A Statistical Analysis of the Change in Age Distribution of Spawning Hatchery Salmon

Emily Barrett, Rachel Macaulay, Grace Penunuri

Outline

1. Background Information
2. Data Description
3. Two Proportion Z Test
4. Chi Squared Test for Association
5. Multiple Linear Regression
6. Impacts
7. Research Experience

Spawning Chum Salmon

Spawning Chinook Salmon

Introduction: Size Decline

- Alaska salmon sizes are declining
  - Maturation at younger ages

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ARTICLE

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Recent declines in salmon body size impact ecosystems and fisheries

K. B. Oke[1,2✉], C. J. Cunningham[2,3], P. A. H. Westley[4✉], M. L. Baskett[5], S. M. Carlson[6], J. Clark[7], A. P. Hendry[8], V. A. Karatayev[5], N. W. Kendall[9], J. Kibele[7], H. K. Kindsvater[10], K. M. Kobayashi[1], B. Lewis[11], S. Munch[1,12], J. D. Reynolds[13], G. K. Vick[14] & E. P. Palkovacs[1✉]

1985

Introduction: Size Decline

- Alaska salmon sizes are declining
  - Maturation at younger ages
- Potential causes
  - Climate change
  - Harvest
  - Largely unknown

1985

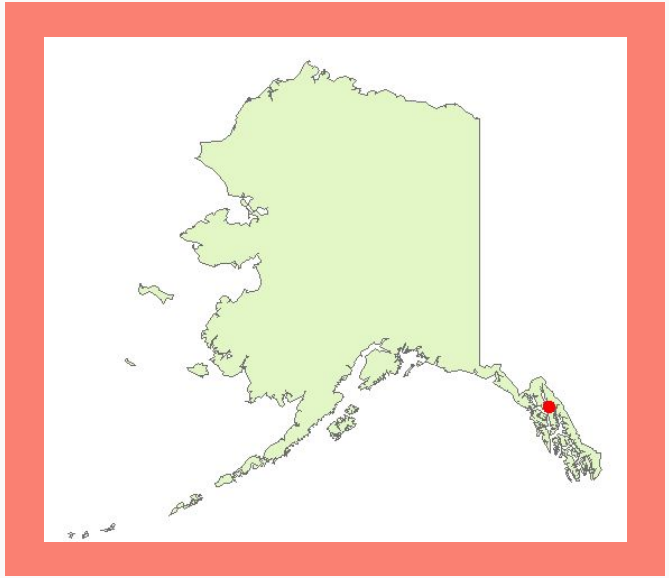
Introduction: Size Decline

- Alaska salmon sizes are declining
  - Maturation at younger ages
- Potential causes
  - Climate change
  - Harvest
  - Largely unknown
- Salmon hatcheries
  - Increase survival through artificial breeding, incubation, and rearing

1985

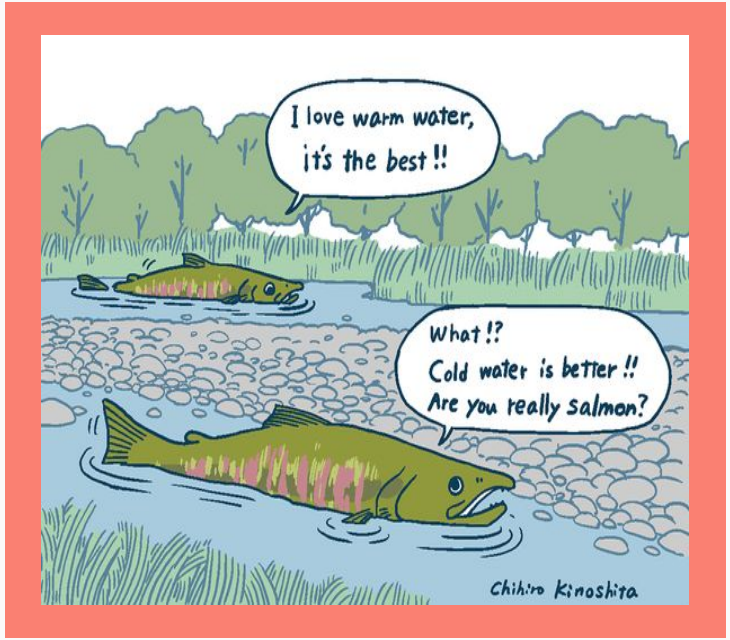
Introduction: DIPAC

- Douglas Island Pink and Chum, Inc (DIPAC) operates a salmon hatchery in Juneau, Alaska
- DIPAC's produces chum, sockeye, coho and Chinook salmon
  - Chum salmon have been DIPAC's primary salmon stock since the mid 1980s

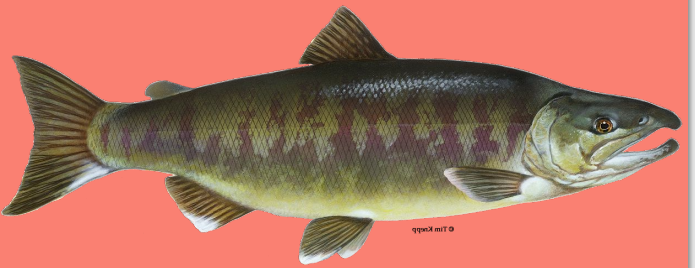


Salmon: Key Information

- Biology
  - Salmon return to their natal streams to spawn
  - Salmon can only spawn once before dying
  - Chum salmon spawn at ages 3, 4, 5, or 6
  - Chinook salmon spawn at ages 2, 3, 4, 5, 6, or 7
- Vocabulary
  - Broodstock
    - Salmon that are used for breeding purposes
  - Fry
    - Early stage in the salmon life cycle



Goals



1. **To examine the change in the age distribution of chum and Chinook salmon**
2. To investigate the average number fry produced by spawning chum and Chinook salmon

Data

- DIPAC is required to provide an Annual Management Plan (AMP)
- Our data sources from DIPAC's 2021 AMP report
  - Age and return year of salmon for broodstock
  - Brood years and number of released fry

Data Description

- Chum
  - Brood year data spans from 1984-2014
  - Return year data spans from 1987-2020
  - Released fry data spans from 1984-2017
- Chinook
  - Brood year data spans from 1987 - 2013
  - Return year data spans from 1994 - 2020
  - Released fry data spans from 1987 - 2017

Brood Years and Number of Released Fry

Table 8. DIPAC terminal area chum salmon brood year performance by age class and release site.

Sheep Creek Hatchery Terminal Area Brood Year Performance by Age Class

Brood Year	No. of Fry Released	No. Adults Returned to Terminal Area				Total Return	Total % Return	% Terminal Run by Age Class			
		Age 3	Age 4	Age 5	Age 6			Age 3	Age 4	Age 5	Age 6
1984	4,291,652	115	35,645	4,804	181	40,745	0.9%	0.3%	87.5%	11.8%	0.4%
1985	7,001,628	-	27,243	50,981	3,001	81,225	1.2%	0.0%	33.5%	62.8%	3.7%
1986	18,971,280	1,545	129,260	152,505	14,950	298,260	1.6%	0.5%	43.3%	51.1%	5.0%
1987	10,122,835	362	14,297	18,253	316	33,228	0.3%	1.1%	43.0%	54.9%	1.0%
1988	26,697,200	3,707	139,072	56,507	1,035	200,321	0.8%	1.9%	69.4%	28.2%	0.5%
1989	3,073,538	1,565	5,695	6,079	947	14,286	0.5%	11.0%	39.9%	42.6%	6.6%
1990	37,874,036	759	123,570	64,153	5,916	194,398	0.5%	0.4%	63.6%	33.0%	3.0%
1991	27,011,585	2,044	21,988	45,632	791	70,455	0.3%	2.9%	31.2%	64.8%	1.1%
1992	27,002,939	15,801	440,329	105,675	756	562,561	2.1%	2.8%	78.3%	18.8%	0.1%
1993	14,635,458	1,206	11,501	2,615	144	15,466	0.1%	7.8%	74.4%	16.9%	0.9%
1994	44,673,729	6,130	47,591	6,594	76	60,391	0.1%	10.2%	78.8%	10.9%	0.1%
1995	41,240,126	1,539	39,059	11,649	841	53,088	0.1%	2.9%	73.6%	21.9%	1.6%
1996	39,278,455	9,058	52,584	24,311	-	85,953	0.2%	10.5%	61.2%	28.3%	0.0%

***** No broodstock collection conducted at Sheep Creek since 1996*****

Reorganizing Data

In the release year ****, age break down of that fish from that release year													
	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
year 2	0	0	0	0	6	748	6	0	12	0	0	9	0
year 3	0	1	22	94	0	13	153	402	69	5	320	19	87
year 4	2	12	22	137	11	110	487	610	69	91	66	54	503
year 5	37	45	82	156	233	313	1437	617	467	132	29	53	1283
year 6	35	31	2	256	555	135	250	687	208	130	0	39	237
year 7	1	0	2	21	48	43	0	14	0	8	0	0	0

In the year ****, how many fish of each age returned													
Reorganized	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
year 2 (x_2)	0	0	0	0	0	0	6	748	6	0	12	0	0
year 3 (x_3)	0	0	0	0	1	22	94	0	13	153	402	69	5
year 4 (x_4)	0	0	0	0	2	12	22	137	11	110	487	610	69
year 5 (x_5)	0	0	0	0		37	45	82	156	233	313	1437	617
year 6 (x_6)	0	0	0	0			35	31	2	256	555	135	250
year 7 (x_7)	0	0	0	0				1	0	2	21	48	43

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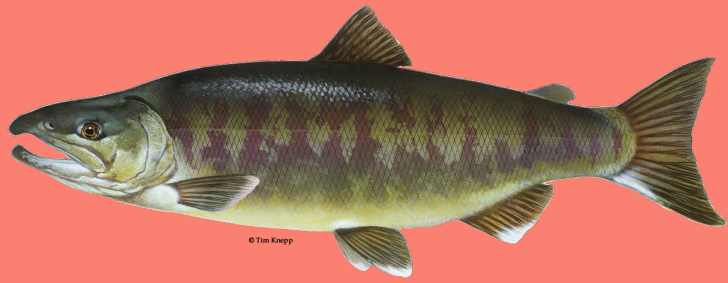
Chum: Two Proportion Z-Test

H_0: The proportion of 3 and 4 year old salmon returning to spawn from 1987 - 2003 is the same proportion in 2004 - 2020

H_a: The proportion of 3 and 4 year old salmon returning to spawn from 1987 - 2003 is the less than the proportion in 2004 - 2020

	1987 - 2003	Proportion	2004 - 2020	Proportion
Ages 3 and 4	2,035,347	69%	3,031,199	74%
Ages 5 and 6	933,508	31%	1,090,928	26%
Total	2,968,855		4,122,127	

Chum: Two Proportion Z-Test



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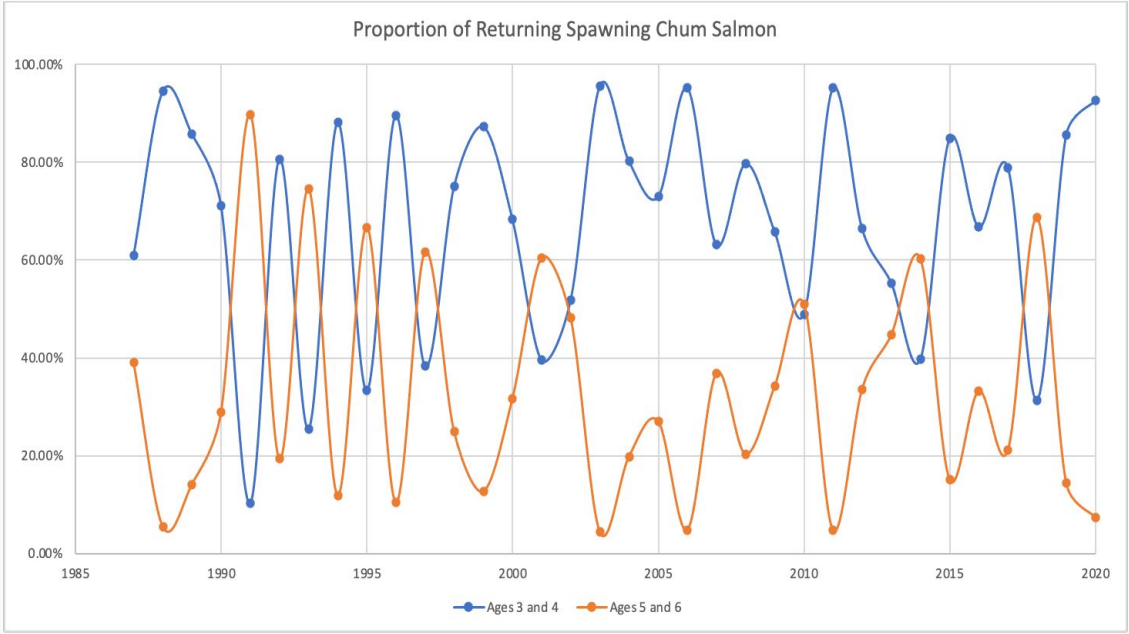
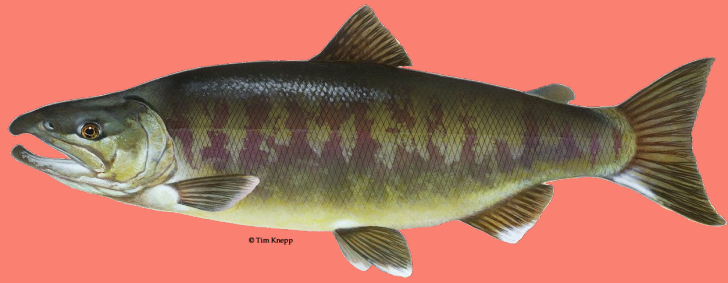


Chum: Two Proportion Z-Test Results



- P-value = $2.2 * 10^{-16}$
- Reject the null hypothesis
- **We conclude that there is strong evidence that suggests that the proportion of 3 and 4 year old salmon returning to spawn from 1987 - 2003 is less than the proportion from 2004 - 2020**

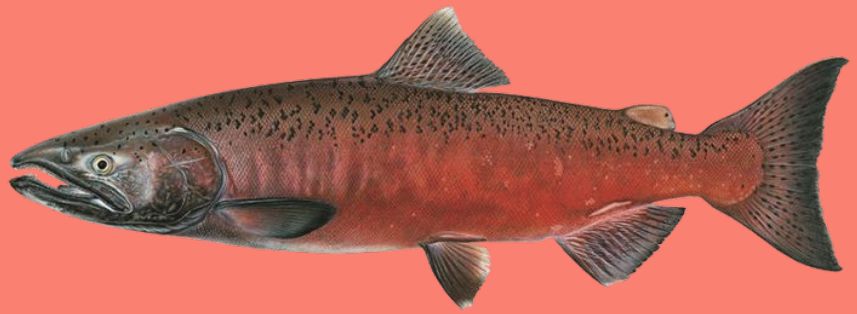
Chinook: Two Proportion Z - Test

H_0: The proportion of 2 - 5 year old salmon returning to spawn from 1994 - 2007 is the same proportion in 2008 - 2020.

H_a: The proportion of 2 - 5 year old salmon returning to spawn from 1994 - 2007 is the less than the proportion in 2008 - 2020.

	1994 - 2007	Proportion	2008 - 2020	Proportion
Ages 2 - 5	13,906	80%	13,670	89%
Ages 6 and 7	3,369	20%	1,717	11%
Total	17,275		15,387	

Chinook: Two Proportion Z - Test



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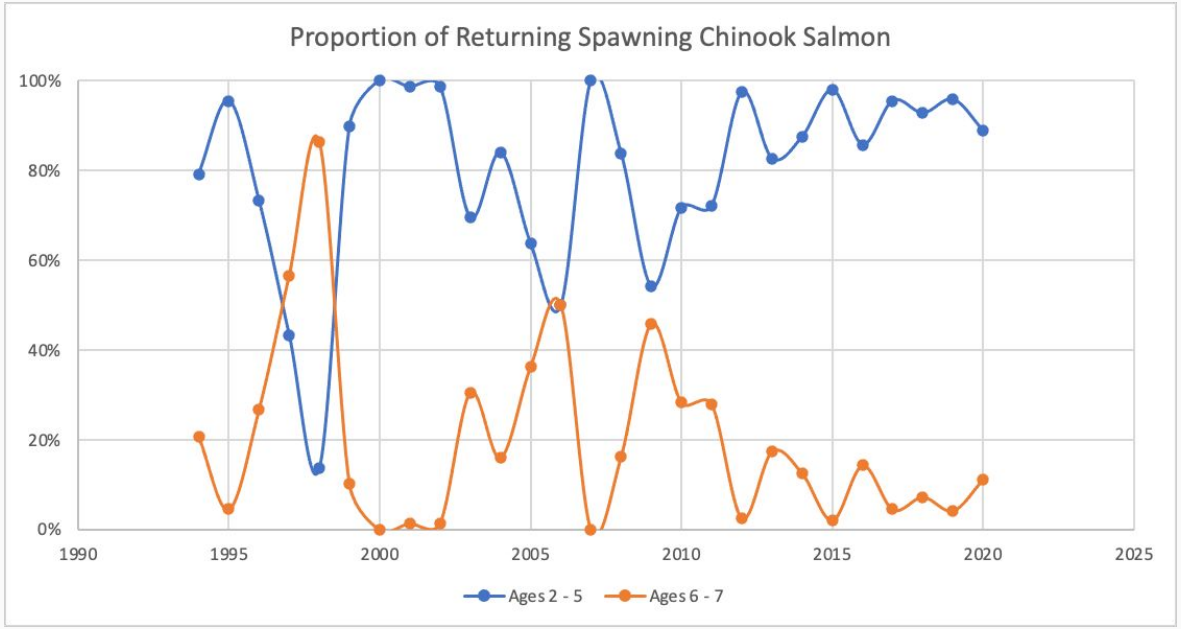


Chinook: Two Proportion Z-Test Results

- P-value = $2.2 * 10^{-16}$
- Reject the null hypothesis
- **We conclude that there is strong evidence that suggests that the proportion of 2 - 5 year old salmon returning to spawn from 1994-2007 is the less than the proportion in 2008-2020.**

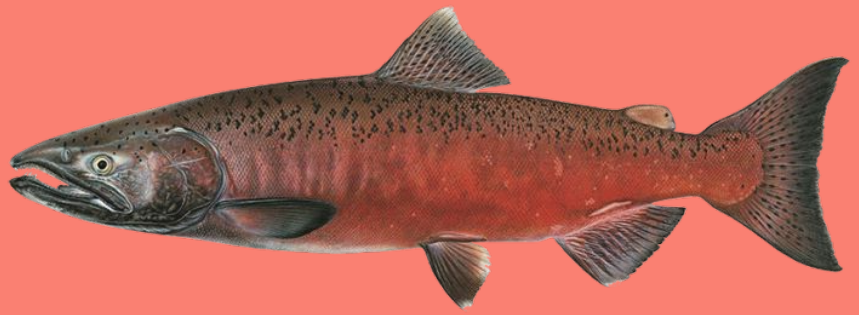
Chinook: Chi Squared Test

H_0: The proportion of a 2 year old salmon returning to spawn from 1994-2007 is the same proportion in 2008-2020.

H_a: The proportion of a 2 year old salmon returning to spawn from 1994-2007 is not the same as the proportion in 2008-2020.

	1994 - 2007	Proportion	2008 - 2020	Proportion
Age 2	829	5%	8	0%
Age 3	800	5%	1,555	10%
Age 4	3,109	18%	2,992	19%
Age 5	9,168	53%	9,115	59%
Age 6	3,274	19%	1,717	11%
Age 7	95	1%	0	0%
Total	17,275		15,387	

Chi-Squared Test for Association



$$X_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

- X_c = Test statistic to determine if the difference is significant
- O_i = The amount of salmon that actually returned in 2008 - 2020
- **E_i = The amount of salmon that we expected to return given that the null hypothesis is true**
- i = age

Chinook: Chi Squared Test

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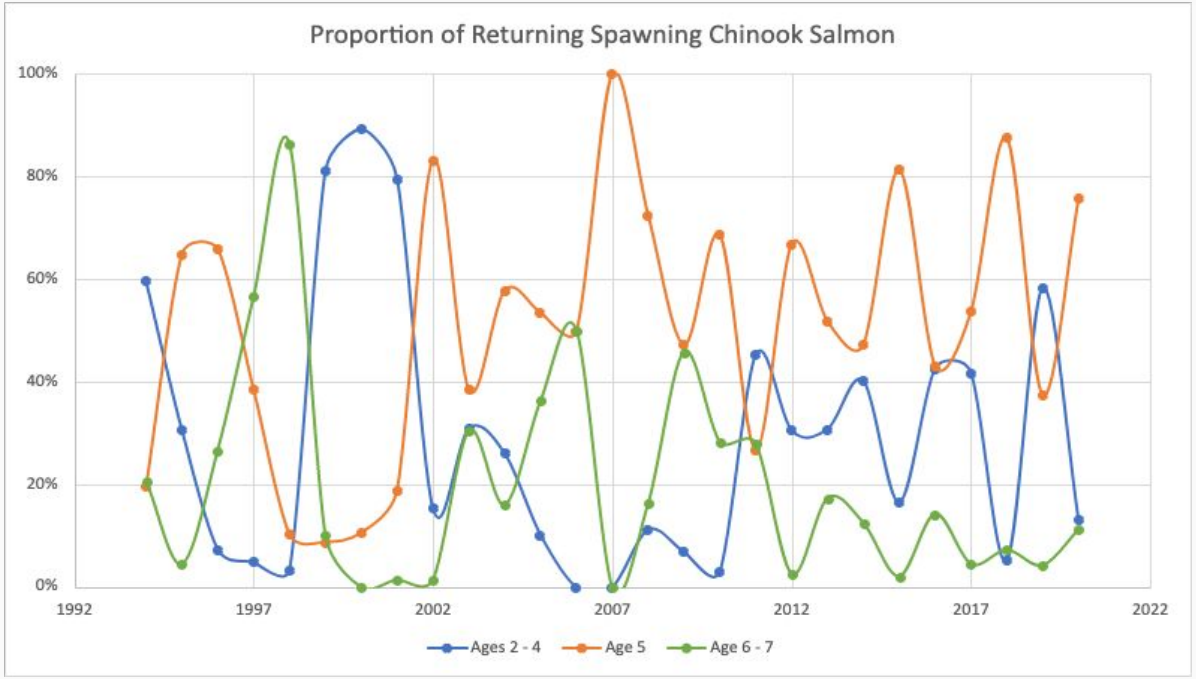
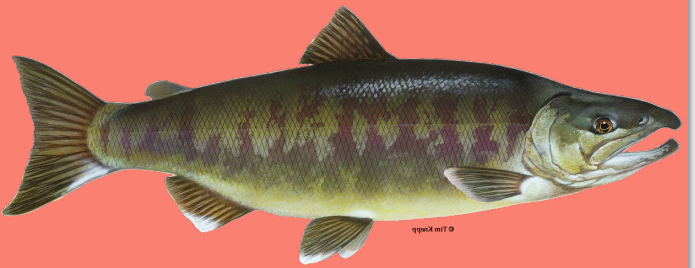


Chinook: Chi-Squared Results

- P-value = $2.2 * 10^{-16}$
- Reject the null hypothesis
- For n = 2, 3, 4, 5, 6, 7
  - **We conclude that there is strong evidence that suggests that the proportion of a n - year old salmon returning to spawn from 1994-2007 is not the same as the proportion in 2008-2020**

Goals



1. To examine the change in the age distribution of spawning chum and Chinook salmon
2. **To investigate the average number fry produced by spawning chum and Chinook salmon**

Multiple Linear Regression

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots + b_n X_n$$

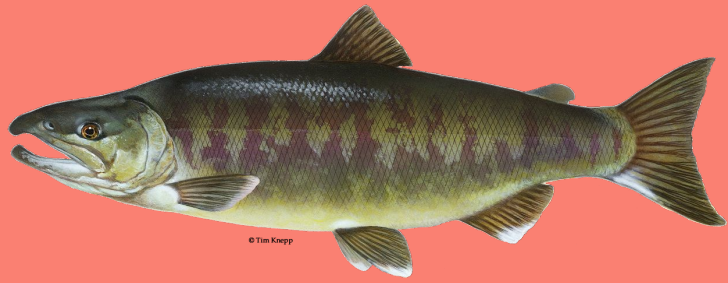
- Y: Number of fry released in that given year
- X□: Number of n-year olds that returned in a given year
- **b□: Average number of fry produced by a n-year old in a given year**

Chum: Multiple Linear Regression

$$Y = b_1 X_1 + b_2 X_2$$

- **b□: Average number of fry produced by a n-year old in a given year**
  - **b_1 = Average number of fry produced by a 3 and 4 year old**
  - **b_2 = Average number of fry produced by a 5 and 6 year old**

Chum: Multiple Linear Regression Results



- 3 and 4 year old spawning salmon produce an average of **59 fry**
  - 95 % confidence interval: [38,80]
- 5 and 6 year old spawning salmon produce an average of of **294 fry**
  - 95% confidence interval: [236, 353]

Chinook: Multiple Linear Regression

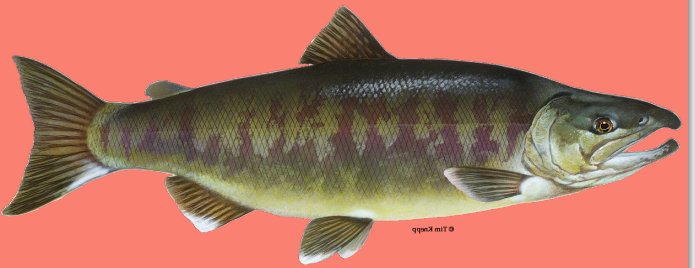
$$Y = b_1 X_1 + b_2 X_2$$

- **b□: Average number of fry produced by a n-year old in a given year**
  - **b_1 = Average number of fry produced by a 2, 3, 4, 5, year old**
  - **b_2 = Average number of fry produced by a 6 and 7 year old**

Chinook: Multiple Linear Regression Results

- 2 - 5 year old spawning salmon produce an average of **90 fry**
  - 95 % confidence interval: [58,122]
- 6 and 7 year old spawning salmon produce an average of of **326 fry**
  - 95% confidence interval: [192, 461]

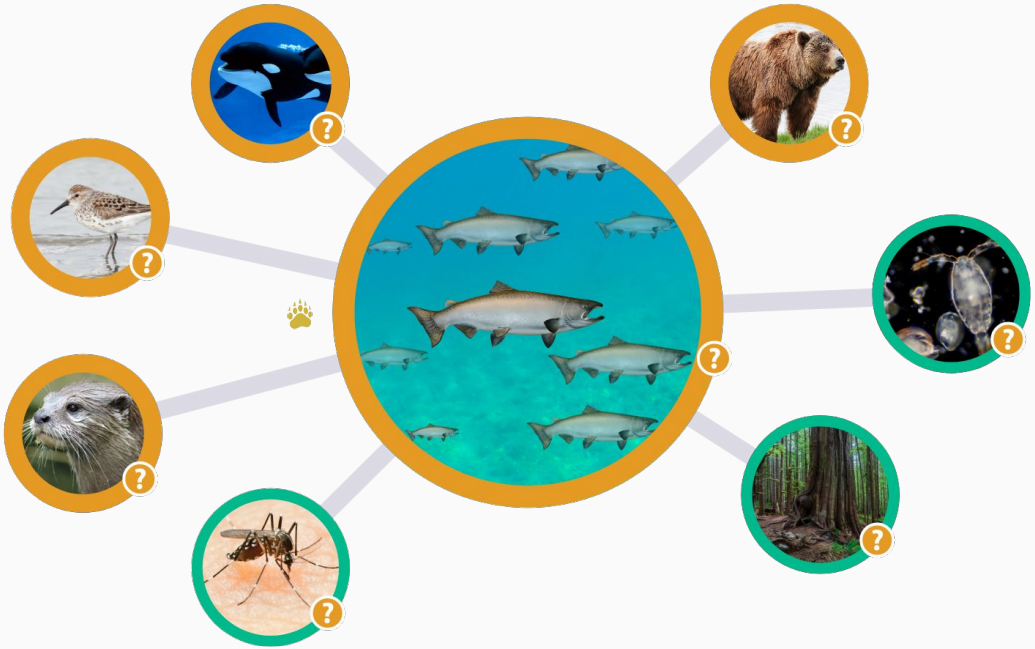
Conclusion



1. There are more younger spawning salmon than older spawning salmon
2. Older spawning salmon produce more fry than younger spawning salmon

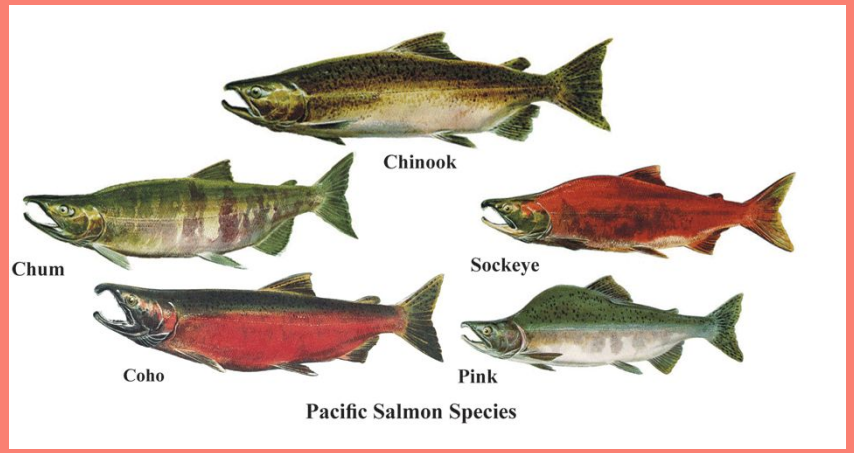
Size Decline: Impacts

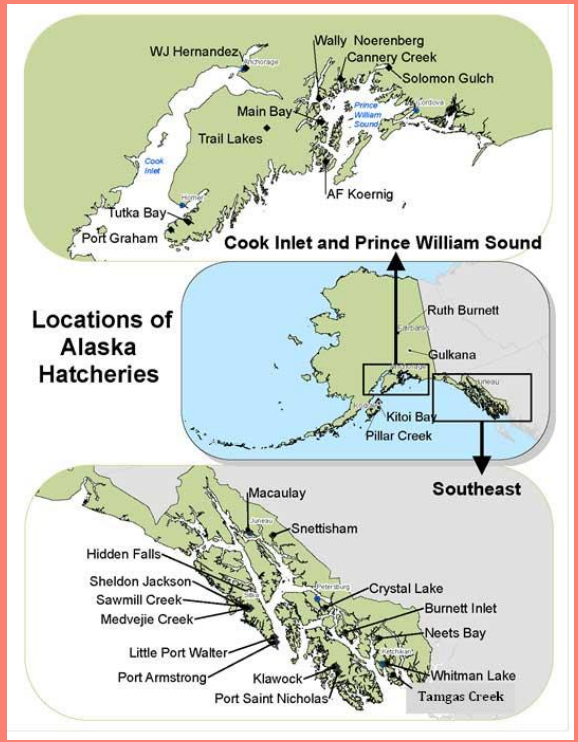
- Indigenous Culture
  - Traditional practices
- Ecosystems
  - Nutrient transport
  - Predators
- Economy
  - Commercial
  - Recreational
  - Subsistence
- Health
  - Food security



Further Research

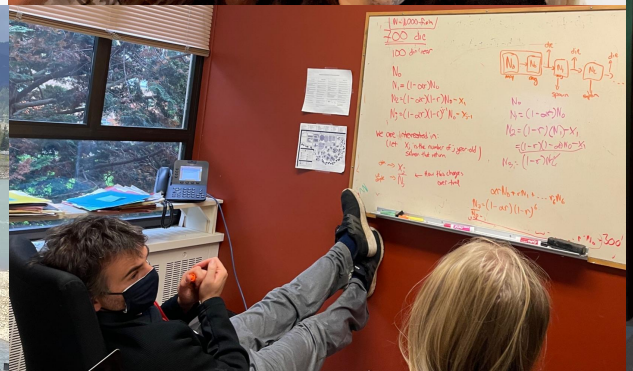
- Other pacific salmon species
- Other hatchery locations





Undergraduate Research Experience

- Topic
- Faculty Advisor
- Trial and Error
- Math Conference!



Thank you!

- Dr. Eli Goldwyn, Assistant Professor
- Adam Zaleski, Research Manager
- University of Portland

University of Portland

DIPAC