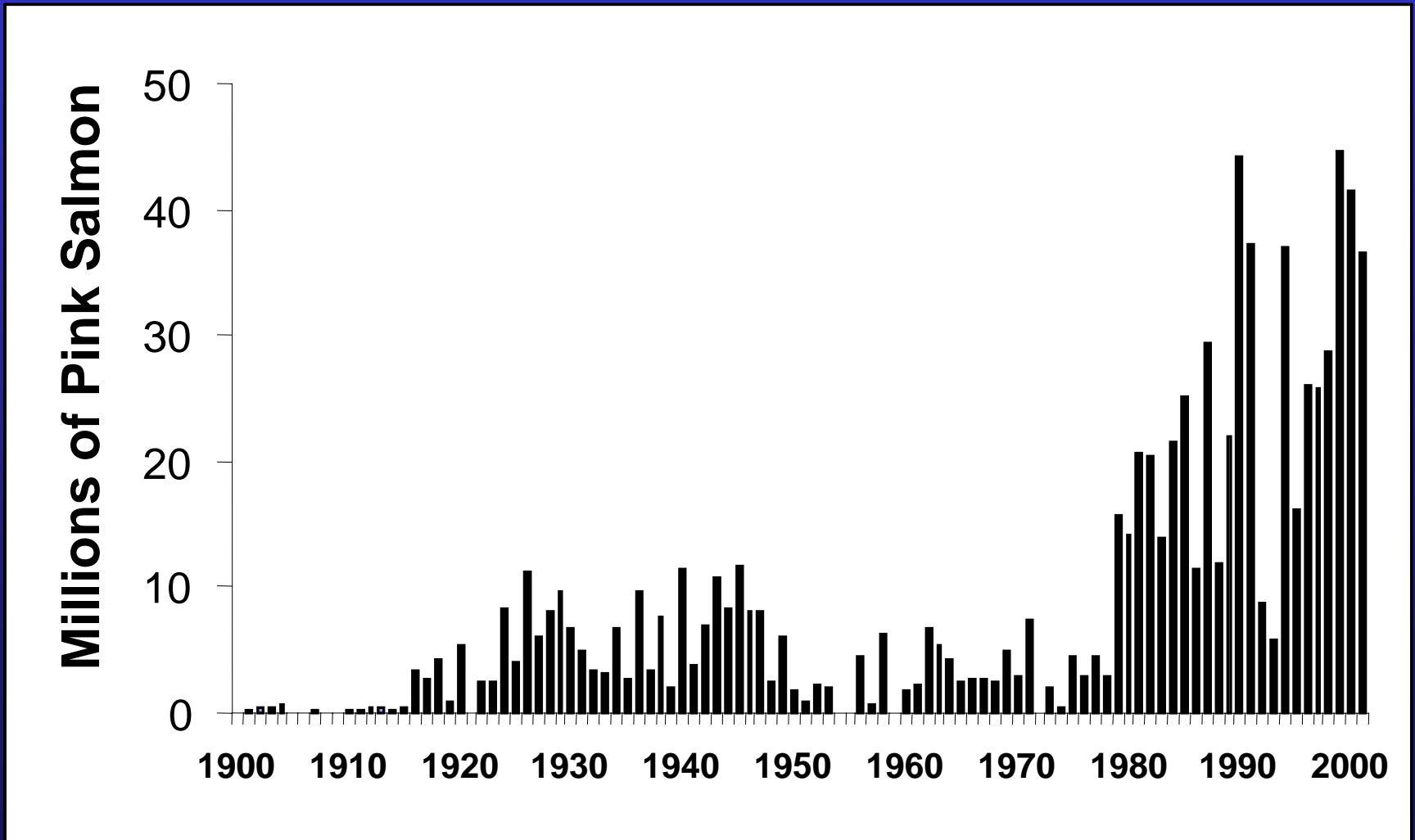
and

William W. Smoker  
(University of Alaska Fairbanks Juneau Center Fisheries  
and Ocean Sciences)

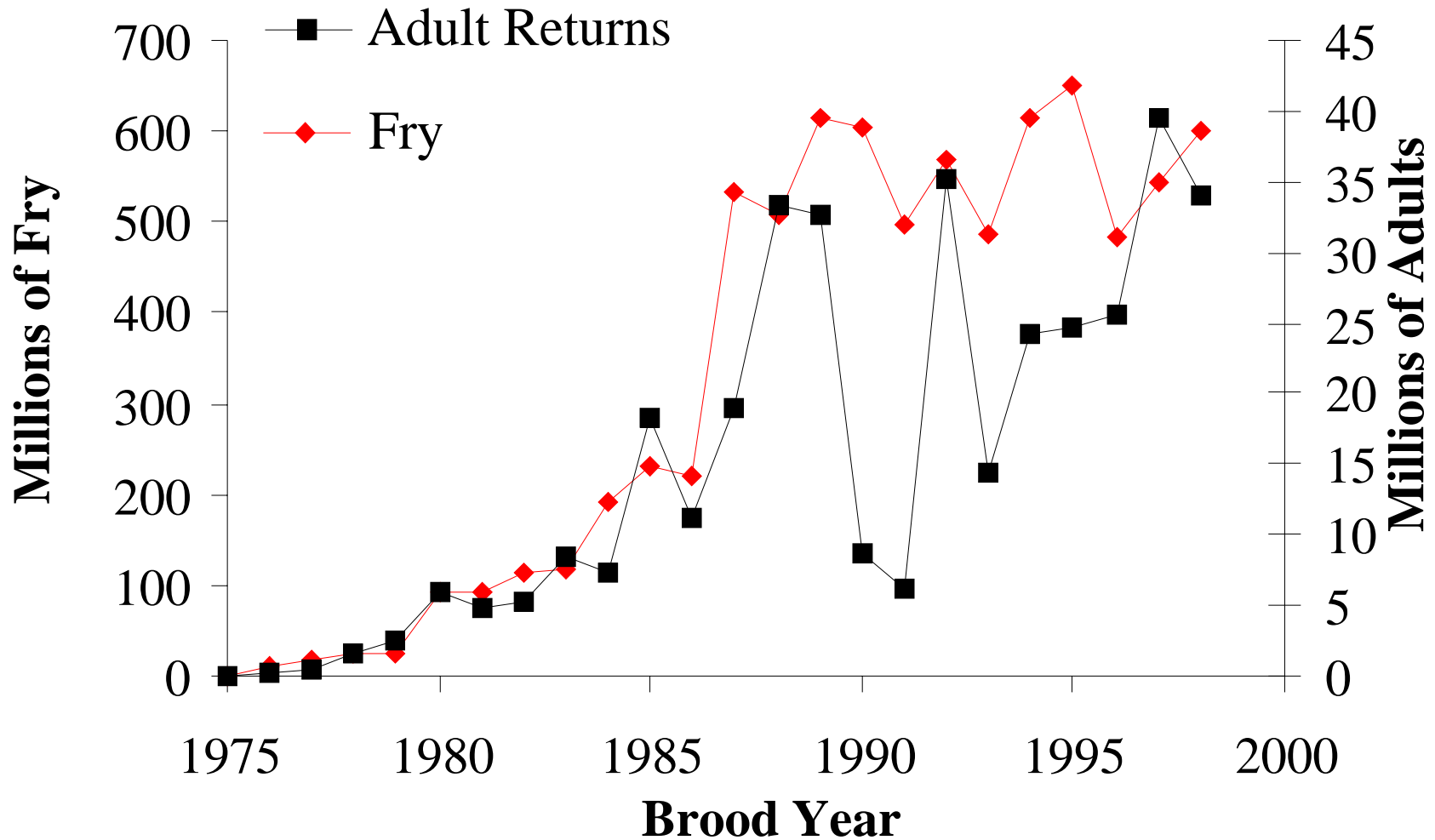
# Prince William Sound



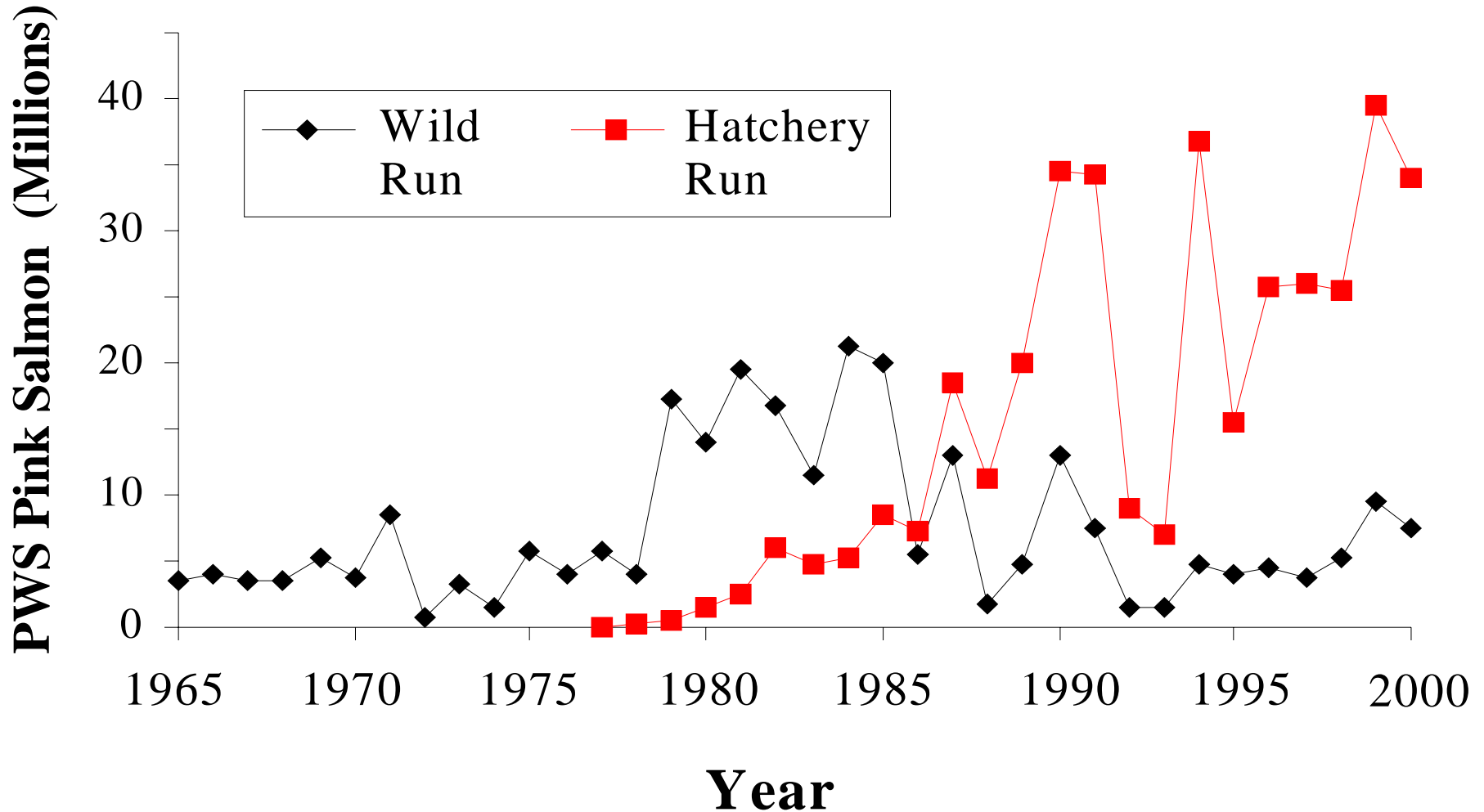
# Pink Salmon Catches in Prince William Sound: 1900-2001



# Fry Releases and Adult Returns of Hatchery Pink Salmon in Prince William Sound



# Hatchery vs Wild Production: Cause and Effect?



# Enhancement or Replacement?

## Contrasting Views of Average Annual Impacts and Benefits of Hatcheries

<b>Authors</b>	<b>Wild Yield Loss</b>	<b>Net Hatchery Gain</b>
<b>Hilborn and Eggers (2000)</b>	<b>17 Million</b>	<b>2 Million</b>
<b>Wertheimer et al. (2001, 2004)</b>	<b>0-5 Million</b>	<b>18-24 Million</b>

# H&E (2000) Simulation Model: Wild Production in the Absence of Hatchery Fry

$$R_{y+2} = \alpha S_y e^{-S\beta} e^{\gamma (fry_{y+1} - \bar{fry})}$$

$$\hat{R}_{y+2} = \alpha S_y e^{-S\beta} e^{\gamma (-\bar{fry})}$$

$$\hat{R}_{y+2} = C \alpha S_y e^{-S\beta}$$

# Generalized Ricker Model:

$$\ln(R/S) = \ln(\alpha) + \beta * \text{Spawners} + b_1 X_1 + \dots + b_n X_n$$

- Consider a broader array of environmental variables, including hatchery releases
- Model built with forward-backward stepwise regression, with  $P < .1$  decision criteria for regression coefficient not equal to zero
- Spawners in model regardless of  $P$ -value for  $\beta$

# Estimates of Annual Wild Yield Loss and Net Hatchery Gain, 1990-2000 (Wertheimer et al. 2004)

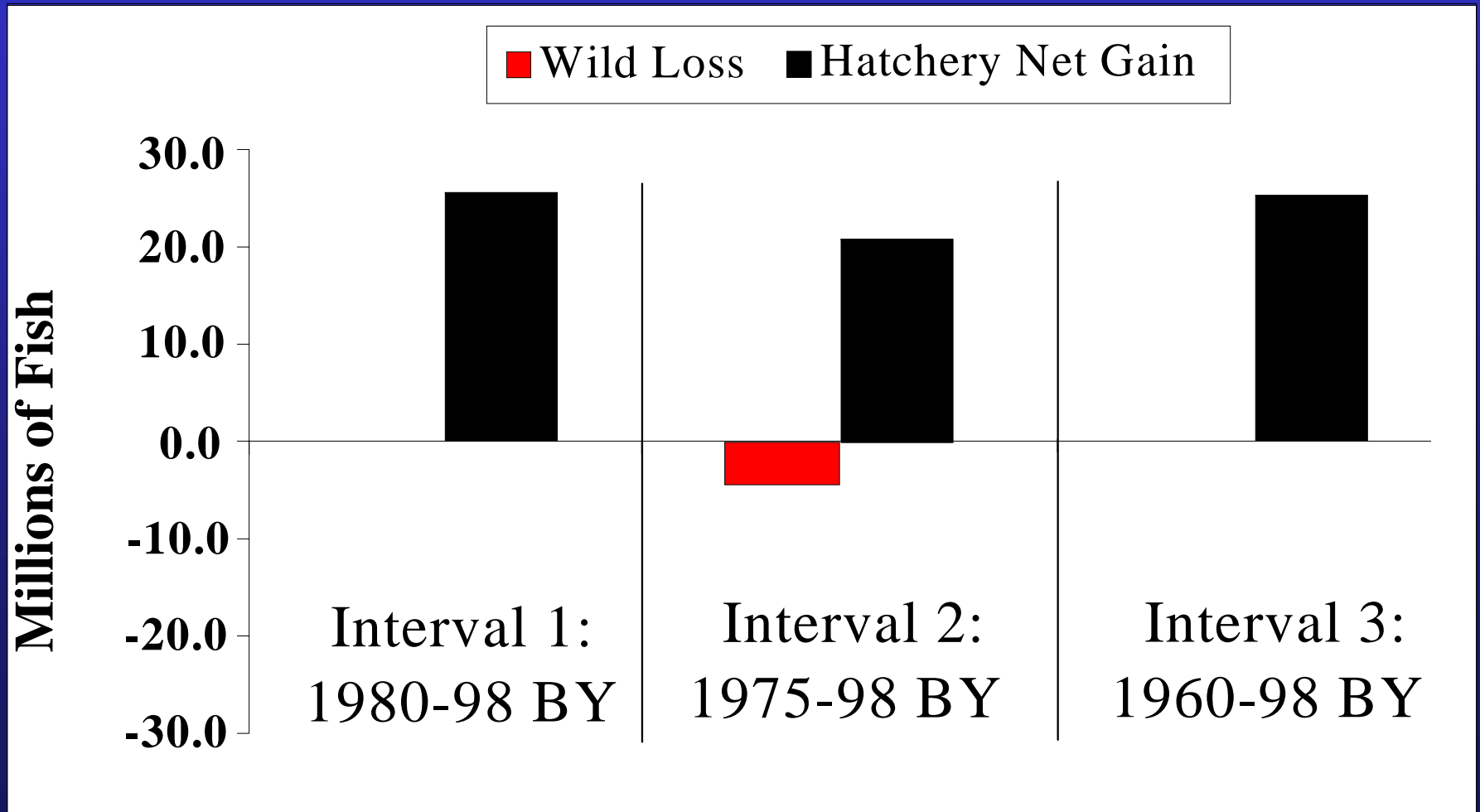
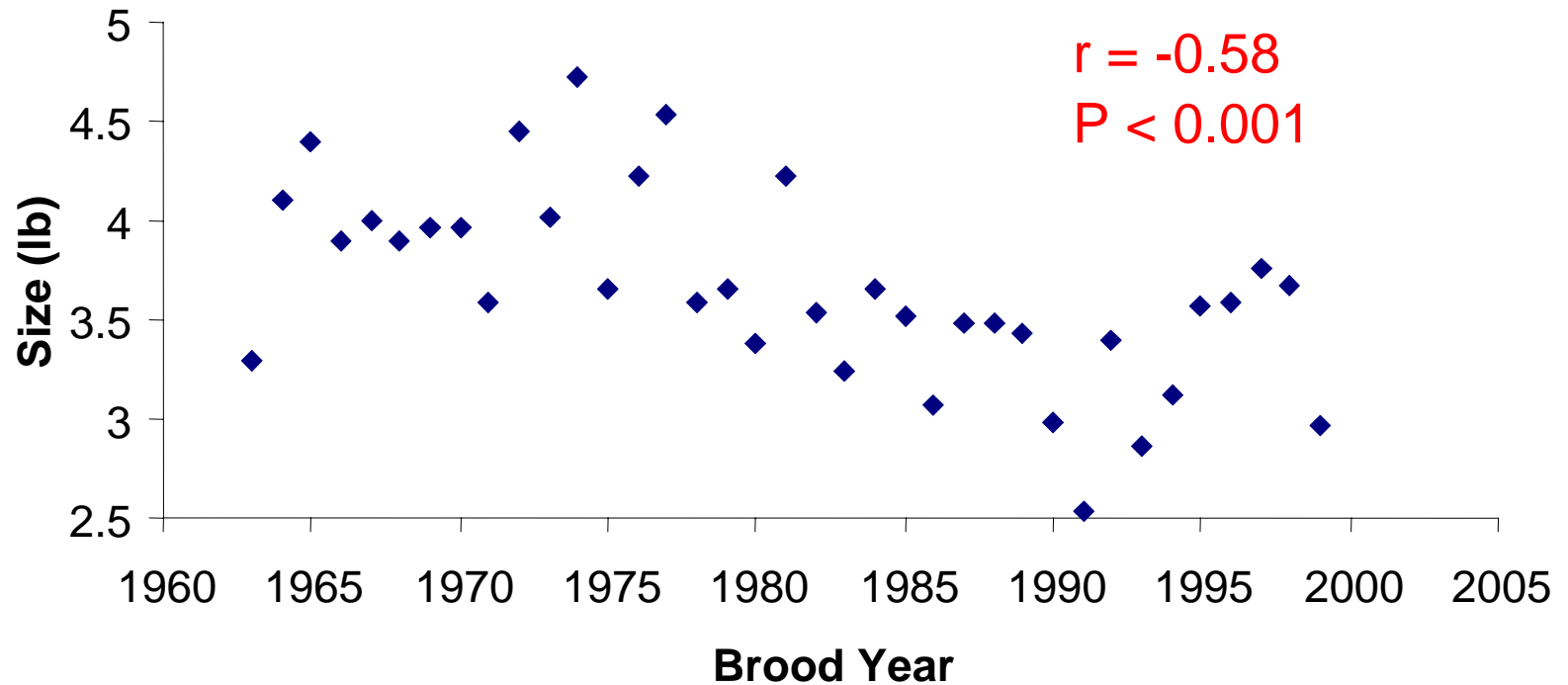




Photo: K Koski

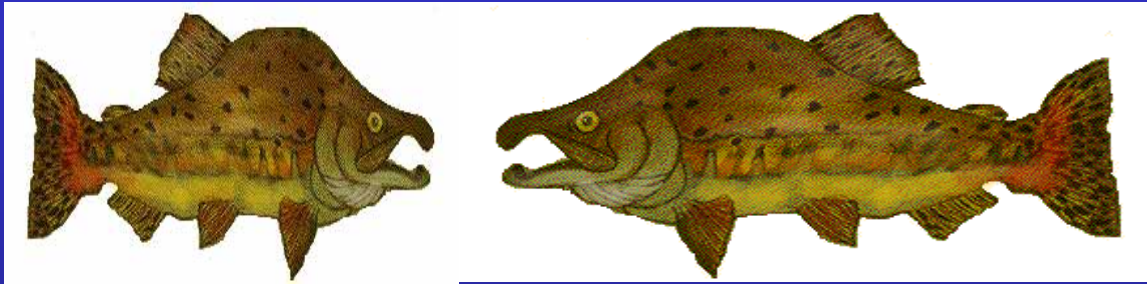
# Size of Pink Salmon in PWS: 1961-1999

PWS Pinks: 1961-1999 Broods



# Within-Year Effects

Individual competitive interactions



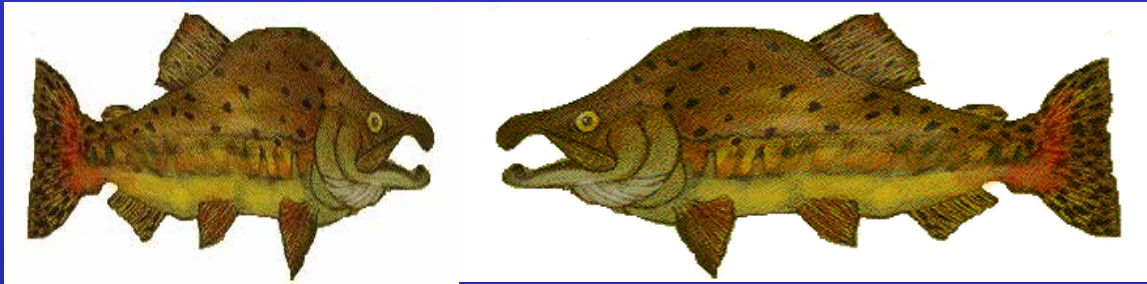
# Between-Year Effects

Size-related differences in annual productivity



# Within-Year Effects

Individual competitive interactions



# Between-Year Effects

Size-related differences in annual productivity



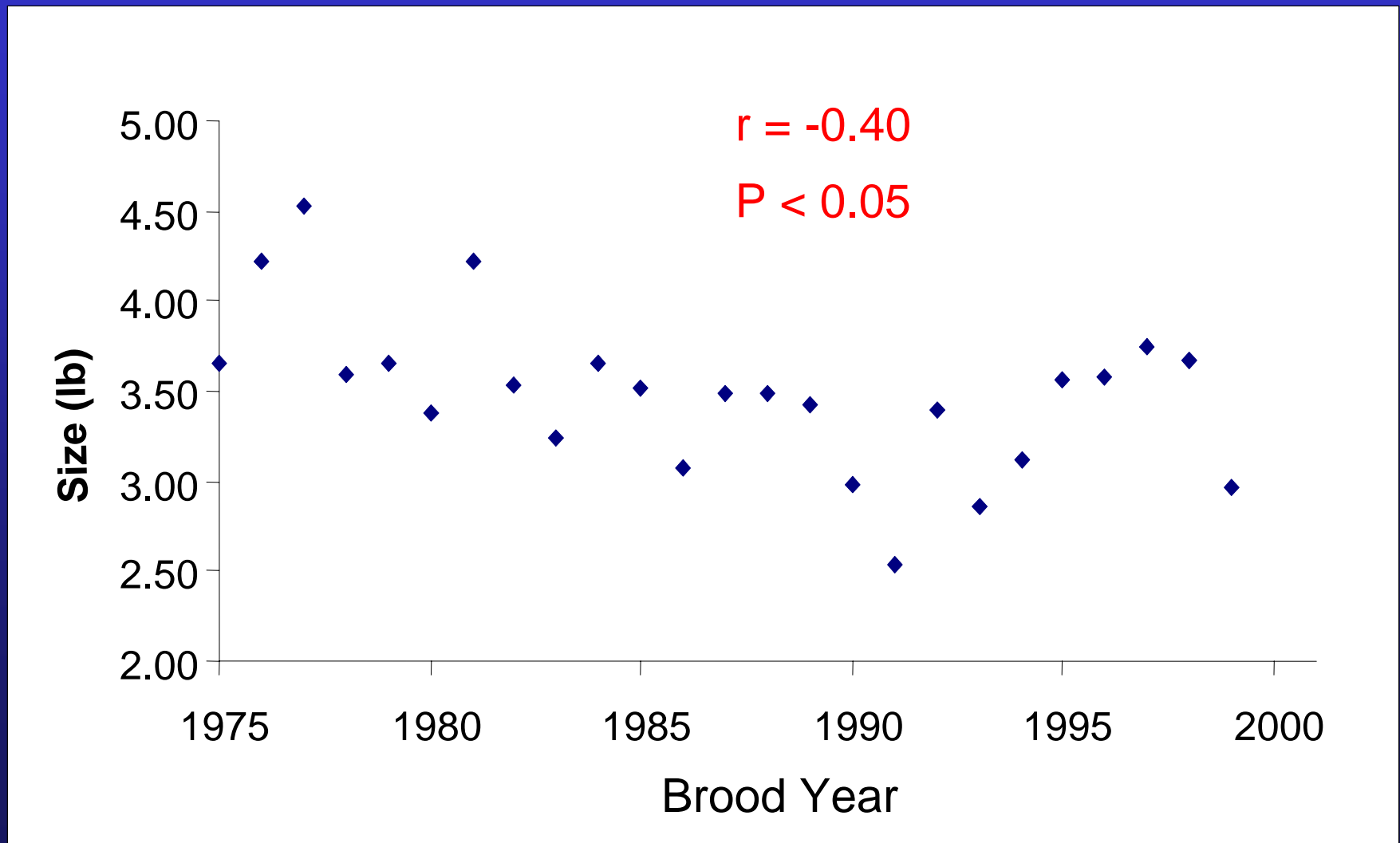
# Objectives:

- **Examine factors affecting average size at return of pink salmon to Prince William Sound.**
- **Determine if size at return affects productivity of wild pink salmon in Prince William Sound.**
- **Estimate impact of large-scale enhancement on wild-stock size and productivity.**

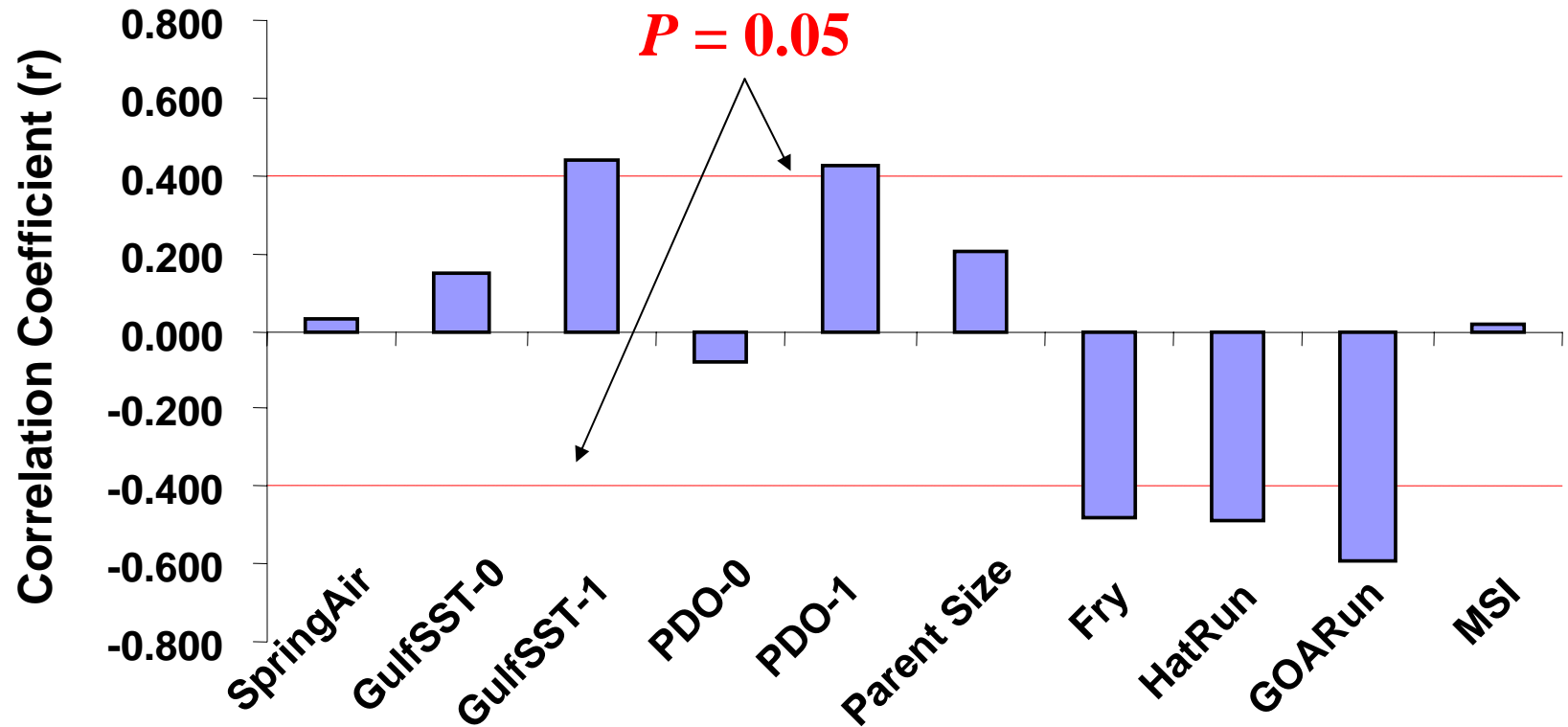
# **Biophysical Factors Potentially Affecting Size at Return**

- 1. Spring Air Temperatures (age-0 spring)**
- 2. Gulf of Alaska SST-0 (age-0 summer)**
- 3. Gulf of Alaska SST-1 (age-1 summer)**
- 4. PDO-0 Winter Index (age-0 “preconditions”)**
- 5. PDO-1 Winter Index (age-1 “preconditions”)**
- 6. Parent Size**
- 7. Fry Release Numbers (age-0 density)**
- 8. PWS Hatchery Run (age-0, age-1 density)**
- 9. Gulf of Alaska Run Index (age-1 density)**
- 10. Marine Survival Index (marine conditions)**

# Size of Pink Salmon in PWS: 1975-1999 BY



# Correlation of Size At Return With BioPhysical Parameters

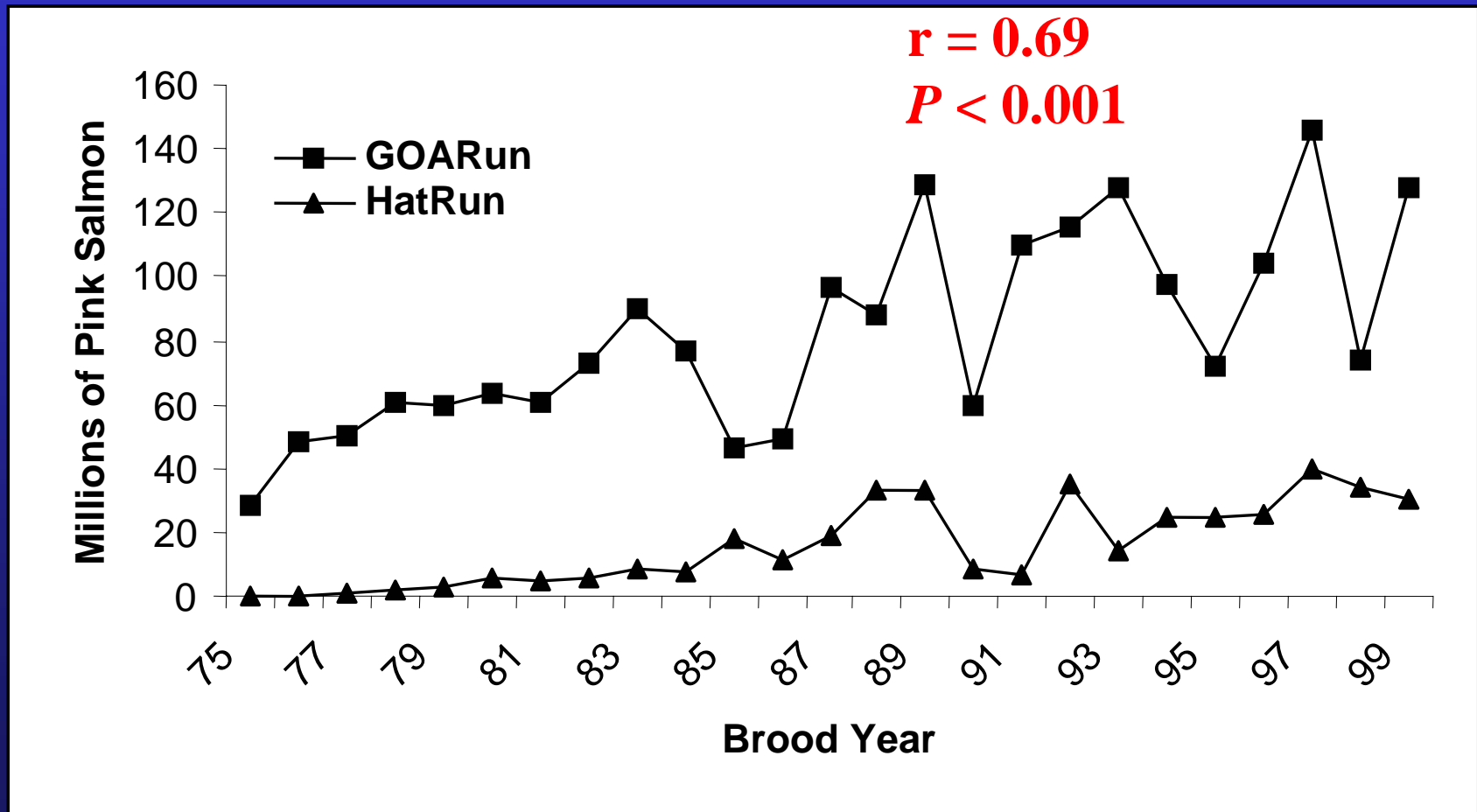


# Factors Affecting Size At Return: Stepwise Regression Fit, Linear Model

$$\text{Size} = b_0 + b_1x_1 + \dots + b_nx_n$$

Step	1	2
GOARun	$P = 0.002$	$P = 0.006$
GulfSST-1		$P = 0.075$
R <sup>2</sup> Adjusted	31.9%	38.5%

# Correlation of Gulf of Alaska Abundance Index and PWS Hatchery Run





# Significant Factors Affecting Average Size at Return

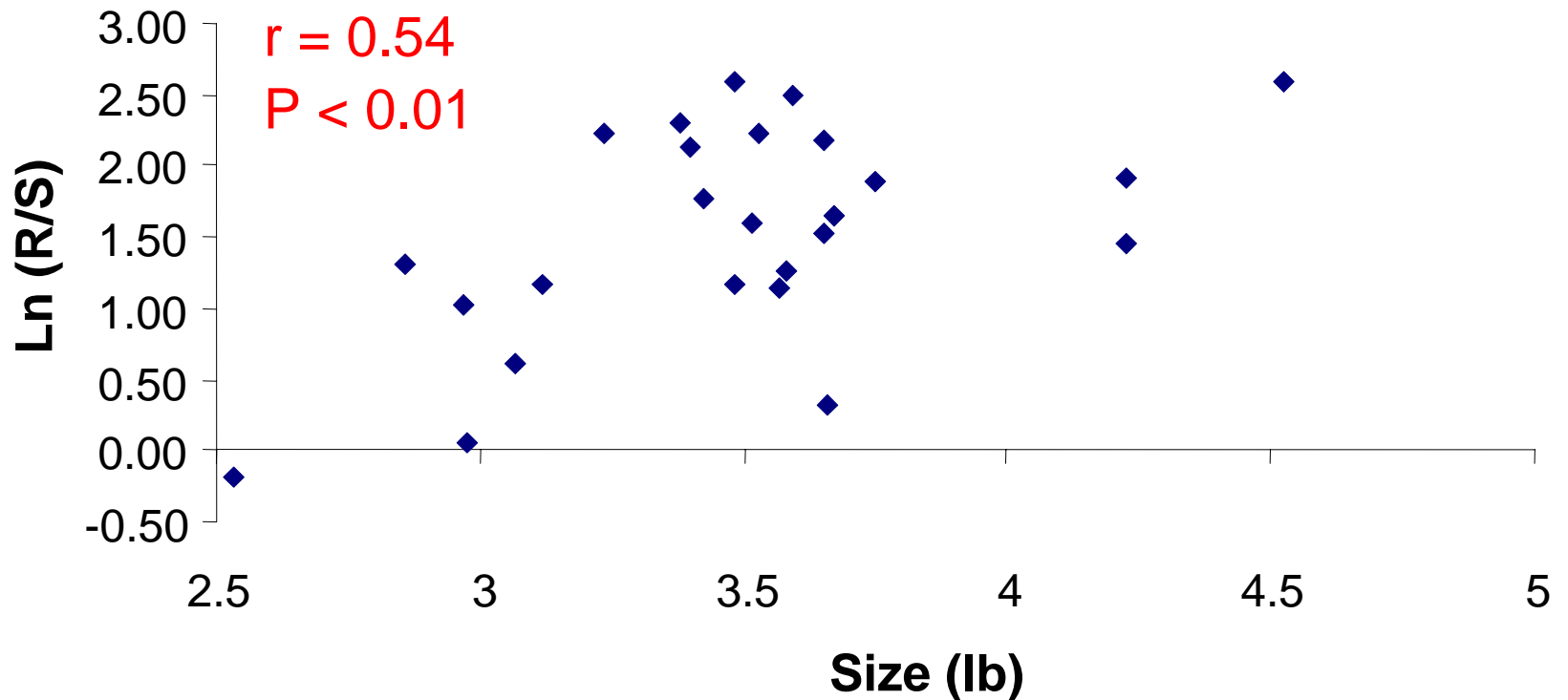
- **GOARun:** Density-dependent growth in the Gulf of Alaska is affecting average size at return
- **GulfSST-1:** Mediated by environmental conditions during age-1 residency

# Objectives:

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# Relationship of Size to Wild Stock Productivity

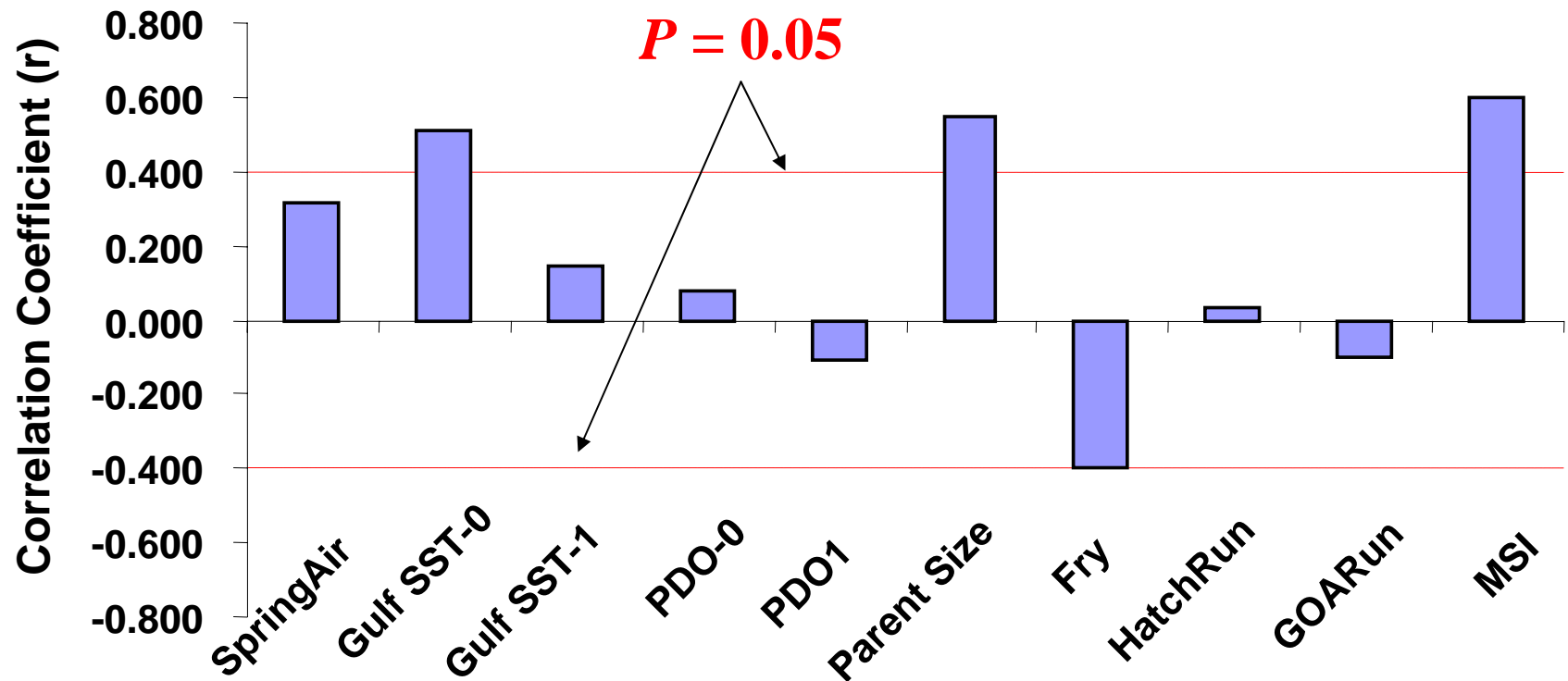
1975-99 BY



# Biophysical Factors Potentially Affecting Wild Productivity

1. Spring Air Temperatures (age-0 spring)
2. Gulf of Alaska SST-0 (age-0 summer)
3. Gulf of Alaska SST-1 (age-1 summer)
4. PDO-0 Winter Index (age-0 “preconditions”)
5. PDO-1 Winter Index (age-1 “preconditions”)
6. Parent Size
7. Fry Release Numbers (age-0 density)
8. PWS Hatchery Run (age-0, age-1 density)
9. Gulf of Alaska Run Index (age-1 density)
10. Marine Survival Index (marine conditions)

# Correlation of Wild Stock Productivity with BioPhysical Parameters

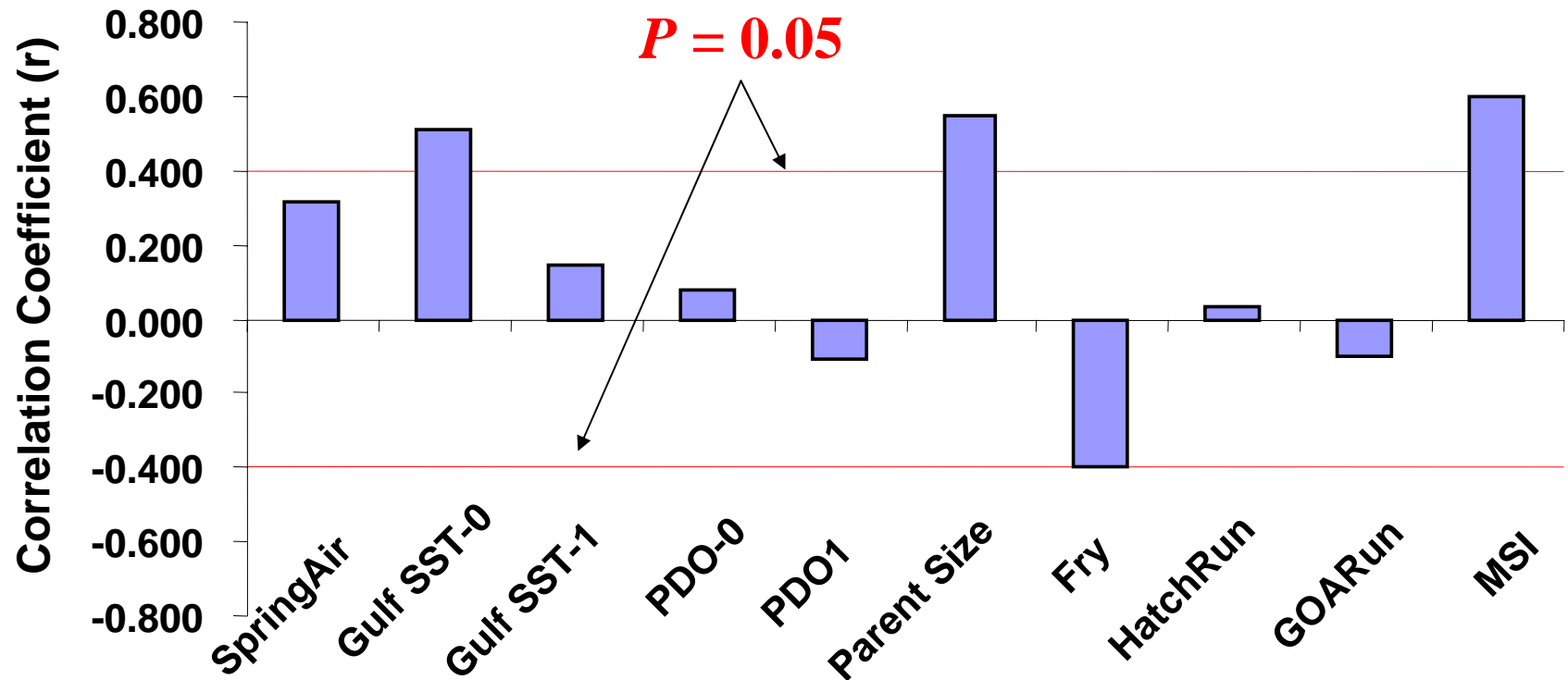


# Factors Affecting Wild Stock Productivity: Stepwise Regression Fit, Linear Version Generalized Ricker Model

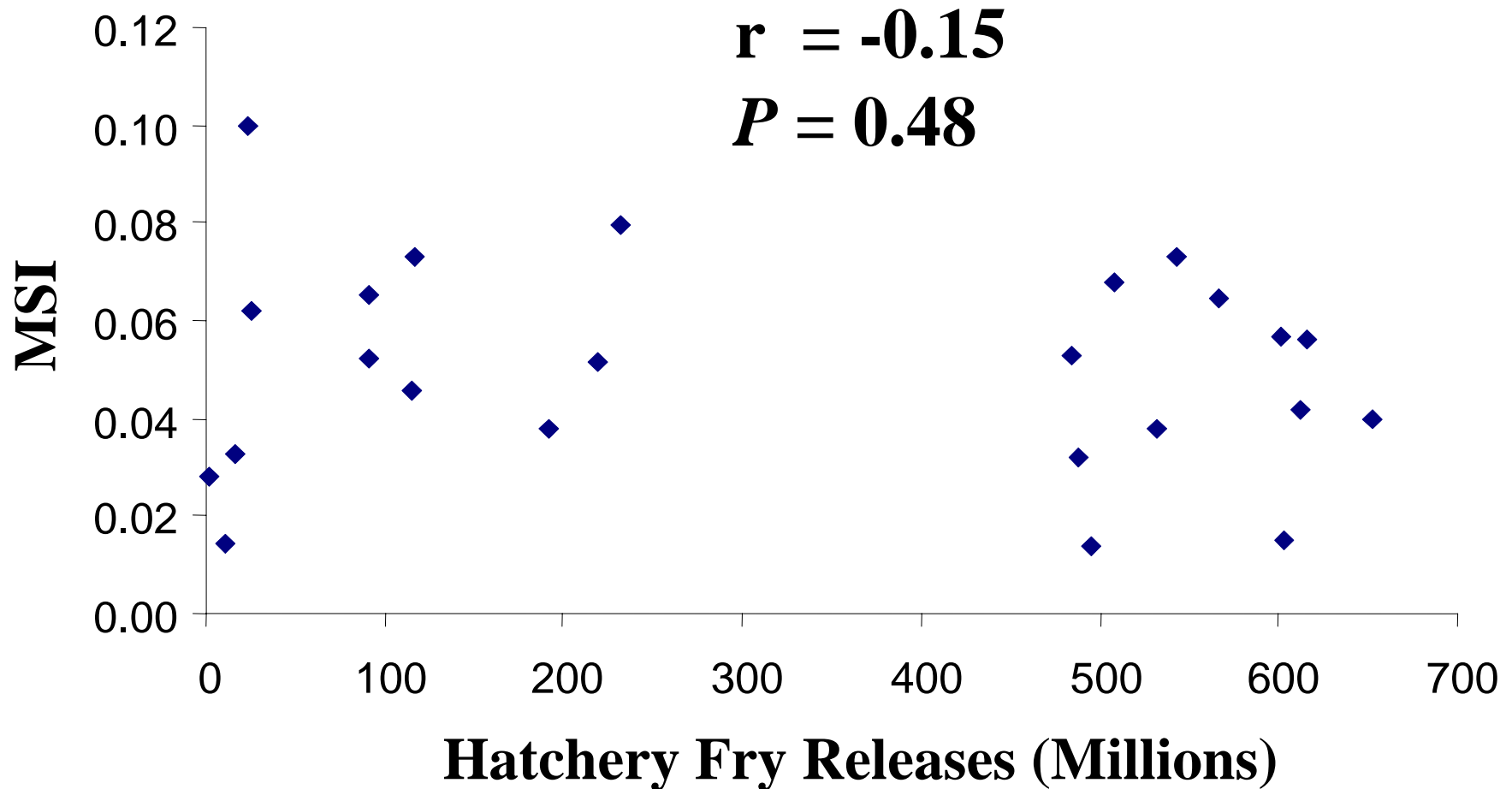
$$\text{Ln}(R/S) = \text{Ln}(\alpha) + \beta * \text{Spawners} + b_1x_1 + \dots + b_nx_n$$

<b>STEP</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>
Spawners	P = 0.261	P = 0.034	P = 0.017	P = 0.051
MSI		P < 0.001	P < 0.001	P < 0.001
Parent Size			P = 0.001	P = 0.004
GulfSST-0				P = 0.046
R <sub>2</sub> (adjusted)	1.4%	43.5%	64.0%	69.2%

# Correlation of Wild Stock Productivity with BioPhysical Parameters



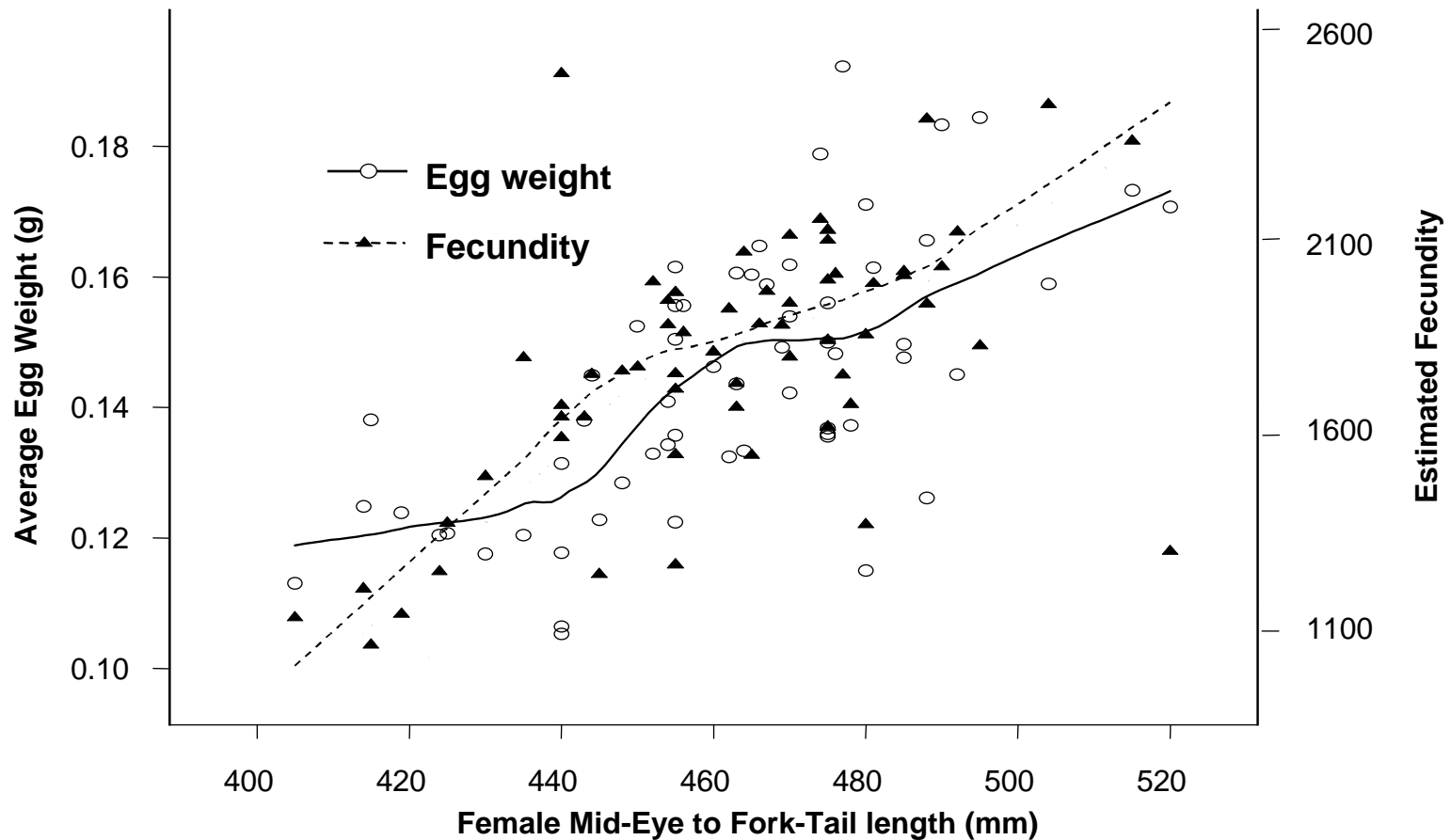
# Correlation of Hatchery Marine Survival to Hatchery Releases 1975-1999 BY



# Potential Mechanisms For Effects of Spawner Size

- Fecundity
- Egg size
- Habitat utilization

# Malecha (2002): LOWESS Analysis Egg Size, Fecundity, and Female Pink Salmon Size



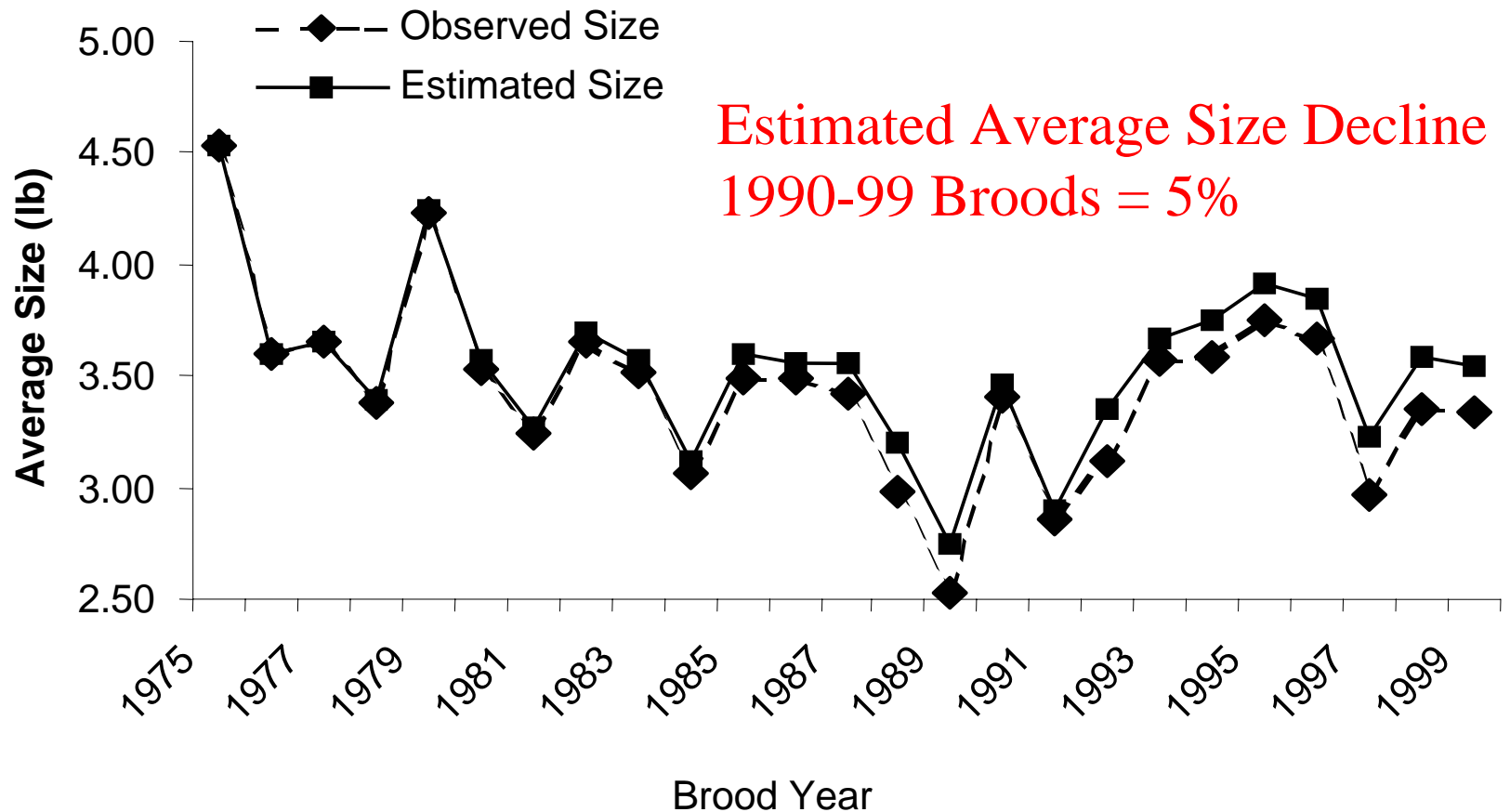
# Objectives:

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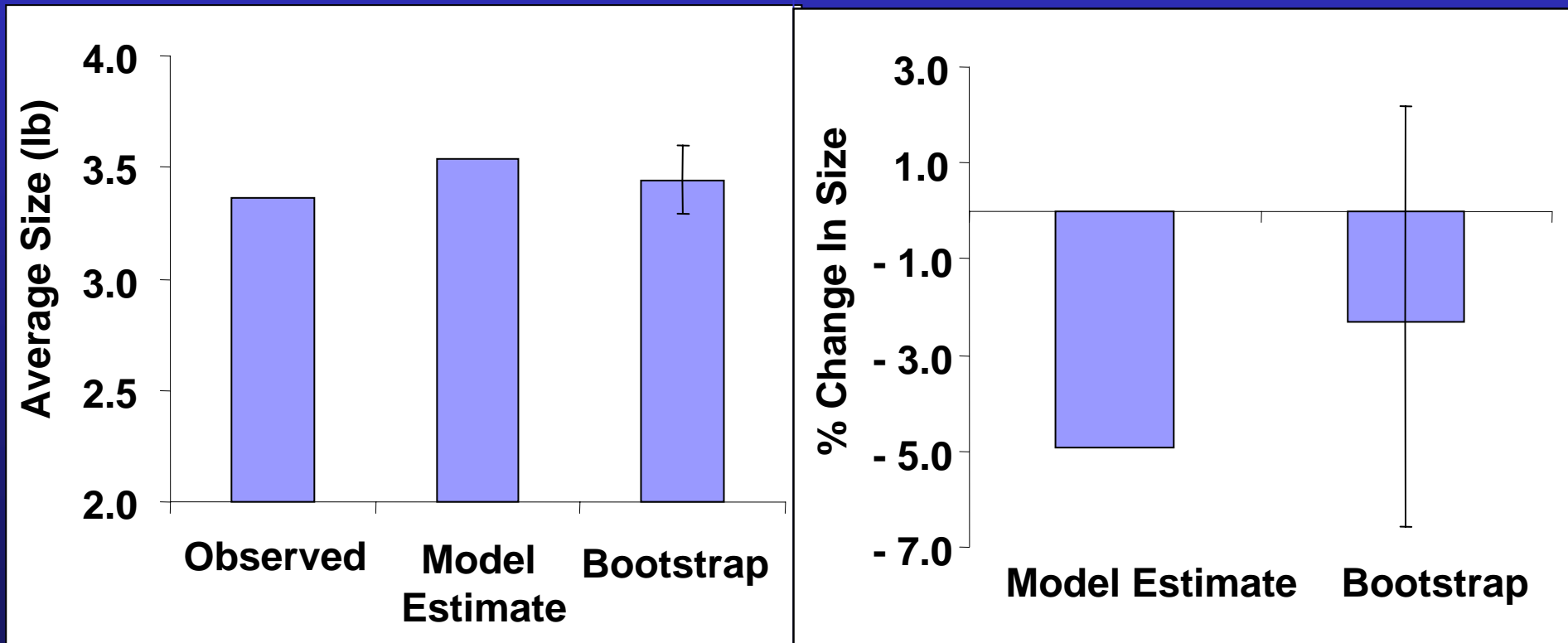
# Impact of Hatchery Production On Average Size At Return

$$\hat{\text{Size}}_i = b_0 - b_1 * (\text{GOARun}_i - \text{HatRun}_i) \\ + b_2 * \text{GulfSST1}_i \\ + \text{Residual}_i$$

# Estimated Impact of Hatchery Production on Size at Return



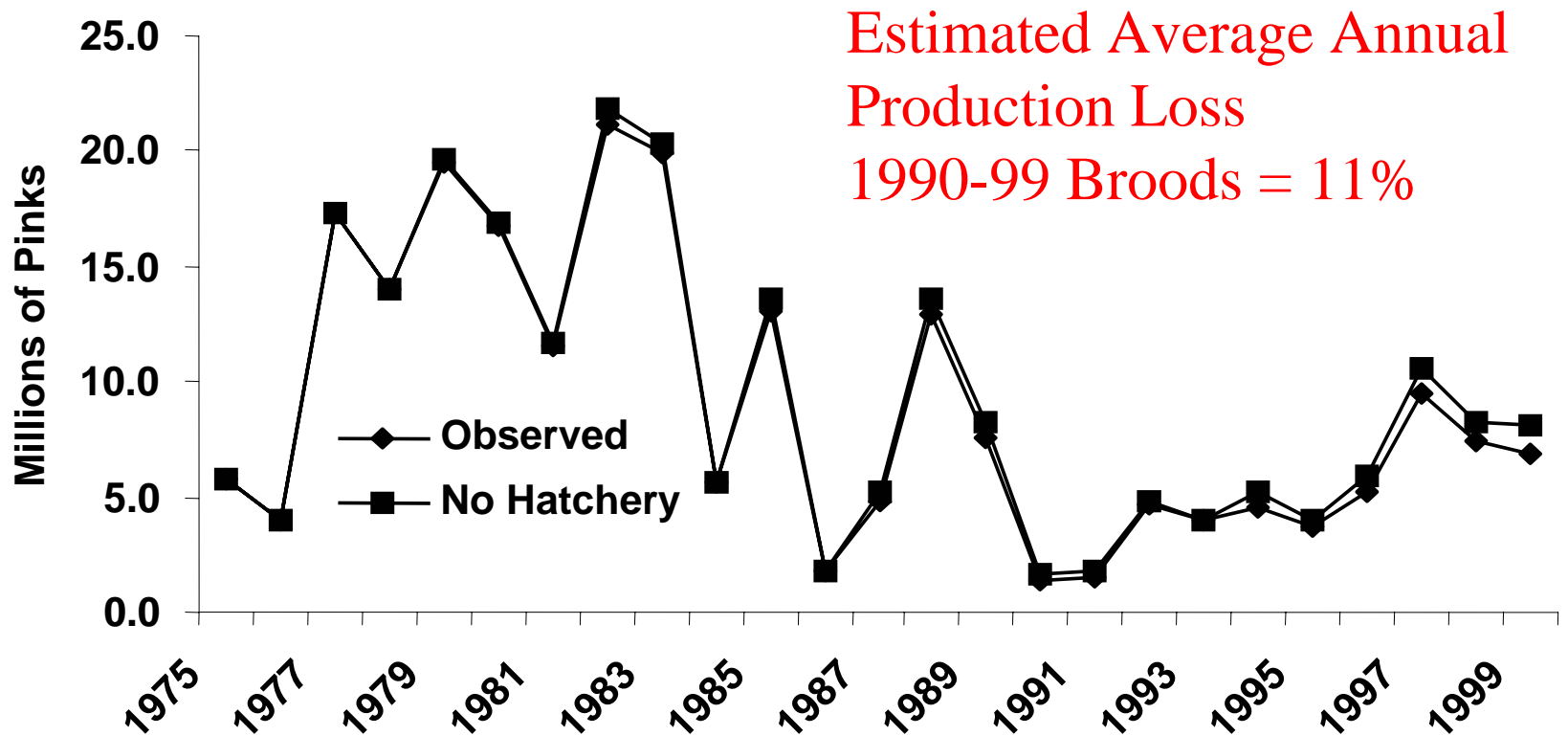
# Non-Parametric Bootstrap 95% Confidence Intervals For Size Impact



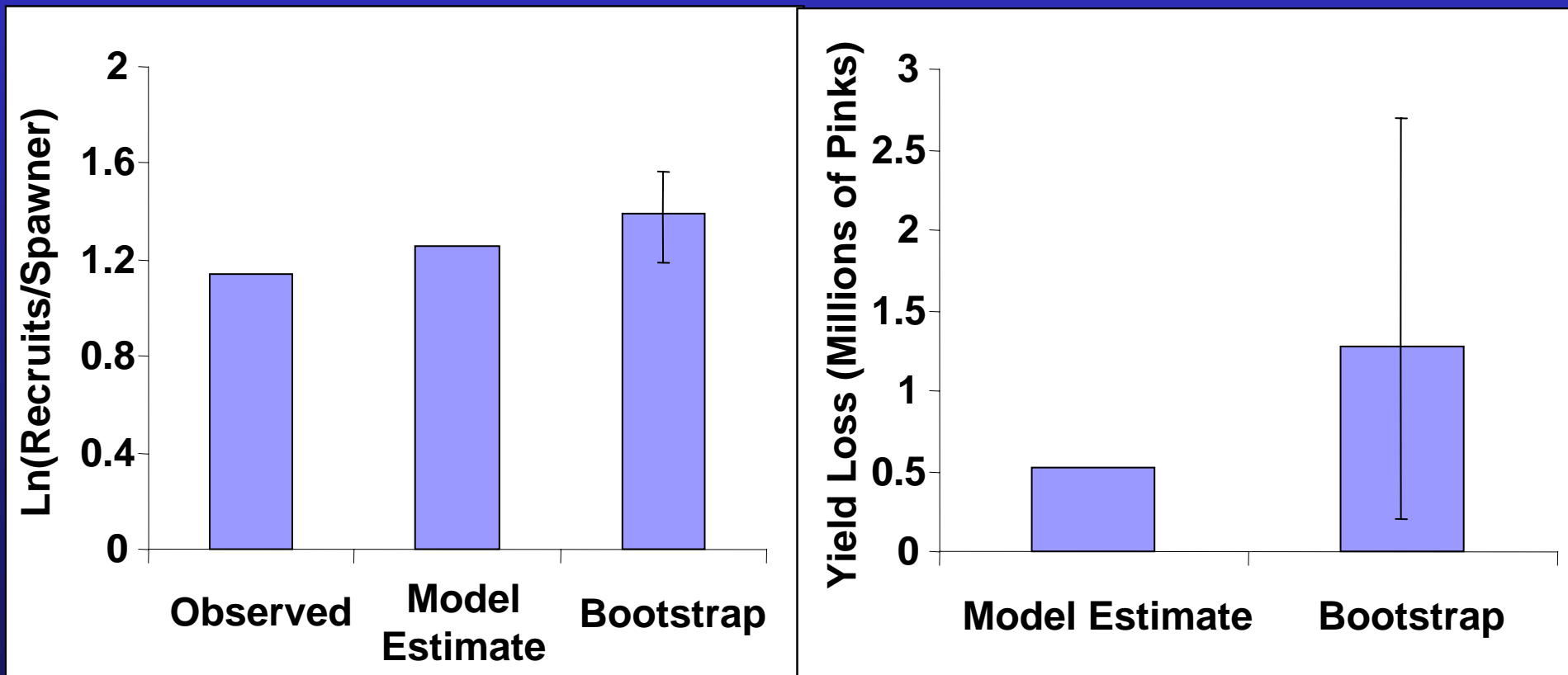
# Impact of Hatchery-Induced Size Decline On Wild Stock Production

$$\begin{aligned} \text{Ln}(\hat{R}_i/S_i) = & b_0 - b_1 * (S_i) \\ & + b_2 * \text{MSI}_i \\ & + b_3 * \hat{\text{Size}}_i \\ & + b_4 * \text{GulfSST}_i \\ & + \text{Residual}_i \end{aligned}$$

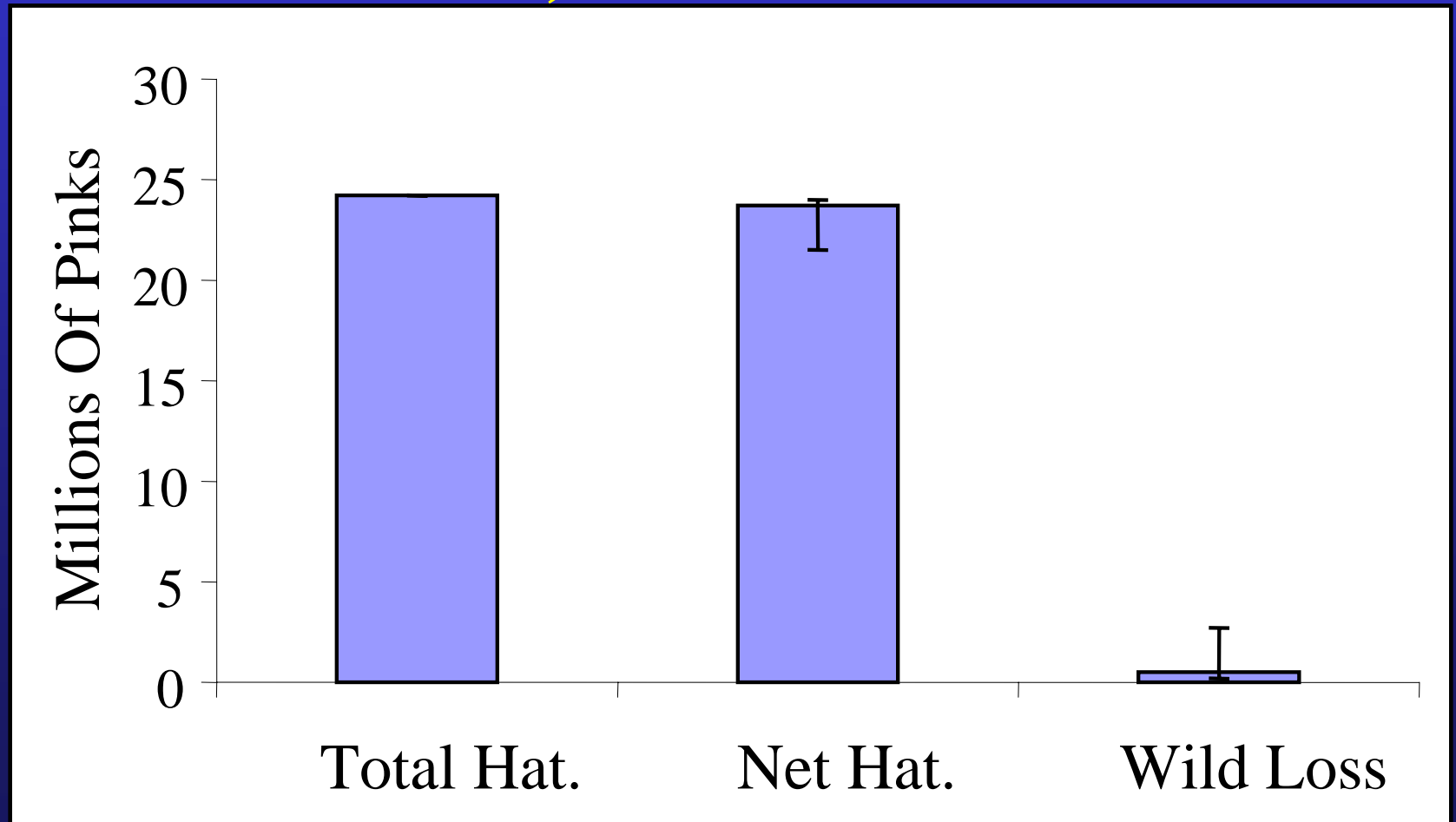
# Estimated Impact of Size Decline On Wild Stock Production



# Non-Parametric Bootstrap 95% Confidence Intervals For Productivity Impact



# Annual Hatchery Catch and Estimated Net Gain and Wild Yield Loss, 1990-1999 Broods



# Conclusions

- **The More the Merrier:** Marine survival of hatchery and wild pink salmon in PWS is driven primarily by density-independent processes.
- **But More Is Also Less:** Size at return of pink salmon to PWS is density-dependent, inversely related to the abundance of pink salmon in the Gulf of Alaska, which in turn is substantially affected by the scale of hatchery production.
- **And Size Does Matter:** Size at return has a significant effect on wild-stock productivity.
- **Enhancement of PWS Pink Salmon Results In Large Net Benefits in Total Production, But Not Without Some Ecological Cost.**

