varying degrees of cortisol elevation can influence reproductive behavior and spawning success of Pacific salmon. Finally, our study is among the first field studies conducted to investigate the ecological consequences of stress during reproduction for a semelparous species.

2. (4.3) Conclusions and Management Considerations

Through river warming and changes in migration behaviour an increasing proportion of adult Fraser River sockeye salmon are undertaking migrations at temperatures that are well above their optimum and occasionally approaching their critical thermal limits, and hence have relatively low aerobic and cardiac scope available to migrate (Eliason et al., 2011; Farrell et al., 2008). Large proportions of the returning runs have perished during migrations as a result of high temperatures (Macdonald et al., 2010; Martins et al., 2011). Our results confirm that even without physical injury, which is a frequent consequence of gear encounters (Davis, 2002), the exhaustive exercise associated with fisheries capture results in substantial physiological stress in sockeye salmon. Air exposure during release results in additional disturbances as was evident from the plasma analyses and the inability of air-exposed fish to maintain equilibrium after release. Even a temporary loss of equilibrium is likely dangerous to fish since it makes them far more vulnerable to repeat fisheries capture, predation, and drifting downstream. Due to the nature of the lower Fraser River fishery, sockeye salmon are very likely to encounter fishing gear (either recreational or commercial) more than once. If release of captured fish is intended as a conservation measure employed by managers, the increased probability of mortality may be a consideration when planning for openings and desired escapement numbers, or when accounting for the impact of non-retention fisheries. While laboratory experiments such as this one on adult salmon have limitations in their applicability to wild migrants, this study was an important first step to understanding thermal impacts on capture-and-release stressors in sockeye salmon. We must acknowledge the caveats that fish in our study benefited from the absence of injuries typically incurred when encountering fishing gears, but were artificially challenged with the stress of captivity. However, the findings still have important implications for capture-and-release of river-migrating fish. Sockeye salmon exposed to our simulated capture treatments were characterized by elevated lactate, sodium, and chloride levels and lower potassium levels compared to their "handling only" counterparts, cortisol and glucose concentrations above expected levels for river-migrants, depressed ventilation,

and the inability to maintain equilibrium. In order to survive, released fish will have to cope with ionoregulatory imbalances, oxygen deficits, and altered acid-base status, and clear lactate and other metabolites from the blood and tissues. The elimination of air exposure in sockeye salmon that will be released, particularly in temperatures ≥19 °C, will increase the probability of their survival through a reduction in equilibrium loss, as well as reducing the magnitude of physiological impairments. We also suggest that future research should investigate easily observable metrics such as equilibrium loss, ventilation rates, and reflex impairment (Davis, 2010; Davis and Ottmar, 2006) that could be developed into real-time tools to understand the physiological status of fish as they are being released. Given that temperatures in the Fraser River are expected to continue to warm in future years (Ferrari et al., 2007; Morrison et al., 2002) and Fraser sockeye salmon have shown declines in productivity over the past 20 years (a federal judicial inquiry is currently examining the potential causes of this decline), field research on survival and fitness consequences on sockeye salmon escaping from fishing gear (e.g. using telemetry to track released fish), particularly on stocks that are less tolerant of high temperatures, is warranted.

D. Fate(s) of Coho Caught and Released

There are at least two coho Catch and Release (C&R) studies that were completed by the Alaska Department of Fish & Game (ADF&G). The first C&R coho study by Doug Vincent- Lang et al. (1993) found a 70% mortality rate, actually died, in the lower reaches of the Little Susitna River. It is thought that this 70% mortality is associated with cohos that had not osmoregulated (physiologically adapted from salt to fresh water). The final fates of these coho were not reported by the Vincent-Lang et al. (1993) report. Thus, the Final Fates, morbidity and mortality of the remaining 30% of the C&R coho was never determined.

The second C&R coho study by Lisa Stuby (2002) occurred in the Unalakleet River on Norton Sound. In this study, the coho had osmoregulated. Blush-colored fish were considered osmoregulated to fresh water. This study also reports an overall mortality rate, actually died, of 15.2%. The Final Fates, morbidity and mortality rates of the remaining coho was never determined.

The conclusion from these two studies shows that each river system in Alaska may be different with regards to C&R mortality on coho salmon with respect to distance from the river. Vincent-Lang et al. (1993) also reported that scale-loss and abrasion of the mucus coat were major factors contributing to mortality rates in coho salmon that were captured and released. It was evident in the Stuby (2002) study that the most

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probable cause of C&R mortality was from bleeding.

E. Application of Catch & Release Mortality

Estimates of C&R Events in Cook Inlet 1996-2009 (ADF&G Reports)

Table2.	Total number of salmon released in Upper Cook Inlet						
Year	Responses with catch	King	Coho	Sockeye	Pink	Chum	Total
1996	15,036	87,006	34,679	154,545	156,626	51,349	484,205
1997	13,368	103,169	64,169	154,443	53,923	36,994	412,698
1998	13,095	70,756	79,991	121,677	217,973	53,121	543,518
1999	13,578	115,015	82,405	173,944	52,498	50,128	473,990
2000	17,608	109,704	153,609	184,033	449,681	76,155	973,182
2001	14,407	102,065	139,320	146,903	108,408	66,663	563,359
2002	13,901	89,887	176,167	220,652	287,010	99,339	873,055
2003	13,502	129,641	118,725	261,515	85,511	84,455	679,847
2004	12,595	99,454	167,114	229,592	280,311	63,298	839,769
2005	12,041	121,662	117,485	251,886	81,842	43,900	616,775
2006	12,104	99,905	133,834	220,149	275,577	50,936	780,401
2007	11,565	96,116	84,676	217,548	120,073	34,109	552,522
2008	11,521	61,537	101,113	180,593	279,875	41,482	664,600
2009	10,970	52,123	91,902	188,791	211,138	37,162	581,116
1996-2009 Average		95,574	110,371	193,305	190,032	56,364	645,646
1996-2009 Total		1,338,040	1,545,189	2,706,271	2,660,446	789,091	9,039,037

Table 3.	Average, 1996-2009, Mortality, Morbidity and Spawning Failures				
Chinook	Coho	Sockeye	Pink	Chum	Total
95,574	110,371	193,305	190,032	56,364	
0.50 [a]	0.50 [b]	0.20 [c]	0.20 [c]	0.20 [c]	
47,787	55,186	38,661	38,006	11,273	190,913
Average 190,913 mortality, morbidity and spawning failures					
[a] Combines non-survivor and spawning failures					
[b] Combines osmoregulated and non-osmoregulated coho					
[c] Utilizes a 20% mortality, morbidity and spawning failures					

Table 4. Total of 1996-2009 Mortality, Morbidity and Spawning Failures					
Chinook	Coho	Sockeye	Pink	Chum	Total
1,338,040	1,545,189	2,706,271	2,660,446	789,091	
0.50 [a]	0.50 [b]	0.20 [c]	0.20 [c]	0.20 [c]	
669,020	772,595	541,254	532,089	157,818	2,672,776
Total 2,672,776mortality, morbidity and spawning failures					
[a] Combines non-survivor and spawning failures					
[b] Combines osmoregulated and non-osmoregulated coho					
[c] Utilizes a 20% mortality, morbidity and spawning failures					

All Five Salmon Species C&R Mortality, Morbidity and Spawning Failures

14 year Chinook Failures	**669,020**
14 year Coho Failures	**772,595**
14 year Sockeye Failures	**541,254**
14 year Pink Failures	**532,089**
14 year Chum Failures	**157,818**
14 Year Cumulative C&R Failures	**2,672,776**

Notes: It was difficult to determine if personal use (dipnet) releases are included in this C&R data

Summary:

It is evident from studying ADF&G reports that these total cumulative mortality, morbidity, or lost spawner rates were never considered, reported or used when presenting biological data, brood tables, escapement goals, or presentations to the BOF, or to the public. On some occasions, a 7% mortality rate was used, but not in a consistent manner.

The following is provided to the Board of Fisheries in order to assist in understanding the significance of some of these C&R events.

Note: This article reviewed 274 C&R studies across North America.

Aaron Bartholomew & James A. Bohnsack

A Review of Catch-and-Release Angling Mortality with Implications for No-Take

Reserves Pages 143 – 144

National Marine Fisheries Service Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149, USA Phone: +1-971-06-5152416; E-mail: abartholomew@ausharjah.edu); American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates

Implications for fisheries

Fisheries are often compared or evaluated in terms of total landings (Coleman et al., 2004; Nussman, 2005). However, direct comparisons can be problematic because commercial landings are measured in weight and recreational landings are measured in numbers and then converted to weight (Department of Commerce, 2000). Weight comparisons alone can obscure the importance of size and age structure, total numbers, or reproductive potential. Landings also do not accurately reflect total mortality or fishing impacts in some fisheries because they do not directly reflect release mortality. Our results indicate that release mortality represents a considerable portion of total fishing mortality in some fisheries. Assuming the mean 18% mortality reported in this study, for the example, the 80% release rate for gray and yellowtail snapper in Biscayne National Park (Harper et al., 2000) is equivalent to 72% of landings in numbers. Our results also indicate that many reported mortality estimates probably underestimate actual mortality, as least for marine species, because they rarely include predation during capture and after release, or consider cumulative mortality from multiple releases.

We have shown that C&R fishing has grown substantially as a total proportion of marine fishing over the last two decades. C&R fishery strategies are based on the principle that short-term lost yield from releasing fishes is compensated for in the long-term by

increased yield from growth of released fish; increased numbers of recruits from greater spawning per recruit; or in the case of C&R fisheries, increased total numbers of C&R encounters.

The effectiveness of C&R strategies depends on achieving adequate release survival. Increased regulatory use of more restrictive minimum sizes, slot limits, bag limits, quotas, and seasonal closures at some point can be expected to face reduced effectiveness because all these measures require more releases and risk higher total mortality.

F. **The following is provided to the Board of Fisheries in order to assist in understanding the significance of some of these C&R events. Retyped from:**

Arctic-Yukon-Kuskokwim

CHINOOK SALMON RESEARCH ACTION PLAN:

Evidence of Decline of Chinook Salmon Populations and Recommendations for Future Research
Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative, AYK SSI Chinook Salmon Expert Panel, August 2013, Pages 51 – 54

5.6   Hypothesis 6 – Escapement Quality

Hypothesis: Selective fishing and natural mortality have altered the genetic character of the stocks so that the expression of size, sex ratio, and composition of life history types have been altered and have contributed to declines in egg deposition to reduce recruitment in AYK Chinook salmon stocks.

5.6.1   Description of the Hypothesis

This hypothesis focuses on the role of genetic selection by the fishery over multiple generations to change the components of age, size, growth, and the time to maturity (phenotypic characters) that are genetically determined. Phenotypic characters are determined both by genetics and the environment. For example, genetics control the potential for growth and the environment provides that controls the expression of that potential. The genetic changes hypothesized could affect the recruitment of subsequent generations of salmon.

5.6.2 Plausibility of the Biological Mechanism(s)

Fishing-induced evolution (FIE) in salmonids is challenging to demonstrate conclusively in the wild. However, declines in Chinook salmon abundance (Yukon and Kuskokwim rivers; JTC 2011; K. Schaberg, ADFG, personal communication), increasingly male-biased sex ratios (Yukon, and Kogrugluk rivers; Hamazaki 2009; K. Harper, USFWS, personal communication), and decreased size of spawners (attributed to declines in size-at-age and declines in the return of the oldest age classes) (Yukon and Kuskokwim rivers; JTC 2011; K. Harper, USFWS, personal communication) are consistent with expected patterns that would result from selective harvest of the largest individuals, particularly when harvest rates increase (Bromaghin et al. 2008, [20011] 2011; Hard et al. 2009). Disproportionate escapement of small fish causing genetic selection could produce lower than expected returns because fecundity and possibly egg quality are positively correlated with female size; male-biased sex ratios also reduce the overall egg production by a population. These effects in the short term can be caused simply by selective fishing affecting the immediate escapement quality and in the long term could be caused via changes in the genetic components that affect age, size, and time of maturity in salmon. Hence, the combined short- and long-term effects of selective fishing illustrate the complexity of this hypothesis. If size- and age-at- maturity are highly heritable, then the effects of selection would result a propensity of stocks to propagate more small young mature fish in subsequent generations. This mechanism could cause a long-term decline in returns-per-spawner in the absence of other processes such as density-dependence and environmental forcing.

5.6.3 Summary of Evidence for Hypothesis

Declines in female composition of escapement and size- and age-at-maturity in both Yukon and Kogrugluk rivers is consistent with the hypothesis that FIE has driven declines in returns-per-spawner. Using realistic estimates of trait heritability (genetics), harvest selectivity, population productivity, and management strategies, recent modeling (Bromaghin et al. 2008, 2011) demonstrated that observed declines in size- and age-at-maturity fell within the range of modeled phenotypic changes attributable to FIE. This model also suggests that efforts to counteract declines would likely require reductions in size selectivity of gear and exploitation rates, and that improvements would be slow to materialize, requiring multiple generations under the new selection regime.

While declines in size- and age-at-maturity of returning adults provide compelling evidence of the potential for FIE to explain patterns in recruits-per-spawner, the available evidence cannot rule out other mechanisms of potential causes for changes in the age and size of returning adults. For instance, environmental variables could be the casual mechanism for the observed declines in age and size of returns, and subsequent waning of recruits-per-spawner ratios in recent years in the AYK region. This alternative mechanism could be more likely if patterns of change occurred also in stocks that have low exploitation rates or where fishing gear is not selective for large, old individuals. Age-at-maturity data collected from projects estimating escapements and commercial harvests of Goodnews River Chinook salmon also show declines, despite the use of small mesh gillnet gear, which is presumably less selective for large individuals, throughout the history of that fishery (J. Linderman, ADFG, personal communication). While there is some synchrony in declines of size- and age-at- maturity and female proportions across the AYK region and across the entire US west coast, the cause and ecological consequences of these declines remain unclear.

5.6.4 Priority Research Themes and Example Questions

<u>Casualty of Genetic Changes/FIE vs. Environmental Variables</u>

1. What proportion of changes in size- and age-at-maturity of returning Chinook salmon adults are determined by changes in genetics caused by selective fishing versus environmental variables?

2. How has size- and age-at-maturity of returning adults changed among stocks, and drainage areas (Yukon and Kuskokwim rivers) and has this occurred synchronously with stocks elsewhere such as in Bristol Bay populations coastwide?

3. What is the relationship between size- and age-at-maturity of returning adults in stocks fished by gear selective for small fish versus gear selective for large fish?

4. Which explanation, genetic selection or changes in environmental parameters (e.g., ocean conditions), better accounts for the phenotypic changes in size- and age-at- maturity of returning adults in stocks? What is the relative contribution of anthropogenic and environmental variables as casual mechanisms for changes in size- and age-at-maturity?

Variables Affecting Spawning and Reproductive Fitness

1. Are fewer eggs being deposited than in the past because the size- and age-at-maturity of returning adults in stocks has changed? What is the relative role of different variables affecting fecundity and egg deposition?

2. Among those salmon that escape and have access to spawning grounds, does size-at- maturity and age-at-maturity of returning adults affect whether they spawn or not, or in the success of their spawning (i.e., successful hatch, juvenile recruitment)? The identification of parent-offspring/sibling relationships in regards to key phenotypes (age- and size-at-maturity, migration timing, and fecundity) and reproductive fitness would illuminate underlying assumptions and could be obtained through pedigree analyses.

3. Do stock-recruit relationships improve if they are expressed in units of eggs rather than as aggregate spawning population numbers?

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- National Marine Fisheries Service Southeast Fisheries Science Center, 75 Virginia
  Beach Drive, Miami, FL 33149, USA Phone: +1-971-06-5152416; E-mail:
  abartholomew@ausharjah.edu); American University of Sharjah, P.O. Box 26666,
  Sharjah, United Arab Emirates

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