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Policy Analysis: Alaska Salmon Hatcheries

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POLICY ANALYSIS: ALASKA SALMON HATCHERIES

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Using an adapted Ecological Risk Assessment (ERA) - Evaluation, this study analyzes policy regulating Alaska salmon hatcheries to evaluate its effectiveness at sustaining wild salmon runs. When Alaska became a state in 1959, its salmon industry was suffering from years of overfishing. Runs were at an all-time low, prompting constitutional drafters to mandate management of salmon via the sustained yield principle. The hatchery system that operates today and is responsible for a third of the commercial catch each year was put in place in the 1970s to help supplement depressed salmon runs. The effects of hatchery salmon on wild salmon populations are escapement inflation from strays, interbreeding of strays and wild salmon, genetic introgression and loss of fitness of hatchery-wild offspring, the potential spread of disease, and competition for food. Policy was created to mitigate these risks and ensure a sustained wild Alaska salmon population. This policy analysis follows the steps of a traditional ERA– planning process, problem formulation, analysis, and risk characterization–and adapts it to evaluate the effectiveness of current policy regulating Alaska salmon hatcheries. Overall, the policy in place does an effective job at minimizing risk and ensuring sustained runs of wild salmon, however, there are critical gaps in enforcement and regulation, the timeliness of the genetic policy, research on straying and other effects of hatchery salmon, and the involvement of stakeholders in the decision-making process.

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Background

The Alaskan Salmon Industry from Purchase to Statehood: Boom and Bust

Before Russians or Euro-Americans claimed stake to Alaska, coastal Alaska Natives inhabited the land and used its resources in a variety of ways: food, tool, or cultural icon, to name a few. One of Alaska's most plentiful resources was and is today salmon. Alaska ethnographer George Emmons wrote of the salmon's importance to native culture: "The most valuable property of the Tlingit [an Alaska Native tribe in Southeast Alaska] was the fishing ground or salmon stream, which was a family possession, handed down through generations, and never encroached upon by others."[1] Long before the first salmon hatchery, there is evidence they manipulated salmon by burying eggs and moving adult salmon to unpopulated streams to spread the resource.[2] When Russians arrived in 1741, their presence on the landscape was limited by Alaska Natives, who, although they were willing to trade fish for other goods, rose in force against their encroaching occupation. Russia's main focus in the area lie in the waters around Alaska: sea otter pelts. In 1867, the United States purchased Alaska from Russia for $7.2 million, roughly 1.7 cents per acre.[3] The purchase, orchestrated by Secretary of State William H. Seward, was referred to in public opinion as "Seward's folly" or "Seward's ice box." Republican Congressman Cadwallader C. Washburn said at the time: "The possession of this Russian territory can give us neither honor, wealth nor power, but will always be a source of weakness and expense, without any adequate return."[4]

In 1869, two years after the United States' purchase of Alaska from Russia, entrepreneurs proved those skeptics wrong and tapped into the immense and valuable salmon resource, and the Department of

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[1] John Sisk, "The Southeastern Alaska Salmon Industry: Historical Overview and Current Status," in *Southeast Alaska Conservation Assessment*, eds. John Schoen and Erin Dovichin (Anchorage, 2007): 1.
[2] Patricia Roppel, *Alaska's Salmon Hatcheries: 1891-1959* (Anchorage: Alaska Historical Commission Studies in History No. 20, 1982), 5.
[3] David Barker, "Was the Alaska Purchase a Good Deal?" University of Iowa, August 10, 2009: 1. http://www.news-releases.uiowa.edu/2009/november/David%20Barker-Alaska.pdf
[4] quoted in Barker, 1.

Alaska's[5] first salmon saltery was built.[6] Salteries processed and packed salmon with salt into wooden barrels for export to Seattle and other markets.[7] Although salteries required little capital to start, shipping their product was expensive because of the additional weight of the barrel and salt. In 1878, a little over a decade past purchase, Alaska's first cannery was built, beginning the large-scale, commercial salmon export industry in the state. Canning provided a solution to mass export salmon in a lighter packing container. The harvest its first year in operation was 56,000 fish.[8] Within a few decades, close to 60 canneries were operating, a number that would grow to 160 by 1920.

In 1891, with the canning industry booming, the first salmon hatchery was built by cannery operators at the Karluk River on Kodiak Island in an effort to sustain salmon runs near their fish processing facilities. The sockeye hatchery was later closed because owners couldn't agree on fishing rights. A year later in Southeast, Alaska, the Department of Alaska's second hatchery was built by private citizen John C. Callbreath.[9] Within the next few years, canneries built four more hatcheries across the state at Klawak Lake, Redfish Bay, Hetta Lake, and Karluk River to replace the one that closed. All were meant to rebuild the canneries' home streams ensuring salmon runs and profitable business into the future. But even with these new hatcheries, salmon runs began to decline as entire populations were prevented from spawning. Canneries barricaded streams with nets or wooden weirs holding schools of salmon downstream of the barricade where they were dipped out and brought to the cannery.[10] All returning salmon were caught leaving none to propagate future runs.

During this time, Alaska fisheries were managed federally, but management and regulation weren't growing at quite the same rate as industry. The 1889 Fisheries Act ("An Act to Provide for the

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[5] Alaska would be called the Department of Alaska until the passage of the Organic Act in 1912 which provided territorial status.
[6] John Clark et al., "The Commercial Salmon Fishery in Alaska," *Alaska Fishery Research Bulletin* 12, no. 1 (2006): 1.
[7] Pat Roppel, "Salting Salmon in Taku Inlet," Alaska Historical Society, January 26, 2013, https://alaskahistoricalsociety.org/tag/saltery/.
[8] ADF&G, *FRED Reports: A Review of Alaska's Fisheries Rehabilitation, Enhancement and Development (FRED) Program 1971-1982*, by S.A. Moberly, No. 3, Juneau, October 1983: 2.
[9] Roppel, *Alaska's Salmon Hatcheries*, 12.
[10] Richard A. Cooley, *Politics and Conservation: The Decline of Alaska Salmon* (New York: Harper & Row, 1963): 72.

Protection of the Salmon Fisheries of Alaska") was the first federal legislation addressing fishing regulation in the Department of Alaska. It prohibited the blocking of streams by dams or other structures to catch salmon but had very little effect on harvest because of the lack of enforcement within Alaska. The same year the Fisheries Act passed, Dr. Tarleton Bean, an ichthyologist with the U.S. Fish Commission, in his *Report on the Salmon and Salmon Rivers of Alaska* to Congress put down on paper what would eventually become the tale of Alaska's salmon runs: "The season of prosperity will be followed by a rapid decline in the value and production of these fisheries, and a point will eventually be reached where the salmon canning industry will be no longer profitable."[11] That year, 1889, the season of prosperity was in swing: 719,196 cases of salmon were packed in Alaska compared to the 477,659 cases from California, Oregon, and Washington canners combined.[12] Congress wouldn't fund enforcement of the act until 1892, and even then the addition of one fisheries agent and his assistant patrolling the thousands of miles of coastline within Alaska did little to quell rampant overfishing.

In 1894, the Assistant Secretary of the Treasury Charles S. Hamlin, and the Inspector of Salmon Fisheries Joseph Murray, visited Alaska to take stock of the state of the fishery. Their report predicted an impending fishery disaster if regulation wasn't revisited, prompting Congress to amend the Fisheries Act in 1896 to further restrict the take of salmon by prohibiting certain gear types and limiting the catch of fish to below the tidewater line in streams and rivers.[13,14] Howard Kutchin, Alaska's sole fisheries agent, wrote in his 1899 annual report: "The uniform conclusion of those who have given investigation and thought to the subject is that the Alaska fisheries are doomed unless swift and thorough measures are put in operation to preserve those which have not yet felt the effect of the destructive practices… and to restore those that are rapidly approaching extinction."[15] With minimal enforcement and a greedy industry

[11] qtd in Cooley, 72.
[12] Ernest Gruening, *The State of Alaska* (New York: Random House, 1954): 247.
[13] Gruening, *The State of Alaska, 247.*
[14] Clinton E. Atkinson, "Fisheries Management: An Historical Overview," *Marine Fisheries Review* 50, no. 4 (1988): 116-117.
[15] quoted in Roppel, *Alaska's Salmon Hatcheries*, 9.

continuing to overharvest the resource, in 1900, the act was again amended making it mandatory that any cannery taking salmon must build a hatchery and produce four times as many sockeye fry as the number of adult salmon harvested.[16] Complaints rose against the law from the canning industry, claiming it would crowd out small canners who were unable to afford the cost of both a cannery and hatchery and was unfair for salters who only worked with chum and pink salmon and didn't want to produce sockeye salmon as the law required. Because there was almost no enforcement, those who complied with the law were in the minority[17] and had little knowledge of how to raise sockeye salmon, releasing them directly into saltwater as fry instead of into the brackish environment their physiology requires at that stage of life.[18] Kutchin commented on the fish rearing attempts: "the packers are not in the business of raising fish, but that of canning them for market."[19] Although none of the hatcheries came close to the 4x requirement, two of the major hatcheries of Southeast Alaska were built during this time: Fortmann Hatchery and Quadra Hatchery.[20] Kutchin thought the solution to the hatchery problem lie in federal control over Alaskan hatcheries, which would provide a more scientific and better executed endeavor.[21]

While legislators on the other side of the country amended law governing Alaska fisheries, on the ground in Alaska competition over salmon was escalating. In Ketchikan, one of the busiest fishing towns in the early 1900s, competition between established canneries and new business led to fighting on the water and a court case in the U.S. Circuit Court of Appeals in 1900. The court ruled in favor of new business: no one, not even established canneries, owned the waterways.[22] Shortly before 1903, an Alaskan Salmon Commission was appointed to investigate the status of Alaska salmon fisheries. In a report to the Bureau of Fisheries, who now had jurisdiction over the Department of Alaska's fisheries under the newly

[16] Roppel, *Alaska's Salmon Hatcheries*, 9.
[17] Roppel, *Alaska's Salmon Hatcheries*, 9.
[18] Atkinson, 117.
[19] Roppel, *Alaska's Salmon Hatcheries*, 10.
[20] Roppel, *Alaska's Salmon Hatcheries*, 12.
[21] Roppel, *Alaska's Salmon Hatcheries*, 13.
[22] Dave Kiffer, "Catching a Can in Ketchikan: A History of the 'Canned Salmon Capital of the World,'" *Stories In The News* (Ketchikan, AK), September 23, 2009.

formed Department of Commerce and Labor, the Alaska Salmon Commission concluded that even with restricted fishing, natural propagation would most likely not be able to keep up with demand. They recommended the establishment of government hatcheries although, they noted, the cost would be significant. In response to the Commission's recommendations, Congress passed a sundry civil bill funding one or more hatcheries in Alaska. Construction on the first federal hatchery in Alaska began that summer in Yes Bay in Southeast Alaska, and the hatchery's first eggs were incubated that fall. A second federal hatchery was built in 1907 in Litnik Bay near Kodiak Island.[23] The year prior, in 1906, remedial legislation eliminated mandatory hatcheries required under the Act of 1899. The act also instituted a rebate system for hatcheries based on cases of salmon sold by canneries in Alaska. The rebate system came with criticism from within the state with critics arguing that it was another way canneries were taking advantage of Alaska.

In 1912, 45 years after its purchase from Russia, the Organic Act of 1912 provided incorporated territorial status to Alaska. In an unprecedented move, Congress retained federal authority over the Alaska's fish and game. All previously established territories had been given autonomous management of their resources with territorial designation. Alaskan citizens were not happy with the inability to manage their own resources especially with the rampant overharvest under federal control. During the 1919 Alaska territorial legislative session, S.B. 29 was passed, creating the Territorial Fish Commission.[24] Although Alaska lacked control over its fisheries, the creation of the Territorial Fish Commission was an attempt to direct some of the territory's funds to the management of its resources as they best saw fit. The Commission's efforts were dedicated mainly to fish culture and removing natural barricades and natural predators of salmon.[25] The Commission consisted of three fish commissioners appointed by the Governor, and they, in turn, appointed a general hatcheries superintendent. Many in the territory

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[23] Atkinson, 117.
[24] Roppel, *Alaska's Salmon Hatcheries*, 21.
[25] Cooley, 184.

criticized the Commission because of the appointee system calling it a "political instrument."[26] The Commission ceased in 1929 when the legislature failed to fund its budget; two years later it was relieved of all responsibilities with the passage of H.B. 103.

At the federal level, there was a flurry of activity over Alaska's fisheries as well. From 1906 until 1924, 42 bills were introduced in Congress proposing regulation on the industry.[27] All attempts at creating new legislation failed due to lobbying by the salmon canning industry. Alaska's congressional delegate James Wickersham commented: "All Alaska gets is a volume of hearings and never any laws for protection."[28] In response to the canning companies' congressional testimony, Wickersham also had this to say: "They resent the suggestion that Alaska or the people of Alaska have any right or interest in the salmon or the fisheries of that country. They are non residents themselves; they do nothing toward the upbuilding of the territory."[29] While Congress deliberated over new law regulating Alaska fisheries, canneries in the territory continued packing fish. During the 18 year stretch from 1906-1924, there was no new legislation concerning Alaska fisheries, and Alaskans' frustrations grew with the federal government's ability to be swayed by lobbyists. Ernest Gruening, Alaska's territorial governor from 1939-1953, would later write of the time in his book, *The State of Alaska*: "And so conservation of the Alaska salmon resource waited, because, apparently, the opponents of its further protection and regulation were powerful enough to prevail."[30]

By the end of the 1910s, salmon runs within the state were in such a precarious state, that even canners saw the need for stricter regulation over salmon harvest. When H.R. 2397 came before Congress in 1920, all but one of the major canners in Alaska testified before Congress that the "measure did not go far enough."[31] New U.S. Fish Commissioner Henry O'Malley later testified regarding the cannery owners'

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[26] Roppel, *Alaska's Salmon Hatcheries*, 23
[27] Clark et al., 2.
[28] quoted in Gruening, 249.
[29] quoted in Gruening, 254.
[30] Gruening, 255.
[31] Gruening, 262.

swing in position: "The salmon packers are always the last to acknowledge that overfishing is having its inevitable result, but as regards to Alaska, they also have joined the ranks of those who agree that immediate action is imperative."[32] The bill was rewritten giving Board of Fish complete control to shut down fisheries, but, with these more stringent authoritarian management additions, the canners changed opinion on the bill, and with their lobbying against it, it failed to pass. Over the next four years, Congress fought over the correct method to regulate salmon fishing. The standstill in management directive prompted President Coolidge to write Congress: "If our Alaskan fisheries are to be saved from destruction there must be further legislation declaring a general policy and delegating the authority to make rules and regulations to an administrative body."[33] In 1924, H.R. 8143 was introduced, mandating a 50% escapement (the number of fish that are not caught and instead allowed upstream to spawn) per stream. What became known as the White Act passed on June 26, 1924 and was hailed for over a decade as having "become a landmark in conservation philosophy and technique."[34]

The Bureau of Fisheries also saw the White Act as success. The average annual commercial salmon harvest in Alaska increased from 70 million in the 1920s to an average of 90 million by the end of the 1930s. Better escapement seemed to increase runs and, in turn, so did harvest. Coastal fishing towns boomed. Throughout the 1930s, the *Ketchikan Chronicle* declared: "More canned salmon is packed in Ketchikan than any other city in the world."[35] The city built an arch downtown welcoming visitors to the "Salmon Capital of the World."[36] These successes suggested that management was possible through regulation and not enhancement. In 1933, new U.S. Commissioner of Fisheries, Frank T. Bell, who viewed hatcheries as a waste of public money, toured the two existing federal hatcheries in the territory and ordered them closed. Within three years, all federal hatcheries in Alaska had ceased production. Instead of artificial propagation, Bell directed management toward regulation. Any area where fishing was depressed

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[32] quoted in Gruening, 264.
[33] quoted in Gruening, 266.
[34] quoted in Gruening, 268.
[35] Kiffer.
[36] Kiffer.

would have higher restrictions. That year the largest catch in Alaska's history, 126.4 million salmon, was recorded.[37] Bell's stricter regulations didn't last long. In response to World War II from 1939-1945, areas closed to salmon fishing were opened and timing restrictions were lifted to help provide food for the war effort. (Spam would take canned salmon's place in meal rations later in the war.[38]) After the war's end, industry argued that returning veterans needed jobs and to reintroduce restrictions would rob them of this right.[39]

Even with robust catches in the 1930s and 1940s, Alaskan fisherman still saw depleted runs and blamed the continued use of fish traps (Figure 1), a method used to catch massive quantities of salmon. 91% of the fish traps in Alaskan waters in 1944 were owned by nonresidents,[40] and over ¼ of those were owned by two companies located in Washington: P.E. Harris Company (which would later become Peter Pan Seafood) based out of Seattle, and Pacific American Fisheries in Bellingham.[41] Frank Peratrovich, president of the Alaska Native Brotherhood, the oldest indigenous civil rights organization in the world,[42] wrote to Congress: "Through a period of fifteen years the fishermen and residents . . . have come to realize that the fish trap must be completely eliminated if we are to maintain an average run of salmon[.] The agitation against the trap has increased within the past four years due to the fact that the decline in the run of salmon is directly traceable to this method of taking salmon."[43] A referendum voted on by territorial citizens passed with 88% voting to eliminate the use of traps in the territory.[44] Even in areas where no traps were used, the majority of voters supported a ban. Native communities, especially those in Southeast Alaska, were overwhelmingly against traps.

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[37] ADF&G, *FRED Reports*, 2.
[38] Kiffer.
[39] Clark et al., 3.
[40] Gruening, 395.
[41] Gruening, 395.
[42] Alaska Native Brotherhood Alaska Native Sisterhood Grand Camp, "About Us," accessed April 13, 2018, https://www.anbansgc.org/about-us/.
[43] quoted in Gruening, 398.
[44] Gruening, 398.

But the voice of Alaskans had little effect on Congress, and the use of traps remained. At the same time, the U.S. Fish & Wildlife Service (USFWS), which had taken control of Alaska fisheries when it was created in 1940, continued Bell's anti-hatchery management philosophy despite the more lenient regulations on the territory's fisheries that had carried over from World War II. USFWS viewed hatcheries as less effective than harvest limits and discouraged any private hatchery efforts within the state: "Careful study of these [past] operations, however, disclosed that natural propagation is more effective than artificial propagation in Alaska and no hatcheries are operated now in Territorial waters. Private hatcheries, therefore, are not encouraged."[45] In 1948, the pack was a paltry 3,968,521 cases, the lowest in Alaska's history, with the exception of 1921, the abysmal catch year that had spurred Congress to pass the White Act.[46] The Territorial Legislature, tired of waiting on Congress to take action, created and appointed an Alaska Territorial Fishery Service to hire and supervise stream watchers and help USFWS with research and stocking. The creation of the Territorial Fishery Service (which later became Alaska Department of Fish and Game) was also a preparatory move by

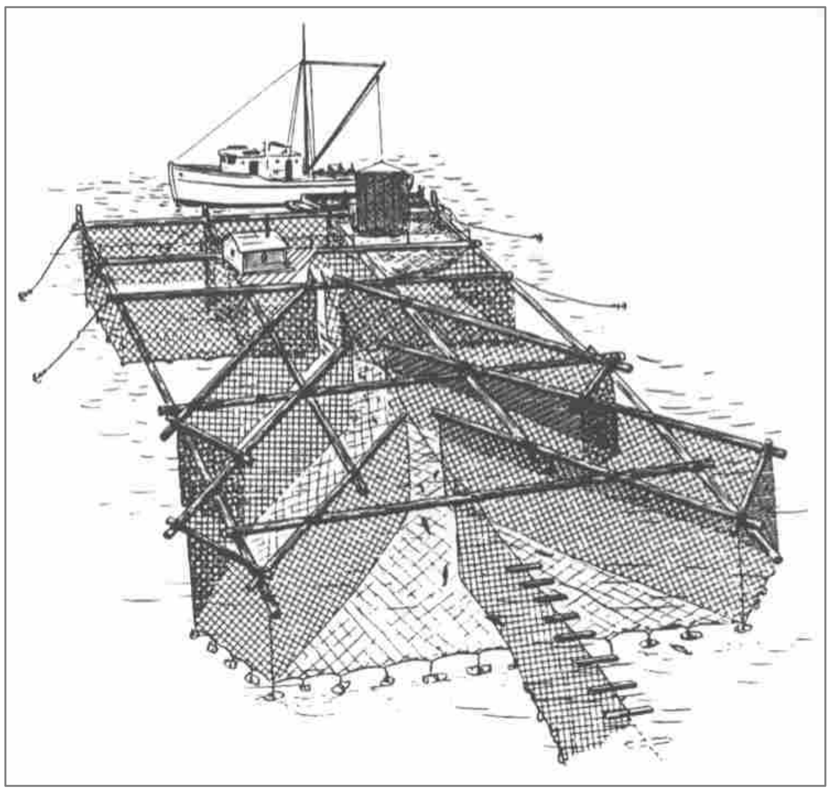

Figure 1. Fish trap

G.T. Sundstrom, "Commercial Fishing Gear of the United States," in *Fish & Wildlife Circular no. 109* (Washington, D.C.: U.S. Fish & Wildlife Service, 1961).

[45] Roppel, *Alaska's Salmon Hatcheries*, 265.

[46] Gruening, 403.

the territory for eventual self-governance of its fisheries.

Even with USFWS discouraging the use of hatcheries to supplement salmon runs, several projects by other federal agencies began to take shape within the territory in the 1950s. The U.S. Department of Fisheries brought salmon eggs from Washington and planted them in streams near Juneau.[47] Egg troughs were built to incubate salmon eggs in a controlled environment on Kodiak Island.[48] And two new

Figure 2. Images from Alaska canneries, 1950s

Alaska Digital Archives, "AMRC-b85-27-1012," "AMRC-b85-27-2012," "AMRC-wws-156-R11," and "ASL-P20-169," Anchorage Museum at Rasmuson Center, Wien Collection, http://vilda.alaska.edu.

[47] Roppel, *Alaska's Salmon Hatcheries*, 267.
[48] Roppel, *Alaska's Salmon Hatcheries*, 269.

hatcheries were also built within the state, the Kitoi Bay Research Station and Deer Mountain Hatchery. The federal Kitoi Bay Research Station on Afogank Island was built with an attached hatchery to supply the facility with fish for research.[49] The Kitoi Bay facility was destroyed less than a decade later by the tsunami following the 1964 earthquake. The Deer Mountain Hatchery, one of the first hatcheries whose main focus was the production of coho and chinook, was funded by the Ketchikan King Salmon Derby Committee and sponsored by the Ketchikan Chamber of Commerce to supply salmon fry for lake stocking. The hatchery is still operating today.[50] Even with the supplemented fish from the new hatchery projects and the Territorial Fisheries Service's efforts, salmon runs in parts of the state were so low that President Eisenhower declared them disaster areas. Pack in 1953 was 2,882,083 cases, the lowest in 32 years.[51] Newspaper headlines in Seattle declared "18,000 TO LOSE JOBS" after the Alaska Salmon Industry, Inc. wrote letters to workers letting them know they wouldn't be rehired the following season.[52] In 1959, the total harvest was 25 million salmon, yet there were "4 times as many fishermen as in the early 1900s."[53] Without proper regulation to slow them, canneries seemed determined to harvest everything they could (Figure 2).

On January 3, 1959, Alaska obtained statehood. The long road to self-governance was over. Alaska finally gained control of the management of its fisheries in 1960, a year later, after proving to the federal government it had the necessary skills and capacity to do so. In January of that year, Governor William A. Egan, in an address to the Joint Assembly of the First Alaska State Legislature, said: "On January 1 of this year, Alaska's Department of Fish and Game was handed the depleted remnants of what was once a rich and prolific fishery. From a peak of a quarter of a billion pounds in 1936, production

[49] Roppel, *Alaska's Salmon Hatcheries*, 270.
[50] Southern Southeast Regional Aquaculture Association (SSRAA), "Deer Mountain Hatchery," accessed April 6, 2018, https://ssraa.org/deer-mountain/.
[51] Gruening, 405.
[52] Gruening, 405.
[53] Clark et al., 3.

dropped in 1959 to its lowest in 60 years. On these ruins of a once great resource, the department must rebuild."

The Alaska fishery failure was caused by several factors. The federal government, who refused to relinquish control of the resource to the territory, had never adequately funded any of the legislation it passed to regulate industry. A lack of research, also due to a lack of federal funding, handicapped employees who were tasked with making decisions to help preserve salmon. Because the canning industry had captured federal positions and used their position to curb regulation in their favor, federal employees in the territory never had full power to make decisions. And finally, it was the fisherman themselves that helped eliminate a once great resource. Out of desperation, they overharvested and illegally took salmon in any effort to compete against the canning companies' monopoly. But the new state was determined to restore its once most profitable resource.

Natural Resources in the Alaska Constitution

The drafting of the Alaska Constitution in 1955-56, a few years before statehood, was a political gamble. There was hope that a good constitution with the backing of people in the territory would propel legislators in Washington, D.C. to grant statehood. Delegates to the constitutional convention (hereafter "delegates") chose the University of Alaska campus in Fairbanks to separate the process from the "smoke-filled rooms" of Juneau.[54] Their desire to produce a strong document was a great motivator for negotiation and compromise, which often led to shorter sections in the final document which deferred decisions to future legislatures. The resulting constitution "speaks only to the broad principles of governmental organization and operation and leaves the details of implementation to the legislature."[55] Delegates choice to give large amounts of power to the state's governor and legislature was also a response to Alaska citizens' limited power during territorial days. At their disposal while crafting the document,

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[54] Alaska Legislative Agency, *Alaska's Constitution: A Citizen's Guide*, by Gordon Harrison, 5th Edition, Juneau, 2012: 3.

[55] Alaska Legislative Agency, 2.

delegates had the newest state constitutions, researchers, consultants, and advisers who had been involved in the drafting of other constitutions. They were able to use the "most modern and progressive concepts of state constitutional draftsmanship."[56] The resulting document, the 50th constitution in the U.S. (Hawaii drafted theirs before Alaska though they wouldn't become a state until after), was a well-thought-out constitution inclusive of several key issues, such as natural resources.

In his keynote address at the constitutional convention, Bob Bartlett, Alaska's delegate to Congress, said: ". . . fifty years from now, the people of Alaska may very well judge the product of this Convention not by the decisions taken upon issues like local government, apportionment, and the structure and powers of the three branches of government, but rather by the decision taken upon the vital issue of resources policy."[57] In 1955-56, as delegates hammered out what would eventually become law, the two main industries in the territory were mining and salmon. Commercial salmon harvest those years were 39.6 million and 50.6 million salmon and had been in decline for two decades.[58] Bartlett and others advised delegates against exploitation and unnecessary disposal of public resources, which was the norm in the early years of statehood for other western states. As a result, the Alaska constitution, at the time of its drafting, was the second in the nation with an article on natural resources. Its natural resources article was also the most extensive. With language reserving natural resources for "the people for common use"[59] and the "maximum benefit of its people,"[60] Article VIII ensured natural resources would be managed as a public trust. In contrast to how resources were often managed under federal control, the article clearly states that resources should be developed but for the good of all.

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[56] Alaska Legislative Agency, 5.
[57] quoted in Alaska Legislative Agency, 129.
[58] North Pacific Anadromous Fish Commission (NPAFC), *Pacific Salmon Status and Abundance Trends – 2012 Update*, by James Irvine, Arlene Tompkins, Toshihiko Saito, Ki Baik Seong, Ju Kyoung Kim, Natalya Klovach, Heather Bartlett, and Eric Volk, May 24, 2013 (Doc 1422, Rev 2): 24.
[59] Alaska Constitution, Art. 8, Sect. 3.
[60] Alas. Const. Art. 8, Sect. 2.

Within Article VII, delegates mandated two seemingly competing management directives: conservation and equal access. Sections 3, 15, and 17 are the "equal access clauses." [61] Section 3 outlines the "common use" of resources; Section 15 maintains "no exclusive right or special privilege of fishery;" and Section 17 created a uniform application of law to "all persons."[62] Although the three clauses are slightly different, the Alaska Supreme Court has acknowledged a significant similarity: "exclusive or special privileges to take fish and wildlife are prohibited."[63] The two clauses sometimes appearing to be in disagreement with the "equal access clauses" are the "conservation clauses," Sections 2 and 4. Section 2 outlines the legislature's duty to "provide for the utilization, development, and conservation"[64] of the state's natural resources. "'Conserving' implies controlled utilization of a resource to prevent its exploitation, destruction or neglect. 'Developing' connotes management of a resource to make it available for use."[65] And Section 4 provides for the sustained yield of natural resources, stating that "replenishable resources belonging to the State shall be utilized, developed, and maintained on the sustained yield principle, subject to preferences among beneficial use." With Sections 2 and 4, delegates provided a clear directive toward the conservation of resources for generations to come. The two directives, conservation and equal access, appear to conflict when management limits equal access to conserve a resource. Delegates provided strong enough wording and definition to assure their intention was conservation for future generations, and the Alaska Supreme Court, interpreting intent, has ruled in favor of conservation in clashes between the two directives in *Kenai Peninsula Fisherman's Co-op Association v. State* (1981), *Meier v. State Board of Fisheries* (1987), *Tongass Sport Fishing Assn v. State* (1987), *State v. Herbert* (1990), *Alaska Fish Spotters Assn v. State* (1992), *State v. Kenaitze Indian Tribe* (1995), and *Interior Alaska Airboat Association v. State* (2001).

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[61] Alaska Legislative Agency, 132.
[62] Alas. Const. Art. 8, Sect. 3, 15, and 17.
[63] *McDowell v. State*, 785 P.2d 1 (Alaska 1989).
[64] Alas. Const. Art. 8, Sect. 2.
[65] *Kenai Peninsula Fisherman's Co-op Association v. State*, 628 P.2d 897 (Alaska 1981).

Definition of Sustainability

In Article VIII, Section 4, delegates put into the constitution a mandate to sustain natural resources, including salmon, for generations to come. The committee guiding delegates in the creation of Article VIII, the Resources Committee of the Constitutional Convention, defined the sustained yield principle:

> "As to forests, timber volume, rate of growth, and acreage of timber type can be determined with some degree of accuracy. For fish, for wildlife, and for some other replenishable resources such as huckleberries, as an example, it is difficult or even impossible to measure accurately the factors by which a calculated sustained yield could be determined. Yet the term 'sustained yield principle' is used in connection with management of such resources. When so used it denotes conscious application insofar as practicable of principles of management intended to sustain the yield of the resource being managed."[66]

After drafting Article VIII, delegates clarified their intent behind the sustained yield principle in the "Report to the People of Alaska" stating: "The article's primary purpose is to balance maximum use of natural resources with their continued availability to future generations."[67] The Alaska state legislature, in 1978, provided the definition for maximum sustained yield in AS 38.04.910 as "the achievement and maintenance in perpetuity of a high level of annual or regular periodic output of the various renewable resources of the state land consistent with multiple use." The constitutional delegates and the 1978 legislature's definition of sustainability wasn't far off from the concept in resource management today, which "provides for the continuity of progressively beneficial and equitable resource use with minimal damage to the ecosystem."[68]

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[66] quoted in *West v. State Board of Game*.
[67] quoted in *West v. State Board of Game*, 248 P.3d 689 (Alaska 2010).
[68] Natalia Mirovitskaya and William Ascher, eds., *Guide to Sustainable Development and Environmental Policy*, (Durham, NC: Duke University Press, 2001), 75.

Creation of the Alaskan Salmon Hatchery System

In 1960, after 66 years of federal management under the jurisdiction of the Treasury Department first, then the Department of Commerce and Labor which became the Department of Commerce, and lastly the Department of the Interior, Alaska finally gained control of its fisheries.[69] With the passage of AS 16.05.020 in 1959, the first state legislature created the Alaska Department of Fish and Game (ADF&G) and tasked the new state agency to "manage, protect, maintain, improve, and extend the fish, game and aquatic plant resources of the state in the interests of the economy and general well-being of the state."[70] In their "Annual Report for 1959," ADF&G discussed the monumental management task ahead: "The [Commercial Fisheries] Division will be responsible for the management of Alaska's rich, varied and complex fisheries, and, as such, must ensure the optimum use of this resource. By optimum use is meant managing on a maximum sustained yield basis—ensuring an optimum broodstock and harvesting all surplus."[71] That same year, the legislature created the Board of Fisheries and Game and regional advisory committees. The Board of Fisheries and Game, a regulatory board separate from the management-oriented ADF&G, was charged with passing regulations "to conserve and develop Alaska's fisheries [and wildlife] resources."[72] It would later be split into the Board of Fisheries and the Board of Game in 1975. Regional advisory committees are comprised of locals from each region that furnish recommendations to the boards on the use of fish and wildlife, and they provide an avenue for citizens to have access and an active part in management of their resources.

With the new management system in place, salmon runs seemed to rebound slightly. A few research facilities, Little Port Walter run by the National Oceanic and Atmospheric Administration (NOAA) and the Auke Bay Fisheries Laboratory run by National Marine Fisheries Service (NMFS), were

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[69] Gruening, 406.
[70] ADF&G, "Our History," About Us, accessed February 12, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=about.history.
[71] ADF&G, *Annual Report for 1959*, Juneau, 1959 (Report No. 11): 42.
[72] ADF&G, "Alaska's Fisheries and Game Board Process," Regulations: Process, accessed February 12, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=process.main.

built.[73] Salmon runs rose to ~60 million per year by the mid 1960's up from 41.5 million average caught in the 1950s.[74] But the rebound didn't last long; by 1967, the salmon harvest was less than 21 million fish, the lowest in territorial and state history.

In 1971, the Alaska State Legislature responded to falling salmon runs with new legislation that created the Division of Fisheries Rehabilitation, Enhancement and Development (FRED) within ADF&G. The FRED Division "was designed to rehabilitate and enhance depressed stocks and to help reduce the economic impact in years of low natural stocks."[75] Rehabilitation was defined as activities that restored salmon to previous levels, and they defined enhancement as providing additional salmon.[76] The division's main thrust became research and salmon hatcheries. To help hatcheries finance their production while they produced salmon for common property fisheries, Article 8, Section 15 was amended in 1972 to provide an exemption to the "no exclusive right of fishery clause" allowing limited entry management (restricting how many boats may fish an area by requiring permits) and providing hatcheries exclusive right to collect broodstock for future runs and to harvest salmon to cover operating costs, called cost recovery.[77] In 1974, legislation passed authorizing private non-profits (PNPs) to build and operate hatcheries. From 1960 until this time, hatcheries had been run by the state. Different from hatchery programs in the lower 48, which aimed to replace salmon stocks lost due to habitat destruction or overharvest, PNPs in Alaska were seen as a way to enhance salmon runs and further the goals of the state's rehabilitation program while providing jobs for residents.[78] In 1974, the legislature wrote:

> "It is the intent of this Act to authorize the private ownership of salmon hatcheries by qualified nonprofit corporations for the purpose of contributing, by artificial means, to the rehabilitation of the state's depleted and depressed salmon fishery. The program shall

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[73] Roppel, *Alaska's Salmon Hatcheries*, 281.
[74] averages extrapolated from data in NPAFC, *Pacific Salmon Status and Abundance Trends – 2012 Update*, 24.
[75] ADF&G, *FRED Reports,* 2.
[76] ADF&G, *FRED Reports,* 2.
[77] ADF&G, *Alaska Fisheries Enhancement Annual Report 2016*, by Mark Stopha, Anchorage, 2017 (Regional Information Report No. 5J17-04): 6.
[78] ADF&G, *FRED Reports,* 5.

> be operated without adversely affecting natural stocks of fish in the state and under a policy of management which allows reasonable segregation of returning hatchery-reared salmon from naturally occurring stocks."[79]

While hatcheries switched from state to PNP management, the FRED Division and other agencies tried varying methods to increase salmon stocks. Habitat was restored by fertilizing lakes to increase phytoplankton and zooplankton blooms which increased prey abundance for salmon fry. Obstructions to salmon returns, such as log jams that blocked waterways, were removed. Fish ladders were put in to help returning adult salmon, lakes were stocked with salmon fry, and more hatcheries were built.[80]

In 1976, legislation created regional aquaculture associations, allowing PNPs a new management system with boards comprised of commercial, sport, and subsistence fishermen, processors, and local community members. These associations quickly became heavily dominated by commercial fishing interests.[81] There have been up to eight regional aquaculture association operating in the state;[82] today there are five (see Figure 4 for hatchery locations and PNP affiliations): Prince William Sound Aquaculture Association (PWSAC), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Cook Inlet Aquaculture Association (CIAA), and Kodiak Regional Aquaculture Association (KRAA). Also in 1976, the legislature created regional plans and subsequently Regional Planning Teams (RPTs) by directing the Commissioner of the Department of Fish and Game "to develop and amend as necessary a comprehensive salmon plan for each region, including provisions for both public and private nonprofit hatchery systems."[83] RPTs are made up of regional aquaculture association representatives, fishermen, and regional ADF&G staff. The RPTs prepare comprehensive salmon enhancement plans that direct enhancement efforts for the region, and

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79 quoted in ADF&G, *Alaska Fisheries Enhancement,* 12.
80 ADF&G, *Alaska Fisheries Enhancement 2016,* 12.
81 ADF&G, *FRED Reports,* 6.
82 ADF&G, *FRED Reports,* 6.
83 quoted in ADF&G, *FRED Reports,* 6.

they also review hatchery permits and management plans and make recommendations to the Commissioner.[84]

The 1980s saw the last significant legislation directed at hatcheries in Alaska passed with the Salmon Enhancement Tax and its amendments. Passed by a vote from commercial fisherman, the tax levies a 2% to 3% tax on all fish caught within established aquaculture regions (the areas surrounding the source that hatchery fish return to, usually a hatchery but also remote rearing sites), also referred to as terminal harvest areas. The boundaries of terminal harvest areas are defined and managed by ADF&G. The tax collected from the Salmon Enhancement Tax is deposited in the general fund and is appropriated to regional aquaculture associations operating within the region where the tax was collected. The amount collected varies annually and is dependent on how many fish are caught in the area and the value of those fish.[85] In 2014, the total taxes collected under the Salmon Enhancement Tax was $12,779,417. In 2017, it was $5,382,662 due to a smaller total harvest.[86] In 2016, one of the five regional aquaculture associations, NSRAA received $1.3 million in appropriations from the fund.[87] With the tax and a voice in the regional planning process, the seven regional aquaculture associations gained influence over production amounts, and production increased.

In the 1970s and 1980s, 44 hatcheries were built and operated.[88] A decade after the creation of the FRED Division, hatcheries were already significantly contributing to commercial fisheries. In 1981, 4.5 million hatchery salmon returned; the next year 6.7 million hatchery fish returned.[89] By 1993, over 33 million returned. The total harvest (hatchery and wild) that year was 193.1 million salmon (Figure 3), a

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[84] ADF&G, "Hatcheries Planning: Regional Planning Teams," Fishing: Hatcheries, accessed April 1, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=fishingHatcheriesPlanning.regional.
[85] AS 43.76.025 (c)
[86] Alaska Department of Revenue, "Salmon Enhancement Tax 2017 Annual Report," Tax Division: Tax Types, accessed February 23, 2018, http://tax.alaska.gov/programs/programs/reports/Annual.aspx?60632&Year=2017.
[87] Northern Southeast Regional Aquaculture Association (NSRAA), *Board Book – Spring 2018*, (Sitka: 2017): 20.
[88] William W. Smoker and William R. Heard, "Productivity of Alaska's Salmon Hatchery Ocean Ranching Program and Management of Biological Risks to Wild Salmon," in *Ecological and Genetic Implications of Aquaculture Activities*, ed. Theresa M. Burt (New York: Springer, 2007), 364. DOI: 10.1007/978-1-4020-6148-6_20.
[89] ADF&G, *FRED Reports,* 5.

record-breaking harvest (a record that would be broken the next year, 196.1 million, and the year after, 218.33 million)[90]. With runs at unprecedented levels, the Alaska Legislature closed the FRED Division in 1993 incorporating its duties into the ADF&G Commercial Fisheries Management and Development Division.[91]

Today, there are 28 hatcheries operating in Alaska: 27 production and 1 research (Figure 4).[92] The majority of hatcheries in the state are operated by PNPs, two are operated by the ADF&G Division of Sport Fish, one is run by the Metlakatla Indian Community, and the one research hatchery is operated by the U.S. NMFS. There are six PNP hatcheries that are permitted but currently inactive. In 2016, 109 million salmon were caught in Alaskan waters, a total exvessel value (the amount paid for the whole fish by a processor) of a little over $406 million.[93] Of those 109 million salmon, 24 million were hatchery originated (22% of the harvest), an $85 million exvessel value.[94]

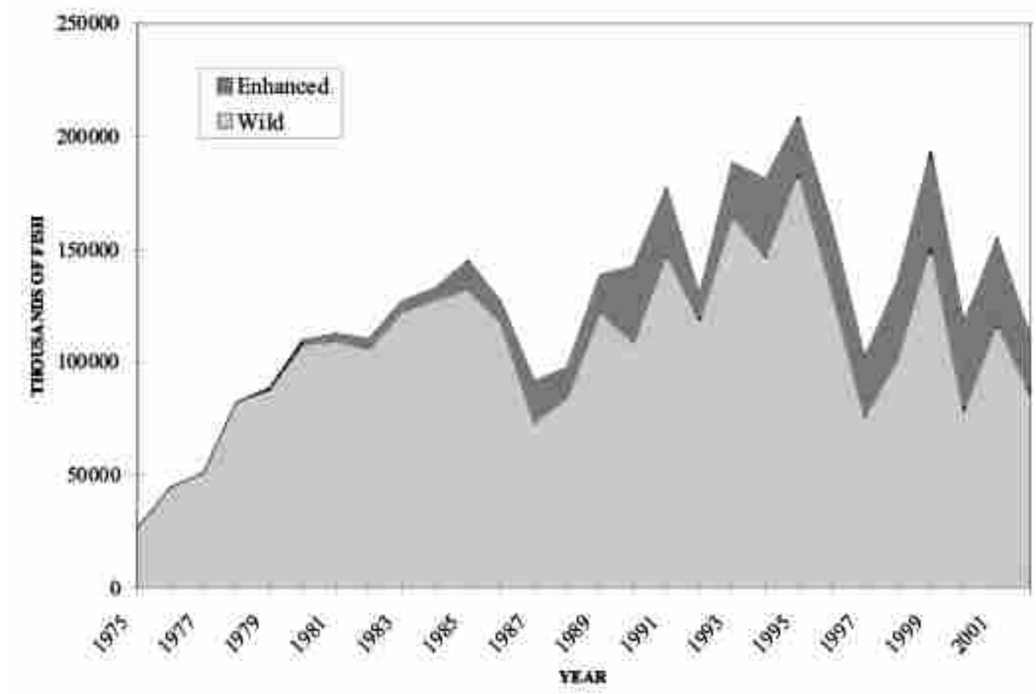

Figure 3. Commercial fishery harvests of wild and enhanced salmon, 1975-2002

Steven McGee, "Salmon Hatcheries in Alaska: Plans, Permits, and Polices that Provide Protection for Wild Stocks," (Juneau, AK).

[90] NPAFC, *Pacific Salmon Status and Abundance Trends – 2012 Update*, 25.
[91] Smoker and Heard, "Productivity of Alaska's Salmon," 364.
[92] ADF&G, *Alaska Fisheries Enhancement 2016*, 13.
[93] ADF&G, *Alaska Fisheries Enhancement 2016*, 41.
[94] ADF&G, *Alaska Fisheries Enhancement 2016*, 7.

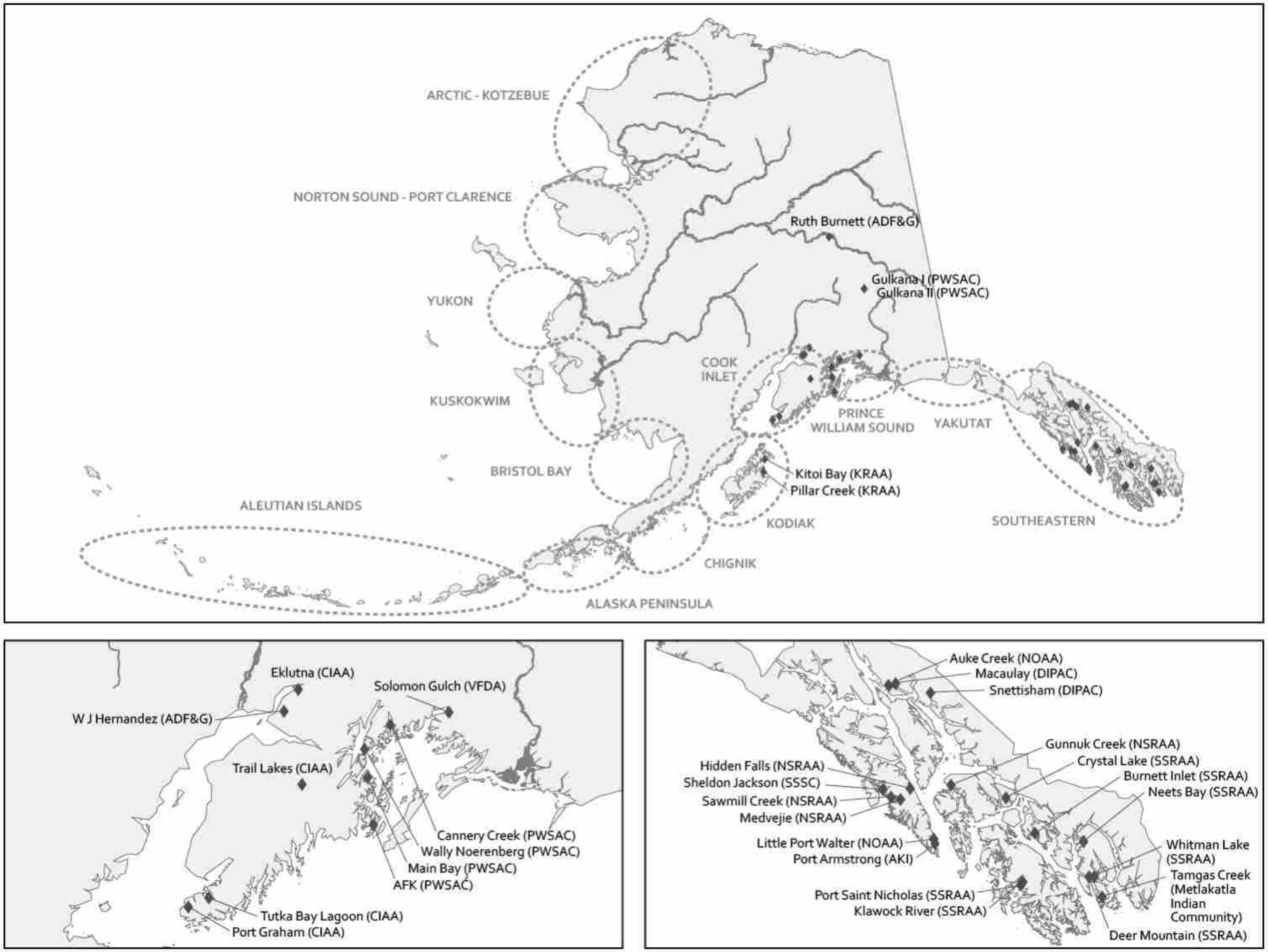

Figure 4. Alaska salmon hatchery locations and fishing regions

Methodology

The framework used for this study is an adapted ecological risk assessment (ERA)(Figure 5).[1] Using scientific data, an ERA is conducted to determine the potential adverse effects of human activities on an ecosystem. Its purpose is to help managers make better-informed decisions before permitting an action. Because policy regulating the sustained yield of Alaskan salmon has already been passed, i.e. the action is already taking place, this study will conduct an ex-post ERA. It will follow the steps of a traditional ERA—planning process, problem formulation, analysis, and risk characterization—to evaluate if an action (Alaskan salmon hatcheries) has adversely affected the ecosystem, but it will also evaluate if policy regulating that action complies with the sustained yield principle as Article VIII of the Alaska Constitution mandates. Through evaluation and an iterative process, the policy can be adapted to reduce uncertainty and improve management. Evaluations also gauge uncertainty by describing the level of confidence in the assessment, which provides managers with areas for future research. Risks outlined in the assessment will be ranked to prioritize areas of higher concern, which can help focus managers' resources. This evaluative ecological risk assessment (ERA-Evaluation) will evaluate policy at a statewide level of analysis providing policy-makers with increased knowledge as they move toward policy reform of Alaskan salmon hatcheries.

Planning Process

During the planning process of an ERA-Evaluation, conducted before problem formulation begins, three products must be produced: (1) clear outline of management goals, (2) characterization of management options, and (3) the scope, complexity, and focus of the assessment set.[2] Management goals

[1] U.S. Environ. Protection Agency (EPA), *Guidelines for Ecological Risk Assessment*, Washington, D.C., May 14, 1998 (Federal Register 63(93):26846-26924).
[2] EPA, *Guidelines for Ecological Risk Assessment*, 13-17.

are a “general statement of the desired condition or direction of preference for the entity to be protected.”[3] These statements are then used to help characterize the management options helping to specify sideboards for the analysis. The last product of the planning process is to determine the scope, complexity, and focus.

Problem Formulation

After the planning process, problem formulation is the process of creating and evaluating hypotheses about the potential effects from human actions.[4] In problem formulation, the reason for the ERA-Evaluation is described, the problem is outlined, and a plan for risk characterization and analysis is determined. The three products of problem formulation are: (1) assessment endpoints, (2) a conceptual model describing relationships between stressor(s) and endpoint(s), and (3) an analysis plan.[5] Assessment endpoints are “explicit expressions of the actual environmental value that is to be protected, operationally defined by an ecological entity and its attributes.”[6] The conceptual model provides a visual representation of the relationships between ecological entities and potential stressors. The model shows the receptor(s) and stressor(s) and the processes and exposure scenarios that link them. The final step in problem formulation is the analysis plan. During this step, the risk hypotheses are assessed to determine how they will be analyzed using available data. The plan includes the assessment design and measures and methods for conducting the assessment.

Analysis

Analysis is directed by the products of problem formulation. It is the phase where data is selected, based on utility, for the rest of the ecological risk assessment. Analysis is the process used to examine

[3] Van Winkle et al., “A Blueprint for the Problem Formulation Phase of EPA-Type Ecological Risk Assessments for 316(b) Determinations.” *The Scientific World Journal* 2, no. 1 (2002): 274. DOI: 10.1100/tsw.2002.862.
[4] EPA, *Guidelines for Ecological Risk Assessment*, 24.
[5] EPA, *Guidelines for Ecological Risk Assessment*, 24.
[6] EPA, *Guidelines for Ecological Risk Assessment*, 28.

exposure and effects and "their relationships between each other and their ecosystem characteristics."[7] After determining the strengths and limitations of known data and its ability to speak to exposure, effects, and ecosystem/receptor traits, the data is then used to produce two profiles: exposure profile and stressor response profile. Characterization of exposure involves evaluating known information to determine the likelihood of exposure to stressors. The exposure profile "identifies the receptor (i.e., the exposed ecological entity), describes the course a stressor takes from the source to the receptor (i.e., the exposure pathway), and describes the intensity and spatial and temporal extent of co-occurrence or contact."[8] Characterization of ecological effects is that, given the exposure, what ecological effects may be expected. The stressor response profile, also called an effects profile, describes what ecological entities are affected, the nature and intensity of the effects, the time scale for recovery (if applicable), and the uncertainty in the analysis. The objective of the stressor response profile is to ensure the required information for risk characterization is available and evaluated, because both profiles (exposure and stressor response) form the foundation of risk characterization.

Risk Characterization

The final phase of a standard ERA is risk characterization. During risk characterization, risk assessors use the products of the analysis phase to estimate risk, "describe the risk estimate in the context of the significance of any adverse effects and lines of evidence supporting their likelihood," and report the risk to risk managers including any uncertainties, assumptions, and qualifiers involved in the risk assessment.[9] Estimating risk involves integrating the known information about exposure and effects and one of many characterization techniques such as categorical rankings, comparisons, and process models. Risk description includes a "technical narrative supporting the risk estimate" which is based on the evidence supporting the risk estimate and the interpretation of that evidence in relation to adverse effects

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7 EPA, *Guidelines for Ecological Risk Assessment*, 52.
8 EPA, *Guidelines for Ecological Risk Assessment*, 65.
9 EPA, *Guidelines for Ecological Risk Assessment*, 99.

on assessment endpoints.[10] The quality of data, degree of uncertainty, and relationship of data to assessment endpoints is evaluated and discussed in the technical narrative. The final step, reporting risk to risk managers, must include the degree of confidence in the ERA, evidence supporting conclusions, and an interpretation of the adverse ecological effects posed to the receptor.

After communicating the risk results to risk managers, it is often beneficial for risk managers to translate results into risk management decisions. Part of this translation is a dialogue between the risk assessors who conducted the ERA and the risk managers and could include questions along the lines of:

- "Are the risks sufficiently well defined (and data gaps small enough) to support a risk management decision?
- Was the right problem analyzed?
- Was the problem adequately characterized? […]
- How confident are you in the conclusions of the risk assessment?
- What are the critical data gaps, and will information be available in the near future to fill these gaps?
- Are more ecological risk assessment iterations needed?
- How could monitoring help evaluate the results of the risk management decision?"[11]

Alternative approaches to reducing or mitigating risk may be the product of these discussions. Risk managers also may have to incorporate public opinion into their final risk management decisions.

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[10] EPA, *Guidelines for Ecological Risk Assessment*, 113.
[11] EPA, *Guidelines for Ecological Risk Assessment*, 122.

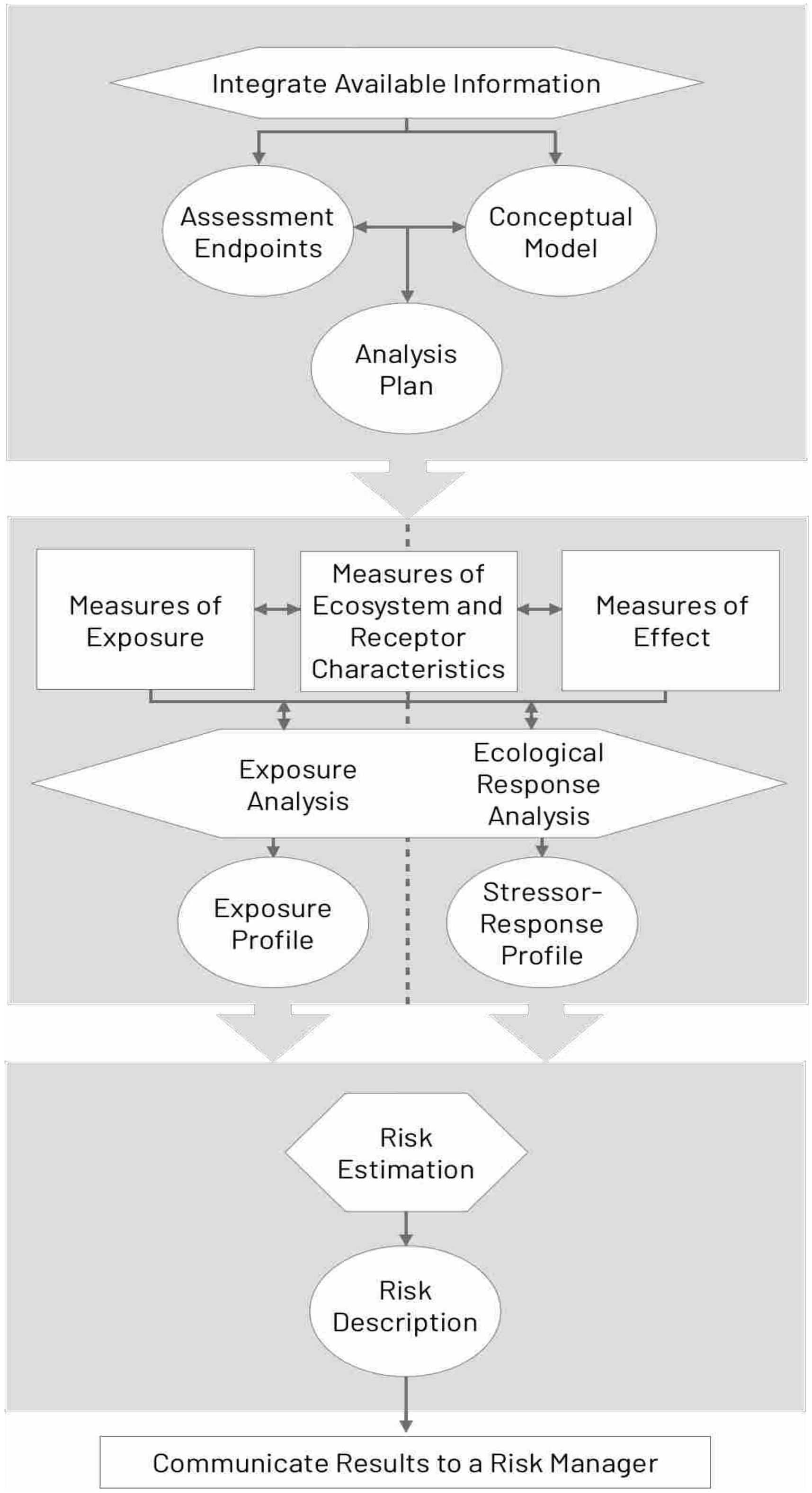

Figure 5. Ecological risk assessment framework

created from U.S. Environ. Protection Agency (EPA), *Guidelines for Ecological Risk Assessment*, Washington, D.C., May 14, 1998 (Federal Register 63(93):26846-26924).

Evaluation

A traditional ERA (Figure 5) is conducted before (ex-ante) the creation of a policy and is used to determine potential adverse effects posed by an action on an ecosystem. Adapting an ERA for policy evaluation involves modifying the framework of an ERA to be applicable after (ex-post) an action. The core framework of an ERA remains the same: planning process, problem formulation, analysis, and risk characterization. But data is pulled from current actions and the stressor/receptor being evaluated when possible (rather than derived from similar scenarios) and an additional step is added after risk characterization: evaluation. While risk characterization uses the stressor response and exposure profiles to describe risk so that risk managers or decision-makers can minimize or mitigate risk in the creation or revision of future policy, evaluation looks at the ability of policy currently in place to address risk. This phase is the systematic evaluation of the policy addressing risks posed to each assessment endpoint. First policy pertaining to each assessment endpoint is detailed. Then the effectiveness of each policy is outlined. Effectiveness is simply: is the policy working to meet its intended purpose? If there are gaps between a policy's aim and what is happening in practice, those are also outlined in this section.

Recommendations

The final phase of this study is recommendations which takes the ERA-Evaluation to an actionable endpoint. It fits within the adaptive management cycle,[12] providing decision-makers with potential areas of most concern to adjust or revise policy to better align with the mandated sustained yield of wild salmon in Alaska. Adaptive management, an approach to natural resource management, emphasizes learning, because all knowledge is incomplete. Through learning, a policy can be adapted to reduce uncertainty and improve management. During an iterative adaptive management cycle, policy is

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[12] Byron K. Williams, "Adaptive Management of Natural Resources – Framework and Issues," *Journal of Environmental Management* 92 (2011): 1347.

planned, implemented, monitored, evaluated, and finally adjusted to incorporate new knowledge.[13] The recommendations section synthesizes the data evaluated during analysis, the categorial risk estimates produced during risk characterization, and the evaluation of current policy to regulate potential negative effects of hatchery salmon on wild populations to provide recommendations to risk managers as they adjust policy regulating the stressor. Recommendations may include addressing gaps in current policy, enforcement to mitigate effects of the stressor, or the creation of new policy to better protect the receptor. The recommendations in this study are not exhaustive but were instead chosen because they address the largest risks to sustained wild salmon runs and/or are achievable significant actions.

[13] Williams, "Adaptive Management," 1347.

Ecological Risk Assessment (ERA) - Evaluation

Planning Process

Alaska constitutional delegates outlined the management goal for Alaska salmon in Article VIII, Section 4: "replenishable resources belonging to the State shall be utilized, developed, and maintained on the sustained yield principle, subject to preferences among beneficial use."[1] The sustained yield principle maintains that a resource's use or harvest should be maximized but with a "continued availability to future generations."[2] To help fully articulate the management goal stated above, management objectives that must be met to sustain wild salmon populations are:

- Maintain habitat to support wild salmon spawning
- Protect adequate wild salmon escapement to ensure future runs
- Maintain adapted wild salmon genetics for fitness
- Prevent disease from infecting wild salmon runs
- Maintain healthy North Pacific food web

Because these management objectives are all mandatory to sustaining wild salmon runs, management outcomes are limited. Either the policy is working and salmon populations remain stable or one or more of the objectives isn't being met or is at risk and policy should be revised.

The scope for the assessment is statewide: wild anadromous salmon originating in waters within the State of Alaska. The temporal scale to be analyzed is from statehood in 1959, when sustainability of natural resources was mandated, to the present. Complexity is limited to previously published scientific literature and data because the timeframe for this assessment does not permit new research. Any uncertainty in data or lack of data to address analysis will be identified in the evaluation phase. The focus

[1] Alas. Const. Art. 8, Sect. 4.
[2] *West v. State Board of Game*

of the assessment is wild salmon populations and Alaskan hatcheries used to enhance wild salmon populations.

Problem Formulation

The impetus of this study is multifarious. The issues currently surrounding salmon management in Alaska range from hatchery impacts, strays, commercial fishing economics, and closures for failed or small runs, to name a few. In 2012, ADF&G commissioned a study on the genetics, straying, and implications for fitness of hatchery salmon "[b]ecause of the value of hatchery production to industry's harvest, and the mandate that hatchery production be compatible with sustainable productivity of wild stocks."[3] In the last few years, the state has seen increased rates of straying with some hatchery fish now inhabiting watersheds hundreds of miles from their natal hatchery. There are contentious debates in coastal towns about the increases in hatchery production potential disruption of the food web and its impact on crustacean and herring recruitment. At the same time, the Alaska salmon fishing industry is experiencing boom or bust cycles. In 2012, the fleet caught the largest harvest of pink salmon in history, and in 2016, the fishery was declared a federal disaster with funds appropriated by congress for disaster relief. There have been emergency order closures for king salmon in Southeast Alaska and declining king salmon numbers statewide for a decade. The average length and weight of king salmon statewide has also decreased considerably.[4] All of these reasons may point to potential shortcomings in policy regulating hatchery enhancement. The problem then becomes (1) is policy regulating the management of Alaskan salmon hatcheries ensuring the sustainability of wild salmon runs or (2) is the policy sustaining runs adequate but hatchery practices are not in alignment with policy?

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[3] ADF&G, "Hatcheries Research: Current Research Project," Fishing: Hatcheries, accessed February 27, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=fishingHatcheriesResearch.current_research.
[4] Ohlberger et al, "Demographic Changes in Chinook Salmon Across the Northeast Pacific Ocean," *Fish and Fisheries* (2018): 1. DOI: 10.1111/faf.12272.

Assessment Endpoints

Assessment endpoints are "explicit expressions of the actual environmental value that is to be protected operationally defined by an ecological entity and its attributes."[5] There are three main criteria used to select the ecological values that may be relevant for assessment endpoints: "(1) ecological relevance, (2) susceptibility to known or potential stressors, and (3) relevance to management goals."[6] The first two, ecological relevance and stressor susceptibility, are mandatory for scientifically defensible assessment endpoints. Endpoints that are ecologically relevant will help sustain the environment, including structure and function, and biodiversity of an ecosystem. The degree to which an ecological value is susceptible to a stressor refers to the value's sensitivity. For example, wild salmon and hatchery salmon spend the majority of their adult lives coexisting in the North Pacific, so the ecological value sustained populations of wild salmon isn't as sensitive to the stressor, hatchery salmon, in the North Pacific ecosystem. However, when the two cohabit the same spawning stream, the potential and degree to which the stressor (hatchery salmon) can impact the receptor (wild salmon) is much greater. The assessment endpoints for this study are (see Figure 7 for a visual representation):

- Wild salmon production and recruitment
- Wild salmon fitness
- Disease-free wild salmon population
- North Pacific ecosystem and food web

Conceptual Model

In traditional ERA conceptual models, relationships between ecological entities and potential stressors are represented through the processes and exposure scenarios that link them. The conceptual model for this study (Figure 6) is slightly different than traditional models. Because there is only one

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[5] EPA, *Guidelines for Ecological Risk Assessment*, 28.
[6] EPA, *Guidelines for Ecological Risk Assessment*, 30.

stressor, hatchery salmon, and the mode of exposure is a form of interaction (competition, breeding, cohabiting, etc.) between hatchery and wild salmon or hatchery salmon and their environment, the traditional conceptual model's levels aren't relevant. Instead of the traditional levels—stressor, source, exposure, receptors, and attribute change—the ERA-Evaluation conceptual model uses risk hypotheses to visually represent the degrees of interaction. Risk hypotheses are assumptions about the relationships between stressor and assessment endpoint response. The risk hypotheses (Figure 7) in this study are:

- Hatchery strays compete with wild salmon for spawning sites.
- Hatchery strays inflate escapement counts.
- Straying salmon can provide demographic rescue.
- Hatchery strays who interbreed with wild salmon reduce the fitness of the offspring.
- Hatchery strays who interbreed with wild salmon affect the run timing of the offspring.

- Hatchery salmon, raised in a dense rearing environment, are at a higher risk to carry and expose wild salmon to disease.

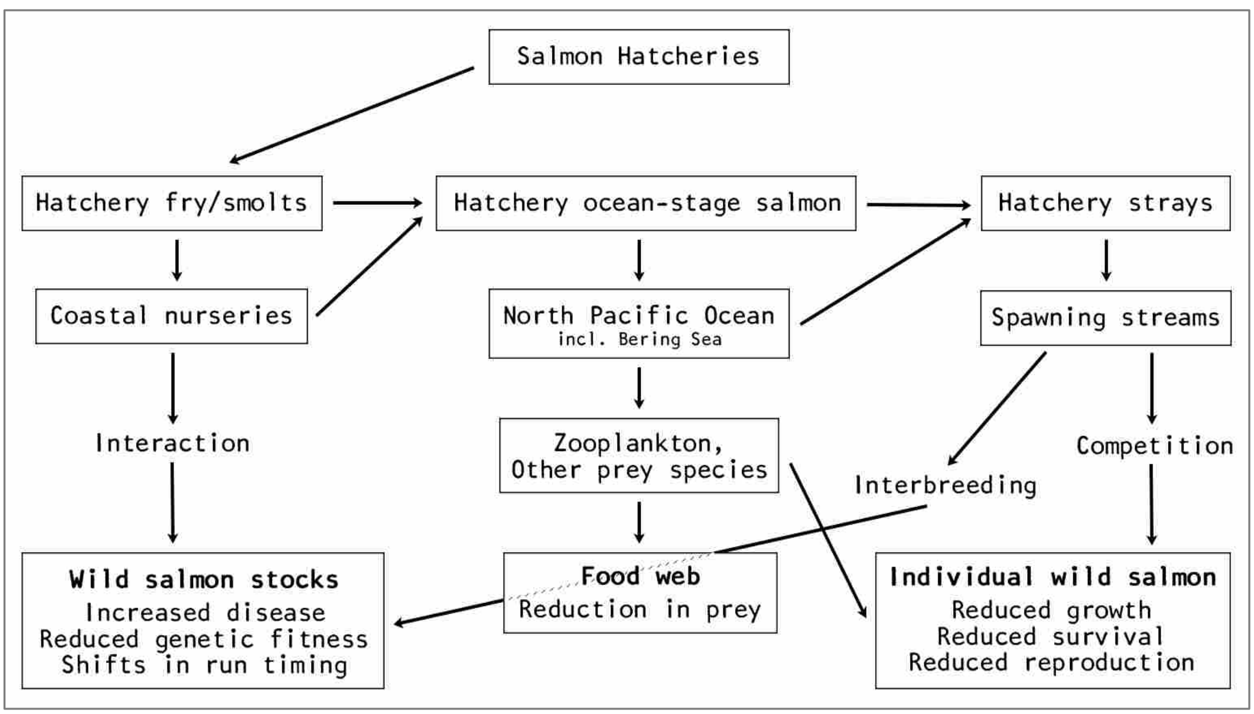

Figure 6. Conceptual model

- The increased number of hatchery salmon in the North Pacific decreases food availability for wild salmon.

Plan for Analysis

The analysis plan is the last step in problem formulation. Planning for analysis involves looking at the risk hypotheses listed above with the goal of determining how they will be analyzed. This study's analysis will extrapolate from existing data to determine whether or not and to what degree the risk hypotheses are impacting wild salmon or if more research is necessary to determine impact. Relationships between hatchery salmon and wild salmon, including competition, breeding, and cohabiting, will be explored. All risk hypotheses will initially be investigated; none will be omitted. If data are insufficient to draw conclusions, it will be noted and a recommendation will be made for further research in the evaluation phase including the feasibility of conducting the necessary research.

Three types of measures used will be: measures of effect, measures of exposure, and measures of ecosystem (Figure 7). Measures of effect, formerly called measurement endpoints, are the "measurable changes in an attribute of an assessment endpoint or its surrogate in response to" the exposure of a stressor (hatchery salmon).[7] The measures of effect in this study are:

- spawning success of wild salmon in streams with low dissolved oxygen (DO) levels
- spawning success of wild salmon in streams with high stray levels
- salmon populations statewide over time
- wild-spawned salmon[8] fitness
- run timing of wild-spawned salmon
- disease levels in wild salmon stocks
- zooplankton levels in the North Pacific

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[7] EPA, *Guidelines for Ecological Risk Assessment*, 47.

[8] Wild-spawned salmon may be the offspring of wild-wild parents, wild-hatchery stray parents, and hatchery stray-hatchery-stray parents. Anything not spawned at a hatchery by hatchery employees is considered wild-spawned and counted by management as wild.

Measures of exposure are "measures of stressor existence and movement in the environment and their contact or co-occurrence with the assessment endpoint."[9] Measures of exposure in this study are:

- hatchery strays in wild streams
- fitness of hatchery strays
- run timing of hatchery strays
- disease levels in hatchery salmon

Measures of ecosystem are measures of "ecosystem characteristics that influence the behavior and location of entities selected as the assessment endpoint, the distribution of a stressor, and life-history characteristics of the assessment endpoint or its surrogate that may affect exposure or response to the stressor."[10] In this study, measures of ecosystem are:

- DO levels in spawning streams
- water temperatures in spawning streams
- water temperatures in the North Pacific
- abundance of suitable food sources in the North Pacific Ocean for wild salmon

Supporting the assessment endpoint 'wild salmon production and recruitment' are the following measures: spawning success of wild salmon in streams with low dissolved oxygen (DO) levels [measure of effect], spawning success of wild salmon in streams with high stray levels [measure of effect], salmon populations statewide over time [measure of effect], hatchery strays in wild streams [measure of exposure], DO levels in spawning streams [measure of ecosystem], and water temperatures in spawning streams [measure of ecosystem]. The measures 'spawning success of wild salmon in streams with low dissolved oxygen (DO) levels,' 'DO levels in spawning streams,' and 'water temperatures in spawning streams' were selected because data has indicated that lower DO levels (which can be caused by factors like increased water temperatures, lower stream flows, or increased densities on the spawn ground) can

[9] EPA, *Guidelines for Ecological Risk Assessment*, 47.
[10] EPA, *Guidelines for Ecological Risk Assessment*, 47.

decrease salmon production by causing pre-spawn mortality.[11] Analysis should show to what extent low DO conditions affect wild salmon production. The measures 'spawning success of wild salmon in streams with high stray levels' and 'hatchery strays in wild streams' were selected because studies have shown that spawning behavior may change (such as circling near inflows of streams, where oxygen levels may be higher, instead of searching for suitable spawn sites) in high density spawn streams decreasing spawning success.[12] Studies have also shown that increased competition for spawn sites (which can lead to redd disturbance) can decrease spawn success.[13] Analysis should show if increased densities in spawning streams because of hatchery strays is affecting wild salmon production. The measure, 'salmon populations statewide over time,' will be used to evaluate wild salmon populations' ability to sustain itself via recruitment. Analysis should show if populations are increasing, decreasing, or constant.

Supporting the assessment endpoint 'wild salmon fitness' are the following measures: wild-spawned salmon fitness [measure of effect], run timing of wild-spawned salmon [measure of effect], fitness of hatchery strays [measure of exposure], and run timing of hatchery strays [measure of exposure]. The measures 'wild-spawned salmon fitness' and 'fitness of hatchery strays' will be used to determine differences in fitness between wild, wild-spawned and hatchery salmon. Studies have shown that hatchery salmon have reduced fitness due to domestication while wild salmon have adapted genetics increasing their fitness.[14] Analysis will show if the reduced fitness of hatchery strays is affecting wild salmon fitness. The measures 'run timing of wild-spawned salmon' and 'run timing of hatchery strays' will be used to determine if hatchery strays are affecting run timing of wild stocks. Because of aggressive broodstock and

[11] Richard E. Brenner, Steve D. Moffitt, and William S. Grant, "Straying of Hatchery Salmon in Prince William Sound," *Environmental Biology of Fishes* 94 (2012): 192. DOI: 10.1007/s10641-012-9975-7.
[12] Michael D. Tillotson and Thomas P. Quinn, "Climate and Conspecific Density Trigger Pre-Spawning Mortality in Sockeye Salmon (*Oncorhynchus nerka*)," *Fisheries Research* 188 (2017): 145. DOI: 10.1016/j.fishres.2016.12.013.
[13] Brenner et al., "Straying of Hatchery Salmon," 192.
[14] Naish et al., "Evaluation of the Effects of Conservation and Fishery Enhancement Hatcheries on Wild Populations of Salmon," *Advances in Marine Biology* 53 (2008): 104. DOI: 10.1016/S0065-2881(07)53002-6.

eggtake methods at the hatchery, studies have shown earlier return dates for hatchery salmon over time.[15] Earlier returns may put salmon on the spawn ground at less than optimal times, such as in low water flow conditions of late summer (for fall runs of salmon). Analysis will indicate if hatchery strays' offspring are returning to spawn earlier, changing wild populations' run timing.

Supporting the assessment endpoint 'disease-free wild salmon population' are the following measures: disease levels in wild salmon stocks [measure of effect] and disease levels in hatchery salmon [measure of exposure]. Both measures, 'disease levels in wild salmon stocks' and 'disease levels in hatchery salmon,' will be used to determine if hatchery salmon increase the disease load in wild salmon populations. It is hypothesized that because hatchery salmon are reared in dense environments, which leads to greater rate of infection because of the increased opportunity for fish to have open sores from rubbing on tanks/pens or nipping at one another, that they may have higher levels of disease.[16] Because hatchery and wild salmon occupy the same waterbodies post-release or outmigration from their freshwater environments, there is opportunity for the spread of disease. If hatchery salmon are carrying disease, that disease may be spread to the wild fish they interact with. Analysis will provide a baseline of disease levels in wild salmon stocks to determine if there is increased spread of disease from hatchery salmon.

Supporting the assessment endpoint 'North Pacific ecosystem and food web' are the following measures: zooplankton levels in the North Pacific [measure of effect], water temperatures in the North Pacific [measure of ecosystem], and abundance of suitable food sources in the North Pacific Ocean for wild salmon [measure of ecosystem]. The measures 'zooplankton levels in the North Pacific' and 'abundance of suitable food sources in the North Pacific Ocean for wild salmon' will be used to determine if hatchery salmon are having an impact on the North Pacific's ecosystem and food availability for wild

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[15] Hayes et al., "Effectiveness of an Integrated Hatchery Program: Can Genetic-Based Performance Differences Between Hatchery and Wild Chinook Salmon Be Avoided?" *Canadian Journal of Fisheries and Aquatic Sciences* 70 (2013): 156. DOI: 10.1139/cjfas-2012-0138.
[16] Naish et al., "Evaluation," 145.

salmon. Studies have shown a decrease in zooplankton due to increasing hatchery production worldwide.[17] Both hatchery and wild salmon spend the majority of their lives at sea making the North Pacific critical habitat for salmon survival. A negative effect on the food availability in the North Pacific has repercussions for wild salmon. Analysis will indicate to what degree hatchery salmon are affecting the North Pacific. The measure 'water temperatures in the North Pacific' will be used to look at trends that may be affecting food availability. Warming water temperatures affect plankton blooms and salmon growth rates.[18] Analysis will help to determine if warmer temperatures are affecting the North Pacific ecosystem and food web or if those effects are due to hatchery salmon instead.

All measures and assessment endpoints will be discussed further in the next section, Analysis.

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[17] Susan P. Johnson and Daniel E. Schindler, "Trophic Ecology of Pacific Salmon (*Oncorhynchus* spp.) in the Ocean: A Synthesis of Stable Isotope Research," *Ecological Research* 24 (2009): 861. DOI: 10.1007/s11284-008-0559-0.

[18] Jared E. Siegel, Megan V. McPhee, and Milo D. Adkison, "Evidence that Marine Temperatures Influence Growth Maturation of Western Alaskan Chinook Salmon," *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 9 (2017): 441. DOI: 10.1080/19425120.201.1353563.

WILD SALMON PRODUCTION AND RECRUITMENT — *assessment endpoint*

risk hypotheses

- Hatchery strays compete with wild salmon for spawning sites.
- Hatchery strays inflate escapement counts.
- Straying salmon can provide demographic rescue.

measures of effect, exposure, or ecosystem

- spawning success of wild salmon in streams with low dissolved oxygen (DO) levels [measure of effect]
- spawning success of wild salmon in streams with high stray levels [measure of effect]
- salmon populations statewide over time [measure of effect]
- hatchery strays in wild streams [measure of exposure]
- DO levels in spawning streams [measure of ecosystem]
- water temperatures in spawning streams [measure of ecosystem]

WILD SALMON FITNESS

- Hatchery strays who interbreed with wild salmon reduce the fitness of the offspring.
- Hatchery strays who interbreed with wild salmon affect the run timing of the offspring.

- wild-spawned salmon fitness [measure of effect]
- run timing of wild-spawned salmon [measure of effect]
- fitness of hatchery strays [measure of exposure]
- run timing of hatchery strays [measure of exposure]

DISEASE-FREE WILD SALMON POPULATION

- Hatchery salmon, raised in a dense rearing environment, are at a higher risk to carry and expose wild salmon to disease.

- disease levels in wild salmon stocks [measure of effect]
- disease levels in hatchery salmon [measure of exposure]

NORTH PACIFIC ECOSYSTEM AND FOOD WEB

- The increased number of hatchery salmon in the North Pacific decreases food availability for wild salmon.

- zooplankton levels in the North Pacific [measure of effect]
- water temperatures in the North Pacific [measure of ecosystem]
- abundance of suitable food sources in the North Pacific Ocean for wild salmon [measure of ecosystem]

Figure 7. Assessment endpoints, risk hypotheses, and measures

Analysis

Exposure Analysis

There are currently 28 hatcheries in Alaska (Figure 4): 27 production hatcheries and 1 research hatchery. All hatcheries in Alaska are located in Southeast Alaska, the Prince William Sound, Cook Inlet, Southcentral Alaska, and Kodiak. The largest hatcheries are located in the Prince William Sound and Southeast Alaska. The presence of hatcheries within a region can significantly affect the salmon fishery there. Hatcheries vary in capacity and species, but the two most common species reared are chum and pink salmon, accounting for 94% of the hatchery fish produced in the last decade.[19] In Southeast Alaska, 81% of the chum caught in 2016 were hatchery originated.[20] And in the Prince William Sound, which has five hatcheries releasing ~640 million pink salmon fry each year,[21] 76% of pink salmon caught in 2016 were hatchery originated.[22] Statewide in 2016, 22% of salmon caught were hatchery salmon.[23]

Hatchery salmon eggs are harvested from returning adult hatchery salmon, called broodstock, in late summer or early fall. Fertilized eggs are seeded into incubators in hatchery incubation rooms. After a month, the salmon have developed eyes within the eggs ("eyed eggs") and can be handled without damaging the fish. At the eyed stage, the eggs are removed from the incubators and shocked by bouncing them against a hard surface which has no effect on the healthy eggs while turning the unfertilized or damaged eggs a white color. The white eggs are then picked out, usually with a sorting device like a JM8 Jensorter or Sustaf egg sorter. The viable eggs are then reseeded into incubators with simulated gravel. Conditions are meant to mimic the natural environment. Wild salmon eggs during this time are buried in redds (nests of gravel essentially) in streams or rivers under snow and with limited daylight, so hatchery incubation rooms are kept cold and dark (workers wear headlamps or use red lights that don't stimulate growth) to help simulate that environment.

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[19] ADF&G, *Fisheries Enhancement Report 2016*, 5.
[20] ADF&G, *Fisheries Enhancement Report 2016*, 26.
[21] ADF&G, *Fisheries Enhancement Report 2016*, 46.
[22] ADF&G, *Fisheries Enhancement Report 2016*, 26.
[23] ADF&G, *Fisheries Enhancement Report 2016*, 7.

Approximately two months after the eggs were taken from the broodstock, the salmon eggs hatch. The salmon, now called alevin, remain in their redds (wild salmon) or simulated gravel (hatchery) using up their yolk sacs. At this stage, hatchery chum, sockeye, and pink salmon and some chinook and coho are "marked" by manipulating water temperatures by at least a 3°C change for 24 to 48 hours creating a dark ring on the salmon's otolith or ear stone[24] (Figure 9). Each hatchery release site has their own pattern of marks assigned by ADF&G in conjunction with the North Pacific Anadromous Fish Commission (NPAFC). The marks have become a tool for fish managers to determine successful escapements. Because hatcheries raise so few chinook and coho in comparison with chum and pinks, they are often tagged with a coded wire tag inserted into the salmon fry's nose[25] (Figure 8). The stainless-steel wire is marked with a code that managers use as a reference to track the salmon's origin and brood year. The fry's adipose fin is then clipped (cut off), which allows fish managers to visually see which adult salmon have a coded wire

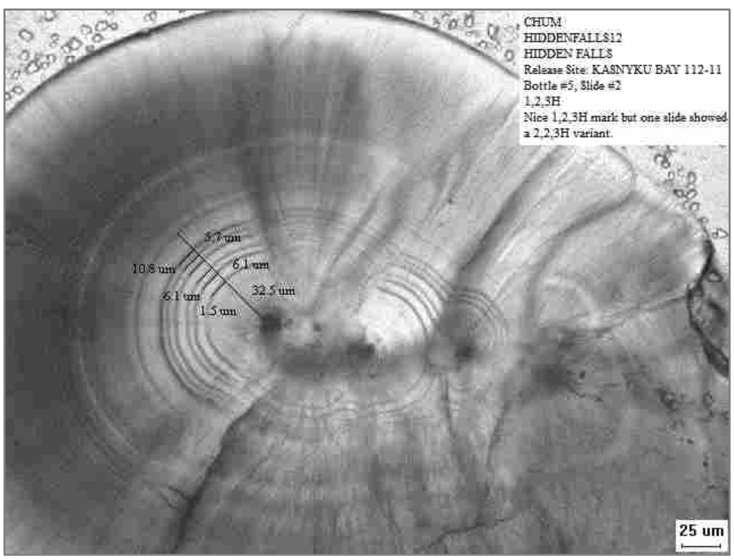

Figure 9. Chum otolith mark

ADF&G, "Mark Characteristic Report: Hidden Falls Chum 2012," accessed March 1, 2018, https://mtalab.adfg.alaska.gov/OTO/reports/VoucherSummary.aspx?mi=HIDDENFALLS12.

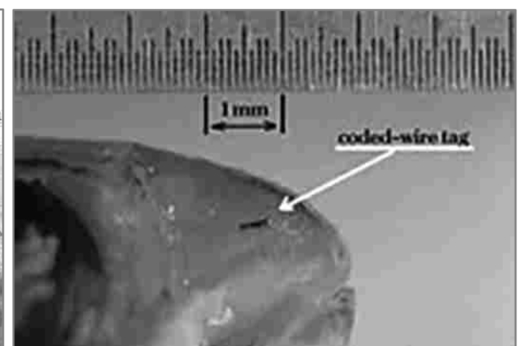

Figure 8. Coded wire tag

USFWS, "Hatchery Evaluation – Coded-Wire Tagging," accessed March 1, 2018, https:// www. fws.gov/redbluff/he_cwt.html.

[24] ADF&G, "Mark Recovery Laboratory: Otolith Marking," Fishing: Research, accessed March 1, 2018, https://mtalab.adfg.alaska.gov/OTO/marking.aspx.

[25] Tagging is a labor-intensive process, which is why it is reserved for small groups of fish like chinook and coho. It would be next to impossible to tag to the quantities of chum and pink salmon that are produced at Alaska hatcheries.

tag. The data is then used to determine broodyear success, determine where the broodyear has been caught, and estimate survival.[26]

When the alevin have used most of their yolk, hatchery chinook, coho, and sockeye will be moved to freshwater rearing containers for another year to year and a half, while their wild counterparts move into lakes. Their physiology requires the extra time in a freshwater environment. Chum and pink salmon fry are ready for saltwater when their yolk is gone. In the wild, they migrate down to brackish environments and the ocean. In the hatchery, they are moved to saltwater rearing pens and fed regularly. Some hatcheries start their fry on feedings every half hour during an eight-hour cycle; some feed on the hour for eight feedings a day. Frequency of feedings at this point is important to encourage growth. Because the fry are in net pens in saltwater environments, greater frequency of feedings allows them more time to access food. Currents can move the feed out of their pen within a few minutes on certain tide cycles. If not started on feed correctly, the fry can fail to eat at all, dying of starvation eventually.

Because hatchery salmon are reared in dense environments, managers monitor conditions closely for pathogens. Some hatcheries push densities to maximize capacity in rearing containers and net pens. Chinook, coho, and sockeye are the most susceptible to disease. Common hatchery pathogens are: BKD, bacterial coldwater disease, bacterial gill disease, furunculosis, *Phoma herbarum*, protozoan parasites, marine flexibacter, and vibriosis.[27] Sockeye are also extremely susceptible to infectious hematopoietic necrosis virus (IHNV). There are a limited number of treatments available for infected fish, including a few oral antibiotics approved by the FDA, hydrogen peroxide or formalin baths, and saltwater treatments (flushing freshwater fish or eggs with doses of saltwater).[28] Chum and pink salmon, because of their smaller size when moved to saltwater, face challenges from certain phytoplankton which can irritate their gills causing the fish to stop eating and vibriosis which occurs with warming water temperatures and can

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[26] ADF&G, "Mark Recovery."
[27] ADF&G, *Common Diseases of Wild and Cultured Fishes in Alaska*, by Theodore Meyers, Tamara Burton, Collette Bentz and Norman Starkey (Anchorage: 2008): 1.
[28] ADF&G, *Common Diseases.*

spread among a net pen of fish within a day causing mass mortality. Some pathogens, like BKD, the fish will host until they die and continue to spread to pathogen-free fish they come into contact with.[29] Others, like vibriosis are environment specific,[30] so when the fish are released and removed from the contaminated environment, they are able to continue disease-free.

In May or early June, hatchery salmon fry[31] are released. Some hatcheries utilize mass releases, sending millions of fry out at once, and some hatcheries use a trickle release method, releasing one or two net pens of 1-2 million fry each, a day. The largest chum hatchery in Alaska, Hidden Falls Hatchery released a total of 46 million chum fry in 2016.[32] The smallest, Sheldon Jackson Hatchery, which was originally an educational hatchery for the now closed Sheldon Jackson College and now partners with the University of Alaska's Fish Technology Program, released 2.4 million.[33] Total, 677 million chum fry were released from Alaska hatcheries in 2016.[34] 894 million pink fry were released, 28 million coho, 11 million chinook, and 49 million sockeye, a combined total of 1.66 billion hatchery salmon fry released from Alaska salmon hatcheries in 2016.[35]

Hatchery fry migrate along coastal Alaska where they remain for several months schooling with other hatchery salmon and wild salmon before eventually reaching the North Pacific where they are now called ocean-stage or ocean-phase salmon. Some populations of coho and chinook remain in coastal waters after migration while others head offshore with chum, pink, and sockeye.[36] Most Alaskan chinook have been found to spend their ocean-phase in the Bering Sea.[37]

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[29] ADF&G, *Common Diseases*, 18.
[30] ADF&G, *Common Diseases*, 30.
[31] At this point in the salmons' life, most have developed into smolts. The physiological process, called smolitification, from fry (which denote young fish in their freshwater life stage) to smolt help the fish adapt for a saltwater environment. In common vernacular, though, the terms smolt and fry are used interchangeably as are they in this paper.
[32] ADF&G, *Fisheries Enhancement Report 2016*, 45.
[33] ADF&G, *Fisheries Enhancement Report 2016*, 46.
[34] ADF&G, *Fisheries Enhancement Report 2016*, 47.
[35] ADF&G, *Fisheries Enhancement Report 2016*, 47.
[36] Johnson and Schindler, "Trophic Ecology," 856.
[37] Siegel, McPhee, and Adkison, "Marine Temperatures," 442.

Hatchery and wild salmon share the same physiological characteristics as adults. Pink salmon spend the least amount of time in the North Pacific Ocean returning in late June to mid-October[38] to their natal streams as two-year olds. Pink salmon who return in odd years are unrelated to those who return in even years because of their unique two-year life cycle.[39] In Alaska, the odd-year pink salmon run has become the larger run with returns 48% greater than those in even years, although some rivers in Western Alaska have stronger runs in even-years.[40,41] Scientists are unsure what has caused this plentiful odd-year phenomenon.[42] Most chum and sockeye salmon return in the summer months as 3 to 5 year olds;[43,44] coho spend 2 years in saltwater, returning as 3 year olds from July to November;[45] and chinook, the largest of the Pacific salmon, spend anywhere from 2 to 5 years at sea before returning to spawn in May through July.[46] Salmon return to their natal streams or hatchery by olfactory and geomagnetic cues.[47] Returning hatchery salmon are either caught by fisherman in both sport fisheries and commercial openers (legal fishing times) or are spawned at the hatchery.

A small percentage of returning hatchery fish do not return to the hatchery and instead stray into wild salmon spawning habitat. Straying is an adaptive trait that has allowed salmon to populate areas that

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[38] ADF&G, "Pink Salmon (*Oncorhynchus gorbuscha*): Species Profile," Species: Animals, accessed March 4, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=pinksalmon.main.
[39] ADF&G, "Pink Salmon (*Oncorhynchus gorbuscha*): Species Profile," Species: Animals, accessed March 4, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=pinksalmon.main.
[40] J.R. Irvine et al., "Increasing Dominance of Odd-Year Returning Pink Salmon," *Transactions of the American Fisheries Society* 143, no. 4 (2014): 944. DOI: 10.1080/00028487.2014.889747.
[41] Alan M. Springer and Gus B. van Vliet, "Climate Change, Pink Salmon, and the Nexus Between Bottom-Up and Top-Down Forcing in the Subarctic Pacific Ocean and Bering Sea," *Proceedings of the National Academy of the Sciences (PNAS)* (March 2014): pE1885. DOI: 10.1073/pnas.1319089111.
[42] Springer and van Vliet, "Climate Change," E1881.
[43] ADF&G, "Chum Salmon (*Oncorhynchus keta*) Species Profile," Species: Animals, accessed March 4, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=chumsalmon.main.
[44] ADF&G, "Sockeye Salmon (*Oncorhynchus nerka*) Species Profile," Species: Animals, accessed March 4, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=sockeyesalmon.main.
[45] ADF&G, "Coho Salmon (*Oncorhynchus kisutch*) Species Profile," Species: Animals, accessed March 4, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=cohosalmon.main.
[46] ADF&G, "Chinook Salmon (*Oncorhynchus tshawytscha*) Species Profile," Species: Animals, accessed March 4, 2018. http://www.adfg.alaska.gov/index.cfm?adfg=chinook.main.
[47] Peter A.H. Westley et al., "Signals of Climate, Conspecific Density, and Watershed Features in Patterns of Homing and Dispersal by Pacific Salmon," *Ecology* 96, no. 10 (2015): 2824. DOI: 10.1890/14-1630.1

were once inaccessible to salmon populations and to move away from unfavorable conditions.[48] Natural straying varies between species, with pink and chum salmon showing the highest tendency to stray and sockeye the least.[49] Studies on sockeye salmon have shown less than 2% of a population straying.[50] Studies on chum stray rates in Japan varied from 3-5.4%.[51] A study on pink salmon in Southeast Alaska has shown similar stray levels: 5.1-5.7%.[52] Pink and chum are thought to stray more because, depending on the stock, they spawn in intertidal areas and populations have less genetic differentiation unlike other Pacific salmon species which require more freshwater, upstream environments.[53] Higher stray rates in the Prince William have been attributed to hatchery broodstock having low fidelity to their natal spawning habitat, such as intertidal spawners.[54] 70% of pink salmon in the Prince William Sound spawn in intertidal areas.[55] Non-native populations, such as hatchery fish, have been shown to stray more than wild salmon, and hatchery fish reared on-site stray less than those reared or released at a different site than the hatchery (which is becoming more common in certain areas of Southeast Alaska).[56] Studies on strays have also shown that straying is a region- and local-scale phenomenon (as opposed to state- or ocean current-scale) that increases due to factors like population density and external forcing (rather than caused by climate change or Pacific Decadal Oscillation as would be seen at state- or ocean current-scales).[57]

The hatchery salmon who do return to the hatchery, now called broodstock, are spawned to collect eggs for future hatchery salmon runs. Some hatcheries outside of Alaska use wild- and hatchery-

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[48] Thomas P. Quinn, "A Review of Homing and Straying of Wild and Hatchery-Produced Salmon," *Fisheries Research* 18 (1993): 29. DOI: 10.1016/0165-7836(93)90038-9.
[49] Thomas P. Quinn, *The Behavior and Ecology of Pacific Salmon and Trout* (Vancouver: UBC Press, 2005): 93.
[50] Quinn, "Homing and Straying," 30.
[51] Quinn, "Homing and Straying," 30.
[52] Andrew P. Hendry et al., "The Evolution of Philopatry and Dispersal: Homing Versus Straying in Salmonids," in *Evolution Illuminated: Salmon and their Relatives*, eds. Andrew P. Hendry and Stephen C. Stearns (New York: Oxford University Press, 2004): 84.
[53] Brenner et al., "Straying of Hatchery Salmon," 192.
[54] Brenner et al., "Straying of Hatchery Salmon," 192.
[55] Brenner et al., "Straying of Hatchery Salmon," 192.
[56] Quinn, "Homing and Straying," 29.
[57] Westley et al., "Signals of Climate," 2832.

originated broodstock to minimize genetic divergence from wild salmon.[58] Alaska hatcheries use only hatchery salmon for broodstock. Hatcheries outside of Alaska are located on rivers where both wild and hatchery fish return making broodstock of both origins easily available. Because hatcheries in Alaska are located in areas where they will not interfere with wild runs, in most cases where there is a sizeable water source inaccessible to wild runs such as a lake with natural barricades in its outlet, there aren't readily available wild salmon to spawn. If a hatchery wants to switch broodstock sources using a better-adapted wild stock, they first must determine there will be no negative effects on the donor population and then apply for a permit issued by ADF&G. For the most part, the mass quantities of eggs that are taken to produce next year's salmon (at some facilities over 150 million eggs) are also prohibitive in using wild salmon as broodstock.

Chum, sockeye, pink salmon broodstock are mass spawned; up to 300,000 eggs are placed inside each aluminum NOPAD incubator. Coho and chinook are oftentimes incubated in smaller incubators, like Heath Trays, that allow managers to track broodstock and eggs for diseases like bacterial kidney disease (BKD) which can be passed from the hen (female) to her eggs; this is called family tracking. Because individual hens' eggs need to be tracked, each hen is spawned with one or two males (bucks) and the eggs are placed in their own numbered tray. If a test result comes back positive, the eggs matching to that hen's number can then be discarded eliminating that disease from the population.

The hatchery tracks and removes BKD from their fish population to prevent the spread of the disease horizontally to other fish in the rearing container. The control of disease is regulated by the state through several policies and by the ADF&G Fish Pathology Section. Alaska Administrative Code addresses several ways to mitigate the spread of disease: fish transport, disease control facilitated by the ADF&G fish pathology staff, and hatchery inspections. Limiting the transport of fish from one major geographic zone (such as Southeast, Prince William Sound, Cook Inlet, Kodiak, Bristol Bay, Arctic-Yukon Kuskokwim, and Interior) to another reduces the risk of an unknown diseased population entering that

[58] Hayes et al., "Effectiveness," 147.

area.[59] To transport fish, including hatchery fish, only certain life stages are allowed to be transferred and only with the approval of a fish transport permit which includes rigorous testing for disease.[60] ADF&G also regulates the release of fry with high levels of disease, including prohibiting the release of a population that has experienced mortality above a certain threshold due to disease.[61] For example, if there is no significant mortality due to BKD, there is no restriction on release. If cumulative mortality due to BKD in the 90 days prior to release is greater than 5%, release is prohibited.[62] Diseased salmon must be destroyed according to department directions.[63] In certain cases, the hatchery may receive special authorization from Alaska's State Fish Pathologist Ted Meyers to release a broodyear with mortality above the threshold.[64] ADF&G pathology department also produces literature with recommended equipment sanitization protocols, proper use of approved drugs, and good fish culturist practices. The literature also outlines criteria to be met during hatchery inspections. Hatcheries are to be inspected by ADF&G fish pathology personnel once every other year or more frequently if the hatchery has had mortality due to disease.[65]

Other policy regulating statewide hatchery influence on wild stocks[66] includes location of hatcheries,[67] egg sources available for hatcheries,[68] reporting requirements,[69] and performance review including survival standards.[70] Hatcheries may not be located on an anadromous stream unless special classification is given by the commissioner; original egg sources must be approved by the department and if possible must be taken from native stocks. By requiring hatcheries to be located away from anadromous

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[59] 5 AAC 41.001-060
[60] ADF&G, *Regulation Changes, Policies and Guidelines for Alaska Fish and Shellfish Health and Disease Control,* by Ted Meyers, Juneau: May 2010 (Regional Information Report No. 5J10-01): 7.
[61] 5 AAC 41.080
[62] ADF&G, *Regulation Changes, Policies and Guidelines*, 12.
[63] AS 16.10.420(5)
[64] Personal communications with hatchery staff.
[65] 5 AAC 41.08(c)
[66] AS 16.10.00(g), 5 AAC 40.220(b)(1), and 5 AAC 40.220(b)(3)
[67] AS 16.10.400(f), AS 16.10.420(10), 5 AAC 40.220(b)(1), and 5 AAC 40.220(b)(1)(3)
[68] AS 16.10.445
[69] AS 16.10.470
[70] 5 AAC 40.860

streams, it prevents potential overharvest of the wild stock. By requiring that eggs be taken from native stocks, it ensures that genetics are adapted to the region. An annual report is required by each permit holder or regional aquaculture association. Performance is evaluated based on survival standards, contribution to the common property fishery, and impact to wild stocks. Controlling hatchery actions is the permit allowing the hatchery to exist. The permitting process includes an application and fee,[71] a public hearing,[72] review by the regional planning team,[73] conditions including water source use,[74] and a process for permit alteration and revocation for failure to meet permit objectives.[75]

The last significant policy limiting hatchery impacts on wild stocks is the genetic policy. Created in 1985, the policy lays out three aspects: stock transport, protection of wild stocks, and maintenance of genetic variance.[76] Similar to the fish transport policy described above, the stock transport policy clearly outlines that fish will not be transported between regions and from areas outside the state of Alaska. Regional fish transports are under the discretion of the Commissioner whose decision is based on the phenotypic characteristics and probability of the transported fish straying. The section outlining the protection of wild stocks begins with: "gene flow from hatchery fish straying and intermingling with wild stocks may have significant detrimental effects on wild stocks."[77] The sections continues explaining the potential consequences of hatchery strays interbreeding with wild stocks. Wild salmon have become rigorously adapted to their environment; whereas hatchery salmon have been "subjected to selection pressure for survival within artificial culture regimes"[78] and could potentially be derived from another stock. The hybridization of wild and hatchery salmon has the potential to reduce fitness and alter the genes of the population. The section on the protection of wild stocks outlines the steps to prevent

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[71] 5 AAC 40.140 and AAC 40.150
[72] AS 16.10.410 and AAC 40.210
[73] 5 AAC 40.170
[74] 5 AAC 40.220
[75] 5 AAC 40.240
[76] ADF&G, *FRED Special Report: Alaska Department of Fish & Game Genetic Policy*, by Bob Davis, Juneau: June 1985.
[77] ADF&G, *FRED Special Report,* 2.
[78] ADF&G, *FRED Special Report*, 5.

detrimental hatchery-wild interactions, such as limited introduction of hatchery fish into areas where they may have significant impact on wild runs, the reintroduction of hatchery fry that originated as wild gametes within one generation into a wild system for enhancement, and the establishment of wild stock sanctuary drainages for genetic protection.[79] Wild stock sanctuaries, which are described in the *Genetic Policy*, are watersheds where hatcheries are not allowed to allow the stocks there to be "'gene banks' of wild-type genetic variability."[80] The only regional planning team to establish wild stock sanctuaries is the Cook Inlet RPT.[81] The protection of wild stocks section emphasizes that the magnitude of straying, which is an indicator of the strays' potential to affect a wild population, is the "most important criterion" to protection of wild salmon.[82] The last section of the genetics policy, maintenance of genetic variance, provides hatcheries guidance on maintaining genetic variation through diversity among hatcheries, a minimum of 400 broodstock per spawn to promote genetic diversity, and spatial diversity in broodstock collection (collecting broodstock from different times during the salmon run).

Although policy strives to minimize impact and consequential interactions, because hatchery salmon are released into the wild instead of being penned until marketable size like farmed fish, there is little that can be done to control interactions once released. Hatchery salmon co-occur and may interact with wild salmon in every physical location—coastal shorelines, straits and bays, the Gulf of Alaska, and the North Pacific—they occupy post-release, but interaction doesn't guarantee an adverse effect on wild stocks.[83] In certain conditions, such as a years of large hatchery releases, hatchery fish can compete for food. Or if a diseased population is released from the hatchery they may spread the disease to wild salmon, although with the lower densities in a saltwater environment this is less likely than in smaller bodies of water with higher densities. Warming water temperatures may also have an effect on food availability and

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[79] ADF&G, *FRED Special Report,* 2-3.
[80] ADF&G, *Genetic Policy*, 7.
[81] ADF&G, *An Evaluation of the Neets Bay Salmon Hatchery for Consistency with Statewide Policies and Prescribed Management Practices*, by Mark Stopha, Anchorage, January 2017 (Regional Information Report No. 5J17-02): 7.
[82] ADF&G, *FRED Special Report,* 6.
[83] Fisheries and Oceans Canada, "Salmon Facts - Pacific Salmon," Pacific Region, modified December 12, 2017, http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especes/salmon-saumon/facts-infos-eng.html.

run timing intensifying potential interactions. Interactions can also be compounded when hatchery salmon stray, competing for spawning sites and interbreeding with wild salmon. Hatchery-wild hybrids are secondary stressors affecting wild salmon populations, as are limited food sources due to increased salmon populations in the North Pacific. The interactions of hatchery and wild salmon are many.

Ecological Response Analysis: Wild Salmon Production and Recruitment

COMPETITION FOR SPAWNING HABITAT BETWEEN HATCHERY AND WILD SALMON

Fisheries managers have limited tools to manage salmon runs on a statewide basis. Modeling and forecasting for future runs is a first step, and once the fish start returning, escapement counts are checked to those models. Escapement is a management term referring to how many fish escape marine mortality and return to a spawn habitat. Optimum escapement goals, set in Alaska by the Board of Fisheries at their meetings held from October to May each year, are "sustainable runs based on biological needs of the stock and ensure healthy returns for commercial, sport, subsistence, cost-recovery, and personal use harvests."[84] Managers at ADF&G use the escapement goals set by the Board of Fish to determine the length and timing of fishing seasons, schedules, and locations. Some saltwater sport fisheries are open year-round, but most commercial salmon fisheries have seasons and are bound by openers and closures. It is generally thought that a large escapement leads to greater abundance. The primary tools for salmon escapement estimates are aerial surveys and weir counts. Both methods use total numbers of fish; hatchery and wild are impossible to differentiate in either method.[85]

When hatchery salmon stray into wild salmon habitat, they complicate escapement estimates and potentially increase harvest pressure on wild salmon.[86] Hatchery strays inflate the wild salmon escapement counts; they essentially lower the total wild salmon passed to meet escapement goals because hatchery

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[84] Amy Carroll, "What are Escapement Goals?" *Alaska Fish and Wildlife News*, modified February 2005, http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=123.
[85] Brenner et al., "Straying of Hatchery Salmon," 193.
[86] Fred Utter, "Genetic Problems of Hatchery-Reared Progeny Released into the Wild, and How to Deal with Them," *Bulletin of Marine Science* 62, no. 2 (1998): 624.

strays are counted as wild which puts more hatchery strays and less wild salmon upstream.[87] In the Prince William Sound, Alaska, an area with significant hatchery influence on commercial fisheries, the Prince William Sound Comprehensive Salmon Management Plan, which was developed by the regional planning team, has a biological goal of less than 2% straying in a wild-hatchery escapement.[88] In the management plan, the planning team cited a loss of productivity and genetic variability in wild stocks when hatchery salmon stray. They also note that with the high levels of hatchery production in the region, "even relatively low straying rates of enhanced stocks may cause reduced genetic variability among affected wild stocks, because the straying rate as a proportion of wild-stock escapement is relatively high."[89] The plan, developed in 1994, also called for more research investigating the effects of strays on wild salmon productivity and a monitoring program to estimate hatchery straying and determine if hatchery production should be modified to reduce straying.[90] The state solicited proposals for its first study on hatchery strays almost 17 years later in 2011.

That study has shown that the average pink salmon straying in the Prince William Sound over a three-year span (2013-2015) is 9.67% hatchery-originated salmon present in wild stream counts, numbers well over the recommended threshold, and in Southeast Alaska, chum salmon were 7% hatchery-originated.[91] For example, Stockdale Creek in the Prince William Sound has an estimated salmon run of 30,000 fish,[92] and in 2017, the percent of strays was 9.5% or 2,850 strays. In 2013, that percent was

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[87] Ricardo O. Amoroso, Michael D. Tillotson, and Ray Hilborn, "Measuring the Net Biological Impact of Fisheries Enhancement: Pink Salmon Hatcheries Can Increase Yield, But with Apparent Costs to Wild Populations," *Canadian Journal of Fisheries and Aquatic Sciences* 74 (2017): 1240. DOI: 10.1139/cjfas-2016-0334.

[88] ADF&G, *Prince William Sound-Copper River Phase 3 Comprehensive Salmon Plan*, Oct 1994 (Pub No 23): vi.

[89] ADF&G, *Prince William Sound*, 26.

[90] ADF&G, *Prince William Sound*, 26.

[91] Ron Josephson, "State of Alaska Hatchery Research Project: A Study of the Interactions Between Hatchery and Natural Pink and Chum Salmon in Southeast Alaska and Prince William Sound Stream (Progress Synopsis May 2017)," accessed May 15, 2018, http://www.adfg.alaska.gov/static/fishing/PDFs/hatcheries/research/alaska_hatchery_research_project_synopsis_may_2017.pdf.

[92] Prince William Sound Science Center (PWSSC), *Interactions of Wild and Hatchery Pink Salmon in Prince William Sound: Final Report for 2017*, by Kristen Gorman, Julia McMahon, Peter Rand, Eric Knudsen, and David Bernard, April 26, 2018 (Alaska Department of Fish and Game Contract CT 160001756): 64.

significantly greater at 73.5% or 22,050 strays.[93,94] Because of the relatively close proximity of hatcheries in the Prince William Sound and large releases and returns at those hatcheries, there are overlapping zones of influence where different hatchery's strays can enter the same wild streams.[95] Most streams sampled had strays from two or three hatcheries.[96] Another example, in Southeast Alaska, hatchery strays have comprised from 44% to 78% of the escapement of the Indian River, a salmon spawning habitat located within a few miles of a hatchery.[97]

Once hatchery strays enter a watershed, they compete with wild salmon for spawning habitat. Studies have shown that limited spawning habitat can be an important factor in reproductive output.[98] Females may disturb or destroy another's redd if there aren't enough suitable spawning sites. An increase in strays heightens this risk.[99] Certain populations of strays, such as in some streams in the Prince William Sound, have occupied spawning grounds later in the run than wild salmon, which increases the chance the strays will disrupt previously spawned habitat.[100] There is also evidence that suggests reproductive success may be density dependent, although it has been difficult to test this theory in the field. Although a large wild salmon escapement may also increase the densities in spawning habitat, the result is wild competing with wild. When hatchery strays are responsible for the increased densities, the result may be wild competing with wild or hatchery. Studies have shown that straying salmon can greatly increase densities of nearby streams.[101]

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93 PWSSC, *Interactions: Final Report 2017*, 10.
94 Because the study is still in its early years, the large swings in stray numbers have yet to be attributed to any one cause or factor. In future years, there may be more insight into the difference in stray percentages.
95 Brenner et al., "Straying of Hatchery Salmon," 192.
96 Brenner et al., "Straying of Hatchery Salmon," 192.
97 Christopher J. Sergeant, J. Ryan Bellmore, Casey McConnell, and Jonathan W. Moore, "High Salmon Density and Low Discharge Create Periodic Hypoxia in Coastal Rivers," *Ecosphere* 8, no. 6 (June 2017): 12. DOI: 10.1002/esc21846.
98 Tillotson and Quinn, "Climate and Conspecific Density," 138.
99 Brenner et al., "Straying of Hatchery Salmon," 192.
100 Brenner et al., "Straying of Hatchery Salmon," 192.
101 Tillotson and Quinn, "Climate and Conspecific Density," 147.

Critically low dissolved oxygen levels, usually due to densities, discharge, or temperatures, may cause sudden die-offs in a spawning stream due to hypoxia.[102] Human-mediated actions, such as hatchery strays, intensify hypoxic events.[103] Increased escapement, whether hatchery or wild, increases the effect of salmon on their habitat. Physical and chemical characteristics of spawning habitat can be affected through the following processes: respiration, carcass decomposition, and nest building.[104] Spawning salmon respiration can cause hypoxia even in streams with cooler temperatures.[105] An increased carcass load in a stream decreases dissolved oxygen. Although carcasses that float downstream can create a barrier preventing more fish from entering the spawn habitat (which may help dissolved oxygen levels), the possibility of this happening is dependent upon habitat conditions.[106] Nest building also increases respiration and stirs sediments into the water column. When hypoxia occurs, the salmon in the stream die-off. Hypoxia-induced mortality leads to a decline in wild salmon productivity.[107] It has been hypothesized that hatchery strays may fill the gap in productivity over the following years since hatchery populations, being artificially spawned, aren't affected by these type of events.[108] Scientists are certain though that the frequency of hypoxic events will continue to increase due to warming temperatures and decreasing winter precipitation.[109]

Pre-spawning mortality (PSM), when most of the female's eggs haven't been spawned before she dies, has also been observed in spawning habitat with high densities of salmon.[110] Anadromous salmon stop feeding upon entering freshwater, so migration and spawn must happen with energy stores the fish has acquired in saltwater. Obstacles to the returning salmon's journey may deplete these reserves and limit

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[102] Eliason et al., "Cardiorespiratory Collapse at High Temperature in Swimming Adult Sockeye Salmon," *Conservation Physiology* 1 (2013): 2. DOI: 10.1093/conphys/cot008.
[103] Sergeant et al., "High Salmon Density," 11.
[104] Sergeant et al., "High Salmon Density," 2.
[105] Sergeant et al., "High Salmon Density," 10.
[106] Tillotson and Quinn, "Climate and Conspecific Density," 146.
[107] Sergeant et al., "High Salmon Density," 12.
[108] Sergeant et al., "High Salmon Density," 12.
[109] Sergeant et al., "High Salmon Density," 11.
[110] Tillotson and Quinn, "Climate and Conspecific Density," 139.

the fish's in-stream lifespan leading to PSM. The aerobic scope, the minimum and maximum oxygen uptake, of salmon can limit upstream migrations. Mortality from this situation isn't rapid suffocation, instead hens live longer but fail to deposit their eggs.[111] Lower oxygen availability (DO levels below 4 mg O_2/L for an extended period of time[112]) in spawning habitat also causes atypical behavior with fish staying near sources of oxygenated water instead of actively trying to spawn, which is a factor in the higher levels of PSM.[113] For those fish that do successfully spawn in these environments, dissolved oxygen and stream temperature may also affect hatch timing and the mortality of their eggs. Stress and competition for spawning habitat may also induce egg retention or PSM.[114] Other causes of PSM are disease and physiological or environmental stressors, such as high temperatures (temps upwards of 16.5℃ for an extended period of time[115]).

Although this study does not investigate the effects of climate change on salmon populations because of the breadth and nuance required to adequately discuss the topic, it is worth mentioning a few scientifically observed effects that have shown to intensify hatchery and wild interactions.[116] Over the last 60 years, Alaska has warmed at "more than twice the rate of the rest of the United States."[117] This had led to a host of changes for salmon habitat including rising spawning stream water temperatures, increased discharge in fall and winter (due to those seasons becoming warmer and wetter which leads to streambed scour when fry and eggs are at their most vulnerable), and melting glaciers.[118] In one study, all of the 347 Southeast Alaska glaciers studied from 1948 to 2009 had receded, with a 23% loss in overall glaciated

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111 Tillotson and Quinn, "Climate and Conspecific Density," 145.
112 Tillotson and Quinn, "Climate and Conspecific Density," 139.
113 Tillotson and Quinn, "Climate and Conspecific Density," 145.
114 Brenner et al., "Straying of Hatchery Salmon," 192.
115 Geist et al., "Survival, Development, and Growth of Fall Chinook Salmon Embryos, Alevins, and Fry Exposed to Variable Thermal and Dissolved Oxygen Regimes," *Transactions of the American Fisheries Society* 135, no. 6 (2006): 1462. DOI: 10.1577/T05-294.1.
116 Schoen et al., "Future of Pacific Salmon in the Face of Environmental Change: Lessons from One of the World's Remaining Productive Salmon Regions," *Fisheries* 42, no. 10 (2017): 553. DOI: 10.1080/03632415.2017.1374251.
117 Schoen et al., "Future of Pacific Salmon," 543.
118 Schoen et al., "Future of Pacific Salmon," 540.

area.[119] Rivers in Alaska are also projected to experience warmer water temperatures and more extreme low flows in summer months.[120,121] The optimal temperature window for performance, T_{opt}, has been shown to be locally adapted to salmon populations.[122] Post-fatigue mortality (mortality caused by exhaustion in high temperatures) in sockeye salmon has occurred at only 3-5°C above T_{opt}.[123] Since the 1950s, summer river temperatures have warmed by around 2°C.[124] And "water oxygen content decreases by around 2% $°C^{-1}$ with increasing water temperature,"[125] limiting oxygen availability. Increasing water temperatures due to climate change may significantly affect salmon in Alaska by causing density-dependence mortality to become more prevalent.[126]

Lower discharge and dissolved oxygen due to climate change will also lower the carrying capacity of spawning streams.[127] Carrying capacity of spawning streams can be difficult to measure because it can vary over time due to factors like streamflow.[128] Research into carrying capacity can provide managers with insight into potential limitations on reproductive success of salmon populations and identify climatic variables that may affect carrying capacity. Species each have their own carrying capacity within a spawning habitat which is limited by their physiological characteristics. Those species that spend less time in freshwater as fry, like chum, sockeye, and pink, can spawn at higher densities. Although, in certain parts of Alaska like the Prince William Sound, their spawning habitat is limited to narrow intertidal areas which are more sensitive to density-dependent effects.[129] Coho and chinook need more freshwater space

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[119] Schoen et al., "Future of Pacific Salmon," 544.
[120] Tillotson and Quinn, "Climate and Conspecific Density," 147.
[121] Bett et al., "Causes and Consequences of Straying into Small Populations of Pacific Salmon," *Fisheries* 42, no. 4 (2017): 223. DOI: 10.1080/03632415.2017.1276356.
[122] Eliason et al., "Cardiorespiratory Collapse," 2.
[123] Eliason et al., "Cardiorespiratory Collapse," 1.
[124] Eliason et al., "Cardiorespiratory Collapse," 2.
[125] Eliason et al., "Cardiorespiratory Collapse," 12.
[126] Tillotson and Quinn, "Climate and Conspecific Density," 146.
[127] Tillotson and Quinn, "Climate and Conspecific Density," 147.
[128] Tillotson and Quinn, "Climate and Conspecific Density," 138.
[129] Brenner et al., "Straying of Hatchery Salmon," 192.

because of the limitations on food availability for fry in freshwater.[130,131] Social factors in crowded habitats may prohibit spawning as well.[132] Juvenile salmonids are territorial by nature, and as the number of fry within a stream increases, so does competition for food[133] (Figure 10). Studies have shown that space is also a factor on fry survival: "many populations of salmonids appeared to thin at gradients consistent with space being the factor that limited carrying capacity."[134] Conditions in freshwater, such as food availability, may influence smolt size and survival at sea.[135]

One positive density-dependence scenario produced by hatchery strays is that high densities may reduce the chance of individual deaths.[136] With an increased food supply for predators, the wild salmon may have better survival reaching their spawning grounds although this is difficult to study in the field.

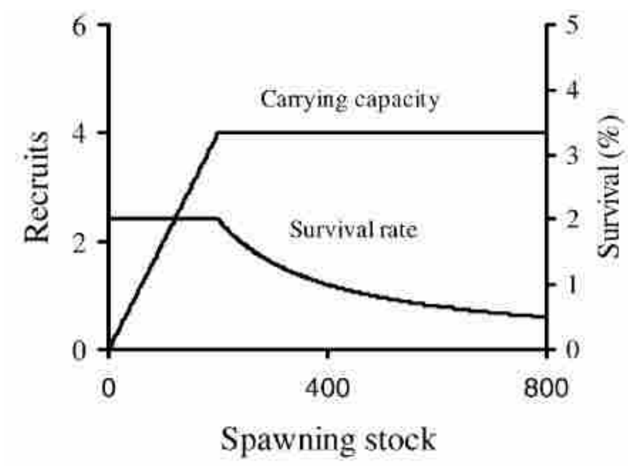

Figure 10. Recruitment constrained by carrying capacity, showing survival rate (% egg to recruit) changing with spawning stock

N.J. Milner et al., "The Natural Control of Salmon and Trout Populations in Streams," *Fisheries Research* 62, no. 2 (May 2003): 114.

DEMOGRAPHIC RESCUE

A small portion of salmon show a tendency to stray.[137] Natural straying in salmon populations has allowed salmon to inhabit areas once covered with glaciers and to spread throughout watersheds from the Atlantic Ocean to the North Pacific. Scientists believe that low levels

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[130] Tillotson and Quinn, "Climate and Conspecific Density," 138.
[131] Milner et al., "The Natural Control of Salmon and Trout Populations in Streams," *Fisheries Research* 62 (2003): 112. DOI: 10.1016/S0165-7836(02)00157-1.
[132] Tillotson and Quinn, "Climate and Conspecific Density," 145.
[133] Milner et al., "The Natural Control," 114.
[134] Milner et al., "The Natural Control," 117.
[135] Milner et al., "The Natural Control," 111-12.
[136] Milner et al., "The Natural Control," 115.
[137] Bett et al., "Causes and Consequences," 221.

of natural straying in wild populations may be beneficial for the longevity of salmon populations in an area.[138] The tendency to stray has also led to demographic rescue (when straying populations save declining populations from extirpation).[139] Demographic rescue can also refer to the supplementation of small populations with low genetic diversities[140] providing a critical influx of new genes to that population.[141] Demographic rescue may also prove to be beneficial as water temperatures continue to warm, providing fish to an area where populations may not be able to adapt.[142] Although natural straying seems to provide benefits to local populations, there is little evidence to support the same conclusions for hatchery strays. Risks of hatchery strays include genetic introgression inducing a loss of fitness in wild populations [refer to section Ecological Response Analysis: Wild Salmon Fitness] and the introduction of foreign pathogens into a local population. A study on chinook, coho and steelhead in Oregon, Washington, and Idaho found that natural reproduction declines as the ratio of hatchery spawners to wild increases.[143] Studies on chinook in Washington have shown that the reproductive success of hatchery male strays was significantly less than their wild counterparts.[144] These results indicated that the risk of fitness costs, "-30% one generation after hatchery propagation,"[145] was not worth the demographic benefit. Other studies have also found fitness decline within one or two generations of hatchery breeding.[146] The potential genetic risks of strays outweigh the benefits of demographic rescue.

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[138] Brenner et al., "Straying of Hatchery Salmon," 189.
[139] Bett et al., "Causes and Consequences," 221.
[140] Brenner et al., "Straying of Hatchery Salmon," 179.
[141] Bett et al., "Causes and Consequences," 222.
[142] Bett et al., "Causes and Consequences," 222-24.
[143] M.W. Chilcote, K.W. Goodson, and M.R. Falcy. "Reduced Recruitment Performance in Natural Populations of Anadromous Salmonids Associated with Hatchery-Reared Fish," *Canadian Journal of Fisheries and Aquatics Sciences* 68 (2011): 518. DOI: 10.1139/F10-168.
[144] Anderson et al., "Reproductive Success of Captively Bred and Naturally Spawned Chinook Salmon Colonizing Newly Accessible Habitat," *Evolutionary Applications* (2013): 165. DOI: 10.1111/j.1752-4571.2012.00271.x.
[145] Anderson et al., "Reproductive Success," 175.
[146] Anderson et al., "Reproductive Success," 166.

Ecological Response Analysis: Wild Salmon Fitness

HATCHERY STRAYS LEAD TO GENETIC INTROGRESSION

Because hatcheries utilize artificial breeding and simulated incubation and rearing environments that promote high rates of survival, progeny exhibiting the traits that favor these environments, even without artificial selection for these traits, will be favored.[147] This is called domestication.[148] Domestication can occur in hatchery salmon within a few generations with substantial adaptation to the hatchery setting occurring after a single generation.[149,150] Degree of domestication is dependent on the number of generations a hatchery fish is removed from wild genetics (most hatcheries in Alaska have been using the same broodstock since the late 1970s to mid 1980s), the selection regimes of the hatchery, and the genetic variation responsible for the fitness of a stock.[151] (Studies have shown though that even when using wild broodstock to supplement hatchery eggtakes, as is practice in some Pacific northwest hatcheries, negative genetic effects still occur due to domestication.[152])

Domestication of hatchery fish leads to concerns when hatchery and wild salmon interbreed.[153] Hybridization of hatchery and wild salmon can decrease the fitness of wild stocks.[154] Fitness, the ability for an animal to survive and reproduce, is a genetically adapted trait in salmon. Different stocks of salmon have become adapted to their environment. For example, certain runs of pink salmon have adapted to spawn in intertidal, brackish areas and others are adapted spawn in freshwater rivers. Some stocks of king salmon have adapted to forgo their year in freshwater and migrate out to saltwater during their first year of life, called zero-checking. Stocks are adapted to the specific environment they're born in and return to.

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147 Utter, "Genetic Problems," 634.
148 Hayes et al., "Effectiveness," 147. - need to add to bibliography
149 Christie et al., "A Single Generation of Domestication Heritably Alters the Expression of Hundreds of Genes," *Nature Communications* (Feb 17, 2016): 2.
150 Hitoshi Araki, Barry A. Berejikian, Michael J. Ford and Michael S. Blouin, "Fitness of Hatchery-Reared Salmonids in the Wild," *Evolutionary Applications* (2008): 342. DOI: 10.1111/j.1752-4571.2008.00026.x.
151 Naish et al., "Evaluation," 104.
152 Naish et al., "Evaluation," 104.
153 Naish et al., "Evaluation," 111.
154 Utter, "Genetic Problems," 626.

Within a single species, there is an array of genetic differences due to adaptation ("several gene loci interact with each other and with the environment to create a range of phenotypes"[155,156]).

Hatchery salmon have adapted to their rearing environment as well. The high density rearing containers or net pens that are relatively protected from predators are often a poor imitation of natural conditions.[157] Increased fitness for hatchery survival has manifested itself through adaptation in "wound healing, immunity and metabolism," which are all responses to dense rearing environments.[158] When wild and hatchery steelhead were spawned in a hatchery, the hatchery steelhead lifetime spawning success was nearly double the wild steelhead.[159] On a study of chinook in Washington, scientists detected 226 unique loci associated with six heritable traits determining fitness: spawn timing, return timing, fork length (measurement from the snout to the 'v' in the tail), weight, age at maturity, and daily growth coefficient.[160] Significant phenotypic differences were seen in hatchery and hatchery-wild hybrid chinook in spawn timing weight and daily growth coefficient.[161] None of the traits changed genetically over time, although they cite their sample size shortcomings (no wild chinook sampled as a control and the use of only two generations of hatchery and hatchery-wild hybrids) as an explanation for their results.[162] Even with the observed lack of genetic change in fitness traits, the study concluded that with current evidence ("phenotypic divergence, greater overlap with outliers in the segregated line than in the integrated line, and temporal consistency"), domestication selection was affecting return and spawn timing.[163] In studies of steelhead, Christie et al. found a difference of 723 gene expressions between hatchery and wild steelhead. Their data suggests that in the initial stages of domestication, large heritable changes to gene

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155 Quinn, "Homing and Straying," 29. - look up if in bib
156 Naish et al., "Evaluation," 101.
157 Naish et al., "Evaluation," 101.
158 Christie et al., "Single Generation," 1.
159 Christie et al., "Single Generation," 2.
160 Waters et al., "Genomewide Association Analyses of Fitness Traits in Captive-Reared Chinook Salmon: Applications in Evaluating Conservation Strategies," *Evolutionary Applications* (2017): 7. DOI: 10.1111/eva.12599.
161 Waters et al., "Genomewide," 12.
162 Waters et al., "Genomewide," 12.
163 Waters et al., "Genomewide," 12.

expression occur in hatchery steelhead.[164] Other studies on steelhead showed fish that grew faster (size is heritable) had a selective advantage post-release; they also showed that hatchery steelhead grew faster and had better survival than wild steelhead.[165] Faster growth in salmonid species can lead to earlier maturation and, in turn, earlier returns. Earlier maturation may affect a fish's ability to compete for spawning sites.[166] The reproductive success of hatchery steelhead was 85% of wild steelhead when spawning in the wild.[167] Maturation also happens at different rates in the two sexes; males mature faster. When males mature faster and return earlier than the females there is a mismatch in male to female ratio on the spawning ground.[168]

A management concern with rapid domestication is that adaptation to a hatchery rearing environment can come with the loss of traits beneficial to the natural environment, decreasing the fitness for natural rearing through phenotypic changes and altered gene frequencies.[169,170] The reduction of fitness is detrimental to wild genetics and potentially disruptive to that stocks' sustainability.[171] When a drop in fitness occurs because of wild-hatchery hybridizations (called outbreeding depression), two main outcomes are possible: ecological outbreeding depression (the loss of local adaptation) and physiological outbreeding depression (the interruption of co-adapted genetic loci responsible for fitness traits).[172] Changes in fitness can be seen in predator avoidance, agonistic behavior, and lower reproductive success in the wild.[173] Other mechanisms that might affect fitness are an enhanced "mutation rate, relaxation selection, chromosomal abnormality, and epigenetic effects."[174] A loss in genetic variability among populations, which has been documented in salmon populations outside of Alaska, is also of major

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164 Christie et al., "Single Generation," 2.
165 Hayes et al., "Effectiveness," 156.
166 Anderson et al., "Reproductive Success," 166.
167 Christie et al., "Single Generation," 2.
168 Naish et al., "Evaluation," 102.
169 Hayes et al., "Effectiveness," 155.
170 Brenner et al., "Straying of Hatchery Salmon," 179-180.
171 Anderson et al., "Reproductive Success," 166.
172 Naish et al., "Evaluation," 108.
173 Araki et al., "Fitness of Hatchery-Reared Salmonids," 342.
174 Araki et al., "Fitness of Hatchery-Reared Salmonids," 352.

concern.[175] Wild populations can be replaced by hybrid populations.[176] Studies have shown a convergence of allele frequencies of wild salmon toward hatchery allele frequencies when the two interbreed.[177] Pressure on allele frequencies happens equally between neutral and adaptive genes in the wild populations causing introgression because of the hatchery allele frequencies present in wild-stray offspring.[178] Adapted genetic distinction among stocks is important for the species continued survival.[179] Most studies conclude that more research is needed into genetic introgression, especially over an extended period of time.[180]

The degree to which hatchery salmon influence wild stocks and the impact of these interactions on the wild gene pool depends on a few factors such as survival of the offspring and degree of interbreeding.[181] In studies of hatchery and wild chum salmon in the Prince William Sound, Jasper et al. found that proximity to the hatchery and magnitude of straying were not as large a factor as was the similarity in run timing of the wild stock and strays.[182] Other models have shown that magnitude of straying does have an impact: over a 10% threshold of hatchery strays may lead to a significant loss in fitness.[183] Again, more research is necessary to determine the degree of hatchery stray influence on adapted genetics.

HATCHERY-WILD INTERBREEDING AFFECTS THE RUN TIMING OF WILD STOCKS

The timing of migration (also called run or return timing) is a heritable trait that can also be affected by the influence of hatchery genetics on wild stocks.[184,185] Timing of migration is incredibly

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175 Utter, "Genetic Problems," 623.
176 Brenner et al., "Straying of Hatchery Salmon," 189.
177 Jasper et al., "Source-Sink," 10.
178 Jasper et al., "Source-Sink," 10. - find out if this is in the bib
179 Utter, "Genetic Problems," 626.
180 Brenner et al., "Straying of Hatchery Salmon," 189.
181 Quinn et al., "Homing and Straying," 29
182 Jasper et al., "Source-Sink," 10.
183 Michael J. Ford, "Selection in Captivity During Supportive Breeding May Reduce Fitness in the Wild," *Conservation Biology* 16, no. 3 (June 2002): 823. DOI: 10.1371/journal.pone.0081916.
184 Hayes et al., "Effectiveness," 156.
185 Waters et al., "Genomewide," 2.

important to individual stocks because spawn success is in part environmentally dependent. Stream discharge and temperature vary from year to year and seasonally as well. Spawning success is dependent upon certain limits of streamflow and temperature.[186] Hatchery practices, such as spawning the first salmon that return to the hatchery, may shift run timing.[187] Some hatcheries mass collect broodstock within a few days using the fishing fleet to move salmon into a holding area. The practice ensures that adequate broodstock are collected and accomplishes collection within a day or two instead of paying employees to count fish as they pass into the holding area on their own over the course of a few weeks. The practice also eliminates variation in the timing of future runs. A study of pink salmon in Southeast Alaska has shown that the main factor contributing to return timing was the date of spawn.[188] That study also suggested that 40% of return timing variation within a population of salmon is due to interacting genes, although they think this estimate is high.[189] Another study on Atlantic salmon showed a larger number of wild salmon (versus hatchery salmon) returning in the fall.[190] A shift in the run timing of the salmon stock may put hybrid progeny on the spawning ground at a non-optimal time.

Return timing is important to the fitness of salmon stocks.[191] The seasonal variability of spawning habitat makes certain times better for spawning than others. In the height of summer, low water flows and low DO levels may prevent successful spawning, and during autumn, high river levels can wash redds out. Also affecting redds is the return of later-run salmon. The eggs of early spawners may not experience disturbance to the extent that mid-run salmon do because the eggs are able to reach the eyed stage (the stage when disturbance will not kill the developing salmon) preserving early run alleles in that portion of

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186 William W. Smoker, Anthony J. Gharrett, and Michael S. Stekoll, "Genetic Variation of Return Date in a Population of Pink Salmon: A Consequence of Fluctuating Environment and Dispersive Selection?" *Alaska Fishery Research Bulletin* 5, no. 1 (1998): 46.
187 Smoker et al., "Genetic Variation," 46.
188 Smoker et al., "Genetic Variation," 51.
189 Smoker et al., "Genetic Variation," 51.
190 Hayes et al., "Effectiveness," 156.
191 Smoker et al., "Genetic Variation," 51.

the run before late returning or high densities on the spawning ground are seen.[192] Late run salmon eggs also have the benefit of increased survival because they aren't exposed to redd superimposition. Broodstock may superimpose their redd on top of another's, potentially killing the other redd but successfully spawning their own.[193] Redd superimposition causing considerable density dependent mortality in pink salmon has been documented.[194] Return timing also affects the timing of fry emergence which in turn affects fitness.[195] Fry emerge a set period after the eggs are spawned, so an early or late spawn might affect food availability to fry during their critical growth period post-yolk sack. A disturbance of adapted run timing through hybridization has the possibility to alter adult returns to a spawn time less suitable for that environment. Researchers have recognized that the variability of run timing and life history traits in general are crucial to the fitness of wild salmon stocks and encourage the conservative management of hatcheries to minimize potential interactions and interbreeding of wild and hatchery salmon.[196]

Ecological Response Analysis: Disease-Free Wild Salmon Populations

HATCHERY SALMON ARE MORE LIKELY TO CARRY DISEASE

Pathogens that cause disease are naturally occurring in salmon populations in Alaska, but there is concern that hatchery salmon may amplify current levels of disease or infect wild salmon populations.[197] All species live with a broad array of pathogens; presence alone does not always lead to disease.[198] When disease does occur, the resulting outcomes for the host fish are mortality, recovery and/or become a carrier of the disease.[199] Several factors come into play to determine the outcome: "species, stock, age,

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[192] Smoker et al., "Genetic Variation," 52.
[193] Smoker et al., "Genetic Variation," 52.
[194] Smoker et al., "Genetic Variation," 52.
[195] Smoker et al., "Genetic Variation," 51.
[196] Smoker et al., "Genetic Variation," 53.
[197] Naish et al., "Evaluation," 141.
[198] Naish et al., "Evaluation," 141.
[199] Naish et al., "Evaluation," 141.

immune status and nutritional state" of the host and "virulence, number and strain" of the pathogen.[200] Environmental factors, such as stressors like adverse water quality and high water temperatures, also affect the host-pathogen balance among salmon stocks.[201] Anthropogenic stressors, like climate change or altered water flows, may compound environmental stressors. Disease has been incredibly difficult to study in wild populations especially in the ocean, because many diseases occur at low levels.[202] Although all pathogens within the state originate from wild salmon populations,[203] the hatchery provides an environment for disease to spread easily because of the high densities in rearing containers, higher stress levels from the higher densities and periodic container transfer, and poorer water quality.[204] Domestication may also lead to higher susceptibility of disease because of lower levels of genetic diversity.[205]

HATCHERY SALMON EXPOSE WILD SALMON TO DISEASE

Concerns over the spread of disease from hatchery to wild salmon arise when hatchery salmon in Alaska come into contact with wild populations. A potential avenue for the spread of pathogens is the transfer or deliberate movement of hatchery salmon from one body of water to another.[206] As a precautionary method, most hatcheries that actively transport salmon fry to other areas self-impose stricter fish health standards and practices to prevent the transfer of pathogens.[207] Another area where hatcheries have been found to impact the health of wild salmon is through a point source infection.[208] In other states where salmon are cultured, the hatchery effluent emptying into small water bodies can

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[200] Naish et al., "Evaluation," 141.
[201] Naish et al., "Evaluation," 141.
[202] Naish et al., "Evaluation," 143.
[203] Naish et al., "Evaluation," 142.
[204] Carl F. Mazur and George K. Iwama, "Effect of Handling and Stocking Density on Hematocrit, Plasma Cortisol, and Survival in Wild and Hatchery-Reared Chinook Salmon (*Oncorhynchus tshawytscha*)," *Aquaculture* 112 (1993): 291.
[205] Naish et al., "Evaluation," 143.
[206] Naish et al., "Evaluation," 144.
[207] Naish et al., "Evaluation," 144.
[208] Naish et al., "Evaluation," 144.

increase the presence and quantities of pathogens in the area.[209] In Alaska, the location of production hatcheries on larger bodies of water and the species raised eliminates most of these concerns. The largest Alaskan hatcheries mainly rear chum and pink which spend very little time in freshwater and are in saltwater during the most disease-susceptible life stage, so hatchery effluents are not a significant enough source for a point source infection.

Of more concern in Alaskan water is the release of infected hatchery fish that come into contact with wild salmon.[210] One of the ways to prevent mortality at hatcheries due to fast-spreading diseases like *Vibrio* is to release the susceptible population into the wild where densities are considerably lower. Another scenario that happens within Alaskan waters is the release of a known infected population of hatchery salmon. Hatchery fish may be carriers of a chronic disease like bacterial kidney disease (BKD) and are still released into the wild. Both of these scenarios (release of susceptible populations and known carriers) have been documented at hatcheries in Southeast Alaska.[211] Hatchery fish may also serve as reservoirs of pathogens.[212] Wild populations in an area may be eliminated by the presence of a virulent disease eventually eliminating the infected hosts and disease from that stock; whereas, hatchery salmon have a protected rearing and spawning environment, making it easier for sick fish to avoid predators, find food, and spawn. Hatchery salmon may also act as reservoirs when hatcheries are located on water sources that contain low levels of certain pathogens in naturally occurring species in the lake that are amplified by the large quantities of hatchery salmon reared within the infected water. For example, BKD is present in some species of trout in Hidden Falls Lake. A wild salmon population wasn't able to become established at in the freshwater habitat below the lake because of an 80-foot waterfall. The hatchery, put in that location because there wasn't a naturally occurring salmon stock, uses the lake as a source for their water supply without filtration. All hatchery salmon reared in freshwater are then exposed to low levels of BKD.

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[209] Naish et al., "Evaluation," 144.
[210] Naish et al., "Evaluation," 145.
[211] Personal communication with hatchery staff.
[212] Naish et al., "Evaluation," 145.

Without the hatchery releasing potentially BKD positive coho and chinook, there would be no BKD present in this area of Chatham Strait. Lastly, the potential for the domestication of hatchery salmon and reduced fitness to increase the likelihood of disease susceptibility is a concern for wild stocks.[213] Part of a reduction in fitness may correlate with preventative methods used to control disease in the hatchery, such as ultraviolet filters to ensure better water quality, leading to relaxed selection.[214] Relaxed selection becomes a concern when hatchery strays interbreed with wild stocks.[215]

However, much of the risk outlined above is speculatory. Although estimates for the effect of hatchery salmon on wild salmon populations, there is very little concrete evidence of many of the processes listed above occurring because of the difficulty studying disease on wild salmon in the field. Most of the research on salmon diseases is actually conducted on salmon at hatcheries because they are an easier population to study and there is a vested interest in eliminating mortality due to disease in the hatchery environment.[216] Because most of the research on disease has taken place at hatcheries, there is a misconception that disease is a common hatchery occurrence.[217] Hatcheries also rear salmon during the life stages when they are most susceptible to disease: fry and juveniles.[218] And when disease is present in an space that both wild and hatchery salmon occupy, it is near impossible to determine the population which carried the pathogen.[219] Nevertheless, hatchery rearing conditions make hatchery salmon more susceptible to disease,[220] and it is likely that in areas with a large hatchery presence, hatchery salmon have an effect on wild salmon populations and may spread pathogens to those stocks.

More research on disease would help clarify the following knowledge gaps: levels present and distribution of pathogens in the natural environment, genetic resistance to disease and heritability, genetic

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[213] Naish et al., “Evaluation,” 146.
[214] Naish et al., “Evaluation,” 146.
[215] Naish et al., “Evaluation,” 146.
[216] Naish et al., “Evaluation,” 143.
[217] Naish et al., “Evaluation,” 143.
[218] Naish et al., “Evaluation,” 143.
[219] Naish et al., “Evaluation,” 145.
[220] Mazur and Iwama, “Effect of Handling,” 291-92.

variation required to maintain healthy populations, the role of domestication in relaxation of disease-resistant genetics, potential vaccines to prevent disease from infecting hatchery populations, and best practices to reduce disease in hatcheries, such as filtration systems, disinfection, and stress reduction.[221]

Ecological Response Analysis: North Pacific Ecosystem and Food Web

INCREASES IN HATCHERY SALMON PRODUCTION DECREASE FOOD AVAILABILITY FOR WILD SALMON

Pacific salmon spend most of their life in the marine environment, a period responsible for more than 95% of their growth.[222] Post-release from the hatchery (approx. 6 months after hatch for chum, pink, and sockeye and 18 months for chinook and coho) all salmon in Alaska, hatchery and wild, inhabit the same water. Hatchery and wild salmon use the same migration routes and compete for the same food sources. Food availability is incredibly important for growth and survival. Chum, pink and sockeye share common migratory patterns and prey at sea,[223,224] such as copepods, amphipods, euphausiids, pteropods, myctopids, small fishes, and squid,[225] making each species more vulnerable to increases in the other.[226] Studies have shown that significant increases in hatchery releases have added pressure to the North Pacific ecosystem and may negatively impact wild chum, pink, and sockeye salmon marine survival.[227,228] The high densities of hatchery fish compete for food, effectively reducing food availability for wild fish, which

[221] Naish et al., "Evaluation," 148-49.
[222] Johnson and Schindler, "Trophic Ecology," 855.
[223] Gregory T. Ruggerone and Brendan M. Connors, "Productivity and Life History of Sockeye Salmon in Relation to Competition with Pink and Sockeye Salmon in the North Pacific Ocean," *Canadian Journal of Fisheries and Aquatics Sciences* 72 (2015): 819. DOI: 10.1139/cjfas-2014-0134.
[224] Johnson and Schindler, "Trophic Ecology," 855.
[225] Johnson and Schindler, "Trophic Ecology," 856, 860.
[226] Distinct from chum, pink, and sockeye are chinook and coho, species that remain in a coastal environment longer than a pelagic one. Chinook and coho share some degree of trophic overlap in both coastal and pelagic environment (from Johnson and Schindler, "Trophic Ecology," 861).
[227] Springer and van Vliet, "Climate Change," E1886.
[228] Johnson and Schindler, "Trophic Ecology," 861.

leads to negative consequences for wild salmon populations.[229] Given the multiyear period spent at sea, a broodyear of hatchery releases may affect the North Pacific in multiyear cycles.[230] Starting in the 1970s, global hatchery production began to increase considerably (Figure 11). In 1970, total hatchery releases for the four top producing countries, United States (including Alaska), Japan, Russia, and Canada, was 857 million salmon.[231] By 2016 production had increased almost six-fold with hatcheries releasing 5.1 billion salmon.[232] Of those 5.1 billion fry released, chum were the most plentiful (3.3 billion), and at 1.2 billion, pink salmon were the second highest species produced.[233] Pink salmon are the most abundant wild Pacific salmon as well, representing approximately 70% of returning adult wild salmon each year in their range.[234]

Several studies have determined that "pink salmon can influence the diet, growth, distribution, age at maturation, and survival of other Pacific salmon"[235] by affecting the standing crop of macrozooplankton[236] and squid availability.[237] In the Prince William Sound, where the greatest production of pink salmon takes place, studies have shown reduced returns of wild pink salmon and reduced growth in those that do return because of limitations on food availability due to hatchery releases.[238] Wild pink salmon fry migrating downstream into the Prince William Sound are met with millions of released hatchery fry all competing for the same food sources.

Hatchery pink salmon also compete with other salmon species for food in the North Pacific. In the early 1990s, scientists began questioning the North Pacific Ocean's salmon carrying capacity. Significant differences in "diets, growth, condition, distribution, and catch" of chum, pink, and sockeye were observed in even versus odd years, suggesting that the abundance of pink salmon in odd years may

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[229] Johnson and Schindler, "Trophic Ecology," 861.
[230] Springer and van Vliet, "Climate Change," E1886.
[231] North Pacific Anadromous Fish Commission (NPAFC), "NPAFC Pacific Salmonid Hatchery Release Statistics," Catch and Hatchery Statistics, updated July 31, 2017, www.npafc.org/new/science_statistics.html.
[232] Ibid.
[233] Ibid.
[234] Springer and van Vliet, "Climate Change," E1881.
[235] Ruggerone and Connors, "Productivity and Life History," 819.
[236] quoted in Ruggerone and Connors, "Productivity and Life History," 829.
[237] Ruggerone and Connors, "Productivity and Life History," 829.
[238] Ruggerone and Connors, "Productivity and Life History," 831.

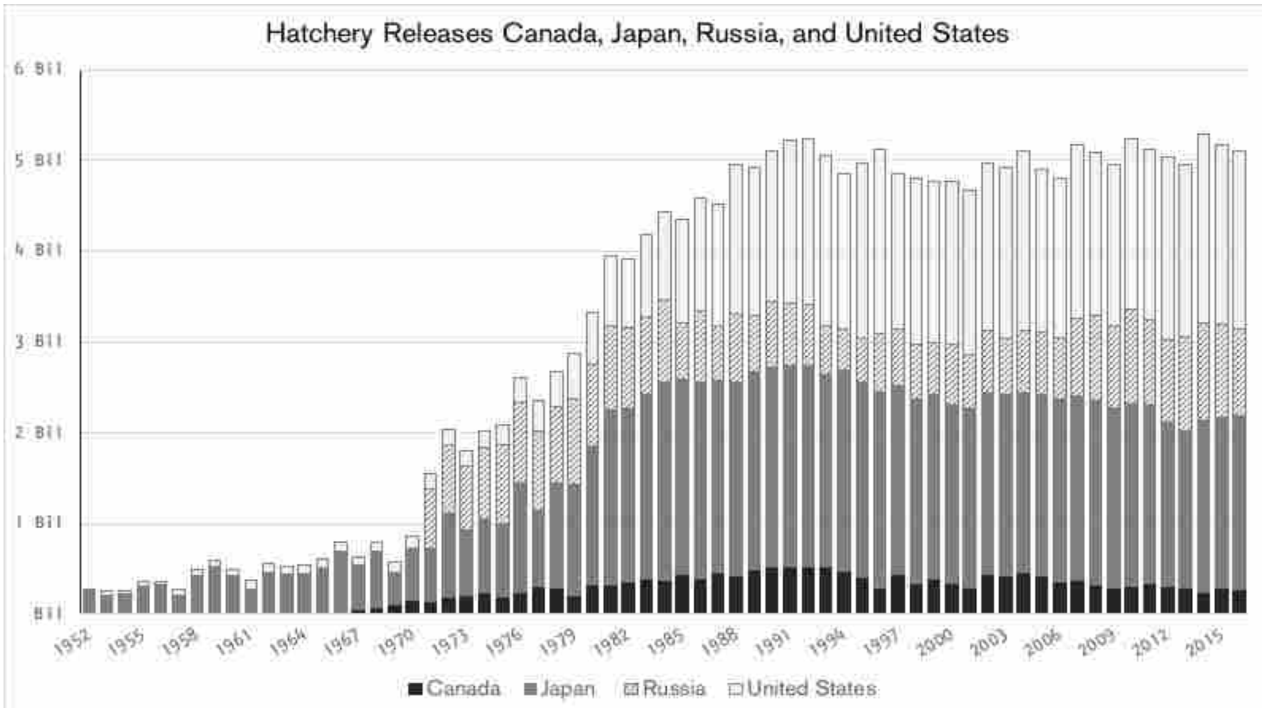

Figure 11. Hatchery Releases Canada, Japan, Russia, and United States, 1952-2016 created with data from NPAFC, "NPAFC Pacific Salmonid Hatchery Release Statistics," Vancouver, last updated July 31, 2017, www.npafc.org/new/science_statistics.html

be influencing production.[239] One model showed that annual coastal and oceanic salmon food consumption tripled post-hatchery production increases.[240] More abundant than other species—from 1952 to 2005, adult pink were 4.7 times more abundant than sockeye[241]—they've begin to affect the North Pacific food web from a top-down position. During odd years, scientists observed depressed levels of macrozooplankton, a primary prey of pink salmon; the depression of zooplankton led to less grazing pressure on and elevated numbers of phytoplankton.[242] By affecting the food web in the North Pacific, pink salmon foraging has had inter- and intra-species effects as well.[243] Sockeye stocks' growth and survival has declined in years with large pink runs in areas of the North Pacific and Bering Sea where the

[239] Springer and van Vliet, "Climate Change," E1881.
[240] quoted in Johnson and Schindler, "Trophic Ecology," 861.
[241] Ruggerone and Connors, "Productivity and Life History," 819.
[242] Springer and van Vliet, "Climate Change," E1881.
[243] Johnson and Schindler, "Trophic Ecology," 856.

two species spatially overlap.[244] Bristol Bay sockeye growth and adult abundance were inversely related to Russian pink salmon levels which scientists hypothesize is due to the competition for food while at sea.[245] Statewide, sockeye salmon populations have declined with the increasing abundance of pink salmon.[246] Abundance of pink salmon has also been shown to affect the diets of chum salmon. In odd years, when pinks are significantly more abundant due to their biennial cycle, chum salmon diets in the North Pacific are primarily "gelatinous taxa such as pteropods, appendicularia, and coelenterates," prey that contains lower lipid levels than their even year diet of copepods, euphausiids, and other crustaceans.[247] Pink salmon predation has a depressing effect on crustacean biomass.[248] Both chum and sockeye diets in the North Pacific show different levels of important, high lipid prey in even and odd years.[249] This diet, controlled by density related food availability, has an effect on growth of salmon at sea and maturation timing.[250] Both reduced growth and delayed maturation can lead to lower survival.[251]

Also affecting salmon productivity is temperature in the North Pacific.[252,253,254] Ocean temperatures in the western Bering Sea and North Pacific have been steadily rising since the middle of last century.[255] Those warmer temperatures correspond to salmon displaying faster growth at sea which leads to earlier maturation.[256] Salmon are ectotherms; their body temperatures are subject to environmental temperatures. Warmer water temperatures increase their metabolism and metabolic demands and also

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[244] Johnson and Schindler, "Trophic Ecology," 856.
[245] Ruggerone and Connors, "Productivity and Life History," 819.
[246] Ruggerone and Connors, "Productivity and Life History," 826.
[247] Springer and van Vliet, "Climate Change," E1885-86.
[248] Springer and van Vliet, "Climate Change," E1885-86.
[249] Springer and van Vliet, "Climate Change," E1885-86.
[250] Ruggerone and Connors, "Productivity and Life History," 828.
[251] Ruggerone and Connors, "Productivity and Life History," 831.
[252] Ruggerone and Connors, "Productivity and Life History," 819.
[253] Siegel, McPhee, and Adkison, "Marine Temperatures," 441.
[254] Franz J. Mueter, Randall M. Peterman, and Brian J. Pyper, "Opposite Effects of Ocean Temperature on Survival Rates of 120 Stocks of Pacific Salmon (*Oncorhynchus* spp.) in Northern and Southern Areas," *Canadian Journal of Fisheries and Aquatics Sciences* 59 (2002): 456. DOI: 10.1139/F02-020.
[255] Springer and van Vliet, "Climate Change," E1886.
[256] Siegel, McPhee, and Adkison, "Marine Temperatures," 441.

potential for growth.[257] If prey are scarce in warmer temperature environments, then a salmon's increased energetic demands may not be met and growth is diminished.[258] Marine temperatures also impact the food web supporting salmon and non-salmon populations.[259] Studies have shown the sea surface temperature (SST) in the Bering Sea has had a significant impact on zooplankton taxa and cascading effects on higher order species,[260] which has led to an increase in pink salmon abundance with warmer temperatures.[261] Studies on pink salmon in the Prince William Sound have shown that in warmer years with abundant zooplankton, pink fry will remain in inshore environments protected from some of their larger predators, like walleye pollock and Pacific herring.[262] As outlined above, an increase in pink salmon creates a trophic cascade and threatens the foods availability for wild salmon.

This study is limited in scope to wild salmon populations in Alaska, but it also worth briefly noting the effects of salmon populations on non-salmon species as well. The North Pacific ecosystem has experienced temperature anomalies in recent years resulting in mass die-offs of murres and sea lions. Starting in 2014, temperatures in the upper water column in the North Pacific were 4.5 degrees warmer than normal.[263] Along coastal Alaska 46,000 dead murres washed ashore, and estimates for the total loss were close to 500,000 birds.[264] Murres that survived were not reproducing, leading to an almost zero percent observed chick production in some colonies.[265] Scientists at the National Marine Fisheries Service later pinned the die-off to a lack of three main food sources: pollock, capelin, and eulachon.[266] Pollock, capelin, and eulachon, whose metabolism is dependent on water temperatures, have to eat significantly

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[257] Siegel, McPhee, and Adkison, "Marine Temperatures," 442.
[258] Siegel, McPhee, and Adkison, "Marine Temperatures," 442.
[259] Siegel, McPhee, and Adkison, "Marine Temperatures," 441.
[260] Siegel, McPhee, and Adkison, "Marine Temperatures," 441.
[261] Springer and van Vliet, "Climate Change," E1886.
[262] Springer and van Vliet, "Climate Change," E1880-81.
[263] Dan Joling, "Warm Ocean Water Triggered Vast Seabird Die-Off, Experts Say," Phys.org, February 10, 2017, https://phys.org/news/2017-02-pacific-vast-seabird-die-off.html.
[264] Joling, "Warm Ocean Water."
[265] Shahla Farzan, "Murre Die-Off Linked to Warm Water Temperatures," KBBI, February 22, 2017, http://kbbi.org/post/murre-die-linked-warm-water-temperatures.
[266] Farzen, "Murre Die-Off."

more in warmer water.[267] All three small fish species feed on zooplankton, which are also affected by the warmer water temperatures and a main source of food for pink salmon. Zooplankton are bigger and fattier in cold water and smaller in warm water.[268] Fish must eat more to achieve the required caloric intake. Although research has not been conducted to link pink salmon abundance with less available food for the pollock, capelin, and eulachon that are a critical part of murres' diet, there is a strong hypothesis for a connection between the two. The North Pacific ecosystem and food web lie in balance[269] that has been upset by a temperature change of few degrees.

The influx of hatchery pink salmon also seems to be tipping the balance for a few other species too. Studies have shown that resident and migratory pelagic seabirds' body mass, diet, and reproductive success are reduced in abundant pink salmon years.[270] Both species of kittiwake that inhabit the Aleutian Islands showed decreased productivity, as much as 62% in one of the two.[271] Shearwaters (*Puffinus tenuirostris*), a migratory seabird from the Southern Hemisphere that spends winters in the North Pacific and Chukchi Sea, were observed with lower body and liver masses and up to five times more strandings in eastern Kamchatka during abundant pink salmon years.[272] Seabirds, salmon, and higher-order predators are linked ecologically within the North Pacific Ocean, and it appears that increased abundance of salmon may be affecting the finite common resources.[273]

Risk Characterization

The risks to the receptor (wild salmon) posed by the stressor (hatchery salmon) are many and vary in degree by assessment endpoint. The least risk is seen in the disease levels of wild salmon

[267] Sierra Doherty, "Common Murre Update: Growing Awareness of Sea Bird Die-off Thanks to Citizen Reporting," ADF&G Wildlife News, April 2016, http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=770.
[268] Farzen, "Murre Die-Off."
[269] Springer and van Vliet, "Climate Change," E1881-82.
[270] Ruggerone and Connors, "Productivity and Life History," 831.
[271] Springer and van Vliet, "Climate Change," E1886.
[272] Springer and van Vliet, "Climate Change," E1881-82.
[273] Springer and van Vliet, "Climate Change," E1880.

populations. The dense rearing environments at Alaska salmon hatcheries provide the ideal conditions for the spread of disease; however, these conditions may not translate to the spread of the disease once the fish are released into a significantly less dense environment. Both wild salmon production and recruitment and wild salmon fitness face more risk: each of these assessment endpoints have experienced negative effects from hatchery strays. Hatchery strays affect wild salmon production and recruitment through inflated escapement counts, competition for spawn sites, and increasing the densities of spawning streams which potentially decreases the stream's carrying capacity. Hatchery strays affect wild salmon fitness when they interbreed with wild salmon depleting the adapted genetics of that salmon stock. The assessment endpoint facing the most risk from hatchery salmon is the North Pacific food web and ecosystem. Because this habitat is shared by all Pacific salmon regardless of origination, large-scale hatchery production has had a direct effect on plankton levels which is felt up the food chain by salmon and non-salmon species alike. Using a categorical ranking system, the risks are outlined further in the Risk Estimation section and accompanying table below (see Table 1).

Table 1. Risk estimation

Assessment Endpoint	Risk Category[274]	Considerations
Wild Salmon Production and Recruitment	Low-Medium	Hatchery strays inflate escapement goals, compete with wild salmon for spawning habitat, and challenge a habitat's carrying capacity by increasing stream densities which can lower reproductive success and decrease dissolved oxygen availability.
Wild Salmon Fitness	Medium-High	Decreased fitness in hatchery salmon due to domestication can affect wild salmon genetics via strays and hatchery-wild hybridizations.
Disease-Free Wild Salmon Populations	Negligible-Low	Disease is present in all species of both wild and hatchery salmon; although the hatchery environment may promote the spread of disease, until further research is conducted effects are simply educated estimates.
North Pacific Ecosystem and Food Web	High	Significant increases in worldwide hatchery production has increased common hatchery species, such as chum and pink salmon, in the North Pacific Ocean leading to a strain on the food web and imbalance in the ecosystem.

- **Negligible** - no effect.
- **Low** - minor effect(s) or predicted effect(s) with the continuation of current practices; effect(s) manageable. Decision-makers need to address if corrective measures are necessary and how to implement those measures or if the risk is acceptable.
- **Medium** - major effect(s) or predicted effect(s) with the continuation of current practices; effect(s) potentially manageable with significant resources. Corrective measures necessary; also requires a plan for incorporating corrective measures into current practices.
- **High** - significant and potentially catastrophic effect(s) or predicted effect(s) with the continuation of current practices; predicted to lead to the elimination of assessment endpoint. Requires corrective action as soon as possible.

Risk Estimation

The first step of risk characterization, risk estimation, integrates potential effects with assessment endpoints qualitatively. The risk to wild salmon production and recruitment is the result of several effects caused by hatchery strays. The first, hatchery strays inflate escapement goals, can potentially be a medium risk. With the high rates of straying shown in some areas of the state (for example, the estimated stray rate in the Prince William Sound is 10% for pink salmon and in Southeast Alaska hatchery chums are

[274] Risk Categories adapted from: World Health Organization, *Risk Characterization of Microbiological Hazards in Food: Guidelines* (Geneva, Switzerland: Food and Agriculture Division of the United Nations, 2009) and Laura-Diana Radu, "Qualitative, Semi-Quantitative, and Quantitative Methods for Risk Assessment: Case of the Financial Audit," *Analele Stiintifice ale Universitatii "Alexandru Ioan Cuza" din Iasi - Stiinte Economice* 56 (2009): 643-657.

estimated at 9%[275]), the potential for strays to skew escapement counts is more than likely to occur, reducing the amount of wild salmon allowed back to their natal stream to spawn. Although this risk is medium in areas with large hatchery influence, the risk is low to negligible in areas with small hatchery influence and straying. Corrective measures should be taken in areas with known straying. Compounded with less wild salmon on the spawning grounds is the second effect, competition for spawning habitat. With hatchery strays counted into the spawning grounds, the wild salmon must compete with strays for suitable habitat. Although wild salmon compete with other wild salmon if strays are not present, if strays are present any loss of habitat to wild salmon is a potential loss of wild eggs and genetics being passed forward. The potential risk for spawn site competition is medium. Proper corrective measures should be taken to reduce hatchery salmon in wild spawning habitat. The third effect, lower reproductive success due to high densities, is a low risk. Wild salmon may encounter, and oftentimes do, high densities in spawn habitat. High densities lead to lower dissolved oxygen and hypoxia and in turn, lower reproductive success. While this does occur with high densities of solely wild salmon, any extra stress caused unduly by strays is a management concern and should be addressed. And lastly, when the carrying capacity of spawning streams is reached, food availability for emerging fry is decreased. Again, while this occurs in wild populations, strays and potential hybrids are an unnecessary element in spawning habitat and, as a low effect, should be managed appropriately.

The risks to wild salmon genetics are decreased fitness due to hatchery-wild hybridizations and shifts in migration timing. Fitness risks come directly from the decreased fitness of hatchery strays that interbreed with wild salmon. Hatchery salmon are adapted to the dense rearing environment of the hatchery, a process that may occur within a few generations. The domestication of hatchery salmon results in decreased fitness in wild habitat. When hatchery salmon stray and interbreed with wild salmon, their domesticated genetics are potentially passed on to their offspring. Because salmon are closely tied to

[275] PWSSC, *Interactions of Wild and Hatchery Pink Salmon and Chum Salmon in Prince William Sound and Southeast Alaska: Progress Report for 2015*, by Eric Knudsen et al. (2015): 5.

their environment, and fitness is an adapted trait, the loss of fitness is a major concern for the sustained runs of wild salmon populations. The loss of variability between populations due to hybridization is also a concern. The medium to high risk involved in this effect mandates corrective measures requiring significant resources. Without addressing this risk, hybridization, especially in areas like the Prince William Sound and Southeast Alaska, has the potential to irreparably alter the genetics of wild stocks decreasing their fitness. A loss of fitness and fish in key commercial fishing areas would put increasing fishing pressure on other areas of the state, so corrective actions should be taken to protect statewide salmon runs. Shifts in migration timing, also caused by hybridizations of hatchery and wild salmon, are also of serious concern. Spawning streams have a seasonally optimal window where temperatures and stream discharge encourage high reproductive success. Outside of this window, wild salmon face low water flows and high water temperatures or inversely high water flows that wash out redds. Spawning practices in hatcheries have led to earlier run timing than may be optimal for wild spawning, so when strays interbreed with wild salmon the offspring show a tendency to return earlier than wild salmon of the same population. Hybridization of wild salmon stocks has the potential to shift migration timing outside of the habitat's optimal window. Earlier spawning, even when successful, also may affect food availability for emerging fry. A shift in run timing is a medium risk to wild salmon populations. In theory, the run would adapt back to the optimal window because of increased survival of eggs spawned within the window, but in areas with large hatchery presence where survival is not based on a seasonally optimal spawn window, the strays have a better chance of survival and continuing to shift run timing. Because of this risk, management practices should be shaped to keep hatchery salmon from interbreeding with wild stocks. In areas with high rates of straying, significant resources should be invested or management regulations tightened to eliminate future strays.

The risks to disease-free wild salmon population is relatively low compared to the risks to other assessment endpoints. Studies have shown that hatchery rearing does lead to domestication and a potential reduction in disease-fighting ability. Hatcheries create environmental conditions, such as the high densities in rearing containers which causes higher stress levels, where salmon are more susceptible disease. Hatchery practices, such as releasing infected fish, also contribute to the spread of disease, and placing hatcheries in areas where there is disease in the water source amplifies disease in areas where wild stocks wouldn't normally be exposed. Hatchery salmon, whether pathogen-free or not, interact with wild salmon in the marine environment, so the risk that hatchery salmon spread disease to wild salmon is likely, although because research on disease is difficult, especially in the ocean, it has prevented a baseline capable of establishing wild and hatchery salmon disease levels. More research is needed to make any definite conclusions as to what degree hatchery salmon may be responsible for contributing to a higher presence of disease and if there are any detrimental effects on wild populations.

The risk posed to the North Pacific ecosystem and food web is high. Significant increases in worldwide hatchery production have increased common hatchery species, such chum and pink salmon, in the North Pacific leading to a strain on the food web and an imbalance in the ecosystem. Studies have documented the effect of significant increases in hatchery salmon production globally on the food chain. With over 5.1 billion hatchery salmon fry released in 2016 (and with similar amounts in the decade prior as well) the competition for food sources in the marine environment has led to depressed levels of macrozooplankton affecting both wild salmon populations and non-salmon species. The chum, pink, and sockeye biomass in the North Pacific is estimated to be 5 million metric tons[276] or ~11 billion pounds. From 1990-2015, hatchery salmon accounted for 40% of the salmon biomass in the ocean.[277] Recent studies showing the broad-reaching effects of increased hatchery production have surprised scientists.[278] Depressed chinook returns in years of large chum releases were documented, running counter to scientific thought because of the two species have different diets. More studies are underway to determine the correlation between the two. The impacts of increased hatchery releases may be more broad reaching than

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[276] Gregory T. Ruggerone and James R. Irvine, "Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015," *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 10 (2018): 152. DOI: 10.1002/mcf2.10023.
[277] Ruggerone and Irvine, "Numbers and Biomass," 152.
[278] Ruggerone and Irvine, "Numbers and Biomass," 152.

originally hypothesized. The high risk of reducing food availability in the North Pacific should be addressed immediately. Chinook returns statewide are at an all-time low and mass die-offs of non-salmon species are potentially linked to the lack of available food caused by hatchery releases. Management must provide corrective action as soon as possible. The North Pacific food web and ecosystem will recover fairly rapidly with reduced releases but individual species already affected will take longer to recover and may not return to their former status.

Risk Description

There is a fair amount of uncertainty in characterizing risk of Alaska salmon hatcheries. Within the wild salmon production and recruitment assessment endpoint, several factors had to be evaluated: escapement inflation, competition between wild salmon and hatchery strays for spawning habitat, and carrying capacity of spawning streams. Few direct studies have looked at escapement inflation. Estimates provide a theoretical framework for evaluating the risk, but without further studies it is impossible to know the extent to which hatchery salmon are being counted during wild salmon escapements. Studies are resource intensive because of the remote nature of most salmon streams and difficult because returning salmon must be euthanized to read otoliths to determine origin or all hatchery releases must be tagged and clipped (near impossible at the scale of hatcheries in Alaska) to physically demarcate hatchery salmon from wild. Models may provide a close estimate for escapement inflation, but research is needed on straying per stream before models may be built. Even without research directly on escapement though, it is possible to predict that hatchery strays are affecting escapement counts. With some streams in the Prince William Sound containing 81% hatchery salmon and all salmon within that stream counted towards escapement, escapement inflation is occurring in those streams. It is worth investigating the effect of escapement, again perhaps through models, because of the direct relation of escapement to wild salmon recruitment. Competition for spawn habitat, also a factor in wild salmon production and recruitment, is no better studied than escapement. The difficulty of documenting competition between wild and hatchery salmon when both species physically look the same is preventative. Again it can be hypothesized with a fair amount of certainty that in areas with large hatchery presence, like the Prince William Sound and Southeast Alaska, hatchery strays compete with wild salmon for spawning habitat. All salmon spawning naturally must compete for suitable habitat. With both hatchery and wild fish present on the spawning grounds competition occurs. Similar to escapement inflation, modeling may be a reasonable way to better estimate to what degree hatchery salmon may be competing for spawn sites. Competition is directly related to wild salmon production which warrants further investigation. Carrying capacity of spawning streams has been better researched. Studies within Alaska in various regions and studies outside of Alaska on Pacific Northwest salmon populations have shown that a stream's carrying capacity is limited by stream discharge, water temperatures, and dissolved oxygen levels. The habitat requirements of individual Pacific salmon species is also well documented. Uncertainty remains because of a warming climate, but scientists are increasingly sure that warmer water temperatures due to climate change will increase stressors on wild salmon. Carrying capacity, although important to wild salmon production, is the least significant factor currently. Competition for habitat and escapement inflation are more pressing factors and pose more risk right now, although climate change could reorder the importance of the three factors.

Within the wild salmon fitness assessment endpoint, two factors had to be evaluated: genetic introgression caused by hatchery strays and a shift in migration timing due to hatchery-wild hybridization. Both factors lack considerable data from Alaskan salmon populations. ADF&G commissioned a study on straying in 2011. The genetic portion of the study will investigate the "ecological and genetic consequences of hatchery strays on fitness."[279] Crews have collected four years of data, but none has been processed yet. The State Gene Conservation Laboratory is finalizing the selection of the genetic markers used to determine parentage. Although Alaskan data is lacking, significant research has

[279] ADF&G, "State of Alaska Research Project: A Study of the Interactions Between Hatchery and Natural Pink and Chum Salmon in Southeast Alaska and Prince William Sound Streams," by Ron Josephson, May 2017, http://www.adfg.alaska.gov/static/fishing/PDFs/hatcheries/research/alaska_hatchery_research_project_synopsis_may_2017.pdf: 4.

been done on salmon stocks in the Pacific Northwest. Those studies have shown domestication and genetic introgression of hatchery salmon, leading to adaptation for dense rearing environments and reduced fitness in the wild. Although extrapolation of data from Pacific Northwest salmon species may provide an indication of what the state study may find, until the data collected in Alaska is processed, a great degree of uncertainty exists. The state study may also show very little difference between hatchery and wild salmon depending on the genetic markers chosen to show parentage. In the Prince William Sound and Southeast Alaska where the study is being conducted, hatcheries have been established since the mid- to late-1970s. Hybridization over the last fifty years may have altered wild stock genetics significantly. The state's study is necessary to begin to fill the research void on hatchery salmon in Alaska. Equally as interesting as the results of the study will be the review of the study to determine if its extent was large enough. The change in run timing of hatchery-wild hybrids is slightly better studied in Alaska, but more current research is needed. A study on pink salmon in Southeast Alaska was conducted in 1998 that showed a shift in run timing. Although the results show a definite shift hatchery-wild hybrid run timing, the study is worth replicating in other areas of the state. Studies on Atlantic salmon have also shown a shift in run timing, but extrapolating from Atlantic salmon to Pacific salmon is not ideal. Models of run timing in areas of heavy hatchery influence might also provide insight into shifts over time. A shift in run timing, especially with a changing climate, may prove extremely detrimental for wild salmon stocks. More research is needed into this factor because of its importance.

Within the disease-free wild salmon population assessment endpoint, the only factor evaluated was the risk posed by increased disease in hatchery salmon populations to wild salmon stocks. There is little uncertainty that hatchery environments promote the spread of disease more so than wild environments, but because of the lack of research on disease in salmon populations in the state, uncertainty on the effect of hatchery salmon on wild salmon disease-load is high. Summaries of potential effects are from hatcheries outside of Alaska, so conclusions have been extrapolated from chinook and other species in the Pacific Northwest to hatcheries in Alaska. Because the scope and locations of hatcheries from those two areas are significantly different, extrapolations also lead to a large degree of uncertainty.

Within the North Pacific ecosystem and food web endpoint, increased hatchery salmon production has decreased food availability was the only factor evaluated. The few studies that have been conducted on the health of the food web in the North Pacific were conclusive: increased hatchery production has affected macrozooplankton levels which has then affected salmon and non-salmon species. The ways in which populations were affected ranged from smaller returning adult salmon size, later breeding dates, and a complete change in diet. More recent studies have furthered the list of species affected by hatchery salmon production to chinook salmon, a species once thought to not be affected due to a different diet than chum and pink salmon (the most common hatchery species). With chinook runs struggling or failing statewide, managers and fishermen alike have been searching for a cause, and new research points to a connection to hatchery production. Because the North Pacific is a critical geographic region for salmon, any detrimental effects caused by hatchery salmon will reverberate through the food web and have an impact wild salmon populations.

Reporting Risks

Overall, the risks to wild salmon populations posed by Alaska salmon hatcheries are many. Hatchery salmon must interact with wild salmon in every stage of life. As fry and smolts they migrate along coastal nurseries where their interactions may lead to the spread of disease. As ocean-stage adults, they compete for food sources with wild salmon. As returning adults, hatchery strays populate wild spawning habitat competing for spawning sites, which can reduce reproductive success of wild populations, and interbreed with wild salmon, which reduces fitness and causes shifts in run timing. Hatchery-wild hybrid fry compete with wild fry for food, which can lead to reduced growth and in turn, reduced survival. The potential for risk by hatchery salmon is inherent in every life stage for wild salmon. All of the four assessment endpoints faced risk (see Table 1).

Data used to analyze and characterize risk was from peer-reviewed studies conducted on salmonid species within and outside of Alaska. When field data collected outside of Alaska was used, uncertainty and extrapolations were noted in the Risk Description section (above). The risk was characterized semi-qualitatively, using a scale adapted from other risk assessments. Because of the scope of the study, a quantitative ranking would've been time prohibitive and non-conclusive because of the lack of research for some of the measures. For example, most studies on the fitness of hatchery-wild hybrids called for more research into specific allele frequencies to determine affects, and almost all the literature on disease transmission from hatchery to wild populations recommended more research. Policy was not mentioned in the majority of the studies with the exception of the effects on the North Pacific food web and ecosystem. Several studies noted that fishery managers should weigh the costs to all species when increasing production, a sentiment that should probably be echoed with the risks to all assessment endpoints.

Evaluation

Hatchery salmon pose considerable risk to wild populations although the degree and scope of risk vary by extent of interaction and life phase. The following elements are necessary for the sustained yield of wild salmon: wild salmon production and recruitment, wild salmon fitness, disease-free wild salmon population, and the North Pacific ecosystem and food web. A loss of one element has the potential to eliminate wild salmon runs in Alaska. Policy regulating Alaska salmon hatcheries strives to minimize the risk to wild salmon populations, aiming to meet the constitutional mandate to manage wild runs sustainably. Policy has, for the most part, clearly articulated goals, and the Alaska Supreme Court has provided further clarification on several sections. The historical context leading to policy development (the federal management of salmon stocks before statehood that led to record low salmon returns followed by years of plenty with the institution of the hatchery system) provides context for the development of policy. The policy is also broad enough to cover most of areas of risk posed by hatchery salmon. Specific policy regulating Alaska salmon hatcheries' risks to the four elements listed above are outlined further in the Policy Evaluation subsections below (see Table 2).

Table 2. Policy pertaining to assessment endpoints

Wild salmon production and recruitment: ▪ Location of hatcheries (AS 16.10.400(f), AS 16.10.420(10), 5 AAC 40.220(b)(1) and 5 AAC 40.220(b)(3)) ▪ Performance review (5 AAC 40.860) ▪ Egg sources (AS 16.10.445) ▪ Hatchery reporting requirements (AS 16.10.470) ▪ Escapement goals (5 AAC 39.223) ▪ Permitting (5 AAC 40.170, 5 AAC 40.210, 5 AAC 40.220 and 5 AAC 40.240)	Wild salmon fitness: ▪ Stock transport (ADF&G *Genetic Policy*) ▪ Protection of wild salmon genetics (ADF&G *Genetic Policy*) ▪ Maintenance of wild stock genetic variance (ADF&G *Genetic Policy*)
Disease-free wild salmon population: ▪ Fish transport (5 AAC 41.001-060) ▪ Disease control (5 AAC 41.080, AS 16.10.420(5), and ADF&G *Regulation Changes, Policies and Guidelines for Alaska Fish and Shellfish Health and Disease*) ▪ Hatchery inspections (5 AAC 41.008(c))	North Pacific ecosystem and food web: ▪ Sustainable salmon fisheries (5 AAC 39.222)

Policy Evaluation: Wild Salmon Production and Recruitment

Wild salmon production and recruitment is regulated by policy on the location of hatcheries (AS 16.10.400(f), AS 16.10.420(10), 5 AAC 40.220(b)(1) and 5 AAC 40.220(b)(3)), performance review (5 AAC 40.860), egg sources (AS 16.10.445), hatchery reporting requirements (AS 16.10.470), and permitting (5 AAC 40.170, 5 AAC 40.210, 5 AAC 40.220 and 5 AAC 40.240). Alaska statute 16.10.400(f) dictates that the location of hatcheries may not adversely affect wild stocks while also allowing for a segregated harvest of hatchery stocks. For example, in Southeast Alaska, where there is an abundance of wild pink salmon stocks, ADF&G has restricted the production of hatchery pinks to almost none eliminating the complication of escapement counts and the potential interbreeding of hatchery and wild pinks. In other areas of the state, where restricting hatchery production of a species to zero isn't possible, allowing for segregated harvest and selecting a location without the potential to adversely affect wild salmon stocks is difficult. Salmon inhabit 19,000 documented streams in Alaska (see Figure 12), and ADF&G estimates another 20,000 bodies of water haven't been documented or specified yet.[280] Finding a location in Alaska that allows for a segregated hatchery harvest is difficult, and during migration many hatchery and wild stocks pass through commercial fishing areas where both are targeted.

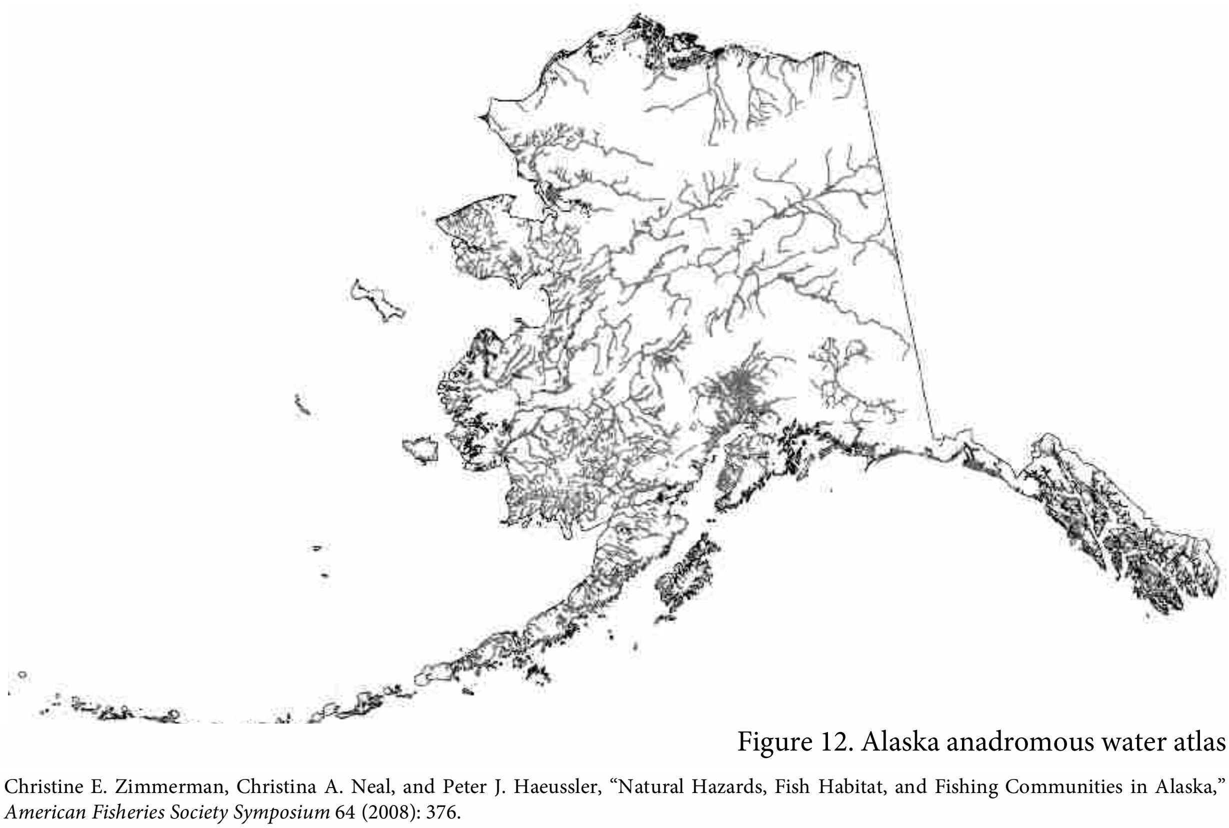

Figure 12. Alaska anadromous water atlas

Christine E. Zimmerman, Christina A. Neal, and Peter J. Haeussler, "Natural Hazards, Fish Habitat, and Fishing Communities in Alaska," *American Fisheries Society Symposium* 64 (2008): 376.

[280] ADF&G, "Anadromous Waters Catalog: Overview," accessed April 1, 2018. https://www.adfg.alaska.gov/sf/SARR/AWC/index.cfm?ADFG=main.home

A performance review, to be conducted by the PNP coordinator, notifies the Commissioner if the "hatchery operator's performance is inadequate."[281] The Commissioner is then free to alter, suspend or revoke the hatchery's permit after considering the following factors: hatchery survivals meet minimum requirements (see Figure 13),[282] contribution to the common property fishery, impact on wild stocks, fulfillment of production objectives, and other circumstances. Ten hatcheries have closed since statehood and eleven more have rescinded their permits. Not all of these were closed or rescinded for failure to pass performance review, the most recent closure in Kake, Alaska, shut its doors due to inability to repay debt. The performance review, though, is not without flaws. The initiation of the performance review is made by the PNP coordinator. In 2011, ADF&G, the PNP coordinator, and the assistant PNP coordinator began evaluating individual hatcheries for "consistency with statewide policies and prescribed management plans." The reports provide a consistent evaluation system conducted by an ADF&G official. Unfortunately, ADF&G doesn't have the resources to conduct the evaluations every year. Within the last 7 years, they've been able to evaluate each hatchery once. With relatively high turnover at some hatchery facilities, an almost entirely new staff may be present for the next performance evaluation. Hatchery evaluations are based on data the hatchery provides to ADF&G. Self-reporting, especially when the stakes are permit suspension or revocation, may not be the best system. Another potential flaw with the performance review is allowance of other considerations or "mitigating circumstances which were beyond

	Survival for this stage	Cumulative Survival
For captured broodstock to egg take	70%	
Green egg to eyed egg	80%	80%
Eyed egg to emergent fry	85%	68%
Emergent to fed fry *1*	90%	61%
Fed fry to fingerling *2*	90%	55%
Fingerling to smolt	75%	41%

1 Fry achieving up to 25% weight gain from swim-up.

2 Fry achieving substantially more than 25% weight gain from swim-up.

Figure 13. Minimum hatchery survival standards

281 5 AAC 40.860

282 5 AAC 40.860(c)

the control of the hatchery operator."[283] When a hatchery experiences a significantly smaller run than predicted or higher saltwater rearing mortality than expected, hatchery operators default blame to one of the many factors involved in marine survival. Low returns could be attributed to ocean conditions or predators. High rearing mortality could be caused by bad plankton blooms, less than ideal water temperatures, or even bad fish food. Because there is very little research on any of these factors, blame is speculative. It also provides an easy and common excuse for hatchery managers: it's just a bad year. Most mortality or poor runs are often attributed to mitigating circumstances beyond the control of hatchery managers.

The source of eggs for hatcheries is limited to "stocks native to the area" or, upon ADF&G's approval, "from other areas, as necessary."[284] This section of the Alaska Statutes is to ensure that genetically different stocks are not moved into a new watershed. Within AS 16.10.420 Conditions of Permit, it further states that "salmon eggs or resulting fry may not be placed in waters of the state other than those specifically designated in the permit." This is another measure to ensure that salmon stocks remain in the watershed they are adapted to. This policy, while ensuring that adapted genetics stay within a system, may also be a cause of the high rates of straying experienced at some hatcheries. Some studies suggest that the proximity of a donor population to the hatchery is a factor in straying.[285] The intermingling of the two populations (wild donor stock and hatchery offspring) during early marine life may play a factor in straying as well.[286] The geographically closer the stock is to the hatchery, the better adapted the fish are to the area, but the geographically closer the stock, the higher the potential for straying, although, more research is necessary before this conclusion can be fully accepted. The other potential consequence of limiting the egg source to certain stocks, is that in areas of the state where hatcheries are in close proximity, they tend to use one source of eggs. This consistency makes it easier for

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[283] 5 AAC 40.860(b)(6)
[284] AS 16.10.445
[285] Brenner et al., "Straying of Hatchery Salmon," 192.
[286] Brenner et al., "Straying of Hatchery Salmon," 192.

hatcheries to share eggs or fry in the event of a broodstock issue or severe incubation losses, but it also creates a monoculture of salmon that lack genetic variation. A monoculture of salmon makes the entire region's hatchery population susceptible to the same diseases. Those genetics may also be passed onto wild fish through strays making wild salmon more susceptible to disease. The necessary diversity among hatcheries is addressed in the Policy Evaluation: Disease-Free Wild Salmon Population subsection a little later in this section, and policy regulating the shared use of egg sources is evaluated there.

Hatchery reporting requirements ensure that ADF&G is aware of hatchery numbers, success, and finances. The hatchery must report, at minimum, on: "information pertaining to species; brood stock source; number, age, weight, and length of spawners; number of eggs taken and fry fingerling produced; and the number, age, weight, and length of adult returns attributable to hatchery releases."[287] Theoretically, the annual report provides a tool for hatcheries to communicate with ADF&G in a systematic way. The remote location of production hatcheries limits the on-site visits ADF&G is able to conduct each year, and most years, the sites are not visited by ADF&G personnel. The self-reporting nature of the annual report is also another cause for concern. Hatchery personnel have noticed discrepancies between hatchery practices and what is published in the annual report.[288] Mortality is often underreported, egg take goals are adjusted to be under the allowed levels (even though it is practice for most hatcheries to take extra eggs that they discard at the eyed egg stage if survival is good), and accidental releases in non-permitted waterways are left out. Again, the remote location of hatcheries allows hatchery operators a certain insulation from state management. More frequent visits to sites by ADF&G personnel would help to decrease the discrepancies in hatchery practices from what is reported.

Policy on escapement goals is meant to ensure the recruitment of wild salmon is managed on the sustained yield principle. The objective of escapement goals, which are set by the Board of Fish and

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[287] AS 16.10.470

[288] Personal communication with hatchery staff.

ADF&G for each region,[289] are outlined within Alaska Administrative Code 39.223. Together, biological escapement goals, optimum escapement goals, sustainable escapement goals, and sustained escapement thresholds, help managers determine an escapement number that will sustain salmon runs while providing maximum harvest. The consistent returns of most Alaskan salmon stocks are an indicator that escapement goals are being met and that wild salmon populations are managed on the sustained yield principle. However, the increasing awareness that hatchery strays may be inflating escapement goals has not been taken into consideration when managers calculate each year's annual returns. Hypothetically, wild salmon populations may be decreasing in certain areas of the state and escapement is instead being met by hatchery strays or hatchery-wild hybrids. Escapement counts are conducted by weir or plane making it almost impossible to determine how many fish passing upriver are hatchery strays and how many are wild without establishing a sampling protocol or basing escapement inflation off of straying models. Studies have shown extremely high counts of hatchery strays on wild spawning grounds in areas like the Prince William Sound and Southeast Alaska. The current state-sponsored study on strays should provide ADF&G mangers the necessary information to adjust escapement goals or hatchery regulations. From the results, models accounting hatchery strays within a watershed should help managers adjust escapement counts to reduce inflation. Regional planning teams, such as the Prince William Sound regional planning team that set the 2% stray threshold, may also choose to use the results of the study to direct ADF&G in how to set escapement goals with known quantities of strays in wild spawn habitat.

The hatchery permitting process is a rigorous one. Comprised of an application, a review by the regional planning team, a public hearing with a presentation of the hatchery plan with the Commissioner present, and a final review by the Commissioner, the process is meant to ensure that each hatchery is "compatible with the appropriate regional comprehensive salmon plan," will contribute to the common

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[289] Carroll, "Escapement Goals." – ADF&G sets the biological escapement goals: "the number of salmon in a particular stock that ADF&G has determined should be allowed to escape the fishery to spawn to achieve the maximum sustained yield." And Board of Fish sets the optimum escapement goals: "allow for sustainable runs based on biological needs of the stock and ensure healthy returns for commercial, sport, subsistence, cost-recovery, and personal use harvests."

property fishery, protect wild stocks, and make sure the hatchery's plan "would make the best use of the site's potential to benefit the common property fishery."[290] The Commissioner's final review considers eight criteria: geographic suitability to enhance common property fisheries, best use of the site's potential, geographic proximity to wild salmon runs and potential disturbance, available egg sources, adequate water source, intake for water system not in flood danger, space for maintenance of intake systems, and reasonability and potential success of hatchery and staffing plans. The permit may be revoked under several conditions as well, such as failure to meet the terms and conditions outlined in the permit. Overall, the hatchery permitting process is rigorous enough that hatcheries have well-developed management plans and objectives. The significant cost of operating a hatchery also contributes to the elimination of permit applications for unnecessary or wasteful hatcheries. Once hatcheries are granted a permit though, the permit change process is much simpler. The four-page application is reviewed by the regional planning team and then approved or denied by the commissioner. The regional planning team meetings are open to the public and participation is encouraged, but the mandatory public hearing portion of the original permit application is eliminated. Hatcheries have been granted permit alterations to transport tens of millions of fry to remote rearing projects, while permit applications for new facilities producing significantly less fish have been denied due to public opposition. The permit alteration process should be changed to consider the quantity and degree of permit change. A large degree of change or large quantity of fish moved should require a more stringent process similar to the original permitting process.

Policy Evaluation: Wild Salmon Fitness

Policy ensuring wild salmon fitness limits stock transport, protects wild salmon genetics, and maintains wild stock genetic variance. Created in 1985, the *Alaska Department of Fish and Game Genetic Policy* is the sole regulatory document addressing salmon genetics. It provides restrictions to protect the

[290] 5 AAC 40.170

"genetic integrity of important wild stocks."[291] The policy statement on stock transport limits the transport of fish interstate, inter-regional, and regionally. Only regional stocks may be transported and only after investigation of the following criteria: amenability of phenotypic characteristics to hatchery management plan and a cautionary note against long distance transports that may promote straying. The policy statement on protection of wild stocks begins: "Gene flow from hatchery fish straying and intermingling with wild stocks may have significant detrimental effects on wild stocks."[292] The section goes on to prioritize the protection of wild stocks through the limitation of introduced stocks, identification of significant or unique wild stocks, limits to stock rehabilitation and enhancement, the establishment of wild stock sanctuaries, and locations for fish releases that minimize wild stock and hatchery interactions. The impact of hatchery strays is addressed as well: "Continued influx of hatchery fish together with the return of hybrids may alter the wild gene pool, reduce stock fitness, and thus threaten the survival of the wild population."[293] Lastly, the section on maintenance of genetic variance limits the use of a donor stock to three hatcheries and establishes a minimum number of broodstock (400) and a limit on broodstock collection in a single run timing window (the practice of hatcheries mass collecting broodstock in a day or two using the fishing fleet). One stock of chinook salmon that is used in Southeast hatcheries is the Andrew Creek stock. In 2015, 5 hatcheries were using the Andrew Creek stock to produce hatchery chinook, which were then released in 9 locations. Sheep Creek Hatchery, one of the 5, has since closed, but with 4 hatcheries still using the stock, the number is over the allowed 3 hatchery stocks. Enforcement of policy is a concern and should be addressed.

The most concerning element of the *Genetic Policy* is its age. The introduction to the *Genetic Policy* concludes: "This policy represents a consensus of opinion and should continue to be periodically reviewed to ensure that the guidelines are consistent with current knowledge. By doing so, we will be able

[291] ADF&G, *Genetic Policy*, 1.
[292] ADF&G, *Genetic Policy*, 2.
[293] ADF&G, *Genetic Policy*, 5.

to meet the goal of great fish production through enhancement while maintaining healthy wild stocks."[294] Those sentences were published 33 years ago. Although ADF&G personnel who helped author the policy had the foresight to recognize certain adverse impacts on wild stock genetics, the policy should be updated to reflect current knowledge. The Research section of the policy starts: "The necessity for much of this policy arises from our ignorance of the genetics of wild salmon populations and the effects of their domestication in hatcheries. The policy is based more on extrapolation from other disciplines such as agriculture than from first-hand knowledge of our resource."[295] The committee then calls for research on topics such as the effect of introgression of genes from hatchery fish into wild populations. The state commissioned a study on this in 2011, 26 years later. More research is needed, as is a revision of the *Genetic Policy*.

Policy Evaluation: Disease-Free Wild Salmon Population

Policy responsible for the continuation of a disease-free wild salmon population addresses fish transport (5 AAC 41.001-060), disease control (5 AAC 41.080, AS 16.10.420(5), and ADF&G *Regulation Changes, Policies and Guidelines for Alaska Fish and Shellfish Health and Disease*), and hatchery inspections (5 AAC 41.008(c)). Similar to the stock transport policy above, fish transport provides further regulation on the transport of broodstock, especially concerning disease. A permit is required for the transport of any fish in any water in the state. The permit ensures that only a certain number of a single disease-free species are transported or taken from a water source. A statement containing the "health or condition of the fish, a disease history of the stock, a disease history of the hatchery or rearing facilities through which they may have passed, and any previous disease treatments or vaccinations" is required in the permit application.[296] If a disease history has not been conducted for the broodstock, one must be conducted by an ADF&G fish pathologist or a designated substitute pathologist. The main focus of the

[294] ADF&G, *Genetic Policy*, 2.
[295] ADF&G, *Genetic Policy*, 11.
[296] 5 AAC 41.010

fish transport policy is to minimize the spread of disease for the "continued health and perpetuation of native, wild, or hatchery stocks of fish."[297] The permitting requirements for fish transport have resulted in very little spread of disease around the state. Limiting transport between major geographic regions has contained naturally-occurring disease in a watershed to only the fish that return there.

Regulation Changes, Policies and Guidelines for Alaska Fish and Shellfish Health and Disease Control also elaborates on the transport of fish, outlining different diseases classes and their individual requirements or prohibitions for transport to control disease. Class I-III diseases must be immediately reported to ADF&G pathology section. Some of the diseases in Class I (diseases of critical concern), such as whirling disease and infectious pancreatic necrosis virus, are extremely rare or not present in Alaska but have caused significant mortality in other areas.[298] Class II diseases (high-risk diseases) can also cause significant and quickly occurring mortality. Diseases include several that are common in Alaska hatcheries such as furunculosis, BKD, and *flexibacter columnaris*.[299] Class III diseases (diseases of concern) are also common hatchery diseases with the potential to cause mortality although at a reduced rate than Class I and II diseases. Any disease found at the hatchery within the three classes must be treated according to their individual class' protocol. Mandatory prerelease examinations of juvenile hatchery salmon also aims to eliminate the spread of disease. To be able to release the broodyear into the wild, the fish must be disease free or if disease is present, mortality thresholds for that disease may not be surpassed. For example, for populations with BKD, "cumulative mortality equal or greater than 5% in 90 days prior to release attributable to BKD will prohibit release."[300] Sockeye salmon also have their own regulations guiding hatchery practices because of their susceptibility to infectious hematopoietic necrosis virus (IHNV), a disease causing extensive, sometimes as much as 100% mortality in a population.[301] Separate policy for separate classes of disease and species like sockeye that are more susceptible to disease

[297] 5 AAC 41.030
[298] 5AAC 41.080(c)(1)
[299] 5AAC 41.080(c)(2)
[300] ADF&G, *Regulation Changes*, 12.
[301] ADF&G, *Common Diseases*, 8.

has helped insulate wild salmon populations from increased disease-load that may be present at hatcheries.

Within the policy, though, there are a few loopholes that allow diseased populations to be released. For example, natural mortality may be removed from BKD's cumulative mortality threshold. If a population is known to have levels of BKD present and a total cumulative mortality of 20%, managers can claim that over 15% was due to naturally occurring mortality or other classes with less restrictions. It is difficult to prove cause of mortality unless all dead fish are autopsied on collection, and even then, decomposition can make results inconclusive. The high rate of natural mortality may also be attributed to a bad year requiring very little, if any, proof. If the 5% threshold for BKD is exceeded and reported by the hatchery to ADF&G pathology, the population may still be released through another loophole: permission of the state pathologist.[302] In certain experimental populations in Southeast hatcheries, cumulative mortality of the fish population has been over 50%.[303] Some years have experienced mortality as high as 65-75%. The populations were still released with the approval of state fish pathologist.[304] That infected population then migrates out to sea with wild stocks and returns to the hatchery where their BKD-positive eggs are taken, perpetuating the spread of disease. Although this scenario is uncommon (most hatcheries family-track to cull diseases like BKD, which can be costly due to lost fish food, labor and smaller future returns, from the population) the potential for a million or more diseased hatchery salmon to spread disease to wild stocks merits a review of the policy. The intent of disease control is valid—cull populations with the most dangerous diseases and limit the spread to others—but the loopholes that allow hatcheries (who have a vested interest in releasing a broodyear of fish every year to ensure runs and return on investment) should be eliminated.

[302] 5 AAC 41.080(g)
[303] Personal communication with hatchery staff.
[304] Personal communication with hatchery staff.

The last policy helping ensure a disease-free wild salmon population are the required hatchery inspections every other year.[305] The inspections confirm that hatchery practices are in line with health standards and that disease reporting is accurate. Again, the intent behind this policy is good. Inspections ensure that hatchery practices promote the highest level of health, but the remote location of most hatcheries also allow them advance notice to make sure hatchery environments are in compliance before ADF&G pathologists arrive on site. Visits last a few hours before the pathologist returns to town. Hatcheries do have a vested interest in maintaining health among their fish populations, and it is rare that major infractions are documented.

Policy Evaluation: North Pacific Ecosystem and Food Web

Management goals for the North Pacific are outlined in Section 5 of the Alaska Administrative Code 39.222 Policy for the management of sustainable salmon fisheries. The goal of the policy is to "ensure conservation of salmon and salmon's required marine and aquatic habitats, protection of customary and traditional subsistence uses and other uses, and the sustained economic health of Alaska's fishing communities."[306] Management options outlined are those that ensure the qualities listed above, including control of the human impact on fishing mortality and protection habitat critical to salmon. The policy advocates for "effective monitoring, compliance, control, and enforcement."[307] The section specifically relating to habitat calls for very specific measures, such as habitats being unperturbed beyond natural variation, access to habitat for salmon to be protected, the protection of salmon within different habitats, habitat conditions monitored and controlled to maintain them and restore them when necessary, and diversity maintained at different levels of classification, such as population, species and ecosystem. The policy also calls for research and assessment of adverse ecological effects. It outlines conservative

[305] 5 AAC 41.080(c)
[306] 5 AAC 39.222(b)
[307] 5 AAC 39.222(c)(3)(E)

management of "salmon stocks, fisheries, artificial propagation, and essential habitats"[308] using the precautionary approach when uncertainty is great. The precautionary approach requires:

> "(i) consideration of the needs of future generations and avoidance of potentially irreversible changes;
> (ii) prior identification of undesirable outcomes and of measures that will avoid undesirable outcomes or correct them promptly;
> (iii) initiation of any necessary corrective measures without delay and prompt achievement of the measures purpose, on a time scale not exceeding five years, which is approximately the generation time of most salmon species;
> (iv) that where the impact of resource use is uncertain, but likely presents a measurable risk to sustained yield, priority should be given to conserving the productive capacity of the resource;
> (v) appropriate placement of the burden of proof, of adherence to the requirements of this subparagraph, on those plans or ongoing activities that pose a risk or hazard to salmon habitat or production."[309]

With the studies showing degradation to the North Pacific's food web and ecosystem coupled with the new research on hatchery production linked to poor chinook returns (a huge concern statewide right now), management should default to the precautionary approach. Corrective measures, which could include a reduction in hatchery production at the state-level, increased funding for research on the carrying capacity of the North Pacific, or an international dialogue on hatchery production limits, should be undertaken without delay. A significant step in transitioning to the precautionary approach would also include the "appropriate placement of the burden of proof." A statewide dialogue on the impacts of hatchery salmon seems a necessary step.

Section 5 AAC 39.222 is extensive, but it is the sole policy addressing the marine environment that salmon are dependent upon for survival. More policy regulating hatchery impacts on critical habitat containing specific management practices is necessary.

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[308] 5 AAC 39.222(c)(5)
[309] 5 AAC 39.222(c)(5)(A)

Recommendations

The intent of this paper was to investigate policy pertaining to Alaska salmon hatcheries and the sustainable management of Alaska salmon stocks. Hatchery production has increased 50-fold[1] since the inception of the Alaska hatchery system's creation in 1976.[2] Established to supplement and aid the recovery of historically low wild salmon populations, within a few years hatchery production had produced more fry than had returned the inaugural year of the PNP system.[3] Now contributing $85 million to the commercial fishing fleet,[4] Alaska hatcheries released 1.66 billion salmon fry last year.[5] They are responsible for fisheries where there were none before. They've alleviated fishing pressure from wild salmon populations allowing them to rebound. They've kept alive an industry at the core of Alaska's history. The hatchery system is integral to maintaining Alaskan fisheries at their current levels. To remove hatcheries would eliminate a third of salmon caught commercially each year.[6] The repercussions would most likely be greater than that third, as more pressure on wild runs would lead to reductions of those runs.

Policy with the foresight to predict potential consequences to wild salmon stocks was enacted to regulate this hatchery system in the late 1970s, and some of that policy proved successful. The rigor of the hatchery permitting process has ensured that hatcheries would be beneficial to common property fisheries and aim to avoid detrimental interactions with wild stocks. Fish transport policy has eliminated risk of diseased eggs or fry being imported from another state. But a system created in the 1970s can't (and shouldn't) function indefinitely without change. Even at the hatchery, practices have evolved over time. Incubators were once made from wood, each weighing roughly 200 pounds without water, fish or

[1] From 32.1 million eggs taken by hatcheries in 1976 (data from *Fred Reports* page 14) to 1.66 billion fry released last year in the state (data from *Fisheries Enhancement Report 2016* page 47).
[2] ADF&G, *FRED Reports,* 2.
[3] ADF&G, *FRED Reports,* 14.
[4] ADF&G, *Alaska Fisheries Enhancement 2016*, 7.
[5] ADF&G, *Fisheries Enhancement Report 2016*, 47.
[6] ADF&G, *Alaska Fisheries Enhancement 2017*, 18.

substrate. Now they're custom built from aluminum, the 50-pound incubators much more manageable and maneuverable. Some of the policy regulating hatcheries is like those 200-pound incubators, outdated or ill-fitted for current practices. Policy-makers need to update management practices to further align with sustainable management and review and revise policy to incorporate new information and technology. The following recommendations are necessary for current policy to better align with the constitutionally-mandated sustained yield management of Alaska salmon (see Table 3).

Table 3. Recommendations for policy revision

- Revise the *Genetic Policy*
- Research on straying, escapement, and disease
- Regulation and enforcement of current policy
- Implement an avenue for a state-wide conversation with stakeholders, managers, and policy-makers

Genetic Policy Revision

Published in 1985, the *Genetic Policy*, which is the only policy addressing the protection of wild salmon genetics, should be revised to reflect updated technology, research, and understanding of the genetics of wild and hatchery salmon. When the policy was written, the field of genetics was very much in its infancy. In 1985, polymerase chain reaction (PCR), a process to produce copies of DNA that has become synonymous with forensics, the development of medicines, and diagnosing genetic disorders, was invented. Discussion about feasibility of the human genome project began in 1986. The project was started the following year, and the first draft of the human genome was published in 2001. Technology is now able to isolate alleles responsible for certain phenotypes and engineer genomes through CRISPR. Also during that time, scientists learned how to isolate loci responsible for adaptation in salmon stocks, pinpoint the genetic differences between fall and spring stocks of salmon, and recognize the importance of a temporally diverse population to prevent the portfolio effect, among other things. All are tools used in current management of salmon stocks today. The authors of the *Genetic Policy* acknowledged their unfamiliarity with salmon genetics when they created the policy: "The necessity for much of this policy arises from our ignorance of the genetics of wild salmon populations and the effects of their domestication in hatcheries. The policy is based more on extrapolation from other disciplines such as agriculture than from first-hand knowledge of our resource."[7] A policy created on knowledge of other disciplines is problematic. It relies on extrapolations and outdated extrapolations at that. Because of its age, the *Genetic Policy* contains perspectives have been proven incorrect. For example, the two perspectives on the genetics of hatchery-wild genetics are (1) that hatchery strays affect the adapted genetics and therefore fitness of wild stocks, and alternatively (2) the genetic impact of hatchery strays is minimal because straying is a natural process and adapted genetics will persevere.[8] The second perspective, although seemingly sound in theory, has been disproven. The effect of hatchery strays is genetic introgression. Policy should reflect current knowledge to be effective.

Creators of the *Genetic Policy* concluded with a call for more "cooperative research efforts among the university, state, federal, and private sectors" in the following areas: (1) develop "performance profiles of hatchery stocks and potential for genetic improvement," (2) ascertain "potential for genetic improvement of cultured stocks," (3) assess the "effect of introgression of genes from hatchery fish into wild populations," and (4) study the "effects of inbreeding and maintenance of inbred lines."[9] Of these four suggested areas for research, the state has taken part in only one: the effects of introgression from hatchery strays. The other three suggestions are outdated and should be eliminated from a revised policy. The state and fishing industry are no longer interested in the manipulation of salmon genetics (which is the conclusion of the first two areas suggested). Performance profiles aren't necessary because other policy has mandated that hatcheries use locally adapted stocks for broodstock, so an updated salmon stock

[7] ADF&G, *Genetic Policy*, 11.
[8] ADF&G, *Genetic Policy*, 5-6.
[9] ADF&G, *Genetic Policy*, 11-12.

would most likely fall outside of that geographic scope. The genetic improvement of cultured stock is also moot. Alaskans have shown immense resistance to the manipulation of salmon genetics. Frankenfish (called AquaAdvantage Salmon by its producer AquaBounty), a genetically modified salmon developed in Massachusetts that grows at twice the average rate of a wild salmon,[10] has been protested by Alaskans from the local level up to representation in Congress. Alaska Representative Lisa Murkowski has co-sponsored the Genetically Engineered Salmon Labeling Act to defend against what she and a lot of Alaskans see as a threat to wild Alaska salmon. She has said: "Alaska's fisheries are world renowned for their high quality, productivity and sustainability, and these genetically modified salmon could potentially devastate our wild populations of salmon and desolate our fisheries."[11] The genetic improvement of cultured salmon as well as the performance profiles of hatchery salmon with their potential for genetic improvement should be eliminated from the policy with revision. Neither are applicable or relevant to salmon in Alaska.

The third recommendation, assess the "effect of introgression of genes from hatchery fish into wild populations," was recently undertaken by the state-commissioned study: "Interactions of Wild and Hatchery Pink and Chum Salmon in Prince William Sound and Southeast Alaska." The study aims to "1) further document the degree to which hatchery pink and chum salmon straying is occurring; 2) assess the range of interannual variability in the straying rates; and 3) determine the effects of hatchery fish spawning with wild populations on the fitness of wild populations."[12] Essentially it looks at how many stray, what causes straying from year to year, and how hatchery fish are changing wild salmon. The project was commissioned in 2011 and field work began in 2012 after the project was granted to the Prince William Sound Science Center (PWSSC) and its partner the Sitka Sound Science Center (SSSC).

[10] Tom Polansek, "U.S. Environmentalists Sue to Overturn Approval of GMO Salmon," *Reuters*, last modified March 31, 2016, https://www.reuters.com/article/us-aquabounty-fda-lawsuit-idUSKCN0WX1PE.
[11] *The Cordova Times*, "Murkowski: Fight Against Frankenfish Isn't Over," last modified May 3, 2018, https://www.thecordovatimes.com/2018/05/03/murkowski-fight-against-frankenfish-isnt-over/.
[12] ADF&G, "Hatcheries Research: Findings and Updates," Fishing: Hatcheries, accessed April 20, 2018, http://www.adfg.alaska.gov/index.cfm?adfg=fishingHatcheriesResearch.findings_updates.

PWSSC and SSSC release an annual project synopsis with methods and preliminary results. Contract work will conclude in 2023. Although the state's study is a step forward in genetics research (one that was requested in 1985 when the *Genetic Policy* was published), waiting until the study's completion to revise policy isn't necessary. Studies on fitness from hatcheries in the Pacific Northwest and privately funded studies on Alaskan salmon have shown the detrimental effect hatchery-wild interbreeding. Policy-makers should utilize this information to manage hatchery production more conservatively and allow room for future revision when state studies are concluded.

State-Sponsored Research on Straying, Escapement, and Disease

The state-commissioned study mentioned above ("Interactions of Wild and Hatchery Pink Salmon and Chum Salmon in Prince William Sound and Southeast Alaska") will provide policy-makers and managers with not only the specific genetic information on the effects of straying hatchery salmon, it will also provide insight into the population structure and the "extent and annual variability" of straying in study areas. Preliminary results show significant straying in some of those areas: the percent of pink salmon hatchery strays in Prince William Sound streams averaged 9.67% from 2013-2015; the percent of chum salmon hatchery in streams studied in Southeast Alaska was 7% during the same years.[13] This study should be expanded geographically to also include other areas with hatchery influence such as Kodiak and Cook Inlet. Last year, straying pink salmon from the Prince William Sound were found in Homer, Alaska, in the Cook Inlet watershed system, hundreds of miles from the hatcheries in Prince William Sound.[14] An expanded study that looks at hatchery influence on these areas may lead to a greater degree of straying than originally hypothesized.

[13] ADF&G, "Hatcheries Research," 1.

[14] Elizabeth Earl, "Data Shows Prince William Sound Pink Salmon in Homer Streams," *Homer News*, last modified December 1, 2017, http://homernews.com/local-news-news/2017-12-21/data-shows-prince-william-sound-pink-salmon-homer-streams.

Expanded straying studies may also speak to escapement inflation. Currently, escapement goals for wild salmon do not address hatchery strays. Alaska wild salmon levels appear to be robust, averaging 100 million fish caught each year since the early 1980s.[15] This number may include hatchery strays which skews escapement numbers. Without research into what percent of strays are populating wild streams, managers cannot accurately estimate a wild salmon stock's population which compounds issues with forecasting for future returns to that area. An expanded straying study to establish straying percentage per stream will provide escapement counts that more accurately numerate the wild salmon returning to a spawning stream.

Lastly, more research is needed on disease in both hatchery and wild populations. Because so little is known about current levels of disease present in wild salmon stocks and the transfer of disease from hatchery populations to wild salmon, it is difficult to establish a baseline of acceptable disease levels. Policy is thorough in breaking down disease by severity into different classes which correspond to different management and hatchery practices, however, without a baseline, it is difficult to evaluate the success of this policy. Loopholes within the policy should also be addressed. The state pathologist should not have approval to release populations of diseased hatchery fish. In circumstances where industry is captured or the hatchery downplays the severity of the outbreak, policy should dictate release. Euthanizing an entire population of hatchery salmon is a loss of hundreds of thousands of dollars for commercial fisherman, but releasing a diseased population contains the risk to have a much broader effect on salmon stocks. Research should indicate to what extent these effects occur.

Regulation and Enforcement of Current Policy

Current policy does well to address many potential concerns and issues with hatchery-wild interactions. It was crafted to minimize detrimental interactions, and the rigorous process involved in the

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[15] ADF&G, *Alaska Fisheries Enhancement Annual Report 2017*, by Mark Stopha, Anchorage, 2018 (Regional Information Report No. 5J18-02): 3.

application and maintenance of hatchery permits eliminates many threats that could be posed by hatchery salmon to wild salmon populations. For example, within the permitting process, one of the requirements is the "proximity of the proposed hatchery to an area that will allow for a segregated harvest of hatchery stocks without adversely affecting natural stocks."[16] This single directive prevents many consequential interactions between hatchery and wild salmon. Other policy, such as policy related to the maintenance of genetic diversity, also serves to prevent potential negative impacts of hatchery salmon on wild salmon populations. The section speaking to genetic diversity states: "A single donor stock cannot be used to establish or contribute to more than three hatchery stocks."[17] Creators of this policy recognized that "[d]iversity tends to buffer biological systems against disaster, either natural or man-made. Developing and maintaining hatchery broodstock from a wide variety of donors will buffer the hatchery system against future catastrophes."[18] However, this policy is not currently enforced as written. As discussed in the Policy Evaluation: Wild Salmon Fitness section (see page 88), certain donor stocks are used more than the allowable "three hatchery stocks."[19] The Andrew Creek chinook stock is currently being used at four different hatcheries in Southeast Alaska and at nine different off-site releases, several of which are used for broodstock collection.[20] Without enforcement of the policy, creator's intentions are simply that: intentions without the regulatory authority to prevent risk.

The precautionary approach, outlined in Section 5 of the Alaska Administrative Code, is similar in its lack of enforcement. Section 5 AAC 39.222, the Policy for the Management of Sustainable Salmon Fisheries, provides that critical salmon habitat must be unperturbed beyond natural variation and that

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[16] 5 AAC 40.220(b)(3)

[17] ADF&G, *Genetic Policy*, 3.

[18] ADF&G, *Genetic Policy*, 8.

[19] ADF&G, *Genetic Policy*, 3.

[20] The section on genetic diversity among hatcheries states in full: "(1) A single donor stock cannot be used to establish or contribute to more than three hatchery stocks. (2) Off-site releases for terminal harvest *rather than development or enhancement of a stock* need not be restricted by III.A.1 [the previous sentence], if such release sites are selected so that they do not impact significant wild stocks, wild stock sanctuaries, or other hatchery stocks [emphasis added]." Because several of the off-site release locations are used for broodstock collection, they directly contribute to the "development or enhancement of a stock" which removes them from the "off-site releases for terminal harvest" designation and provides they should be regulated by the first sentence in the section.

habitat conditions must be monitored and controlled for maintenance and restoration when necessary. The policy also calls for research and assessment of adverse ecological effects. Pacific salmon spend most of their life in the marine environment, a period responsible for more than 95% of their growth.[21] Most of their time in the marine environment is spent in the North Pacific where food availability is incredibly important for growth and survival. Studies have shown the negative effect of hatchery salmon, especially pink and chum salmon, the two most common hatchery species, on the North Pacific's food web. There is a documented perturbation beyond natural variation in the North Pacific, which is when the precautionary approach must be applied.

Section 5 AAC 29.222 dictates that in the face of uncertainty or if critical habitat is degraded, management must default to the precautionary approach which requires management to "correct [undesirable outcomes] promptly" and initiate "necessary corrective measures without delay" with "prompt achievement of the measures purpose on a time scale not exceeding five years, which is approximately the generation time of most salmon species."[22] The precautionary approach requires the "appropriate placement of the burden of proof […] on those plans or ongoing activities that pose a risk or hazard to salmon habitat production."[23] The aim of the precautionary approach is the protection of critical habitat ensuring protection of the resource for future generations.[24] Currently management is not managing the resource per the precautionary approach. With studies on the food web in the North Pacific, a critical habitat, showing conclusive evidence that hatchery salmon are affecting zooplankton populations and other salmon species and non-salmon species, the precautionary approach must be employed. The high risk of reducing food availability in the North Pacific should be addressed immediately with management providing corrective action as soon as possible. Within the precautionary

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[21] Johnson and Schindler, "Trophic Ecology," 855.
[22] 5 AAC 39.222(c)(5)(A)
[23] 5 AAC 39.222(c)(5)(A)
[24] 5 AAC 39.222(c)(5)(A)

approach a greater international dialogue should be initiated to limit hatchery production to a level not affecting food availability for wild salmon species.

All policy, including the limits on egg donor stock's use and the potential implementation of the precautionary approach, should be enforced. Tighter enforcement will help eliminate discrepancies between policy and practice helping to ensure the sustainable yield of wild salmon populations.

Initiate a State-Wide Conversation on Hatchery and Wild Salmon Stocks

The production of hatchery salmon requires tradeoffs that seem to be currently unaddressed by policy or the current management system. Tradeoffs include a reduction in resiliency of wild salmon,[25] landscape changes,[26] and ecological effects including competition between hatchery and wild salmon and hatchery and non-salmon species.[27,28] The importance of salmon to commercial and recreational fisheries, indigenous communities, and the cultural identity of Alaskans tied to salmon makes discussion on tradeoffs important. Acknowledging that increased production potentially affects a host of other species, including wild salmon, should be a first step in policy revision. The North Pacific ecosystem doesn't exist within a vacuum. The international release of 5.1 billion hatchery salmon fry each year will have an effect on that ecosystem. Policy that doesn't directly state that this occurs does a disservice to effective management.[29,30] The importance of both sustained wild salmon runs and hatchery salmon production to the future of Alaska fisheries calls for a balance of the resources. Without hatcheries, the commercial salmon fishing industry could not exist at present levels; and without wild salmon stocks, the resiliency required for continued runs, especially facing stressors like climate change, is not possible. Policy needs to

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[25] Schoen et al., "Future of Pacific Salmon," 553.
[26] Schoen et al., "Future of Pacific Salmon," 553.
[27] Ruggerone and Connors, "Productivity and Life History," 831.
[28] Springer and van Vliet, "Climate Change," E1880.
[29] Springer and van Vliet, "Climate Change," E1886.
[30] Araki et al., "Fitness of Hatchery-Reared Salmonids," 352.

address the importance of both, the tradeoffs required to sustain both, and provide managers with clear, practicable standards.

As the ADF&G publication *Pacific Salmon: Alaska's Story* says: "Everyone who depends on the salmon must play a role in ensuring its survival."[31] Discussions are happening around the state at the local level concerning the expansion of hatcheries,[32] the proposed drilling of Pebble Mine at the headwaters of Alaska's (and the world's) largest wild salmon run, and ballot initiatives like Stand for Salmon which proposes altering policy regulating human actions in salmon habitat. Different forums for discussion, like the Alaska Humanities Forum's Salmon Fellows which is a group "representing communities, cultures, sectors, and interests across Alaska and with varied relationships to salmon,"[33] have been created by private entities. But it is time to broaden these conversations to all stakeholders: commercial fisherman, sport anglers, Alaska Natives, subsistence users, fishery managers, youth, tourism business owners, hatchery staff, and others. Alaskans have a significant connection to salmon. 90% view their connection as important, and 75% of those view it as very important.[34] They created this connection through the eating and enjoyment of it, its status as symbol of Alaska and Alaskan identity, and its high quality which is known world-wide.[35] Alaskans deserve to have a voice in the process and an opportunity to discuss the tradeoffs involved; the impact of hatchery salmon warrants at least a conversation. Policy-makers should use this as an opportunity to begin that conversation through townhall forums and extend the conversation with organized committees or collaboratives separate from the systems already in place.

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[31] ADF&G, *Pacific Salmon: Alaska's Story* (Santa Barbara, CA: Albion Publishing, 1996): 27.
[32] see http://homernews.com/homer-news/local-news/2017-01-11/contentious-resolution-on-tutka-bay-hatchery-fails and http://www.homertribune.com/article/1720tutka_bay_hatchery_debate_resurfaces for more info
[33] Alaska Humanities Forum, "Alaska Salmon Fellows," accessed May 30, 2018, https://www.akhf.org/fellows.
[34] The Salmon Project, *What Alaskans Are Thinking About Salmon: Alaskan Connections to the Wild Salmon Resource* (2013): 3.
[35] The Salmon Project, *Salmon*, 3.

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