On-Time Public Comments

Hatchery Committee

Anchorage, March 23, 2022

On-Time Public Comments

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Anchorage, March 23, 2022

AFDF
Alaska Fisheries Development Foundation, Inc.

PSPA
PACIFIC SEAFOOD
PROCESSORS ASSOCIATION

March 7, 2022

Alaska Board of Fisheries
Marit Carlson-Van Dort, Chair
Via email: dfg.bof.comments@alaska.gov

RE: On-time comments for March 23 Hatchery Committee

Chair Carlson-Van Dort and Board Members:

Thank you for the opportunity to comment in advance of the Alaska Board of Fisheries (Board) Hatchery Committee scheduled for March 23.

The Pacific Seafood Processors Association (PSPA) is a nonprofit seafood trade association representing seafood processing businesses across coastal Alaska, including several shorebased processors located in Southeast, Prince William Sound, and Kodiak, which are dependent on commercial salmon fisheries.

The Alaska Fisheries Development Foundation (AFDF) is a non-profit organization that represents harvesters, processors, and support sector businesses with a mission to identify common opportunities in the Alaska seafood industry and to develop efficient, sustainable outcomes that provide benefits to the economy, environment, and communities. AFDF also facilitates the sustainability certification of the Alaska salmon fishery by third parties under two separate global standards: the Responsible Fisheries Management (RFM) and the Marine Stewardship Certification (MSC) programs. The Alaska salmon fishery, including the salmon enhancement program, remains certified under both of these programs. These certifications specifically include criteria to measure fishery management and its use of the precautionary principal to protect wild stocks. Providing highly nutritious Alaska salmon and salmon roe protein as a source of essential omega-3 fats and vitamins B and D to world markets requires compliance with these very high certification standards.

PSPA and AFDF are supportive of Alaska's hatchery program and the long-term research undertaken to ensure that hatchery production is compatible with the sustainable productivity of wild stocks. Hatchery pink and chum salmon are crucial for Prince William Sound, Kodiak, Cook Inlet, and Southeast processors because they provide the volume and stability needed to keep plants operating. Processors and harvesters have made significant long-term investments in processing plants and their fishing businesses, respectively, based on this program and permitting decisions. In addition, tenders, support vessels, support businesses, transportation companies, sportfish businesses, and community governments (through fish taxes) are dependent on the direct and indirect economic activity that the hatchery programs provide. Alaska's salmon hatcheries contribute nearly a quarter of the value of our state's salmon harvests and generate $600 million in economic output, with impacts throughout the economy. More than 16,000 fishermen, processing employees, and hatchery workers can attribute some portion of their income to Alaska's salmon hatchery production. In addition, more than 270,000 hatchery-origin salmon are harvested annually in sport and related fisheries, and these numbers are considered conservative (McDowell, 2018).

The State of Alaska established the hatchery program in 1971—at a time when Alaska's salmon returns were at historic lows—to provide for more stable salmon harvests and to bolster the economies of coastal communities that would not otherwise have viable economies. Since the beginning, the hatchery program was designed to supplement natural reproduction, not replace it, and to minimize negative interactions with naturally occurring populations of salmon. Alaska's program is unlike any other, and bounded by statute, regulations, and policies to prioritize the health of wild stocks. A testament to Alaska's design is that wild pink and chum salmon returns and harvests have improved since the inception of the program, and wild and hatchery runs tend to have very similar trends.

Given the interest in and dependence on the hatchery program and the overwhelming public support for the program conveyed at your last Hatchery Committee meeting, we appreciate the Board continuing to convene the Hatchery Committee and supporting the intent of the Joint Protocol on Salmon Enhancement. This protocol is intended to highlight statewide perspectives on issues associated with hatchery production of salmon and to provide a forum for open discussion of hatchery topics, including updates and preliminary results from the ongoing Alaska Hatchery Research Project. We also appreciate the Board's support of the research project as a means to collect unbiased and critical data that serve to protect and maximize Alaska's salmon resources.

Given the dependence on and benefits of the hatchery program to commercial, recreational, and subsistence salmon fishermen, and the overwhelming public support for the program conveyed at every related meeting since 2018, we thank the board for again convening the Hatchery Committee and look forward to participating.

Sincerely,

Chris Barrows
President
Pacific Seafood Processors Association

Julie Decker

Julie Decker
Executive Director
Alaska Fisheries Development Foundation

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I grew up in Kodiak, Alaska, and I participate in commercial fishing in Alaska. I've fished herring for about 20 years and I've been longlining halibut for over 35 years. I have not missed a salmon season since 1966. Salmon fishing in Alaska has been my main income all my life.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

Alaska created the Fisheries Rehabilitation Enhancement Division (FRED) within the Department of Fish and Game in 1971. Later, in an effort to privatize salmon enhancement, the private nonprofit Hatchery Act of 1974 was created allowing for the application of hatchery permits by Alaskans. Alaska's hatcheries were founded as private nonprofit entities to benefit the entire state of Alaska, its fisheries, and user groups.

The Alaska hatchery program is designed to increase salmon abundance and enhance fisheries while protecting wild stocks. Fisheries enhancement projects are not permitted by the Department of Fish & Game if they are anticipated to have a significant negative effect on natural production. The fisheries enhancement program is designed to supplement natural production, not replace or displace it. The Alaska salmon hatchery program, in place for over 40 years, is one of the most successful public-private partnership models in Alaska's history. Alaska's hatcheries are important infrastructure across the state and benefit our communities, economy, and harvesters.

Alaska's hatcheries provide measurable economic impacts to the region by providing additional salmon for harvest by all user groups, reducing harvest pressure on returning wild runs in years of low abundance. These significant positive impacts are applied to the economies of coastal communities through the direct benefit of hatchery operations, increased landings, and raw fish taxes of salmon at local ports.

Alaska's salmon hatcheries account for the annual equivalent of 4,700 jobs and $218 million in total labor income, including all direct, indirect, and induced economic impacts. A total of $600 million in annual economic output is connected to Alaska salmon hatchery production. The economic footprint of Alaska's

hatcheries includes $95 million in labor income associated with commercial fishing, $82 million in labor income associated with processing, and $25 million connected to hatchery operations.

Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Armin Reimnitz

Submitted By
Ben Van Alen
Submitted On
10/6/2021 9:41:15 AM
Affiliation

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3860 Caroline Street
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I recommend that an assigment for the Alaska Board of Fisheries Hatchery Committee is to assess how releasing salmon from hatcheries is justified ecologically and economically. The Alaska Board of Fisheries Hatchery Committee must seek additional information on the ecologic and economic impacts of hatchery releases. Here are some of my ecologic observations and comments to help frame this topic. For hatcheries to have economic merit they must have ecological merit.

Ecologically, it appears that salmon hatcheries in Southeast Alaska are being operated in violation of the “sustained yield principal” for natural/wild resources that is mandated in Article VIII of Alaska’s Constitution and multiple Administrative Codes (i.e., 5 AAC 39.220, 39.222, 39.223, and 41.030). Forty-plus years into Alaska’s modern hatchery era, it is clear that the sustaining and rebuilding of wild runs is impossible in the face of continued hatchery releases. Where do we have hatchery releases and not declining or depressed salmon, herring, or eulachon? The intent of Alaska’s “ocean ranching” hatchery program is to rehabilitate and enhance wild salmon resources (from historical overfishing). Hatcheries are to supplement NOT supplant wild fish. However, it is ecologically impossible for hatchery fish not to supplant wild fish much less supplement them. Hatcheries have no place in sustainable salmon management.

The production and productivity of wild salmon has been directly compromised by the industrial-scale releases of hatchery Chum, Pink, Coho, Chinook, and Sockeye salmon in the area and into the ocean. The growth and survival of “ocean ranched” hatchery salmon is in direct competition with the growth and survival of wild fish. Salmon production is ultimately limited by the environment’s carrying capacity and only wild salmon help to sustain the natural marine-terrestrial-marine nutrient cycle productivity by returning to spawn and die in thousands of natal streams. Thus, hatchery salmon are both supplanting and eroding wild salmon production. Coastwide, we observe declining and depressed wild runs of salmon, herring, and eulachon wherever there are production releases of hatchery salmon. Hatchery releases must be restricted or eliminated to sustain the health and productivity of wild fish.

In Southeast Alaska, the total wild and hatchery salmon harvests have been in decline since hatchery releases exceeded about 450 million fish in the 1990s. Total commercial harvests in 2018 and 2019 were approaching to the mid-1970s, need-to-rebuild, levels. Over 550 million fish are now released from hatcheries in Southeast Alaska and hatchery planners and operators are continually planning for larger releases of larger fish in additional release sites. Alaskan hatchery releases represent about a third of the 4.5 billion “ocean ranched” salmon now released each year into the North Pacific. The hatchery releases of chum salmon in Southeast Alaska, pink and chum salmon in Prince William Sound, and pink salmon in Kodiak are a large share of the hatchery releases but releases of Coho salmon, Chinook salmon, and Sockeye salmon are also of significant numerical and ecologic importance in these areas too.

The total production of plants and animals is always limited by habitat capacity more than reproductive capacity (numbers of seeds or young). Agriculturally, we know that crop yield is ultimately limited more by the size of the field and the productivity of the soil than the number of seeds planted. We know that maximizing the yield is best done by fertilization and not by planting more and more seeds. We know that planting too many seeds will crowd the plants and lower the yield. The same is true with aquaculture/ocean ranching. There is a finite, but climate-ocean variable, carrying capacity in the ocean for salmon to grow and survive. Wild and hatchery salmon are in direct competition for this niche. Competition for space and food in the early marine niche is certainly intense. Wild fish can fill the ocean’s carrying capacity and maximize returns but we have allowed, and encouraged, hatchery operators to supplant natural production with hatchery releases. In fact, we have allowed, and encouraged, hatchery operators to employ whatever rearing and release strategies they can afford to help give their releases a survival advantage over wild fish. This is usually to release them larger than their wild counterparts. How is this a wild stock priority?

Agriculturally, again, the farmer knows he must remove whatever is naturally growing on his field (trees, bushes, grasses, etc) before planting. The ocean is already a “field” full of fish. There is not, and will never be, a big open niche for hatchery fish. When hatchery fish survive, wild fish die.

Nevertheless, what happens naturally *is* the positive result of millions and billions of experiments in the competition and cooperation among biota in the biosphere. We can’t make more fish than we could have naturally and a big, unnatural, and unintended, consequence of hatchery fish is that they are lowering the productivity of marine and terrestrial environments. Wild salmon invest in the natural marine-terrestrial-marine nutrient cycle by spawning and dying in thousands of natal streams. In contrast, nearly all the hatchery adults are caught, and should be, and their marine derived nutrients are removed from the nutrient cycle. This “nutrient mining” by hatchery fish gradually erodes the productivity of estuarine, coastal, and oceanic habitats and lowers the productivity for all biota in the biosphere. Releases of hatchery salmon into lakes and streams also mines nutrients from the watersheds. We have allowed billions of hatchery fish to elbow their way into the ecosystem potluck without bringing a dish.

The many unnatural parts of the business of hatcheries – from unnatural selection, to unnatural rearing, to unnatural straying, to unnatural releases, to unnatural predation, to unnatural harvesting – all compromises the fitness, biodiversity, and sustainability of wild salmon. It is not hatchery production but wild reduction. Wild fish are affected, negatively affected, wherever they share habitats with hatchery releases. There might be a niche for hatchery releases if we destroy habitats that salmon need to migrate, spawn, and rear in, or if we grossly overfish, but this not our management intent or even sustainable. Of all the harvest pressure, climate change, and funding challenges we face in managing wild salmon, at least we have full control over the number of fish released from hatcheries. If a fraction of the millions of dollars spent on hatchery releases was spent on the basic stock assessment and management of wild runs we would have more salmon today and a management program to sustain them. Looking at all the hatchery programs, and release efforts, that have come and gone since 1971 should have us questioning the wisdom of hatchery investments – a “do better than what happens naturally” investment we’ve been spending in the region since 1891 – with no evidence of actually, sustainably, boosting salmon production. Commercial gear groups (seine, gillnet, troll) should note that hatcheries often take the largest share of the salmon harvest. The proportion of the run now taken by this newest and largest “user” group is comparable to the proportion of the wild salmon run that is allowed to spawn and rejuvenate the watersheds.

It is time for the “Scientific Method”. Years ago, many assumed that hatcheries would help rebuild and enhance Alaska’s wild salmon runs. Now, after observing declining and depressed runs of wild salmon, herring, and eulachon wherever we have industrial-scale hatchery releases (Columbia River, Puget Sound, Fraser River, Georgia Strait, Southeastern Alaska, Prince William Sound, South Central, Kodiak) we must toss the “hatcheries are good” assumption. Especially since returns of hatchery fish are now declining too. For example, in Chatham Strait, after forty-plus years of industrial-scale hatchery releases from Hidden Falls Hatchery what do we have? Thirty-plus years of declining returns of hatchery Chum, Coho, and Chinook Salmon and drastic declines in wild salmon stocks throughout the area. Meanwhile, the hatchery is still interested and permitted to maintain release levels as if the carrying capacity is unlimited and wild resources are unaffected. Likewise, industrial-scale releases of Chum, Coho and Chinook Salmon at Neets Bay Hatchery remain high despite declining hatchery returns and the collapse of nearby stocks of Unuk eulachon and Chinook Salmon, McDonald Sockeye Salmon, and West Behm Canal herring. Speaking of herring, the decline below fishable levels of herring stocks in Prince William Sound, Lynn Canal, Revillagigedo Channel, and Sitka Sound all followed the buildup of production hatchery releases in those areas. And, speaking of Chinook Salmon, our hatcheries have been releasing more and more, bigger and fatter, Chinook salmon for decades despite declining returns and harvests of wild and hatchery fish. The same is true for Coho Salmon. Southern Southeast Regional Aquaculture Association, Northern Southeast Regional Aquaculture Association, and Douglas Island Pink and Chum have all had concerns meeting brood stock and cost recovery goals in recent years despite decades of industrial-scale hatchery releases. Again, where are there industrial-scale hatchery releases and not declining runs of eulachon, herring, and salmon? Where are their sustainable returns of hatchery salmon?

Our industrial-scale “ocean ranching” hatchery releases exceed (overshoot) carrying capacity thresholds and contribute to highly variable survivals and returns of both wild and hatchery salmon. Poor survivals of wild salmon results in low returns and low escapements and years of fishery restrictions to rebuilt escapements and returns. A hatchery-induced death spiral we must avoid. It takes wild fish to make fish because wild fish are dying for more. Again, the sustaining and rebuilding of wild runs is impossible in the face of continued hatchery releases.

Closing salmon hatcheries in Southeastern Alaska would set an example for closing hatcheries statewide and elsewhere. Closing salmon hatcheries will greatly simplify regulations and management of salmon fisheries throughout the region. “Housekeeping” proposals at future Board meetings to repeal all the hatchery allocation and management plans will cut about a third of the regulation verbiage. There will no longer be the incentive to resolve allocation issues with promises of hatchery fish nor the challenges and expense of managing for and around hatchery fish. Most importantly, we will be better able to manage natural resources on a sustained yield basis, and for a wild stock priority, as mandated by Alaska’s Constitution and Statutes.

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Ketchikan, Alaska, three months out of the year and I work as a seafood processor in Alaska. Alaska General Seafoods (AGS) is a socially responsible seafood processing company that purchases fresh seafood from independent fishermen, who harvest their wild catch from sustainable fisheries in a responsible manner from the cold pristine waters of Alaska. AGS produces canned, fresh and frozen seafood and sells to wholesale customers around the world. Our seafood products are manufactured in processing facilities which are certified at the highest levels, by both state and federal regulators and independent food inspection agencies, to ensure our seafood products are wholesome and of high quality.

Wild salmon play a critical role in Alaska's economy, are greatly valued in the commercial and sportfishing industries, and to their cultural and dietary importance to Indigenous populations throughout the state. Wild salmon, like many species of fish, are some of our world's last natural foods. When fished responsibly, salmon provide a variety of health benefits through human consumption. They are high in protein, low in calories and contain a health-promoting omega-3 which helps minimize the risk of heart disease and diabetes.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

Alaska created the Fisheries Rehabilitation Enhancement Division (FRED) within the Department of Fish and Game in 1971. Later, in an effort to privatize salmon enhancement, the private nonprofit Hatchery Act of 1974 was created allowing for the application of hatchery permits by Alaskans. Alaska's hatcheries were founded as private nonprofit entities to benefit the entire state of Alaska, its fisheries, and user groups.

The Alaska hatchery program is designed to increase salmon abundance and enhance fisheries while protecting wild stocks. Fisheries enhancement projects are not permitted by the Department of Fish & Game if they are anticipated to have a significant negative effect on natural production. The fisheries enhancement program is designed to supplement natural production, not replace or displace it. The Alaska salmon hatchery program, in place for over 40 years, is one of the most successful public-private partnership models in Alaska's history. Alaska's hatcheries are important infrastructure across the state and benefit our communities, economy, and harvesters.

Alaska's hatcheries provide measurable economic impacts to the region by providing additional salmon for harvest by all user groups, reducing harvest pressure on returning wild runs in years of low abundance. These significant positive impacts are applied to the economies of coastal communities through the direct benefit of hatchery operations, increased landings, and raw fish taxes of salmon at local ports.

Alaska's salmon hatcheries account for the annual equivalent of 4,700 jobs and $218 million in total labor income, including all direct, indirect, and induced economic impacts. A total of $600 million in annual economic output is connected to Alaska salmon hatchery production. The economic footprint of Alaska's hatcheries includes $95 million in labor income associated with commercial fishing, $82 million in labor income associated with processing, and $25 million connected to hatchery operations.

Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Brad Wilkins

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Clam Gulch, Alaska, and I participate in commercial fishing in Alaska. I've been a Cook Inlet setnetter since 1962. I'm on Cook Inlet Aquaculture Association Board of Directors and am a past president. My wife and I have made the vast majority of our income for our entire lives by commercial fishing.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska’s hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Brent Johnson
ragweb@icloud.com
(907) 262-4763

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live on the Kenai Peninsula and I participate in sport fishing and as a hatchery employee in Alaska. I am a first line observer of the health of fish migrating in and out of important watersheds. I do some work with school children and teach them to respect and appreciate Alaska's salmon. I also volunteer for various fishery related events. I take great pride working in fisheries. Hatcheries are our savings account for future generations. I have worked with salmon for over 22 years. I depend on the fisheries for my livelihood and it is an important food source for my family.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Cathy Cline

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Cordova, Alaska, and I participate in subsistence fishing, commercial fishing and sport fishing in Alaska. Three generations of our family have been and are residents of Alaska, commercial fishermen, and seafood processors. As rural residents with a consistent resource for income, we are provided opportunities for volunteering, serving on boards, and investing, both monetary and self, in our community. The state's initiation of the salmon hatchery program contributed to consistency to salmon resources for 40 years, an important factor to our economy and well being. With the continuance of the hatchery program, we are hopeful the salmon resource will allow the next generation of fishermen and processors to thrive and contribute to our communities.

Our initial commercial income was derived from crab, halibut, herring and salmon fisheries. Now, salmon and halibut are those available for commercial harvest opportunities, salmon populations being significantly enhanced by the hatchery program. As we are dependent on resources for our subsistence lifestyle, economically necessary in rural Alaska, a great portion of our neighbors in Cordova are employed in seafood processing, plus dependent on local resources for subsistence. The hatchery program provides a consistent resource for these endeavors.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Cecilia Wiese

Submitted By
Cole McLaughlin
Submitted On
2/18/2021 10:05:14 AM
Affiliation
Blatchley

Proposal #172: in support

Shrimp Harvest Season

I am writing in support of proposal 172, moving the shrimp fishery from October to May. If we move the shrimp fishery to May, there wouldn't be eggs on the shrimp and the fishermen wouldn't have to kill the mother and the eggs would stay safe and hatch. Secondly, the shrimp would be able to reproduce more and people would be able to catch more. Third, Canada did it and it worked, so why can't we? Lastly, if we move the fishery to May, marine biologists would have more time to study the shrimp. Also, if you like eating the eggs, then there could be a law where you can only take a few shrimp with eggs. To restate, my first reason for why we should move the shrimp fishery from October to May is that there wouldn't be eggs on the shrimp, my second reason is that the shrimp would be able to reproduce more, my third reason is Canada did it so we can at least try too, and my last reason is that marine biologists would have more time to study the shrimp.

March 8, 2022

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Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Homer, Alaska, and I participate in commercial fishing, sport fishing, and public use fisheries in Alaska. I'm a fourth generation commercial fishermen. My great grandparents came to Homer and homesteaded in the 1930s. Salmon fishing is and has been my primary income for 14 years as an adult. I grew up fishing with my dad, and he with his dad. My mother's side of the family fished is Kachemak Bay and Cook Inlet starting in the 1930's. Fishing is not only our family culture, but it is also our way of life, our pursuit of happiness. Hatcheries are vital to a consistent annual harvest. They provide jobs and a valuable resource that is enjoyed by all user groups.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

Alaska created the Fisheries Rehabilitation Enhancement Division (FRED) within the Department of Fish and Game in 1971. Later, in an effort to privatize salmon enhancement, the private nonprofit Hatchery Act of 1974 was created allowing for the application of hatchery permits by Alaskans. Alaska's hatcheries were founded as private nonprofit entities to benefit the entire state of Alaska, its fisheries, and user groups.

The Alaska hatchery program is designed to increase salmon abundance and enhance fisheries while protecting wild stocks. Fisheries enhancement projects are not permitted by the Department of Fish & Game if they are anticipated to have a significant negative effect on natural production. The fisheries enhancement program is designed to supplement natural production, not replace or displace it. The Alaska salmon hatchery program, in place for over 40 years, is one of the most successful public-private partnership models in Alaska's history. Alaska's hatcheries are important infrastructure across the state and benefit our communities, economy, and harvesters.

Alaska's hatcheries provide measurable economic impacts to the region by providing additional salmon for harvest by all user groups, reducing harvest pressure on returning wild runs in years of low abundance. These significant positive impacts are applied to the economies of coastal communities through the direct benefit of hatchery operations, increased landings, and raw fish taxes of salmon at local ports.

Alaska's salmon hatcheries account for the annual equivalent of 4,700 jobs and $218 million in total labor income, including all direct, indirect, and induced economic impacts. A total of $600 million in annual economic output is connected to Alaska salmon hatchery production. The economic footprint of Alaska's hatcheries includes $95 million in labor income associated with commercial fishing, $82 million in labor income associated with processing, and $25 million connected to hatchery operations.

Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Colten Tutt

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Cordova, Alaska, and I participate in subsistence fishing, commercial fishing, and sport fishing in Alaska. I am currently a PWSAC board member and have firsthand knowledge that without aquaculture in Area E, there would be massive lost opportunity for all Alaskan residents. Salmon provide a living for me and my family.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Darin Gilman

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I spend summers in Cordova, Alaska, and I participate in commercial fishing in Alaska. I have commercial fished on Prince William Sound and Copper River Flats since 1983 and I am a Real Property owner in Cordova. For the last 39 years, the commercial salmon fishery, both hatchery and wild, has been a the major source of income for myself and family.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

David Blake

Submitted By
David Martin
Submitted On
3/7/2022 9:34:45 PM
Affiliation

Board of Fish Members,

I strongly support the Alaska's Salmon Hatchery Program. The hatcheries provide salmon for all user groups, recreation, commercial, suibsistence and personal use. They also provide sustainable salmon for interstate commerce, food supply and the National interest. The hatchery programs are highly regulated by the State to not negatively affect the wild salmon stocks and marine ecosystems. The hatcheries operate on the best scientific practices and must not be hampered by unnecessary restrictions for political or non-scientific purposes.

Thank you,

David Martin

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Whittier and Cordova, Alaska, and we purchase local Prince William Sound harvested salmon for our small cruise ship guests' meals. We own and operate the longest running "Small Ship Cruise" business in Alaska. We often visit Esther Island and Lake Bay to show our guests the salmon hatchery located there. Our guests are amazed by the positive impact that salmon hatcheries have made on not only local coastal Alaskan commercial fishing economies, but on the wild resource itself. We often stop by any of our friends' gill netter, or seiner or tender to show our guests how commercial salmon fishing in conducted.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Dean Rand

Submitted By
Dennis M Zadra
Submitted On
3/1/2022 9:37:15 AM
Affiliation

Phone
907-253-3718
Email
dennis@idohuntak.com
Address
PO Box 2348
Cordova, Alaska 99574

I have been a commercial fisherman out of Cordova and elsewhere for 32 years. Hatchery salmon production has been a vital component to my livlihood and to the economic stability of small communities like Cordova. The real science does not support the speculation that hatchery production is detrimental to wild stocks. Please do not allow special interest groups to reduce hatchery production.

Thank You.

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Ninilchik, Alaska, and I participate in subsistence fishing, commercial fishing, sport fishing, public use fisheries, seafood processing, and as a regional director and entrepreneur in Alaska. I've been personally and professional involved in Alaska's salmon fisheries for over 40 years.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Jeff Berger

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I participate in commercial fishing and sport fishing in Alaska. I have supported my family with salmon seining for the past 45 years. Hatchery production has been a large part of making that possible.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Jeffrey Golden

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Seward, Alaska, and I participate in commercial fishing in Alaska. I am a year-round resident whose main income is generated during the summer season from commercial fishing. Commercial fishing for salmon is the main source of income for my household. The future of sustainability for salmon fisheries is of the utmost importance for sport, subsistence or commercial fishing alike. Hatcheries, along with proper management will help secure a healthy fishery that supports many aspects of the community - tourism, local jobs, seasonal jobs, fish tax and small businesses to name a few. It's important to carry on Alaska's deep connection to this species and support it where possible.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Jenny Nakao

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Skagway, Alaska, and I participate in subsistence fishing and sport fishing in Alaska. I have lived and fished in Skagway for 48 years. While we had a small SI-Fi hatchery at the Skagway school, fishing was good. With it gone, fishing is now poor and bleak. Many Skagway people sport and subsistence fish for food supplementation. With Chinook fishery closed again. the only options are pink and sockeye with subsistence nets.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

John Tronrud

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Clam Gulch, Alaska, and I participate in commercial fishing and sport fishing in Alaska. Hatcheries help fisheries to maintain a consistent harvest. I am a born and raised Alaskan who grew up commercial and sports fishing on the Kenai Peninsula. Commercial fishing is the way I make my income so fishing is especially essential for me.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Judy Johnson

Title

Reduced relative fitness in hatchery-origin Pink Salmon in two streams in Prince William Sound, Alaska

Running Title

Relative fitness of Pink Salmon

Authors

Kyle R. Shedd[1*], Emily A. Lescak[1], Christopher Habicht[1], E. Eric Knudsen[2], Tyler H. Dann[1], Heather A. Hoyt[1], Daniel J. Prince[1], and William D. Templin[1]

Contact Information

[1]Alaska Department of Fish & Game 333 Raspberry Road, Anchorage, AK 99518

[2]Prince William Sound Science Center (PWSSC), 300 Breakwater Ave, Cordova, AK 99574

*Corresponding author; kyle.shedd@alaska.gov

Abstract

Previous studies generally report that hatchery-origin Pacific Salmon (*Oncorhynchus spp.*) have lower relative reproductive success (RRS) than their natural-origin counterparts. We estimated the RRS of Pink Salmon (*O. gorbuscha*) in Prince William Sound, Alaska (PWS) using incomplete pedigrees. In contrast to other RRS studies, Pink Salmon have a short freshwater life history, freshwater habitats in PWS are largely unaltered by development, and sampling was conducted without the aid of dams or weirs resulting in incomplete sampling of spawning individuals. Pink Salmon released from large-scale hatchery programs in PWS have interacted with wild populations for more than 15 generations. Hatchery populations were established from PWS populations but have subsequently been managed as separate broodstocks. Gene flow is primarily directional, from hatchery strays to wild populations. We used genetic-based parentage analysis to estimate the RRS of a single generation of stray hatchery-origin Pink Salmon in two streams, and across the odd- and even-year lineages. Despite incomplete sampling, we assigned 1,745 offspring to at least one parent.

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/EVA.13356

Reproductive success (RS), measured as sampled adult offspring that returned to their natal stream, was significantly lower for hatchery- versus natural-origin parents in both lineages, with RRS ranging from 0.03 to 0.47 for females and 0.05 to 0.86 for males. Generalized linear modeling for the even-year lineage indicated that RRS was lower for hatchery-origin fish, ranging from 0.42 to 0.60, after accounting for sample date (run timing), sample location within the stream, and fish length. Our results strongly suggest that hatchery-origin strays have lower fitness in the wild. The consequences of reduced RRS on wild productivity depend on whether the mechanisms underlying reduced RRS are environmentally driven, and likely ephemeral, or genetically driven, and likely persistent across generations.

Keywords

Relative reproductive success; Fitness; Alaska; Aquaculture; Fisheries; GT-seq; Hatchery; Straying; *Oncorhynchus*; Pedigree; Population genetics; Pink Salmon

Acknowledgements

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Conflict of Interest Statement

Research presented in this manuscript is part of the larger Alaska Hatchery Research Program (AHRP) which has received funding from the State of Alaska, private non-profit (PNP) hatcheries, the seafood processing industry, National Oceanic and Atmospheric Administration (NOAA) 2016 Pink Salmon Disaster funds, the North Pacific Research Board, NOAA Saltonstall-Kennedy grant program, and the Pacific Salmon Treaty Northern Endowment Fund. This program is designed to collect information to inform Alaska Department of Fish and Game (ADF&G) policy regarding hatchery permitting and release levels. Bill Templin, Chief Fisheries Scientist, shapes ADF&G policy and Chris Habicht, ADF&G Principal Geneticist, implements genetic policy during hatchery permit reviews. Private non-profit hatchery operators are supported by fish taxes and must secure permits from the State of Alaska to operate hatcheries and release fish. The seafood processing industry benefits from the PNP hatchery programs that augment wild production and stabilize harvests. The State of Alaska manages fisheries with a wild-stock priority and the seafood industry has a vested interest in sustainable fisheries management both for third party certification from the Marine Stewardship Council and the United Nations Responsible Fisheries Management Program and for its long-term viability.

Author Contributions

BT and CH oversaw study implementation and were members of the AHRP Science Panel. EEK coordinated field sampling. THD designed the GT-seq panel used for parentage analysis and assisted with early versions of the power analysis. HAH oversaw lab work including DNA extraction and genotyping. DJP performed the bioinformatics to obtain genotypes. KRS did the power analysis. KRS and EAL analyzed the data and led the manuscript writing. All authors reviewed drafts and gave approval for final publication.

Introduction

The extent to which hatchery- and natural-origin (i.e. salmon spawned in the wild that may have a mix of hatchery and wild ancestry) salmon interact, interbreed, and influence each other's fitness in natural systems is controversial (e.g., Araki & Schmid, 2010; Buhle et al., 2009; Evenson et al., 2018; Hilborn & Eggers, 2001; Koch & Narum, 2021; McGee, 2004; Naish et al., 2007; Pearsons, 2008; Smoker & Linley, 1997; Wertheimer et al., 2004, 2001). Relative reproductive success (RRS) is a widely used measure of fitness of hatchery-origin salmon compared to natural-origin salmon spawning in the same streams (e.g., Araki et al., 2008; Christie et al., 2014; Koch & Narum, 2021). In these studies, reproductive success (RS) is often defined as the number of adult offspring produced by an individual parent that return to the natal system, typically excluding any adult offspring that stray (donor strays; see Table 1 in Knudsen et al., 2021 for definitions of straying terminology used in this paper) into unmonitored systems or those harvested in fisheries. While results vary based on species, hatchery broodstock practices, and the statistical power of study designs (e.g., Araki et al., 2008; Christie et al., 2014; Koch & Narum, 2021), the overall pattern across studies indicates reduced fitness of hatchery fish spawning in the natural environment. However, most RRS studies to date on Pacific Salmon (*Oncorhynchus spp.*) focus on species that spend over a year rearing in freshwater after hatching (but see Berejikian et al., 2009); populations spawning and rearing in human-altered freshwater habitats; and study designs allowing for nearly complete sampling of all parents and offspring in the population, resulting in pedigrees in which both parents are known for most offspring.

In Alaska, hatcheries began practicing extensive ocean-ranching aquaculture (i.e., fish are spawned in the hatchery, reared, and released as fry or smolts into the ocean) of Pacific Salmon in the 1970's to supplement common property fisheries and support salmon-dependent communities. Alaskan hatcheries currently release approximately 1.8 billion juvenile salmon annually, with over 700 million Pink Salmon (*O. gorbuscha*) fry released in Prince William Sound (PWS; Wilson, 2020). Hatchery-origin Pink Salmon are produced by four private non-profit (PNP) hatcheries in PWS (Figure 1) and are differentiated from natural-origin fish by internal thermal otolith marks applied during hatchery incubation (Volk et al., 2005). These PWS hatcheries differ from many other hatchery programs where RRS has previously been studied, not just in terms of species studied (see Koch & Narum, 2021 for a recent review), but also in sheer scale of production.

Pink Salmon have distinctive life history traits relative to other Pacific Salmon (Figure S1). First, Pink Salmon spend a shorter time (overwinter) rearing in freshwater after hatching prior to outmigration as smolt (Groot & Margolis, 1991). Second, Pink Salmon have a fixed two-year generation time that results in genetically distinct odd- and even-year lineages and no overlapping cohorts to buffer against interannual environmental variation. Third, Pink Salmon tend to spawn in both the freshwater and intertidal habitats of short, steep, coastal streams. The low environmental variation among spawning streams reduces the potential for local adaptations. Fourth, Pink Salmon have relatively high natural stray rates among populations, likely due to a combination of the lack of overlapping age cohorts and reduced environmental variation among spawning sites, particularly for intertidal spawners (Quinn, 2018; Salmenkova, 2017). High natural stray rates lead to increased gene flow among populations which contributes to the observed relatively low levels of genetic differentiation among stocks within lineages compared to other Pacific Salmon species (Aspinwall, 1974; Beacham et al., 2012; Cheng et al., 2016; Christensen et al., 2021; Olsen et al., 1998; Seeb et al., 1999; Tarpey et al., 2018).

Pink Salmon hatcheries in PWS were founded with broodstock from multiple donor sources local to PWS in the late 1970's and early 1980's (Habicht et al., 2000). Broodstock are currently collected at the hatcheries by volitional entry through fishways or fish ladders into brood holding ponds (PWSAC, 2021a, 2021c, 2021b; VFDA, 2021). Fish are spawned without regard to origin status, which is unknown to hatchery culturists due to the lack of external marks and inability to process hundreds of thousands of otoliths in-season during egg take. However, otolith sampling from broodstock of three PWS Pink Salmon hatcheries in 2008 indicated that almost all broodstock (>99.7%) are hatchery-origin (Smoker, 2009), resulting in *de facto* segregated broodstock (see definition in Box 1 of Koch & Narum, 2021) with virtually no gene flow from wild to hatchery populations.

The commercial fishery in PWS is managed as a mixed-stock fishery with the dual and often competing goals to both ensure wild stock escapement into streams and target a high proportion of hatchery-origin Pink Salmon (Vega et al., 2019). This management strategy requires differential harvest rates of hatchery and wild stocks and is partially, but imperfectly, facilitated by spatial and temporal differences in migratory behavior between hatchery and wild fish and in-season monitoring of hatchery proportions in the harvest via otolith sampling (Alaska Department of Fish and Game, 1994; Knudsen et al., 2021). Despite these run timing differences, there is a high degree of spatio-temporal overlap between hatchery and wild stocks in commercial fisheries occurring along migration corridors (Hilborn & Eggers, 2000; Vega et al., 2019).

The total run of hatchery-origin Pink Salmon to PWS is much larger than that of natural-origin Pink Salmon, with hatchery-origin fish contributing an average of 70% of the total return of Pink Salmon to PWS between 2013 and 2015 (overlapping with the years of this study and the only three-year period with full run reconstructions; Knudsen et al., 2021). During this period, 95–99% of the hatchery-origin Pink Salmon return in PWS were either harvested in common property fisheries or hatchery cost-recovery fisheries, or taken as broodstock by the hatcheries, compared to a harvest rate of 27–50% for natural-origin Pink Salmon. The remaining 1–5% of hatchery-origin Pink Salmon that were not harvested or taken as broodstock, representing hundreds of thousands of fish annually, strayed into natural streams (donor stray rate). Hatchery-origin spawners made up 5–15% (recipient stray rate) of the total annual escapement for PWS Pink Salmon in 2013–2015 due to the magnitude of the total hatchery-origin return relative to the wild return. The proportion of hatchery-origin spawners (pHOS; recipient stray rate) in 27 sampled PWS streams ranged from 0 to 98% with higher pHOS values generally associated with smaller populations and streams located closer to hatchery release sites (Knudsen et al., 2021), as was also noted by Joyce and Evans (1999) and Brenner et al. (2012).

Concerns regarding PWS Pink Salmon hatcheries center around recipient stray rates of hatchery-origin salmon in wild streams (pHOS), the counting of hatchery strays towards wild-stock escapement goals, the potential for fitness declines resulting from genetic introgression, and competition between hatchery and wild stocks (Alaska Department of Fish and Game, 1994; Amoroso et al., 2017; Davis et al., 1985; Grant, 2012; Lewis et al., 2009). Some argue that hatchery-origin Pink Salmon in PWS displace wild stocks and do not increase the net production (production after accounting for broodstock needs and hatchery cost recovery fisheries) above what would be expected of natural populations without hatchery supplementation (Hilborn & Eggers, 2000). Others, however, argue that hatchery-origin fish increase harvest opportunities without negatively impacting natural stocks (Wertheimer et al., 2001, 2004). More recent analyses suggest that hatchery releases diminish the productivity of wild stocks of Pink Salmon to PWS (Amoroso et al., 2017; Ohlberger et al., 2021), despite recent record wild stock returns in the odd-year lineage (Haught et al., 2017; Knudsen et al., 2021).

We hypothesized that RS differences between hatchery and wild stocks in PWS Pink Salmon due to domestication selection of hatchery fish would be smaller than what has been observed in other studies due to differences in hatchery history and practices in PWS as compared to the Pacific Northwest. These differences include 1) shorter hatchery residency (overwinter) resulting in reduced potential for domestication selection during juvenile life stages in hatcheries (Berejikian et al., 2009); 2) large hatchery broodstock sizes that reduce the likelihood of genetic divergence from wild stocks due to genetic drift, diminishing the potential for outbreeding depression when hatchery strays spawn in streams; and 3) previous and ongoing gene flow from the hatcheries to the natural populations due to hatchery straying may have already eroded local adaptations in wild stocks. We measured RRS over a single generation after 16 to 20 generations of hatchery production (Figure S1), in streams with consistently high pHOS and therefore high potential for previous introgression (Brenner et al., 2012; Knudsen et al., 2021). These conditions may be expected to reduce the apparent effect of hatchery-origin on fitness, since we do not know the extent to which the natural-origin fish in our analysis have hatchery ancestry (Willoughby & Christie, 2017).

However, many mechanisms other than domestication selection may influence RRS (reviewed by Naish et al., 2008) including: 1) relaxation of natural selection such that hatchery-origin fish are not locally adapted to streams (Mobley et al., 2019); 2) heritable epigenetic changes due to differences between the hatchery and wild environments (Gavery et al., 2018, 2019; Le Luyer et al., 2017; Leitwein et al., 2021); 3) behavioral and ecological differences associated with broodstock sources and hatchery experience (Hughes & Murdoch, 2017; Thériault et al., 2011); and 4) study methodology (Christie et al., 2014; Hinrichsen, 2003; Koch & Narum, 2021).

The Alaska Hatchery Research Program (AHRP) was formed by the Alaska Department of Fish and Game (ADF&G) and PNP hatchery operators in 2011 to investigate these concerns by studying genetic and ecological interactions between hatchery and wild stocks in Alaska. One of the priority questions raised by the AHRP was: what is the impact of stray hatchery fish on the fitness of wild populations (Taylor, 2013)? We used genetic parentage analysis and recovery of thermally marked otoliths to estimate the RRS of hatchery-origin Pink Salmon relative to natural-origin Pink Salmon spawning in wild systems, as a proxy for fitness. The AHRP will eventually examine two brood years of first generation RRS and one brood year of second generation (grandparent) effects in odd- and even-year lineages of Pink Salmon for five PWS drainages (Figure S1). Here we present results for the first generation of RRS for two PWS drainages, Hogan Bay and Stockdale creeks: short, steep, island streams that support both intertidal and upstream spawners.

This is the first study to estimate the RRS of hatchery-origin fish in multiple remote streams without the benefit of in-stream infrastructure to aid in sampling (i.e., dams, weirs, etc.). An underlying assumption of our study was that carcass sampling was representative of all spawners in each stream since census sampling was logistically prohibitive. Verifying this assumption was critical given that 1) there are known differences in run timing between wild stocks and hatchery-origin Pink Salmon (Knudsen et al., 2021), and 2) our estimates of RRS only account for offspring that were sampled in the study streams (excluding offspring that strayed into unmonitored streams or that were harvested in commercial fisheries). Our primary objective was to test the null hypothesis that hatchery- and natural-origin fish have equal RS (RRS = 1) against the alternative hypothesis that RRS is not equal to 1 by calculating unweighted RRS as the average RS of hatchery-origin fish divided by the average RS of natural-origin fish. Our secondary objective was to test whether run timing (sample date), spawning location (sample location), and body length differences between hatchery- and natural-origin fish affected RRS by using generalized linear models (GLMs) to isolate the effect of hatchery-origin from these potentially confounding covariates (Koch & Narum, 2021).

Methods

Study Sites and Sampling

Field collections

Pink Salmon were sampled in Hogan Bay Creek (60.19668ºN, 147.757ºW; hereafter referred to as Hogan Bay) and Stockdale Creek (60.31813ºN; 147.202ºW; Figure 1) from early August through late September, annually from 2013 to 2016 (Figure 2). Hogan Bay has ~550 meters of stream spawning habitat, most of which is tidally influenced, whereas Stockdale has ~1,500 meters, much of which is above tidal influence. We relied on instream sampling from carcasses to concurrently collect genetic tissue and otolith samples after fish had the opportunity to spawn, due to the lack of external markings (i.e., adipose fin clips) to identify hatchery-origin fish and because collecting otoliths requires destructive sampling. At times sampling was limited due to tidal stage, stream access due to flooding or high bear activity, and limited fish abundance (Knudsen et al., 2015). These limitations prevented us from collecting all potential parents and offspring in each generation and affected the statistical power of our study design (see Box 1). GPS locations were recorded for processing areas (locations on a stream during a survey where a set of specimens were gathered, measured, and sampled), which were located at the center of, and limited to specimens collected within, a 200-meter stream reach (Knudsen et al., 2015). At each processing area, paired otolith and heart tissue samples (for DNA extraction) were collected concurrently into a 2 ml cell of a 48 deep-well plate and preserved in reagent alcohol (BDH1156, VWR International LLC, Radnor, PA) to prevent DNA degradation (Gorman et al., 2018). Sex, length (mid-eye to hypural plate), and sample date were recorded for each fish. We predicted both streams were likely to have high statistical power to detect differences in RS if RRS <= 0.5 based on power analyses conducted after the 2014 field season (Shedd et al., 2014; Box 1). We tested for significant differences in body length, run timing (sample date), and spawning location (processing area) between hatchery- and natural-origin fish using two-sided *t*-tests (length) or Wilcoxon tests (date and location), performed separately for each stream, sex, and lineage to determine whether these factors might explain differences in RS.

Otolith analysis

We sent otoliths to the ADF&G Cordova Otolith Laboratory where they were analyzed for the presence of hatchery thermal marks (see Supplemental Methods).

Genotyping

We genotyped individuals using a panel of 298 single nucleotide polymorphism (SNP) amplicons (210 single [unlinked] SNPs and 88 microhaplotypes [two linked SNPs within a single amplicon]; Table S1). We genotyped both hatchery- and natural-origin fish (determined by otolith readings) for the parental run years (2013 and 2014) and only natural-origin fish for the offspring years (2015 and 2016), as we were only interested in the returning adult offspring. The amplicons were selected specifically for parentage analysis in PWS (Dann et al. *in prep*) from among thousands of SNPs discovered using restriction site-associated DNA sequencing (Baird et al., 2008) of PWS Pink Salmon collected in 2013 and 2014.

We attempted to genotype at least 500 potential parents of each origin, if available, and as many potential offspring (i.e., natural-origin fish collected in 2015 and 2016) as possible to maximize our statistical power (Shedd et al., 2014; Box 1). We randomly subsampled individuals for genotyping within each origin from available samples with known origin based on otolith reads and known sex (see Tables 1 and S2 for sample sizes of fish genotyped and Tables S3 and S4 for sample sizes of fish collected). We followed the Genotyping-in-Thousands by sequencing (GT-seq) methods described in (Campbell et al., 2015), other than deviations at the second PCR step (PCR2), purification, and quantification steps (see Supplemental Methods). The final pooled library was sequenced at a concentration of 3.5 pM on an Illumina NextSeq 500 with single-end read flow cells using 150 cycles. Post-sequencing, we split reads from individual samples based on their DNA barcodes and called genotypes according to counts of amplicon-specific alleles (Campbell et al., 2015) using GTscore (McKinney et al., 2020), modified from the default settings to reduce the maximum allowed p-value of genotype likelihoods from 0.05 to 0.001. Genotypes were imported and archived in the ADF&G Gene Conservation Laboratory database. Genotyping quality control (QC) and quality assurance (QA) steps are described in Supplemental Methods.

Data Analysis

Parentage simulations

We estimated our Type I (number of individuals incorrectly assigned to parents) and Type II (number of assignments that were missed) parentage assignment error rates using simulated genotypes. We simulated 3,000 offspring genotypes for each lineage from Hogan Bay using the SNP panel and assigned the simulated offspring back to parents using the pedigree reconstruction program *FRANz* (Riester et al., 2009) with the parameters in Run 1 (Table S5). We used *FRANz* because likelihood- and Bayesian-based parentage analyses have been shown to perform better than exclusion-based techniques (Anderson & Ng, 2014; Harrison et al., 2013; Hauser et al., 2011; Jones et al., 2010; Steele et al., 2013). Additionally, a full-probability Bayesian model for pedigree reconstruction is better suited for studies that are not able to sample all potential parents and offspring because the model accounts for unsampled parents and can use sibships among sampled individuals to infer parental genotypes from offspring and fill out sparse pedigrees (Jones et al., 2010; Riester et al., 2009). Finally, we followed code from Baetscher et al. (2018) to use the CKMRsim R package (https://github.com/eriqande/CKMRsim) to evaluate the power of our SNP panel to accurately make parent-offspring and full- and half-sibling assignments.

Parentage analysis

We combined individual genotypes from our SNP panel with collection year and sex data to create input files for *FRANz*. We ran three analyses for each stream/lineage combination using the parameters in Table S5. We used genotyping error rates derived from our QC pipeline and doubled them to understand the effect of error rates on parent-offspring assignments. Values for the maximum number of potential parents by sex (N_{mmax} and N_{fmax}) were based on aerial and foot survey estimates of escapement (i.e., spawning population area under the curve estimates by ADF&G that incorporated stream life and method-specific observer efficiency; M Stopha, 2016, 2017; Vercessi, 2014, 2015). We limited final parentage assignment to those parent-offspring pairs that had a posterior probability of assignment > 90%.

Relative reproductive success estimates

We tested the null hypothesis that RS would not differ between hatchery- and natural-origin Pink Salmon by calculating RRS separately for males and females for both lineages and streams since most of our parentage assignments were to a single parent only (parent-offspring dyads; Table 1). These estimates based on parent-offspring dyads included all sampled potential parents (even those not assigned offspring, i.e., RS = 0). We refer to these RRS estimates as unweighted. We calculated 95% confidence intervals (CIs) around our unweighted RRS estimates following the methods of Kalinowski & Taper (2005). We tested for significant differences in RS between natural- and hatchery-origin fish using a non-parametric one sample permutation test ("oneway.test" function in the coin package in R; Hothorn et al., 2006), as testing for differences in RS is equivalent to testing if RRS ≠ 1 (Araki & Blouin, 2005).

We tested the null hypothesis that RS would not differ among crosses between two natural-origin parents, two hatchery-origin parents, and one hatchery-origin and one natural-origin parent by calculating RS separately for the four types of crosses: hatchery-hatchery, natural-natural, hatchery-natural (hatchery female and natural male), and natural-hatchery (natural female and hatchery male). This analysis was restricted to parent-pair-offspring trios (triads) that produced at least one offspring (RS ≥ 1), as there was no way to infer that a mating occurred if RS = 0.

Associating RS with explanatory variables

We used GLMs to test for associations between RS and parent life history variables previously shown to affect RS (Ford et al., 2012; Janowitz-Koch et al., 2019). We restricted GLMs to streams and years with pedigrees that had at least 30 offspring assigned to each origin group. Prior to modeling, we checked for multi-collinearity among variables by calculating correlation coefficients to avoid testing models containing highly correlated variables. We tested the null hypothesis that RS did not differ due to parent origin, body length, sample location (distance from stream mouth), date, or sex using a negative binomial distribution GLM with a log-linked function ("glm.nb" function in the MASS package in R; Venables & Ripley, 2002). Distance from the stream mouth was determined using the R package *riverdist* (Tyers, 2020). We created the categorical variable 'Intertidal' to differentiate between fish sampled in the intertidal area versus those sampled in freshwater upstream, using intertidal benchmarks derived from mean high tide coordinates provided by field crews. Sample location and intertidal were never included in the same model, as they were confounded. Following Berntson et al. (2011), we set up 131 models *a priori*, which included squared terms for body length and sample date based on visual relationships, identified statistically significant variables, and selected the best model for each stream based on Akaike's Information Criterion (AIC). We ran models with all parents combined and also separately for males and females, following Janowitz-Koch et al. (2019). To assess model fit, we calculated percent of deviance explained, the GLM analog of R^2, for models from each stream and sex. The percentage of deviance explained was calculated as 1 – (residual deviance / null deviance), and is not the percentage of variance explained by the model, but rather a ratio indicating how close the model fit is to a perfect fit (interpolation) or the worst possible model (intercept only; García-Portugués, 2021). For the top ranked models, we used hierarchical partitioning to determine the relative importance of each independent variable ("hier.part" function in the hier.part package in R, modified to support the negative binomial model; Chevan & Sutherland, 1991; MacNalley & Walsh, 2004).

Data and R code are available at: https://github.com/krshedd/Relative-fitness-of-Pink-Salmon, and data are openly available on the Knowledge Network for Biocomplexity (KNB) at: https://knb.ecoinformatics.org/view/doi:10.5063/F1DR2SWP.

Results

Field collections

Field crews collected samples from a total of 46,281 individuals from Hogan Bay and Stockdale Creek, with 45,025 otoliths readable to determine origin (Table S4). Agreement between first and second readers was 96–97% for differentiating hatchery thermal otolith marks versus wild origins and was 93–97% for distinguishing among hatcheries for both streams combined (Jenni Morella, ADF&G Otolith Lab, pers. comm.). All PWS Pink Salmon hatcheries contributed hatchery strays during at least some of the sampling periods with 71% overall deriving from Armin F. Koernig Hatchery, the most proximate hatchery to both streams (Figure 1; Table S4). Hatchery-origin fish had larger average body sizes, later sample dates, and more upstream sampling locations than natural-origin fish (Table 2).

Genotyping

We selected 10,007 individuals from Hogan Bay and 15,706 individuals from Stockdale Creek for genotyping, representing an estimated 2–54% of the escapement for a given year and stream (Tables S2 and S3). In 2015 and 2016, hatchery-origin fish were not genotyped (Table S4). After quality assurance, we retained genotypes from 85 to 99% of Hogan Bay individuals and 74 to 93% of Stockdale Creek individuals of each origin and year for parentage analysis with a final sample size of 9,183 fish from Hogan Bay and 13,020 fish from Stockdale Creek (Table S2). Variation in genotyping success tended to correlate with how degraded tissues were when sampled in the field. Final sample sizes ranged from 163 to 6,053 individuals across streams, origins, and years (Tables 1 and S2). The overall background genotyping error rate among streams and years was 0.54% and ranged from 0.31 to 0.73% for Hogan Bay and 0.32–0.71% for Stockdale Creek across years.

Parentage simulations

FRANz correctly reconstructed parent-pair offspring trios for all simulated offspring from both the odd- and even-year lineages, resulting in no detectable Type I or Type II error (i.e., no false or missed assignments). Simulations performed in CKMRSim demonstrated the ability of our SNP panel to distinguish between potential offspring and unrelated individuals and our known age data allowed us to unequivocally distinguish between parent-offspring and sibling relationships (Figure S3).

Parentage analysis

Hogan

Exclusion probabilities from *FRANz* for our SNP panel in both the even- and odd-year lineages were equal to 1.00 and all posterior probabilities of assignment were equal to 1.00. All three *FRANz* runs produced identical parentage assignments for the odd-year lineage, while two additional offspring were assigned parents in runs 2 and 3 for the even-year lineage (see Table S5 for run parameter values). These two individuals were excluded from downstream analyses because their posterior probabilities of assignment did not meet our cut-off of > 0.90. In the odd-year lineage, all offspring assignments were dyads, but for the even-year lineage, *FRANz* made 22 parent-pair offspring trio assignments, which included all possible cross types (Table 1; Figure S6).

Stockdale

In the odd-year lineage, all cumulative exclusion probabilities were 1.00, and all posterior probabilities of assignment were equal to 1.00. All offspring assignments were dyads (Table 1). In the even-year lineage, our sensitivity analysis in *FRANz* indicated that increasing the maximum number of parents and genotyping error rate led to one additional parent-offspring assignment, which did not meaningfully change our estimate of RRS. We report results with the more conservative escapement estimate (4,038) and genotyping error rate (0.60%). The cumulative exclusion probabilities for parent assignments were all equal to 1.00 and all parentage assignments had a posterior probability of 1.00, except for four individuals whose assignments were split among multiple potential parents. *FRANz* reconstructed both dyad and triad offspring assignments (Table 1; Figure S4).

Relative reproductive success estimates

Unweighted RRS point estimates ranged from 0.03–0.86 and was significantly less than one for both streams and lineages for females, but not always significantly less than one for males (Table 1).

Reproductive success was highly variable among individuals, varying between 0–41 detected offspring, with most parents assigned zero offspring (Figure 3). Offspring from all four potential types of crosses (two hatchery-origin parents [HH], two natural-origin parents [NN], hatchery-origin female with natural-origin male [HN], and natural-origin female with hatchery-origin male [NH]) were represented in our parent-pair offspring trios for both Hogan Bay and Stockdale creeks in the even-year lineage (Table S6; Figure S4). Reproductive success was significantly higher for crosses between two natural-origin parents as compared to two hatchery-origin parents for the Stockdale Creek even-lineage (Table S6; Figure S4). However, RS for crosses between one natural-origin and one hatchery-origin parent were intermediate and did not significantly differ from crosses between two hatchery-origin or two natural-origin parents (Table S6).

Associating RS with explanatory variables

We used GLMs to determine the relative influence of covariates (sample date, body length, sample location, and origin) on RS for the even-year lineage pedigrees. We did not use GLMs to test for associations between RS and parent life history variables for the odd-year lineage due to the low number of offspring assigned to hatchery-origin parents in both streams (Table 1).

Hogan

None of the explanatory variables were highly correlated (Table S7), so we included them together in the same GLM models (Table S8). The top model for females explained 6% of the deviance and included date, length, origin, and intertidal (Table 3; Table S8; Figures 4-6). Origin was the most important variable in the model with 65% of the independent effects, followed by intertidal (26%), date (6%), and length (3%; Table 3). The incident ratios (exponents of model coefficients to transform out of logit link function) indicate that the modeled RRS of hatchery-origin to natural-origin Pink Salmon was 0.42 (95%CI: 0.24–0.71), when accounting for variation in other variables (length, intertidal, and date; Table 3). The mean number of offspring increased by ~3% for every day later that a parent was sampled and ~1% for every mm in parent length. Parents sampled upstream had 59% as many offspring on average as Pink Salmon sampled in the intertidal (Table 3).

The top model for males explained 4% of the deviance and included length and distance (Table 3; Table S8). Length accounted for 60% of the independent effects, with the remaining 40% attributed to distance (Table 3). The mean number of offspring increased by ~1% for every mm increase in parent length and decreased by ~0.3% for every meter further upstream that a parent was sampled (Table 3).

GLM-derived RRS estimates were not calculated for even-year males because origin was not a significant explanatory variable.

Stockdale

None of the explanatory variables were highly correlated (Table S7), so we included them together in the same models. The top model for females explained 25% of the deviance and included length, distance, date, and origin (Table 3; Table S9; Figures 4–6). Distance was the most important variable in the model with 74% of the independent effects, followed by origin (20%), date (5%), and length (1%; Table 3). Using the incident ratios, we calculated the modeled RRS of hatchery-origin to natural-origin females as 0.60 (95%CI: 0.45–0.79), when accounting for variation in other variables (length, distance, and date; Table 3). The mean number of offspring did not significantly vary with parent length, decreased by ~0.2% for every meter further upstream that a parent was sampled, and decreased by ~3% for every day later that a parent was sampled (Table 3).

The top model for males explained 36% of the deviance and included length, distance, date, and origin (Table 3; Table S9; Figures 4–6). Distance was the most important variable in the model with 44% of the independent effects, followed by origin (28%), length (16%), and date (12%; Table 3). We used incident ratios from the GLMs to calculate the modeled RRS of hatchery-origin to natural-origin males as 0.43 (95%CI: 0.31–0.60), holding all other variables (length, distance, and date) constant. The number of offspring increased by ~2% for every mm increase in parent length, decreased by ~0.2% for every meter further upstream that a parent was sampled, and decreased ~5% for every day later in the season that a parent was sampled (Table 3).

Discussion

This study quantified the RRS of Pink Salmon hatchery-origin strays in PWS streams to assess the fitness impact to wild systems. Point estimates for RRS ranged from 0.03–0.86, which include some of the smallest RRS values ever observed in Pacific Salmon, along with estimates that are consistent with the wide ranges reported in previous studies (Christie et al., 2014). Natural-origin parents had higher RS than hatchery-origin parents across streams and years, although reductions in RS for male hatchery-origin fish from Hogan Bay even-year and Stockdale Creek odd-year lineages were not statistically significant. However, statistical power was lower for the odd-year lineage comparisons due to the lower number of potential parents sampled and lower offspring sampling rate (see Box 1 and Christie et al., 2014 Box 2). Additionally, we note that lineage effects (different genetic ancestries in even- and odd-years) were confounded with year effects (different environmental conditions from year to year), which prevented us from disentangling the relative importance of standing genetic variation within each lineage and annual environment conditions. Ongoing work across additional years and streams within the AHRP will help to account for interannual and environmental sources of variability.

An important consideration when comparing our RRS estimates to studies in which both parents are known (parent-pair offspring trios) is that our estimates of RRS are largely based on single parent assignment (parent-offspring dyads) due to incomplete sampling of potential parents. Estimates of RRS based on single parent-offspring dyad assignments would underestimate the RRS effect of hatchery-origin fish if reductions in RS are additive. Hybrids would increase the average RS of hatchery-origin fish (if the natural-origin mate is unknown) and decrease the average RS of natural-origin fish (if the hatchery-origin mate is unknown).

Our limited cross type data suggest that crosses between two natural-origin fish have higher RS than those between two hatchery-origin fish, with hybrids displaying intermediate RS (Table S6). Differences in run timing between hatchery- and natural-origin Pink Salmon in PWS (Knudsen et al., 2021) may reduce, but not eliminate, the potential for interbreeding. Previous genetic studies on Chum Salmon in PWS found that run timing differences between hatchery- and natural-origin fish reduced, but did not completely prevent, interbreeding and introgression of hatchery alleles (Jasper et al., 2013). In steelhead, in Forks Creek on the Willapa River, Washington, interbreeding was not prevented even though hatchery-origin fish were selected to spawn earlier than natural-origin individuals; up to 80% of natural-origin steelhead were hatchery/natural hybrids (Seamons et al., 2012).

The magnitude of RRS reductions that we documented were somewhat unexpected if it is assumed that the sole mechanism for the reduction was due to domestication selection of hatchery fish. If there are heritable reductions in fitness associated with hatchery rearing, multiple generations of gene flow from hatchery-origin individuals into wild populations might have eroded wild stock fitness over time. This decrease in wild stock fitness due to introgression would result in overestimating the relative fitness of hatchery-origin individuals (Willoughby & Christie, 2017).

Additionally, the short hatchery residency period of Pink Salmon has been hypothesized to reduce the opportunity for domestication selection (Berejikian et al., 2009). However, modeling efforts by Baskett and Waples (2013) indicate that the timing when selection occurs is critical for predicting the fitness consequences of hatchery-origin fish spawning in wild populations. Specifically, if natural selection occurs after reproduction and before hatchery release then hatchery-origin fish from segregated broodstock programs may be maladapted to spawning in streams and their offspring may have lower fitness (Baskett & Waples, 2013). The low levels of genetic differentiation among PWS Pink Salmon populations and hatchery broodstocks measured at putatively neutral genetic markers (Cheng et al., 2016) do not preclude potentially important differences at adaptive loci under selection that may render hatchery strays similar enough to natural-origin fish to survive and reproduce in streams, but different enough from natural-origin fish to cause significant fitness declines.

Other mechanisms may also explain the observed reductions in RRS. Recent work in Steelhead and Coho Salmon has demonstrated significant epigenetic differences between hatchery and wild populations despite nonsignificant levels of genetic differentiation (Gavery et al., 2018; Le Luyer et al., 2017). Further evidence suggests that these epigenetic differences may be heritable (Leitwein et al., 2021) despite significant within-family effects (Gavery et al., 2019).

While every effort was made by field crews to obtain representative carcass samples, our unweighted RRS estimates were likely influenced by unrepresentative sampling by timing and/or location, given known timing differences between hatchery- and natural-origin fish and potential for sampling rate differences throughout the season (Knudsen et al., 2015). Low sampling rate and high escapements in 2013 resulted in sub-optimal sampling of potential parents and therefore low offspring assignment rates in 2015 (about 2.5% for both streams). Although sampling rates were higher for the smaller runs in 2014 and offspring assignment rates increased (Table 1), there is still potential for non-representative sampling to affect our unweighted RRS estimates. For both parental and offspring sampling years, field crews most likely oversampled the beginning and end of the run, when there were fewer fish, relative to the middle of the run, when the abundance was much greater and sampling all available fish was impractical (Figure 2).

Reproductive success tended to be higher in natural-origin fish from Stockdale Creek and Hogan Bay earlier in the season, likely due to a combination of reduced density on the spawning grounds and the later run-timing of hatchery-origin fish. Higher rates of commercial fishery removals later in the season likely affected the number of adult offspring that were able to return to the streams. If high heritability values underly run timing (Dickerson et al., 2005; Smoker et al., 1998), then fisheries may preferentially target the offspring of stray hatchery-origin parents, violating the assumption of equal harvest and stray rates of natural- and hatchery-origin offspring and potentially underestimating the RS of hatchery-origin fish. Testing these hypotheses by sampling the fishery is unfortunately impractical given that harvests range into the tens of millions.

Hatchery- and natural-origin fish were distributed in different locations in the stream (particularly for Stockdale Creek), but it is unclear why hatchery-origin fish traveled further upstream, where RS was lower (Hughes & Murdoch, 2017). They may have experienced lower RS because they were strays and were not locally adapted to the spawning habitat (Mobley et al., 2019). Alternatively, they may have traveled further upstream to less suitable spawning habitat and avoided the intertidal zone because many of the hatchery brood sources came from upstream freshwater sites and hatchery-origin fish imprint on freshwater sources as embryos and fry in the hatcheries (Habicht et al., 2000; Mark Stopha, 2013). If upstream locations were not sampled as consistently as the intertidal, then the RS of hatchery-origin fish may have been underestimated if their offspring inherited their proclivity to avoid spawning in the more productive intertidal zone.

Our GLM results suggest a strong negative effect of hatchery-origin on an individual's RS after accounting for the effect of covariates (parent sampling location, sample date within the weeks-long term of spawning, and body length), although the percent of deviance explained by the top models ranged from 4–36% (Figures 4–6; Table 3). The lower percent of deviance explained is likely due to the high inherent variability in individual RS, despite the large population-level differences between hatchery-origin and natural-origin RS. The GLM results were consistent regarding the effect of fish length (i.e., large fish had higher RS than smaller fish; consistent with Dickerson et al., 2002) and sample location (i.e., fish spawning closer to the intertidal had higher RS). While sample date, our proxy for run timing, was correlated with RS, the direction and magnitude of the effect was inconsistent among streams and years. The GLM approach is not a panacea for resolving the unweighted RRS estimates because it does not provide a method to weight RRS to obtain a representative estimate. Rather, the GLM allows us to understand how other explanatory variables may influence RRS. If we did indeed oversample the tails of the run relative to the middle, we could weight our estimates of RS based on abundance within a sampling stratum, if we had reliable abundance data. Despite the limitations of both the unweighted and GLM methods, the general conclusions from these two approaches remain the same and provide context for interpretation.

Conclusions

We measured a reduction in fitness of ~50% for hatchery strays spawning in streams for the even-year and still lower for odd-year lineages, despite the shorter hatchery residence period of Pink Salmon, low population genetic structure in PWS Pink Salmon, previous documentation of introgression from the hatchery fish to wild populations, and incomplete sampling of spawners for our pedigrees. These results have important implications regarding the evaluation of PWS Pink Salmon hatchery programs and their unintended impacts on wild populations. However, potential management responses will depend on the causal mechanisms underlying observed RRS reductions in these two streams and the impact of 16–20 generations of potential background introgression. The causal factors are currently unclear but may involve a combination of multiple mechanisms (reviewed by Naish et al. 2008), including genetic, epigenetic, behavioral/ecological, and/or methodological. Domestication selection in PWS Pink Salmon hatcheries may result in traits that are beneficial in the hatchery environment, but maladaptive in wild streams (Christie et al., 2012). Such traits may be passed on genetically or by heritable epigenetic changes (Leitwein et al., 2021). Alternatively, hatchery-origin fish that stray into streams may have reduced RRS due to a lack stream-specific local adaptations possessed by natural-origin fish originating from that stream. Furthermore, environmental factors such as freshwater imprinting in PWS hatcheries may cause hatchery strays to ascend further upstream into less suitable spawning habitat beyond the intertidal influence. Finally, we cannot rule out the possibility that offspring of hatchery strays may be harvested at higher rates in the commercial fishery than offspring of natural-origin fish, due to differences in run timing and fishery management.

Future results from the ongoing AHRP study, including three additional streams with more complete sampling, will allow us to better understand the variability in RRS across streams, years, and lineages. Additionally, data from a second generation (i.e., F_0 to F_2) from each stream may help elucidate the extent to which fitness reductions of hatchery strays are ephemeral (i.e., mostly impacting a single generation) and likely environmentally driven, or persistent across generations and likely genetically driven. Taken together, data from this and other AHRP studies will provide information for policy makers evaluating both the benefits of hatchery programs to the economic wellbeing of the fishing industry and communities relying on fishing revenues, and long-term risks to wild stocks.

Data Availability Statement

The data and R code that support the findings of this study are available at: https://github.com/krshedd/Relative-fitness-of-Pink-Salmon, and data are openly available on the Knowledge Network for Biocomplexity (KNB) at: https://doi.org/10.5063/F1DR2SWP.

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Box 1: Statistical power to detect a difference in relative reproductive success (RRS) with incomplete sampling

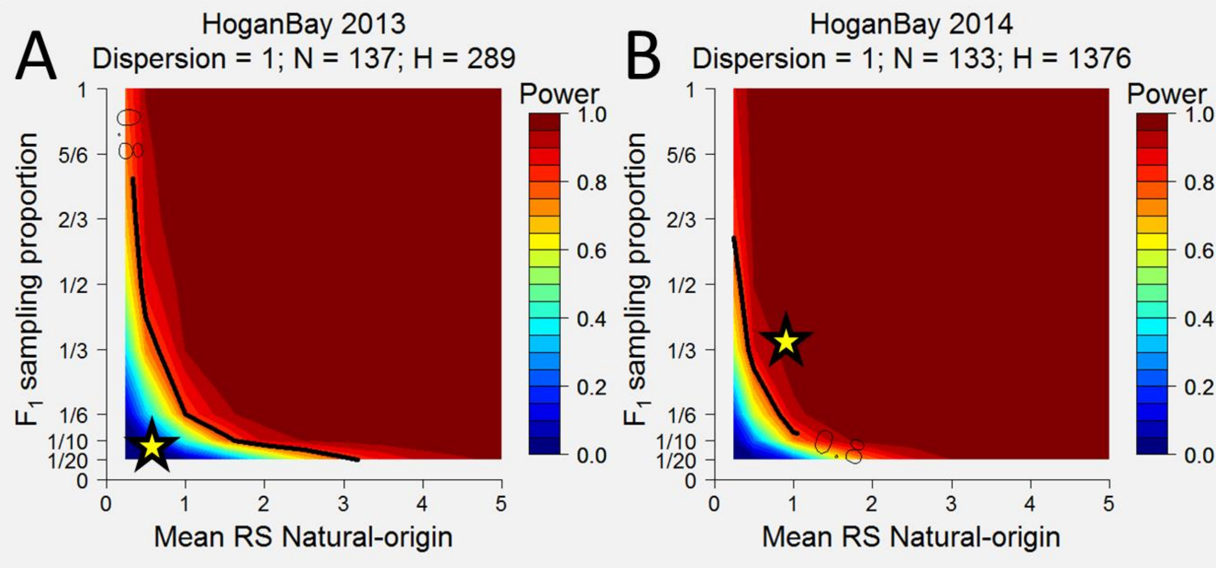
Statistical power refers to the probability of detecting a difference between sampled distributions if there is truly a difference in the underlying distributions. In RRS studies, the statistical power to detect a difference in the reproductive success (RS) between groups, such as hatchery-origin and natural-origin, is affected by: 1) sample sizes of parents, 2) proportion of parents from each group (i.e., proportion of hatchery-origin spawners), 3) proportions of offspring sampled , 4) stock productivity, and 5) effect size (Hinrichsen, 2003). Each of these variables can shape the sampled distributions of RS for each group and thus affect the ability to determine whether the distributions are statistically different from one another.

The underlying distribution of RS often approximates a negative binomial (J. H. Anderson et al., 2013; Christie et al., 2014). To illustrate the power relationship between the sample size of parents and the effect size (true RRS), Christie et al. (2014) used a heuristic approach to simulate distributions of RS and statistically compared them for different sample sizes of parents and RRS effect sizes. This work demonstrated that at least 400 parents (equal proportion hatchery and wild) would need to be sampled to detect RRS = 0.8 at least 80% of the time (power = 0.8), given their assumed distribution of RS and complete sampling of all offspring.

Here we extend the simulation approach from Christie et al. (2014) to relax the assumed distribution of RS (i.e., stock productivity, mean and variance of the negative binomial) and allow for incomplete sampling of offspring to more precisely estimate the statistical power of our RRS study in a natural Pink Salmon stream in PWS, Alaska. Statistical tests rely on comparing the absolute difference between sample distributions, not the relative difference. This means that anything that lowers the average RS of the sample population (i.e., incomplete sampling of offspring or low production) will inherently lower the statistical power to detect RRS < 1. Stock productivity for Pink Salmon can vary between odd- and even-year lineages, as well as over time. In years of high production (high return per spawner), we expect that it would be easier to detect a difference in RS between hatchery- and natural-origin spawners than in years of low productivity. For example, it is easier to differentiate a distribution of RS with an average of 8 offspring per parent from one with an average of 4 offspring per parent (RRS = 0.5) than a distribution of RS with an average of 3 and 1.5 offspring per parent (RRS = 0.5). Incomplete sampling of offspring does not affect the RRS between groups, so long as sampling is unbiased. However, incomplete sampling does lower the average RS of the sampled distribution, and thus decreases the absolute difference in average RS between groups for a given effect size, making it more challenging to determine whether the distributions of RS are statistically different.

For our simulations, we wanted to determine the statistical power to detect an RRS of 0.5, the level of RRS the study was designed to detect, for a given number of hatchery- and natural-origin parents sampled over a range of stock productivities (mean and variance of negative binomial) and a range of proportions of offspring sampled. We varied the mean of the negative binomial RS distribution for natural origin from 0.25 to 5, the dispersion (variance) of that distribution from 1 to 10, and the sampled proportion of offspring from 0.05 to 1. To test for differences in mean fitness (RS), we used a non-parametric permutation (randomization) test. For each combination of negative binomial mean and dispersion and offspring sampling proportion, we assigned offspring to hatchery- and natural-origin parents assuming perfect genetic assignment and used a permutation test to determine whether the mean RS of hatchery-origin fish was different than the mean RS of natural-origin fish (RRS = 0.5). If a parent did not have any offspring assigned to it, it had an RS value of 0 (regardless of whether we knew that the parent truly did not produce any offspring or whether its offspring were not sampled). We repeated this process 2,000 times and calculated power as the proportion of trials that had a *P*-value < 0.05 (i.e., the proportion of times the true difference in RRS was statistically detected). Values for statistical power were interpolated between points to generate a heatmap based on the mean stock productivity and the offspring (F_1) sampling proportion.

Panels A and B show the expected statistical power for Hogan Bay brood years 2013 and 2014 prior to knowing the F_1 sampling proportion. Each of these plots assumed that the dispersion parameter for the underlying negative binomial defining RS was 1 and that the effect size was RRS = 0.5. The number of natural-origin parents is denoted by N and the number of hatchery-origin parents is denoted by H, since sampling of the parental generation had already occurred when these analyses were done (winter of 2014/2015). Statistical power increases for both increasing productivity of the stock (mean RS) and increasing proportion of F_1 offspring sampled. The yellow stars indicate the likely stock productivity of each brood year and the sampling proportion of F_1 offspring (sampled fish/aerial survey indices). Similar analyses were performed for Stockdale as well (data not shown). The difference in expected power for RRS = 0.5 between these streams was demonstrated in our results.



Acknowledgments

Mark Christie graciously provided the R code for the simulations in (Christie et al., 2014). We adapted that R code for our work here.

Tables

Table 1. Summary of proportion of hatchery-origin spawners (pHOS) for the brood year (BY), numbers of individuals genotyped of hatchery- (H) and natural-origin (N), offspring assigned via parentage analysis, and estimates of relative reproductive success (RRS) for both odd- and even-year lineages from two streams, Hogan Bay (Hogan) and Stockdale Creek (Stockdale). Confidence intervals for RRS were calculated following (Kalinowski & Taper, 2005). Note: “Dyads” refer to single parent-offspring pairs (only one parent is known) and “Triads” refer to parent-pair-offspring trios (both parents are known). RRS is calculated as the average reproductive success of hatchery-origin fish divided by the average reproductive success of natural-origin fish. **Bold** RRS values indicate *p*-value < 0.05 from one sample permutation test.

			# Genotyped								RRS (95% CI)	
			Parents		Offspring	Offspring Assigned					Hatchery / Natural	
Stream	Year	pHOS (BY)	H	N		%	H	N	Dyads	Triads	Male	Female
Hogan	13/15	64%	442	321	3,775	2.9%	6	104	110	0	**0.05 (0.01-0.17)**	**0.03 (0.01-0.08)**
	14/16	92%	437	214	3,994	11.3%	265	208	451	22	0.86 (0.67-1.12)	**0.47 (0.37-0.62)**
Stockdale	13/15	16%	163	811	6,053	2.1%	10	119	129	0	0.69 (0.31-1.35)	**0.17 (0.03-0.55)**
	14/16	74%	436	358	5,199	20.3%	373	865	1,055	183	**0.28 (0.24-0.34)**	**0.42 (0.35-0.50)**

Table 2. Body size, sample date, and distance from stream mouth for hatchery- and natural-origin Pink Salmon males and females in odd- and even-year lineages from two streams, Hogan Bay (Hogan) and Stockdale Creek (Stockdale). **Bold** values indicate *p*-value < 0.05 from *t*-test (length) or Wilcoxon test (date and location) for significance of comparison.

			Mean length + SD (mm)		Mean date + SD (day)		Mean location + SD (m)	
Stream	Sex	Year	Hatchery	Natural	Hatchery	Natural	Hatchery	Natural
Hogan	Male	2013	401.7 ± 24.0	398.3 ± 29.1	**Sep 3 ± 3.5**	**Aug 27 ± 7.4**	**360.5 ± 76.2**	**321.1 ± 74.4**
		2014	**435.7 ± 25.3**	**417.5 ± 31.6**	**Aug 31 ± 6.5**	**Aug 26 ± 6.2**	**353.0 ± 95.1**	**330.5 ± 85.4**
	Female	2013	**407.4 ± 20.6**	**400.6 ± 19.9**	**Sep 3 ± 3.4**	**Aug 31 ± 6.0**	369.6 ± 83.1	359.4 ± 87.7
		2014	**441.9 ± 19.4**	**434.0 ± 20.4**	**Aug 31 ± 5.5**	**Aug 29 ± 6.4**	**368.4 ± 98.7**	**340.5 ± 96.7**
Stockdale	Male	2013	390.2 ± 18.0	389.7 ± 22.9	**Sep 4 ± 5.2**	**Sep 2 ± 7.2**	**178.6 ± 218.3**	**224.4 ± 220.9**
		2014	**430.3 ± 29.1**	**419.1 ± 31.6**	**Aug 30 ± 4.1**	**Aug 26 ± 4.5**	**583.0 ± 350.8**	**395.3 ± 296.4**
	Female	2013	**398.8 ± 20.1**	**393.4 ± 19.9**	Sep 4 ± 5.3	Sep 4 ± 5.8	180.5 ± 214.6	218.1 ± 213.6
		2014	**436.6 ± 16.8**	**422.1 ± 20.3**	**Sep 1 ± 3.6**	**Aug 31 ± 4**	**668.7 ± 316.2**	**443.2 ± 304.1**

Table 3. Incident ratios (95% confidence intervals), percent of independent effects of variable contribution to the model (%IE), and overall percent deviance explained from top ranked generalized linear models calculated for Pink Salmon from Hogan Bay (Hogan) and Stockdale Creek (Stockdale) even-year lineage sampled in 2014. Explanatory variables include: “Length (mm)” = parent mid-eye to fork length, “Origin” = parent origin (hatchery- vs. natural-origin), “Date (day)” = parent sample date as day of year, “Distance (m)” = parent sample location in terms of distance above the upper extent of the intertidal, and “Intertidal” = categorical variable of parent sample location within or above the upper extent of the intertidal. Incident ratios were derived from the models with the best fit, as determined by Akaike Information Criteria. Note that incident ratios are presented in the units of each variable. Variables not included in a model are indicated by NA.

Stream	Sex	Length (mm)	%IE	Origin	%IE	Date (day)	%IE	Distance (m)	%IE	Intertidal	%IE	% Deviance
Hogan	Females	1.01 (0.99-1.02)	3%	0.42 (0.24-0.71)	65%	1.03 (0.98-1.07)	6%	NA	NA	0.59 (0.33-1.05)	26%	6%
Hogan	Males	1.01 (1.00-1.02)	60%	NA	NA	NA	NA	0.997 (0.994-1.000)	40%	NA	NA	4%
Stockdale	Females	1.00 (1.00-1.01)	1%	0.60 (0.45-0.79)	20%	0.97 (0.94-1.00)	5%	0.998 (0.998-0.998)	74%	NA	NA	25%
Stockdale	Males	1.02 (1.01-1.02)	16%	0.43 (0.31-0.60)	28%	0.95 (0.91-0.98)	12%	0.998 (0.997-0.998)	44%	NA	NA	36%

Figure Legends

Figure 1. Map of Prince William Sound, Alaska, showing locations of Hogan Bay (red) and Stockdale Creek (green), additional fitness streams sampled as part of the Alaska Hatchery Research Program (green), and hatcheries (blue and purple). Cannery Creek (CC), Armin F. Koernig (AFK), and Wally Noerenberg (WN) are all managed by the Prince William Sound Aquaculture Corporation (PWSAC), while Solomon Gulch (SG) is managed by the Valdez Fisheries Development Association (VFDA). Inset shows location of Prince William Sound in Alaska.

Figure 2. Number of Pink Salmon samples genotyped during the odd- and even-year lineages from Hogan Bay and Stockdale Creek, Prince William Sound, Alaska by lineage. Within each lineage, the upper graph shows the parent year and the bottom graph shows the offspring year. Hatchery-origin fish (strays) were excluded in the offspring year since only natural-origin fish could have been the offspring from the fish spawning in each creek during the parent year. Samples were collected throughout the duration of the run with sampling frequency increasing across years and higher proportions of the total escapement sampled in offspring years (2015 and 2016).

Figure 3. Distribution of reproductive success (number of adult offspring per parent) for female and male natural- and hatchery- origin Pink Salmon for the odd (top) and even (bottom) lineages in Hogan Bay and Stockdale Creek, Prince William Sound, Alaska. Note: the x-axis for the Hogan odd-year lineage female plot excludes one individual assigned 41 offspring. Reproductive success was highly variable among individuals, with most potential parents assigned zero offspring and a low proportion of parents assigned high numbers of offspring.

Figure 4. Association between reproductive success (RS) and parent sample date for Hogan Bay (Hogan) and Stockdale Creek (Stockdale) in 2014. Data for females are shown in the top plots and males in the bottom plots. Lines represent LOESS best fit with shaded areas representing 95% confidence intervals. Points are jittered on the x-axis to prevent overplotting. Note different x-axis scales for the two streams. While RS was variable across parent sample dates, mean RS was higher for natural-origin fish towards the beginning and end of the run, particularly for Stockdale Creek.

Figure 5. Association between reproductive success (RS) and parent sample location for Hogan Bay and Stockdale Creek in 2014. Data for females are shown in the top plots and males in the bottom plots. Lines represent LOESS best fit with shaded areas representing 95% confidence intervals. Points are

jittered on the x-axis to prevent overplotting. The vertical black line represents the upper extent of the intertidal. Note different x-axis scales for the two streams. While RS was variable across parent sample locations, mean RS was higher near the intertidal zone.

Figure 6. Association between reproductive success (RS) and parent length (mm) for Hogan Bay and Stockdale Creek in 2014. Data for females are shown in the top plots and males in the bottom plots. Lines represent LOESS best fit with shaded areas representing 95% confidence intervals. Points are jittered on the x-axis to prevent overplotting. Note different x-axis scales for the two streams. While RS was variable across parent body length, mean RS was higher for larger natural-origin males, particularly for Stockdale Creek.

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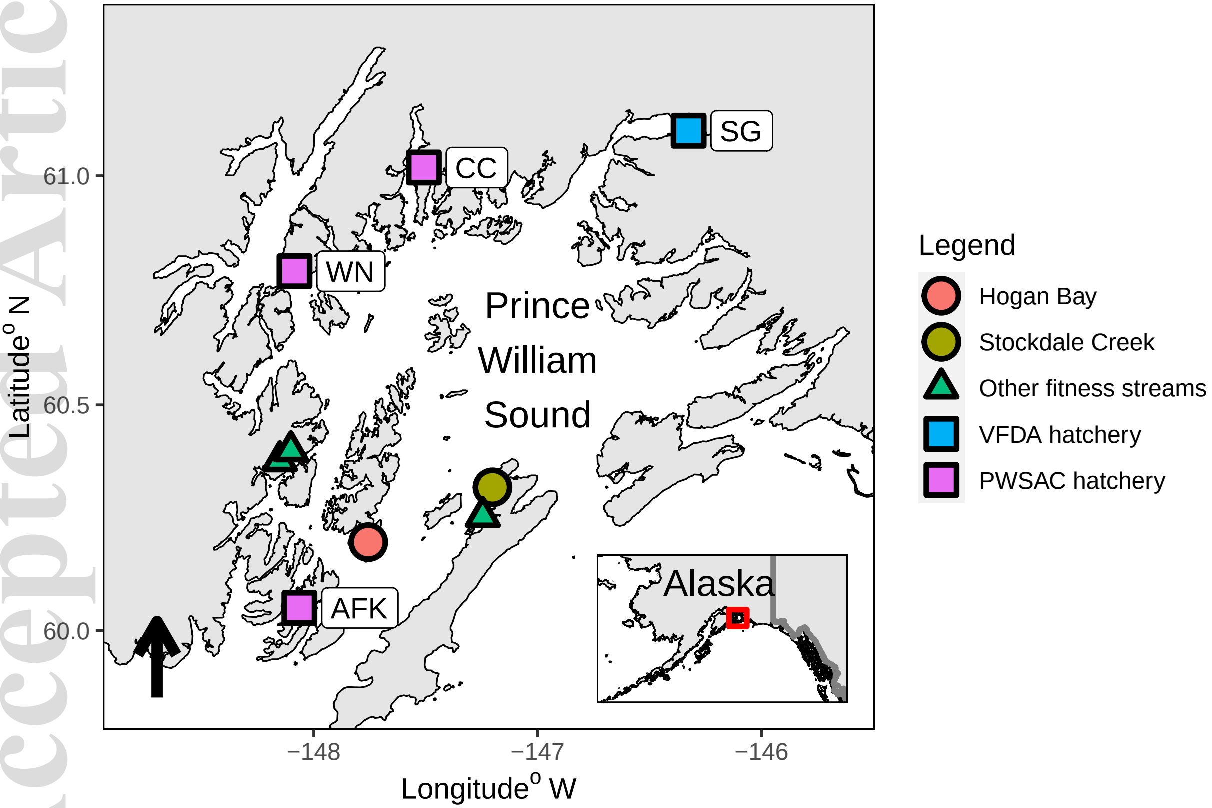

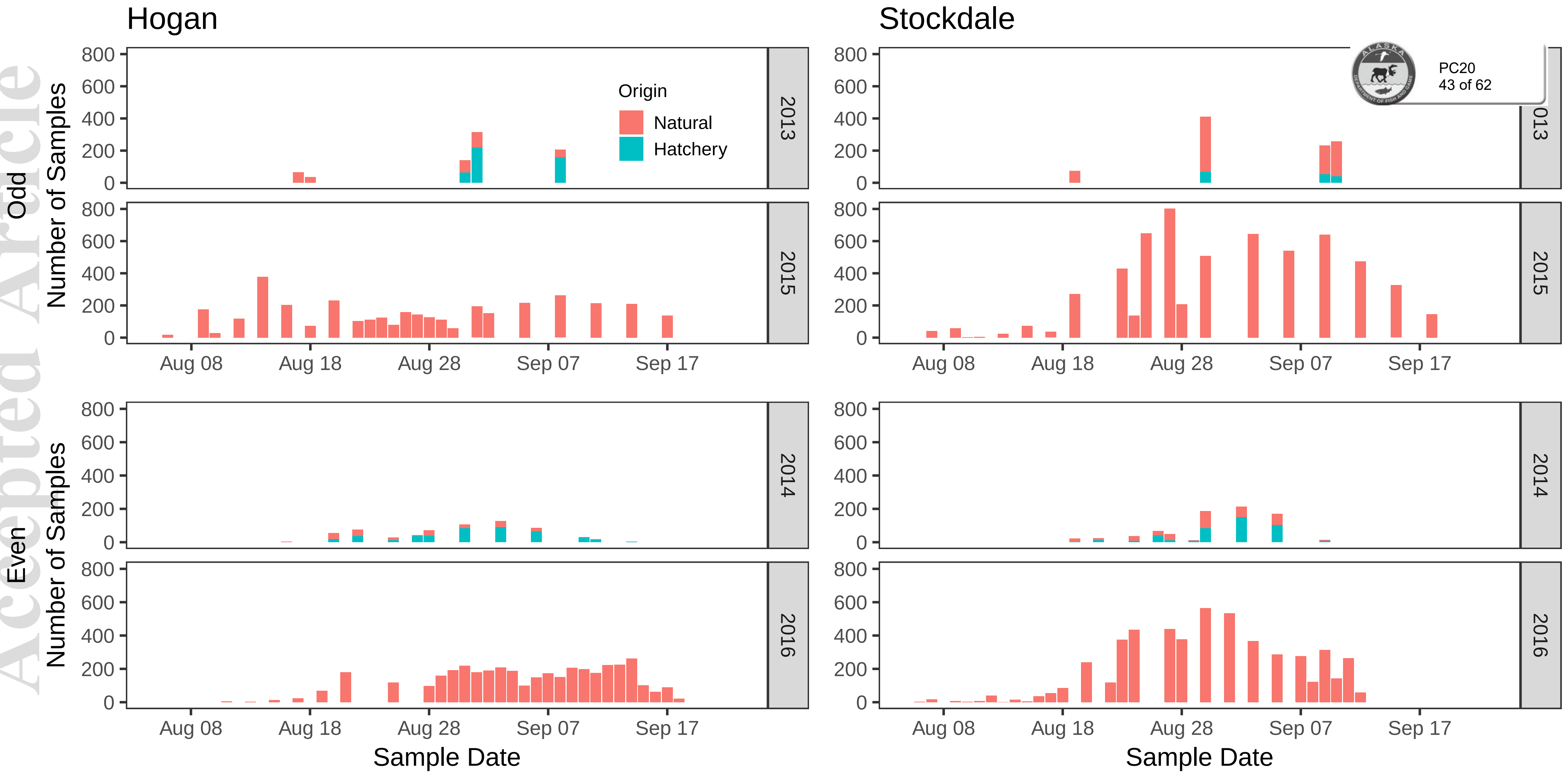
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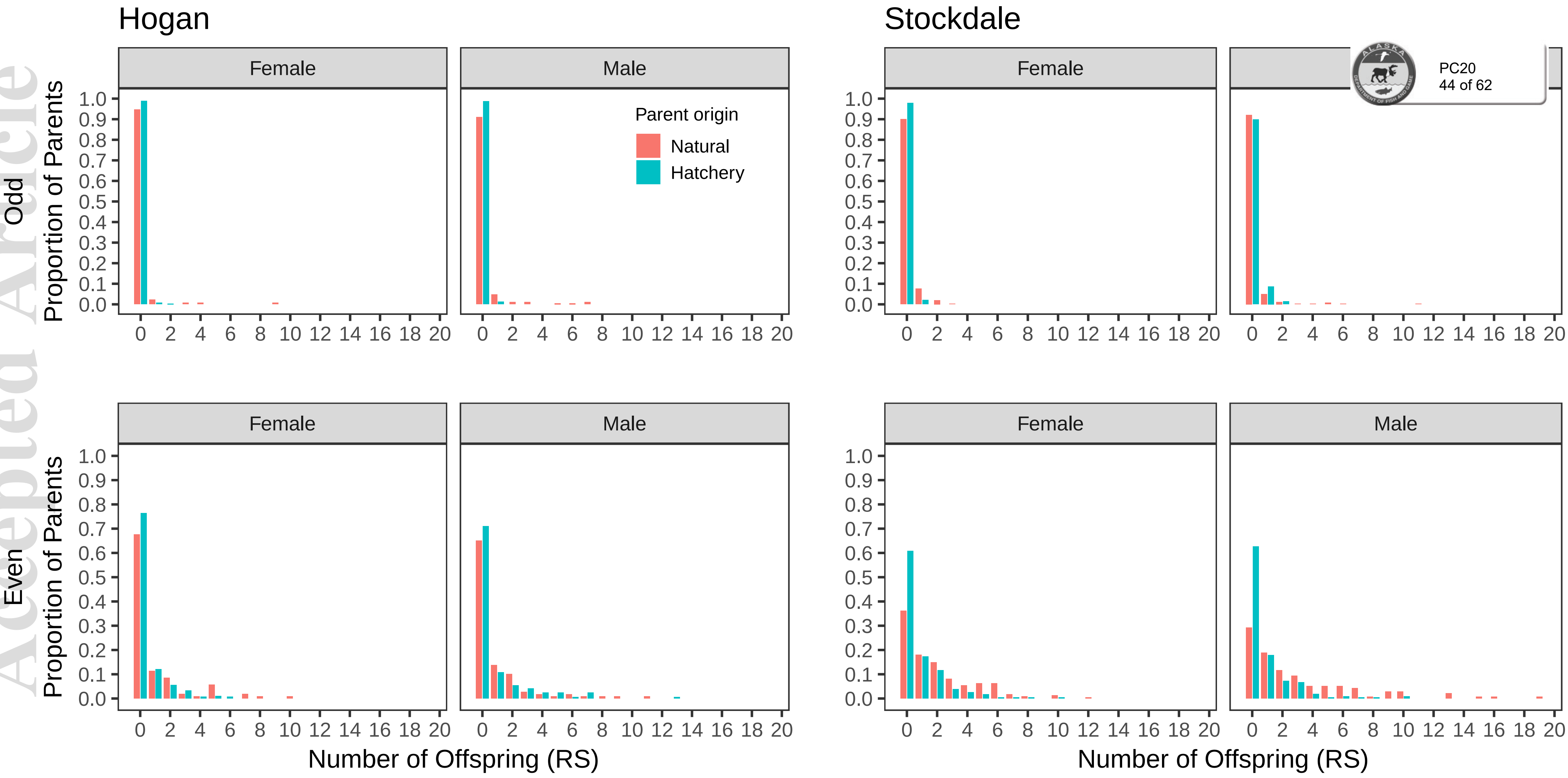
Hogan
Stockdale
Female
Male
Female
Male
Female
Male
Odd
Even
Proportion of Parents
Parent origin
Natural
Hatchery
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0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
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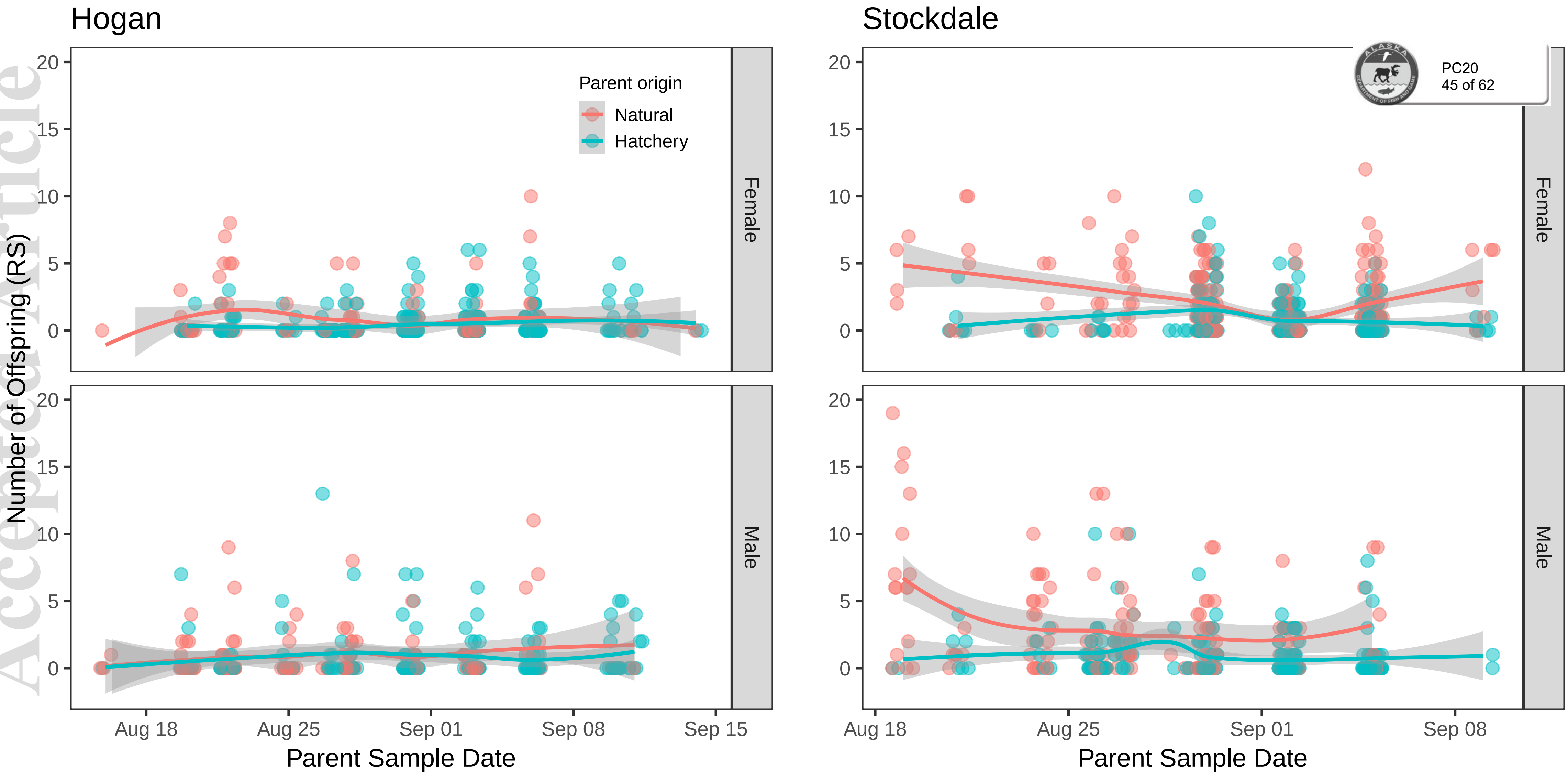
2
4
6
8
10
12
14
16
18
20
Number of Offspring (RS)
Number of Offspring (RS)


Hogan
Stockdale
Parent origin
Natural
Hatchery
Number of Offspring (RS)
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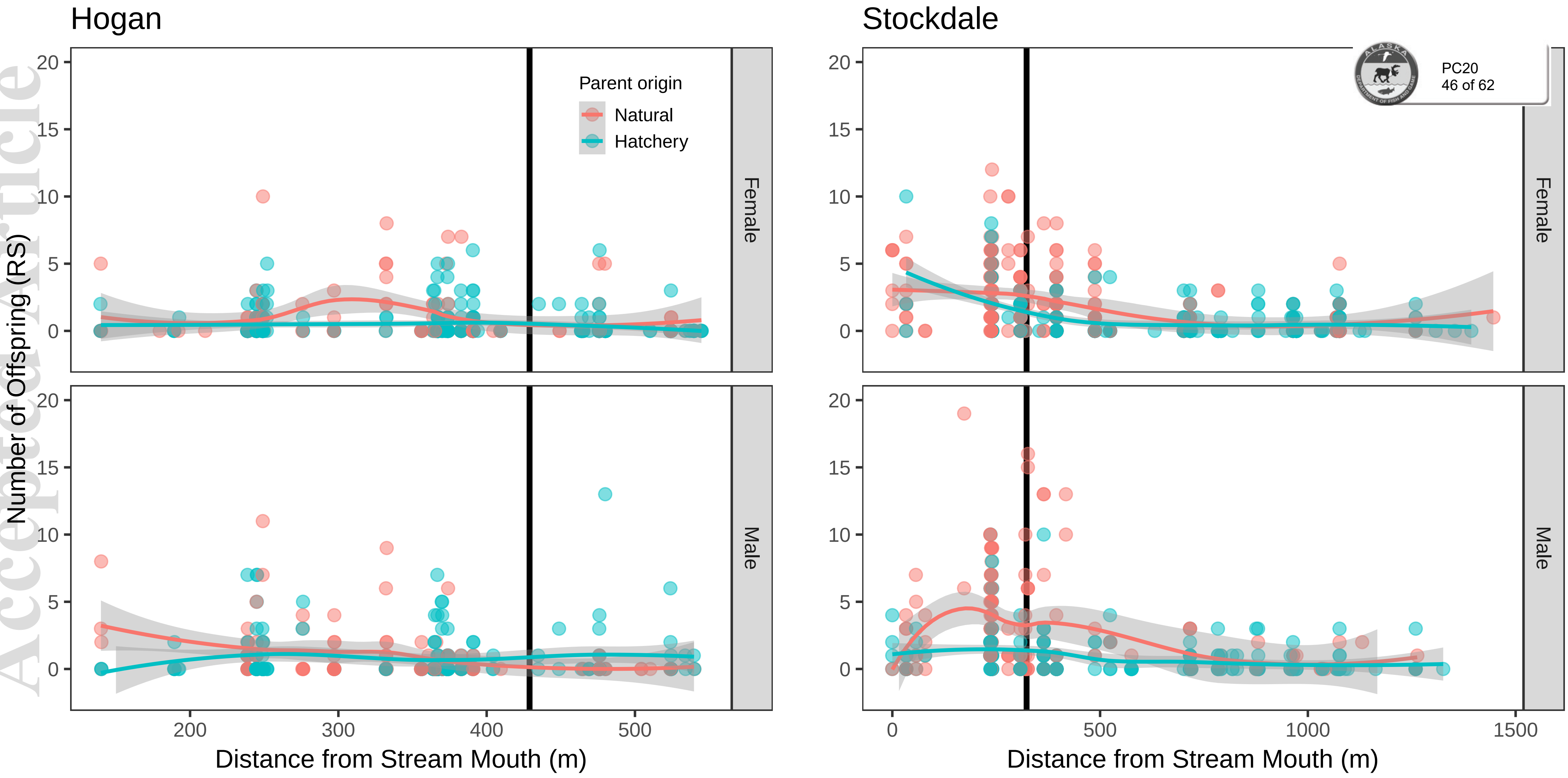
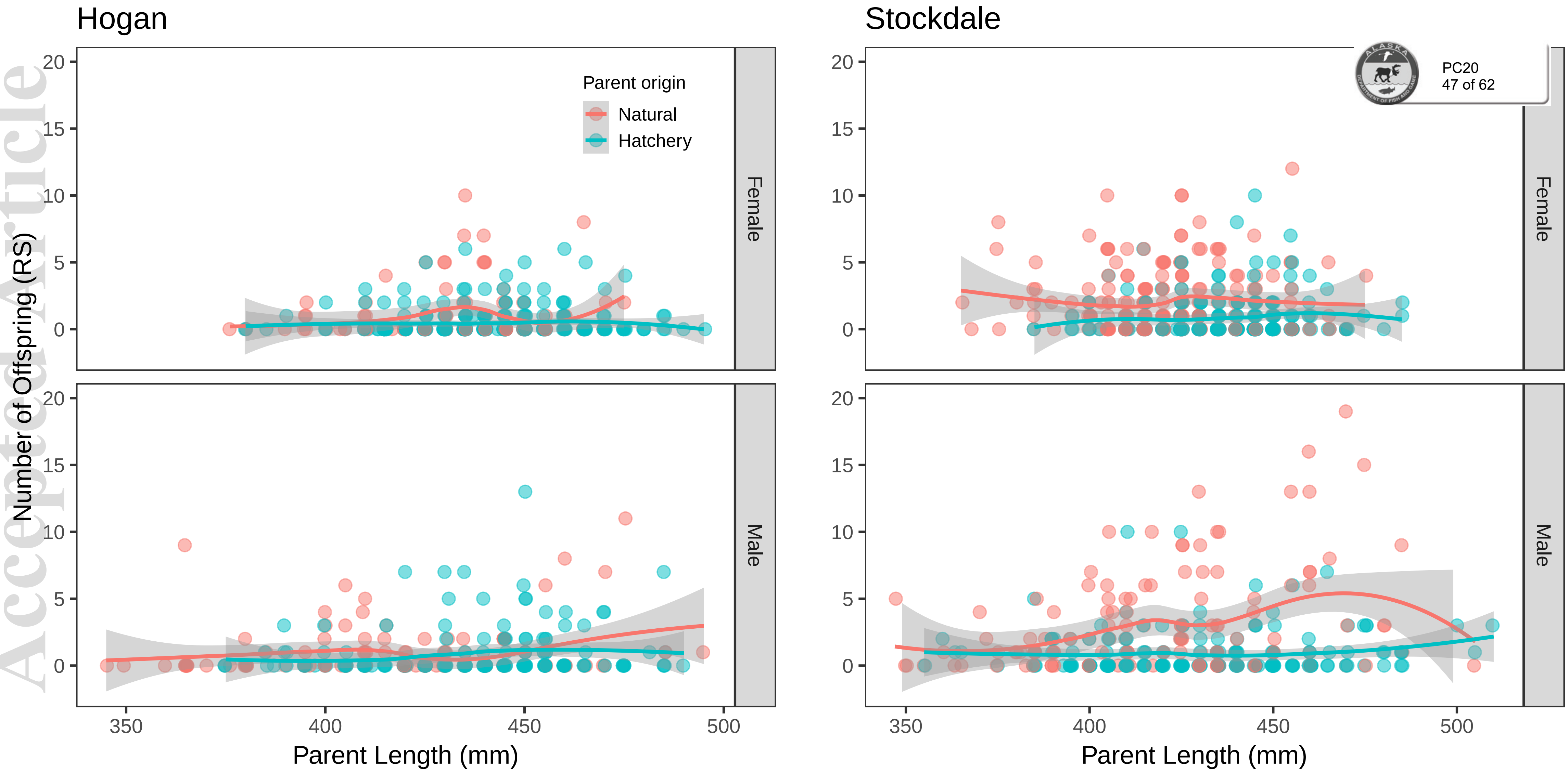
5
10
15
20
Female
Male
Aug 18
Aug 25
Sep 01
Sep 08
Sep 15
Parent Sample Date


Hogan
Stockdale
Parent origin
Natural
Hatchery
Female
Male
Number of Offspring (RS)
0
5
10
15
20
200
300
400
500
0
500
1000
1500
Distance from Stream Mouth (m)
Distance from Stream Mouth (m)


Hogan
Stockdale
Parent origin
Natural
Hatchery
Female
Male
Number of Offspring (RS)
20
15
10
5
0
350
400
450
500
Parent Length (mm)

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RESEARCH ARTICLE

Non-stationary and interactive effects of climate and competition on pink salmon productivity

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Abstract

Pacific salmon (*Oncorhynchus* spp.) are exposed to increased environmental change and multiple human stressors. To anticipate future impacts of global change and to improve sustainable resource management, it is critical to understand how wild salmon populations respond to stressors associated with human-caused changes such as climate warming and ocean acidification, as well as competition in the ocean, which is intensified by the large-scale production and release of hatchery reared salmon. Pink salmon (*O. gorbuscha*) are a keystone species in the North Pacific Ocean and support highly valuable commercial fisheries. We investigated the joint effects of changes in ocean conditions and salmon abundances on the productivity of wild pink salmon. Our analysis focused on Prince William Sound in Alaska, because the region accounts for ~50% of the global production of hatchery pink salmon with local hatcheries releasing 600–700 million pink salmon fry annually. Using 60 years of data on wild pink salmon abundances, hatchery releases, and ecological conditions in the ocean, we find evidence that hatchery pink salmon releases negatively affect wild pink salmon productivity, likely through competition between wild and hatchery juveniles in nearshore marine habitats. We find no evidence for effects of ocean acidification on pink salmon productivity. However, a change in the leading mode of North Pacific climate in 1988–1989 weakened the temperature–productivity relationship and altered the strength of intraspecific density dependence. Therefore, our results suggest non-stationary (i.e., time varying) and interactive effects of ocean climate and competition on pink salmon productivity. Our findings further highlight the need for salmon management to consider potential adverse effects of large-scale hatchery production within the context of ocean change.

KEYWORDS
climate, competition, density dependence, hatcheries, ocean acidification, population productivity, salmon

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[Correction added on 31-January-2022, after first online publication: The copyright line was changed.]

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1 | INTRODUCTION

Pacific salmon (*Oncorhynchus* spp.) inhabiting the North Pacific Ocean and adjacent freshwater habitats are exposed to natural environmental changes and anthropogenic stressors. The joint impacts of stressors such as changes in climate, ocean acidification, and industrial scale hatchery production (the release of artificially propagated juvenile salmon into the ocean) on the productivity of wild salmon populations have received increasing attention in recent years (Cline et al., 2019; Connors et al., 2020; Cunningham et al., 2018). Understanding how multiple stressors interact to influence wild salmon populations is critical for anticipating future responses to global change and for improved resource management.

Pink salmon (*O. gorbuscha*) are the most abundant salmon species in the North Pacific Ocean, and their numbers have more than doubled over the past 50 years due to strong production of wild and hatchery populations (Ruggerone & Irvine, 2018). The majority of hatchery produced pink salmon originate in the state of Alaska, where they were used in the 1970s as a management tool to supplement low abundances of wild populations. Pink salmon have trophic impacts on marine ecosystem components, including phytoplankton and zooplankton (Batten et al., 2018; Shiomoto et al., 1997), other salmonids (Cline et al., 2019; Kendall et al., 2020; Ruggerone & Connors, 2015; Ruggerone & Nielsen, 2004), and predators such as seabirds (Springer & van Vliet, 2014; Springer et al., 2018; Toge et al., 2011). While pink salmon are considered a keystone species in the North Pacific due to their broad impacts on other organisms, less is known about factors that limit population productivity and abundance of pink salmon. Understanding these factors may help inform management decisions in Alaska and beyond, including other parts of the world where pink salmon are increasing in abundance and considered invasive (Nielsen et al., 2020; Sandlund et al., 2019).

About 5 billion hatchery salmon, primarily chum (*O. keta*) and pink salmon, are released into the North Pacific Ocean each year (Ruggerone & Irvine, 2018). Hatchery fish account for roughly 40% of the total salmon biomass in the North Pacific Ocean (Ruggerone & Irvine, 2018). Supplementation from hatcheries can affect wild populations in multiple and complex ways. Hatchery programs were developed primarily to mitigate declines in wild populations; however, concerns over adverse genetic or competitive effects of hatcheries on wild salmon have been raised repeatedly (Araki et al., 2007; Hilborn, 1992; Jasper et al., 2013; Naish & Hard, 2008; Waples, 1991). Although the majority of hatchery reared pink salmon returning as adults are harvested in ocean fisheries, several million fish that spawn in regional streams may interbreed with wild-origin fish (Knudsen et al., 2021). Some hatchery programs might replace rather than augment wild production due to increased competition for resources, as has previously been suggested for pink salmon in Alaska (Hilborn & Eggers, 2000; but see Wertheimer et al., 2001). The potential for negative impacts of increasing abundances of hatchery reared salmon in the ocean has led to calls for an open dialogue on the number of hatchery fish being released each year (Connors et al., 2020; Holt et al., 2008).

Long-term trends in environmental conditions may pose substantial threats to salmon survival. Ocean acidification has been identified as a potential stressor for aquatic species globally, including in the Northeast Pacific (Feely et al., 2016; Orr et al., 2005), for example due to the dissolution of pteropods that are a primary food source for pink salmon (Bednarsek et al., 2021). Experimental studies have also found negative effects of ocean acidification on the growth and behavior of coho (*O. kisutch*) and pink salmon (Ou et al., 2015; Williams et al., 2019).

Furthermore, climate regime shifts have occurred in the Northeast Pacific Ocean in 1976–1977 and 1988–1989 (Hare & Mantua, 2000; Irvine & Fukuwaka, 2011). While the 1976–1977 event was characterized by a change in sign of the Pacific Decadal Oscillation Index (PDO), the 1988–1989 shift involved a change in the leading mode of North Pacific climate variability, from PDO-like to more North Pacific Gyre Oscillation (NPGO)-like (Yeh et al., 2011). Recent work has shown that the effects of ocean temperature on salmon productivity, including on pink salmon, have changed around 1988–1989, with generally weaker links after the 1988–1989 event (Litzow et al., 2019, 2020). Non-stationary relationships among physical and biological variables indicate that the effects of environmental conditions, such as temperature, on population processes, such as recruitment, can vary over time in intensity and/or direction.

In contrast to other species of Pacific salmon, pink salmon have a fixed 2-year life history such that all fish return to reproduce 2 years after eggs were deposited in the gravel (Ricker, 1962). Odd- and even-year lineages that spawn in the same rivers are thus reproductively isolated and genetically distinct (Aspinwall, 1974; Beacham et al., 2012). One of the broodlines is typically more abundant than the other, causing 2-year cycles in pink salmon returns. This pattern of broodline dominance can shift over time and varies among regions along the west coast of North America (Irvine et al., 2014; Krkosek et al., 2011). Cycles in return abundances likely result from a combination of stochastic recruitment and density-dependent interactions between broodlines, such as competition, cannibalism, or disease transmission (Krkosek et al., 2011). Competition for resources in pink salmon may arise from interactions within broodlines, between broodlines, or with other salmon species, including both wild and hatchery fish.

We investigated the combined effects of changes in ocean conditions and salmon abundances (pink, chum, and sockeye salmon) on the productivity of wild pink salmon in Prince William Sound (PWS), Alaska. Each year about 600–700 million hatchery pink salmon fry are released into PWS, which constitutes roughly 50% of the global pink salmon hatchery production in recent years (NPAFC, 2020;

Stopha, 2019). We used 60 years of available time-series data (1960–2019) on wild pink salmon abundances based on catch and escapement records from PWS to study how wild pink salmon productivity is affected by changes in ocean temperature and acidification, as well as competition among pink salmon, including hatchery reared fish, and interspecific competition with other species of Pacific salmon.

2 | MATERIALS AND METHODS

2.1 | Pink salmon ecology

Pink salmon eggs are laid in late summer to fall in coastal rivers, streams, and brackish estuaries (year of spawning is referred to as "brood year," BY). They are semelparous and die after spawning (Quinn, 2005). Juveniles do not reside in fresh water for an extended period and migrate to sea during their first spring (BY+1). Prince William Sound pink salmon spend the summer in nearshore habitats of PWS before entering the Gulf of Alaska (or early fall and migrate southwest in association with the Alaska Current and the Alaska Coastal Current (Armstrong et al., 2008). The typical migration pattern of PWS pink salmon and the general ocean distribution of other Pacific salmon is illustrated in Figure 1. When adults return to PWS the following summer (BY+2) they may overlap with juveniles of the other broodline in coastal environments before entering their natal streams to spawn. Pink salmon primarily feed on zooplankton, pteropods, squid, and other fishes, and diet overlap is largest with sockeye salmon (*O. nerka*) and chum salmon (*O. keta*) (Johnson & Schindler, 2009; Kaeriyama et al., 2000).

2.2 | Hatchery pink salmon

The State of Alaska hatchery program was developed in the early 1970s in response to declining salmon abundances, with the goal of supplementing wild stock abundance for the public benefit (Wilson,

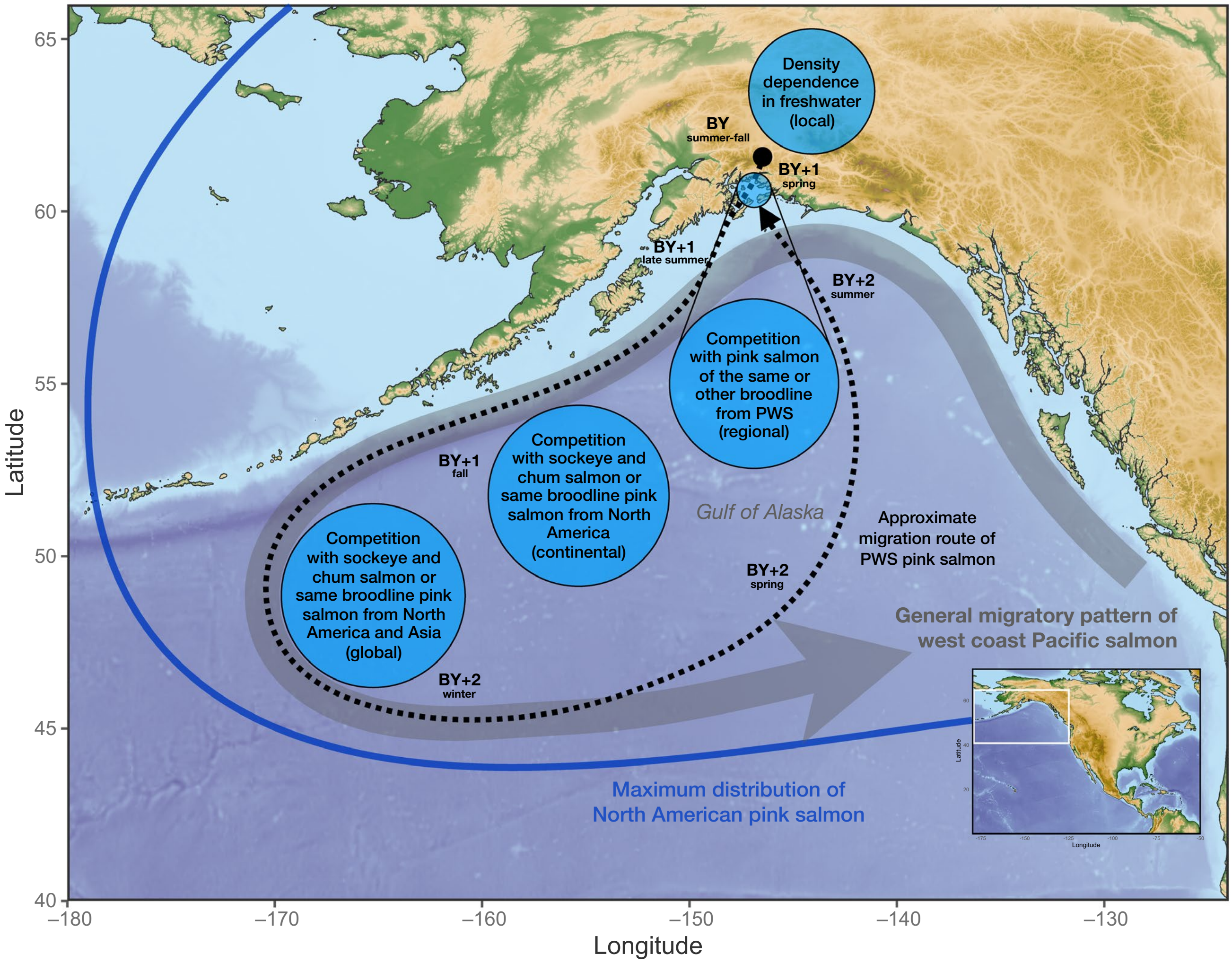

FIGURE 1 Map of the Northeast Pacific Ocean. Shown are the typical migration routes of pink salmon originating from Prince William Sound (PWS, black dotted line) and other west coast Pacific salmon (thick gray line). Filled blue circles indicate hypothesized effects of competition during the pink salmon life cycle. Thick blue line shows the maximum distributions of North American pink salmon

2020). Hatchery reared pink salmon are currently released into PWS as fry by four major hatcheries operated by the Prince William Sound Aquaculture Corporation (PWSAC: Armin F. Koernig, Cannery Creek, Wally Noerenberg) and the Valdez Fisheries Development Association (VFDA: Solomon Gulch). Another facility, Main Bay Hatchery (PWSAC), released pink salmon until 1989. The PWSAC operates the largest hatchery program in North America (Hilborn & Eggers, 2000). These hatcheries are located in close geographic proximity to wild spawning areas, and hatchery reared juveniles occupy similar nearshore marine habitats as juveniles from wild populations (Boldt & Haldorson, 2004; Moss et al., 2005). Like wild pink salmon, hatchery fish attain most of their growth in the ocean, and return during the year following their ocean entry.

2.3 | Data sources

We obtained estimates of escapement, harvest, and total run size of PWS wild pink salmon, as well as release and harvest statistics of PWS hatchery pink salmon from the Alaska Department of Fish and Game (ADF&G) (Figure 2a, d). Pink salmon harvest statistics were downloaded from the ADF&G electronic fish ticket database (ADF&G, 2019), where hatchery contributions are assessed by examining otoliths for hatchery thermal marks and expanding the estimates to the entire catch (Haught et al., 2019). Hatchery release numbers were obtained from the ADF&G Mark, Tag, and Age Lab (https://mtalab.adfg.alaska.gov/cwt/reports/hatcheryrelease.aspx). Estimates of spawning escapement that produce PWS wild pink salmon were derived from annual aerial surveys of index streams (Russell & Haught, 2020). Specifically, area-under-the-curve (AUC) estimates of daily stream counts were divided by stream-specific average stream life of the fish and expanded to account for mean observer efficiency (0.436) (Bue et al., 1998) and the proportion of escapement in non-aerial index streams (0.20) to estimate total spawner escapement. Our escapement estimates are identical to the methodology used by the Alaska Department of Fish and Game, but these approaches do not account for time-varying observation errors or changes in methodology. Observation errors may depend on conditions during surveys such as tides, visibility, survey frequency, and variation in observer efficiency (Fried et al., 1998). Methodological changes include changes in the number of streams assessed over time and changes to escapement goals (Haught et al., 2017). We assume that effects of observation errors and changes in methodology over time are relatively small compared with the year-to-year variation in the numbers of pink salmon spawning in PWS. Similarly, aerial escapement surveys do not discern between hatchery and wild fish, and the fraction of hatchery-origin fish on the spawning grounds varies over time and space (Brenner et al., 2012; Joyce & Evans, 1999; Knudsen et al., 2021). A recent study estimated the contribution of hatchery fish to spawning streams at 5%–15%, based on a subset of streams sampled over a period of 3 years (Knudsen et al., 2021); however, straying proportions for individual streams can be substantially higher (Brenner et al., 2012; Joyce & Evans, 1999).

Temperature time series were obtained Reconstructed Sea Surface Temperature dataset (ERSSTv4, Huang et al., 2015) for the years 1960–2019. Winter and spring sea surface temperature (SST) anomalies in the eastern and western GoA were calculated as averages for the months November to March and April to June, respectively (Litzow et al., 2020). Reconstructions of pCO_2 and pH in the GoA and PWS, which are used as proxies for ocean acidification, were taken from a recently developed regional ocean biogeochemical model of the GoA that were available for the time period 1980–2013 (Hauri et al., 2020). We averaged over three spatial areas representing ocean conditions in PWS, the Gulf of Alaska south of PWS, and the central subpolar gyre (Hauri et al., 2021), defined by latitudes and longitudes 60°–61°N and 146°–148°W, 57.5°–59°N and 148°–151°W, and 55°–57°N and 147°–150°W, respectively. In addition, we used reconstructions of the Northern Gulf of Alaska Oscillation (NGAO), an index of sea surface height variability that is directly linked to changes in upwelling of nitrate and dissolved inorganic carbon and thus ocean acidification in the northern Gulf of Alaska (Hauri et al., 2021). Finally, abundances of other Pacific salmon, including sockeye (*O. nerka*) and chum salmon (*O. keta*), were taken from Ruggerone and Irvine (2018) for the return years 1960–2015, and Ruggerone et al. (2021) for the return years 2016–2019.

2.4 | Statistical analyses

Our analysis is based on the Ricker model (Ricker, 1954) that describes the relationship between spawner abundance, that is, the number of fish that escape the fisheries and are assumed to reach the spawning grounds, and subsequent recruitment. The linearized version of the Ricker function is:

$$\ln\left(\frac{R_y}{S_{y-2}}\right) = \alpha + \beta S_{y-2} + \epsilon_y.$$

Recruitment R_y can be measured at juvenile or adult stages and here we use the latter (recruitment defined as catch plus escapement in return year *y*), S_{y-2} is spawner abundance 2 years prior, α is the intercept, β is the rate at which population productivity declines with spawner abundance ($\beta \leq 0$), and $\epsilon_y \sim N\left(0, \sigma^2\right)$ are normally distributed errors. Here e^{α} is the initial slope of the stock–recruit curve which reflects the number of recruits per spawner at low spawner abundance. This linearized Ricker model can be extended by incorporating additional explanatory variables to model changes in productivity over time:

$$\ln\left(\frac{R_y}{S_{y-2}}\right) = \alpha + \beta_0 S_{y-2} + \beta_1 X_1 + \cdots + \beta_n X_n + \epsilon_y,$$

where $\beta_1, \ldots, \beta_n$ are the regression coefficients and $X_1, \ldots, X_n$ are the covariate time series lagged relative to return year when the covariate is hypothesized to affect pink salmon productivity. We

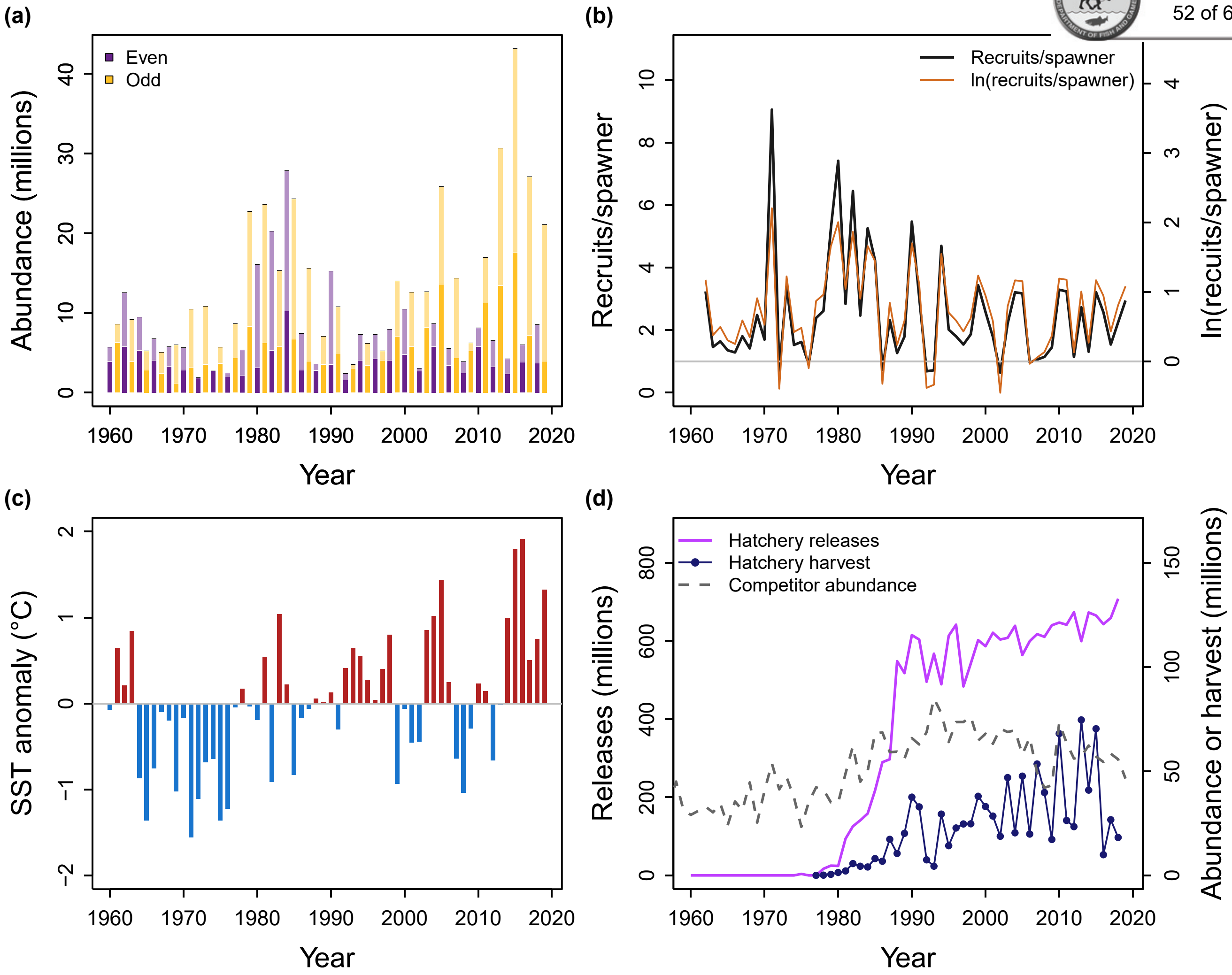

FIGURE 2 Time series of response and predictor variables. Shown are time series of (a) wild run size as escapement (dark) plus harvest (light) of even-year (purple) and odd-year (yellow) pink salmon in PWS, (b) recruits per spawner and ln(recruits/spawner) for wild pink salmon in PWS (gray line indicates replacement at one recruit/spawner), (c) spring sea surface temperature (SST) anomaly in the eastern GoA, and (d) hatchery releases of juvenile pink salmon into PWS (purple, solid line), harvests of adult hatchery pink salmon returning to PWS (blue line and circles), and competitor abundance (sockeye and chum salmon) in the GoA (gray, dashed line)

thus used the natural logarithm of recruits per spawner as our metric of population productivity. An alternative and commonly used metric of population productivity is the residuals of a Ricker stock–recruitment fit. As a sensitivity analysis, we performed a second round of modeling, fitting a Ricker model to the data with different stock–recruit relationships in each broodline. We subsequently compared the model residuals to the ln(recruits/spawner) time series. These two time series showed a high correlation (Pearson correlation of 0.92, Figure S1), and using Ricker residuals as an alternative metric of productivity would yield similar results. Because correlative statistical analyses carry the risk of identifying spurious correlations, we limited our full model to only incorporate covariates with hypothesized mechanisms that may affect pink salmon growth or survival (Table 1). All covariate time series were standardized to a mean of zero and one standard deviation for the analysis. Centering ensures that main effects are biologically interpretable in the presence of interactions or polynomials, and standardization of covariates results in standardized slopes that are comparable within and between models (Schielzeth, 2010).

We considered the following continuous predictor variables in addition to spawner abundance: total run size of the other broodline in the previous year (wild plus hatchery adults returning to PWS during the year of wild juvenile outmigration), hatchery releases of the same broodline (released in the year of wild juvenile outmigration), competitor abundance in the GoA (sockeye and chum salmon from Kodiak to Washington State), competitor abundance in the North Pacific Ocean (sockeye and chum salmon from Asia and North America), proxies of ocean acidification in PWS, the GoA, and the subpolar gyre (pCO_2, pH, NGAO), and spring or winter sea surface temperature (SST) in the eastern or western GoA. We also considered nonlinear effects of the biotic covariates (total run, hatchery releases, competitor abundance) and temperature by

TABLE 1 Explanatory variables considered in the model. Shown are names, species or season, rearing type or location, spatial scale, unit, and hypothesized mechanism for each covariate (including the lag in years relative to the year of wild return)

Covariate	Species/Season	Type/Location	Spatial scale	Unit	Mechanism
Spawner abundance[1]	Pink	Wild	Local/Regional	Millions of fish	Competition for spawning sites or juvenile resources (spawners two years prior)
Hatchery releases same broodline[2]	Pink	Hatchery	Regional	Millions of fish	Competition among juveniles during first summer in PWS (previous year)
Total run size other broodline[1,3]	Pink	Wild and hatchery	Regional	Millions of fish	Competition between juveniles and returning adults in PWS (previous year)
Abundance of competitors[4]	Sockeye + chum	Wild and hatchery	Continental or global	Millions of fish	Interspecific competition in the GoA or North Pacific (return year)
Sea surface temperature[5]	Winter or spring	GoA	Regional	°C	Changes in growth or survival in the ocean (previous year)
Northern Gulf of Alaska Oscillation[6]	Annual	Northern GoA	Regional	–	Changes in growth or survival in the ocean (previous year)
Carbon dioxide partial pressure or pH[6]	Annual	PWS or GoA	Regional	µatm (–)	Changes in growth or survival in the ocean (previous year)

Note: Data sources: [1]Russell & Haught, 2020, [2]ADF&G Mark, Tag, and Age Lab, [3]ADF&G electronic fish ticket database, [4]Ruggerone & Irvine, 2018, Ruggerone et al., 2021, [5]ERSSTv4, Huang et al., 2015, [6]Hauri et al., 2020, 2021.

including quadratic terms in addition to the lin ries used in the selected covariate model are presented in Figure 2, and other time series considered in the model selection are presented in Figure S2.

We assumed that the even and odd pink salmon broodlines were separate populations as they are reproductively isolated and genetically distinct (Aspinwall, 1974; Beacham et al., 2012), with different relationships between population productivity and spawner abundance estimated for each broodline. We therefore included spawner abundance, broodline (odd/even), and a spawner abundance by broodline interaction as fixed terms. In addition, we considered a binary predictor representing the period before and after the 1988–1989 climate regime shift as a factor in interaction with SST. This interaction allows for different relationships between temperature and salmon productivity during each regime, as identified in previous studies on Pacific salmon (Litzow et al., 2019, 2020). We considered an interaction of regime with spawner abundance by broodline to allow for different relationships between productivity and spawners during each regime. We did not include a main effect for regime, which was strongly confounded with hatchery releases (hatchery production was limited in the 1970s and early 1980s). Confounded predictors can cause inaccurate parameterization and exclusion of important predictor variables during model selection (Graham, 2003). We used variance inflation factor analysis to assess multicollinearity among explanatory variables and to determine which variables could be included in the same model (threshold of 5, Zuur et al., 2010).

Because the initial model selection did not support the inclusion of ocean acidification proxies, which had relatively short time series (1980–2013), model selection was repeated using the full time series (1960–2019) of other explanatory variables. We used combined sockeye and chum salmon abundances as an index of competition, because time series of non-PWS pink salmon in the GoA and North Pacific strongly covaried with PWS hatchery releases and total returns. The different spatial aggregates of competitor abundances or SST could not be included in the same model such that we ran the model selection with one of the time series at a time and compared models based on their AICc values. The full model included wild spawner abundance in interaction with broodline and regime, total return of the other broodline in the previous year, hatchery releases of the same broodline, an index of competitor abundance in the GoA or North Pacific, and spring or winter SST in the eastern or western GoA in interaction with regime. All sub-models of the full model were tested as part of the model selection.

2.5 | Diagnostics and interpretation

We performed AICc-based model selection (Burnham & Anderson, 2002), where the model with the lowest AICc value was selected using the *dredge* function of the package *MuMIn* (v. 1.43.15) in R (R Core Team, 2020). We present results for the top model and the model selection, instead of using model averaging which may not be reliable when models contain interactions between explanatory variables (Cade, 2015). To evaluate whether these regression results were specific to the choice of model framework used, we also constructed models using random forests (using the R package *randomForest*, version 4.6–14; Breiman et al., 2006). Because random forest models are nonparametric, coefficients cannot be extracted for each predictor, but these models can be used to calculate the relative importance of each variable. Specifically, we calculated the percent increase in mean squared errors of out-of-sample predictions when excluding a predictor as our metric of variable importance (Liaw & Wiener, 2002).

Finally, we performed a cross-validation to assess the ability of covariate models of different complexity to make out-of-sample predictions. The cross-validation was performed by splitting the data into a training and a test dataset. Models were run on the training data (44 years, 75% of data) to get parameter estimates that were used to predict the remaining test data (14 years, 25% of data). This procedure was repeated 1000 times by randomly drawing the training and test datasets to achieve reliable estimates of the root mean squared prediction error (RMSE). The procedure was applied to all sub-models of the selected model to assess whether any of the simpler models would produce better out-of-sample predictions compared to the selected model.

Model code is available at: https://github.com/janohlberger/PinkSalmon2021Ohlberger.git, and data are openly available in Zenodo at: https://doi.org/10.5281/zenodo.5780246.

3 | RESULTS

Run sizes and escapements of wild pink salmon in PWS have varied considerably over the past 60 years (Figure 2). Return abundances of the even-year broodline have varied between 1.9 and 27.9 million with a mean of 8.0 million fish, and abundances of the odd-year broodline have varied between 3.5 and 43.2 million with a mean of 14.3 million fish. Population productivity measured as ln(recruits/spawner) has also varied substantially over time, between −0.45 and 2.2 with a mean of 0.74 (Figure 2).

We find evidence that the productivity of wild pink salmon is affected by multiple biotic and abiotic factors, including changes in ocean climate and competition, but not ocean acidification. The selected model included several explanatory variables in addition to the fixed model terms spawner abundance (S_{y-2}), broodline (B_i, odd/even), and their interaction (Table S1):

$$\begin{aligned}\ln\left(\frac{R_y}{S_{y-2}}\right) &= \alpha+\beta_0 S_{y-2}+\beta_1 B_i+\beta_2 S_{y-2}B_i\\ &\quad+\beta_3 S_{y-2}B_iD_j+\beta_4 T_{y-1}+\beta_5 T_{y-1}D_j\\ &\quad+\beta_6 P_{y-1}^2+\beta_7 H_{y-1}+\beta_8 C_y^2+\epsilon_y,\end{aligned}$$

where T_{y-1} is the sea surface temperature in the GoA during spring of wild juvenile outmigration, P_{y-1} is the total pink salmon return (wild and hatchery) in the year of wild juvenile outmigration, H_{y-1} are hatchery releases of pink salmon into PWS in the year of v tion, C_y is the competitor abundance in the GoA (sockeye and chum salmon) in the year of wild return, and D_j is the ocean regime (before or after 1988–1989).

Negative density dependence, that is, lower productivity at higher spawner abundance, was found in both broodlines; however, the even-year broodline showed stronger density dependence after the 1988–1989 regime shift (Figure 3a), whereas the odd-year broodline showed weaker density dependence after the regime shift (Figure 3b). Overall, the odd-year broodline had a slightly higher productivity than the even-year broodline (Figure S3). The relationship between pink salmon productivity and temperature has shifted from positive and significant before to non-significant after the 1988–1989 regime shift (Figure 3c). The total run of wild and hatchery pink salmon to PWS had a nonlinear effect on wild pink salmon productivity from the following brood year (Figure 3d), where the highest total runs were associated with low wild pink salmon productivity, indicating competitive interactions between returning adults and juveniles in nearshore habitats. Wild pink salmon productivity was negatively associated with pink salmon hatchery releases, suggesting adverse effects of hatchery production (Figure 3e). The relationship between productivity and the abundance of sockeye and chum salmon in the GoA was nonlinear (**f**), indicating a threshold effect where increasing interspecific competitor abundances show a positive association up to a threshold, above which additional competitors are associated with reduced productivity of wild pink salmon. Model parameter estimates and confidence intervals are provided in Table S1 and Figure 4.

The model explained about 62% of the variance in ln(recruits/spawner) over time (Figure S4). For comparison, a model without any covariates (but allowing for independent stock–recruitment relationships by broodline) explained only 10% of the variance (Figure S5). Model diagnostics indicated normality and homogeneity of residuals (Figure S6). The percent increase in mean squared errors when excluding predictors from the model suggested that the most influential variable, besides the fixed terms spawner abundance and broodline, was SST anomaly, followed by hatchery releases, regime, total returns, and competitor abundance (Figure S7). The selected covariate model had the highest out-of-sample prediction ability, as indicated by the lowest root mean squared error (RMSE), compared to any of the simpler models that included fewer predictors (Figure S8). A sensitivity analysis of the model selection and parameter estimates that simulated varying degrees of observation error in recruits/spawner estimates further indicated that our findings are robust to low and moderate levels of observation error (Figure S9).

Scaling up hatchery releases of pink salmon from 0 to 700 million fish each year decreased the expected wild productivity under average conditions of the other predictors by ~55% for both broodlines (Figure 5). The absolute change in expected recruits per spawner depends on other factors such as the ocean regime and wild escapement (Figure S10). These estimates account for negative effects of hatchery juveniles released into PWS (competition within the same brood year), but do not account for potential impacts of returning

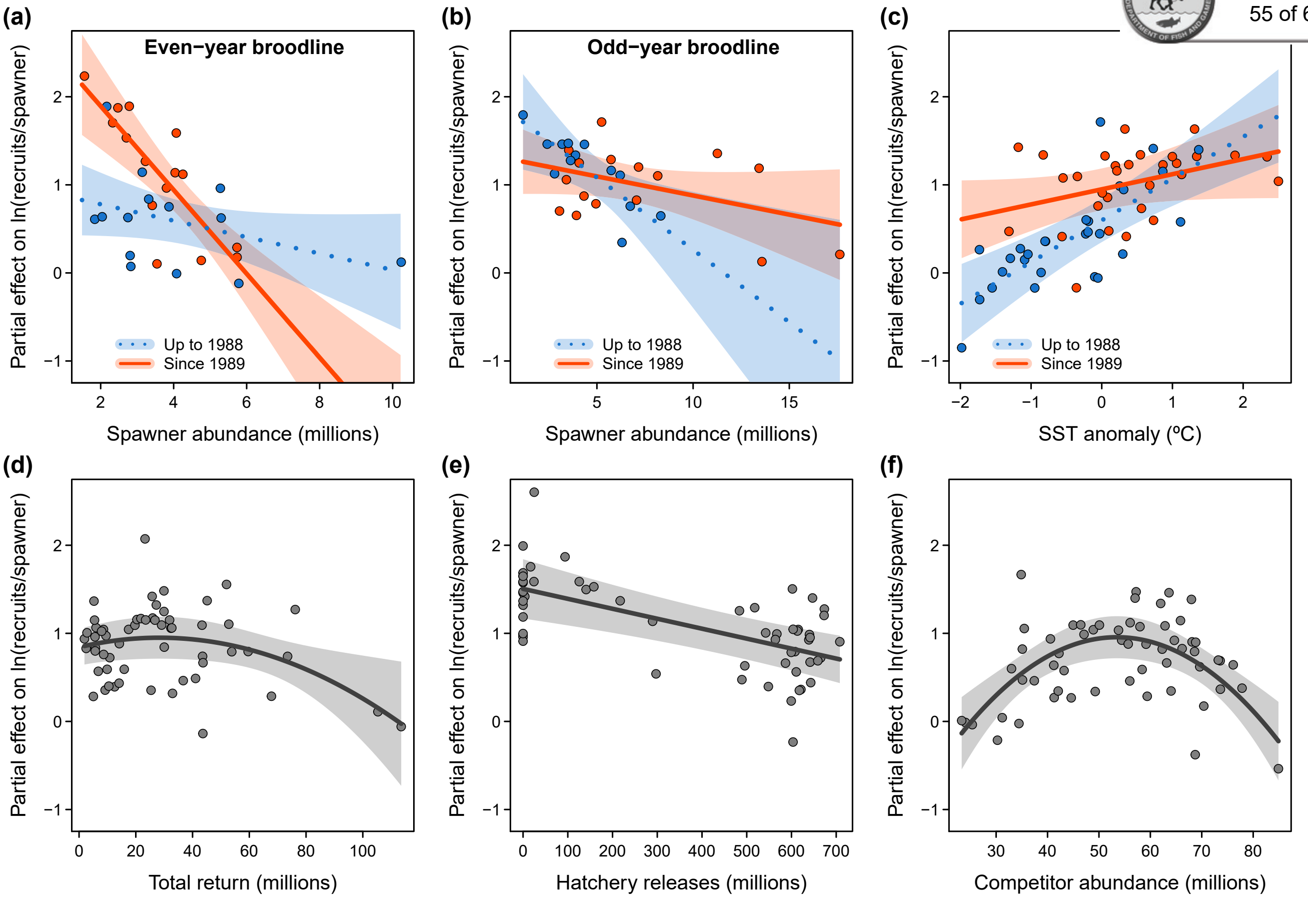

FIGURE 3 Predicted partial effects on wild pink salmon productivity. Shown are effects of (a/b) spawner abundance for the even-year and odd-year broodlines during the previous (blue, dashed line) and current (red, solid line) ocean production regime, (c) spring SST in the eastern GoA in the year of juvenile outmigration for the previous (red) and current (blue) ocean regime, (d) total run size of wild plus hatchery pink salmon of the other (previous year) broodline to PWS, (e) hatchery releases into PWS in the year of juvenile migration, and (f) abundance of competitors (chum and sockeye salmon) in the GoA in the year of adult return. Polygons are 95% confidence intervals

adults (competition from the previous brood year), because the effect of total return was only apparent at very high abundances, and the effects of hatchery versus wild adults could not be distinguished. The resulting effects of hatchery releases on the expected wild return are presented in Figure 6. While the percent decline in the expected wild return when increasing hatchery releases is independent of the level of wild escapements, negative impacts of hatchery releases in terms of forgone wild returns (i.e. the expected additional wild return in the absence of hatchery releases) are greater when wild escapement is intermediate to high (Figure 6).

4 | DISCUSSION

We find evidence that density dependence in pink salmon is caused by intraspecific interactions at the regional scale and that hatchery releases can negatively affect the productivity of wild populations. We also find that the 1988–1989 ocean regime shift was associated with changes in the temperature–productivity relationship and affected the strength of density dependence within pink salmon broodlines. Our results suggest that climate and competition can have non-stationary and interactive effects on salmon and that potential adverse effects of large numbers of hatchery reared fish on wild populations should be considered in salmon management.

Hatchery releases of pink salmon in PWS have increased over time, especially during the 1980s, and currently amount to ~700 million fry annually such that returning hatchery fish now greatly outnumber returning wild pink salmon. While there is no evidence for a significant increase or decrease of pink salmon hatchery production in the near future, we predicted the effects of higher or lower hatchery releases on wild pink salmon productivity based on our model results. We estimate that the productivity of wild fish would be reduced to around one recruit per spawner (replacement) under average wild escapements and environmental conditions, if current hatchery releases were doubled. Conversely, the expected recruits per spawner of wild fish would increase by about 50% if hatchery releases were halved to ~350 million annually (from 2.33 to 3.50 and from 2.63 to 3.96 recruits per spawner for the odd and even broodlines, respectively, Figure 5).

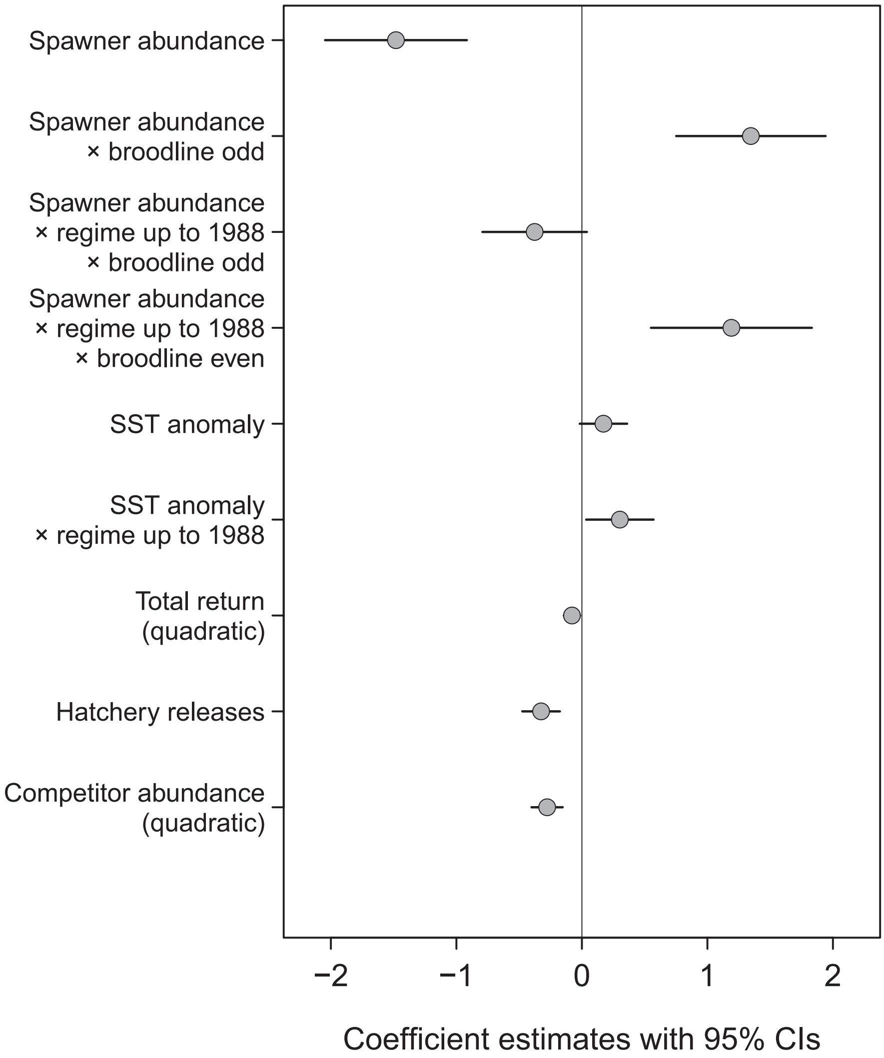

FIGURE 4 Model p Shown are parameter estimates with 95% confidence intervals for all terms included in the selected covariate model

Previous work suggested that hatchery production contributed to declining run sizes of wild pink salmon in PWS (Hilborn & Eggers, 2000, 2001; but see Wertheimer et al., 2001; Shuntov et al., 2017). Hatchery fish most likely reduce the productivity of wild populations due to competition for resources between hatchery and wild juveniles in nearshore marine habitats, which can negatively affect body growth and reduce survival of wild pink salmon, because fast-growing juveniles experience higher survival rates (Cross et al., 2008, 2009; Moss et al., 2005). Hatchery production may have little or even no detectable effects on wild pink salmon populations in regions where hatchery programs are spatially segregated by larger distances from nearshore rearing habitats of wild juveniles. Accordingly, productivity trends of pink salmon in nearby Cook Inlet and Kodiak have differed from those in PWS (Amoroso et al., 2017; Hilborn & Eggers, 2000; Malick & Cox, 2016). Decreasing the number of hatchery pink salmon released into nearshore areas that constitute important habitat for wild juveniles may thus be an effective management strategy to reduce potential negative effects of hatchery supplementation on the productivity of wild pink salmon. The observation that the nearby Cook Inlet and Kodiak regions of Alaska have experienced different productivity trends supports the conclusion that the decline in productivity of PWS pink salmon was linked to hatchery releases, and less so to large-scale changes in ocean conditions linked to the 1988–1989 regime shift. However, because the time series of hatchery releases is confounded with the regime shift, due to very low releases in the 1970s and early 1980s, uncertainty in the hatchery effect is likely larger than indicated by our model.

The question remains whether negative impacts of pink salmon releases on the productivity of wild populations are acceptable considering that hatchery production increases total abundances of pink salmon (Amoroso et al., 2017). Higher hatchery return abundances increase harvest opportunities, but do not appear to stabilize revenue of pink salmon fisheries in PWS (Ward et al., 2018). Furthermore, because Pacific salmon migrate long distances at sea, large-scale hatchery production may have unintended adverse effects on other species of salmon originating from distant regions (e.g. Connors et al., 2020; Cunningham et al., 2018; Ruggerone et al., 2012). Hatchery salmon interbreeding with wild salmon can also affect the genetic composition and reproductive success of wild salmon (Naish & Hard, 2008; Waples et al., 2020). Hatchery pink salmon that stray into wild streams have lower reproductive success

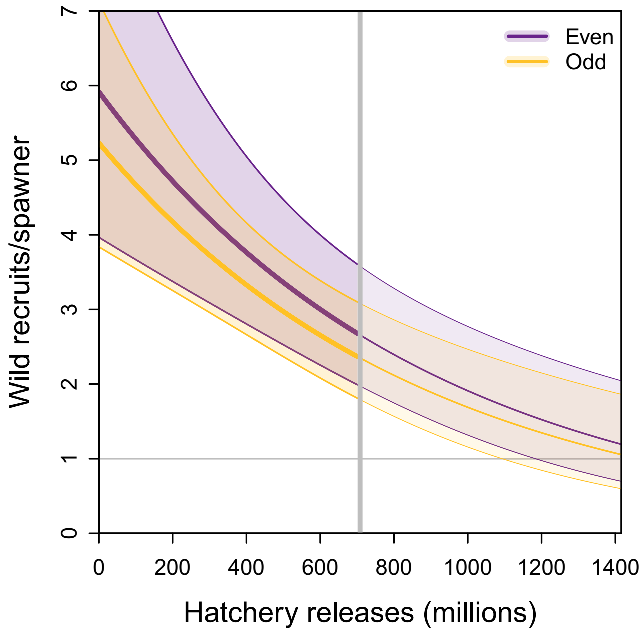

FIGURE 5 Predicted wild recruits per spawner as a function of hatchery releases. Shown are predictions for the even-year (purple) and odd-year (yellow) broodlines during the current regime while setting all other predictors (wild escapement, temperature, total return, competitor abundance) to median values. Thin lines show predictions beyond the highest number of hatchery fish that has been released into PWS (~700 million, gray vertical line). The gray horizontal line indicates population replacement at one recruit per spawner and the gray vertical line indicates the highest historical hatchery releases. Polygons are 95% confidence intervals

than wild fish (Lescak et al., In Press) and coul dependence on the spawning grounds, which may bias estimates of wild recruits/spawner when escapement surveys do not discern between hatchery and wild fish. Quantifying the tradeoffs between industry performance in the fishery supported by the large hatchery program and productivity and abundance of wild salmon populations within and outside PWS are left for future extensions of this work.

In addition to hatchery releases in the year of wild juvenile outmigration, the model included the total run of hatchery and wild fish as a predictor variable, suggesting additional negative effects of returning adults on wild juveniles during their first summer at sea. While the effect was only apparent for the largest returns to PWS (over 50 million returning adults), it is conceivable that hatchery pink salmon compete with wild juveniles both when released into the ocean and as returning adults. Competition among juveniles that have recently entered the ocean and returning adults of the previous brood is consistent with other studies that have suggested that odd–even-year cycles, as commonly observed in pink salmon returns, are caused by direct interactions between broodlines (Krkosek et al., 2011). Such direct interactions may also be responsible for the switch in odd–even dominance of western Kamchatka pink salmon (Ruggerone & Nielsen, 2009). Our results provide some evidence for such delayed density dependence and indicate that the more abundant broodline may be able to suppress the productivity of the other broodline at extremely high abundances.

While large abundances of pink salmon have previously been linked to declines in the growth and survival of other salmon

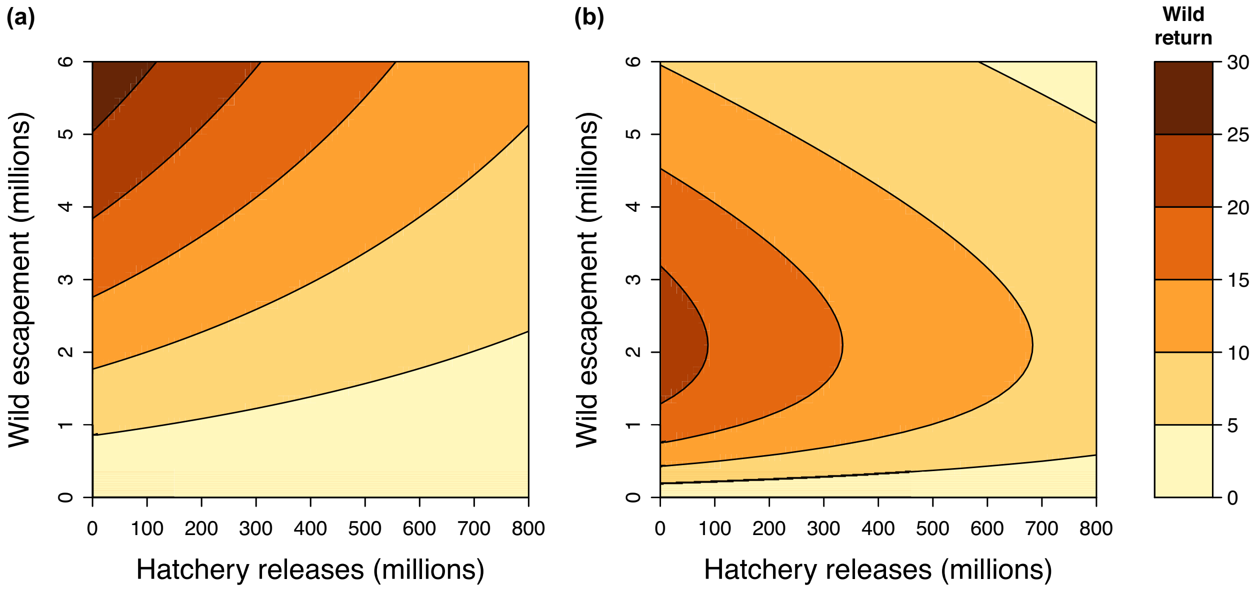

FIGURE 6 Predicted return of wild pink salmon as a function of wild spawner escapements and hatchery releases. Shown are predicted wild pink salmon returns (contour, millions of fish) for the (a) odd-year broodline and (b) even-year broodline during the current ocean regime. Other predictors were set to median values for that regime. Note that the even-year broodline shows stronger density dependence compared to the odd-year broodline during this regime. Predictions do not account for uncertainty in model parameter estimates

species in the North Pacific Ocean, in particular sockeye salmon (Cline et al., 2019; Connors et al., 2020; Pyper & Peterman, 1999; Ruggerone & Connors, 2015; Ruggerone & Nielsen, 2004; Ward et al., 2017), competition from other Pacific salmon on the productivity of wild pink salmon has been studied much less, possibly because pink salmon are the most abundant salmonid. Our results suggest a nonlinear effect of sockeye and chum salmon abundance, indicating a potential threshold abundance above which competitors reduce the survival of wild pink salmon. The positive association at low competitor abundances might be a result of shared responses to environmental change at large spatial scales. The abundance of sockeye and chum salmon originating from Kodiak to Washington State was more closely related to pink salmon productivity than basin-wide abundance including populations from western Alaska and Asia. However, conclusions about the spatial scale of density dependence need to be made with caution due to multicollinearity among candidate time series of competitor abundance, including different spatial aggregates, time lags, and species compositions.

The relationship between ocean temperature and pink salmon productivity has varied over time. Productivity was positively associated with temperature prior to the ocean regime shift, but the relationship was non-significant after 1988–1989, suggesting that pink salmon productivity under the current regime is less dependent on temperature. This time dependence suggests caution when using observed temperature–productivity relationships to project possible future effects. Large-scale climate indices such as the PDO and NPGO were considered in our initial modeling efforts but not included in the final models as they were not supported as important predictors of pink salmon productivity. It should also be noted that the Exxon Valdez oil spill in PWS occurred in 1989 during the NE Pacific regime shift. However, previous work found no evidence for a link between wild pink salmon productivity and the Exxon Valdez oil spill in PWS (Ward et al., 2017). Our finding that pink salmon productivity is linked to regional-scale temperature conditions is also in line with previous studies (Mueter et al., 2002; Springer & van Vliet, 2014). Finally, similar non-stationary climate–productivity relationships have been reported for other species of Pacific salmon, including sockeye and chum salmon, indicating that salmon productivity was positively related to sea surface temperature in the GoA in the 1970s and 1980s, but unrelated to SST after the 1988–1989 regime shift (Litzow et al., 2019, 2020).

The climate regime shift of 1988–1989 in the Northeast Pacific Ocean further affected the stock–recruitment relationship of the two broodlines in opposite ways. The effect of spawner abundance was much stronger after compared to before the regime shift for the even-year broodline, suggesting intensified density dependence, whereas it was slightly weaker for the odd-year broodline. These contrasting responses in the strength of density dependence may be linked to different environmental conditions. Pink salmon egg survival and fry growth are higher for the even-year compared to the odd-year broodline at cold incubation temperatures (Beacham & Murray, 1988). It has been suggested that increasing dominance of odd-year brood lines along the North Ame caused by warming freshwater habitats (Irvine et al., 2014). While pink salmon in PWS have historically not shown any clear dominance of either broodline, it appears that an odd-year dominance has emerged during the past two to three decades. Our results indicate that the climate regime shift altered the spawner–recruit relationships of the broodlines such that population productivity has declined for even-year pink salmon but increased for odd-year pink salmon at high spawner abundances. This interaction between density and climate might contribute to recent shifts toward increasing abundances of odd-year pink salmon in PWS and possibly in other regions, as has been observed throughout the North American range (Irvine et al., 2014).

Factors other than those accounted for in this study can affect wild pink salmon productivity, including environmental conditions during freshwater rearing. For instance, a consequence of a warming climate in Pacific salmon ecosystems is loss of glacier coverage and the resulting changes in freshwater and estuarine habitats (Schoen et al., 2017). Glaciers in western North America are currently losing about 3% of their volume per year (Pitman et al., 2020). The PWS watershed still features significant glacier coverage (~18%), yet continued glacier loss in the region might affect wild pink salmon productivity and interact with other factors, such as those related to competition for resources in freshwater and estuarine habitats. These habitats are modified by glacier retreat via a variety of mechanisms that may increase or decrease the productivity of wild salmon depending on current thermal, biogeochemical, and hydrological conditions (Pitman et al., 2020). While we did not detect any links between variation in pCO_2 or pH and PWS pink salmon productivity, this should not be interpreted as conclusive evidence for the lack of an effect, because the reconstructed time series that we used as a proxy for ocean acidification were relatively short and based on a regional ocean biogeochemical model, rather than observations. Furthermore, our analysis assumes that estimated spawner escapements represent true values. While these estimates are likely associated with error due to a number of factors, we believe that the values in this study are the best available as they correct for observer efficiency, stream life, and the proportion of escapement assessed by the aerial survey program (Fried et al., 1998). Observation error can cause bias in estimates of population productivity derived from stock–recruit analyses (Hilborn & Walters, 1992), and observation error in pink salmon escapement estimates can be considerable (Bue et al., 1998; Hilborn et al., 1999). However, our sensitivity analysis suggested that the findings of this study are relatively robust to low and moderate levels of observation error in recruits/spawner estimates.

Our findings highlight that the benefit of higher wild escapements for producing greater recruitment of wild pink salmon diminishes with increasing hatchery releases. Reduced productivity due to hatchery supplementation likely contributes to lower population resilience in wild pink salmon. Further increasing hatchery releases might therefore jeopardize the ability of wild populations to withstand other environmental and/or human stressors.

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CONFLICT OF INTEREST

The authors have declared that no conflict of interests exist.

AUTHOR CONTRIBUTIONS

J.O., E.J.W., R.E.B., and M.E.H. designed the study; J.O., E.J.W., R.E.B., M.E.H., S.B.H., M.A.L., G.T.R., and C.H. curated the data; J.O. and E.J.W analyzed the data; J.O. wrote the first draft of the manuscript. All authors contributed to interpretation of results and writing of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Zenodo at: https://doi.org/10.5281/zenodo.5780246.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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Hatchery Committee Meeting
Pioneer Alaskan Fisheries Inc.
Box 674 Homer, Alaska 99603
907-399-7777
March 8, 2022

Greeting Board of Fisheries

1. Please consider applying the Sustainable Salmon Policy 5 AAC 39.222 as a guide for the Hatchery Committee to create specific frameworks for meaningful non regulatory actions for hatchery issues of concern.

> 5 AAC 39.222(a)(3) To effectively assure sustained yield and habitat protection for wild salmon stocks, fishery management Plans and programs require specific guiding principles and criteria, and the framework for their application contained in this policy.

Three concerns that would be assisted with a framework are to

1. determine acceptable or unacceptable stray rates,
2. transparently archive hatchery data and activity on the ADFG website
3. Rebalance Regional Planning Teams ADFG voting members with backgrounds in ecology genetics and other species.

Alaska has specific hatchery guiding principles and criteria in our laws and policies to assure sustained yield. Few comprehend and apply hatchery principles and criteria, because most have never read the complex hatchery laws and policies so application languishes or is not consistent.

Hatchery Fishermen are confused by the lack of framework that clarifies there is more than **Economy** involved in artificial production of salmon. There is also **Ecology** and **Genetics** purposely designed into law to effectively assure sustained yield of wild salmon starting with the mandated intent of the PNP Hatchery Act.[1]

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[1] **PNP Hatchery Act** Section 1. INTENT. 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 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.

When these laws and policies were created, they were attended by 147 ADFG personnel of the FRED[2] Division. This army had no harvest constituency but was disbanded in 1991, so the ADFG oversight over hatchery laws has been fragmented ever since.

Just stating “we follow the laws” without following the laws, jeopardizes salmon. It needs application.

The sustainable Policy asks for a “framework for their application contained in this policy”. The Hatchery Committee can begin to provide with the department, this structure of guidance to apply these principles and criteria.

Acceptable stray rate

Mark tag lab hatchery stray sampling proportion data needs to get off the shelf and be integrated into guiding principles and criteria using the anadromous waters catalogue for a living working structure designed to ensure wild fish productivity and genetic diversity is not overwhelmed further by hatchery fish genetics.

This is a sorely needed specific framework to guide the department on a defined acceptable or unacceptable rate of straying under the hatchery permits. This problem has no consistency to align with the Genetic Policy, Comprehensive Plans, Escapement Goal law and the Sustainable Salmon Policy. Presently this known risk to wild salmon has no metric.

For the application of sound, precautionary, conservation management practices,[3] unacceptable straying in wild systems can use the framework already available of the interactive anadromous waters catalogue by applying a GIS layer where the Mark Tag Lab otolith sampling results of straying can be applied and a sliding scale using software that “considers factors including environmental change, habitat loss or degradation, data uncertainty, limited funding for research and management programs, existing harvest patterns, and new fisheries or expanded fisheries"[4] which in hatchery terms means remote release sites.

Archive Hatchery Data Means having easily accessible information open to the BOF, the Department and the public to provide history of annual Management Plans AMP’s, Permit Alteration Requests PAR, Regional Planning Team minutes, Hatchery Permits, Hatchery Service Contracts, egg sales, etc.

Regional Planning Team diversity of knowledge creates impartial voting

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[2] Fisheries, Rehabilitation, Enhancement and Development Division

[3] 5 AAC 39.222 (a)(1)

[4] 5 AAC 39.222 (a)(2)

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Cordova, Alaska, and I participate in commercial fishing and subsistence fishing in Alaska.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

Alaska created the Fisheries Rehabilitation Enhancement Division (FRED) within the Department of Fish and Game in 1971. Later, in an effort to privatize salmon enhancement, the private nonprofit Hatchery Act of 1974 was created allowing for the application of hatchery permits by Alaskans. Alaska's hatcheries were founded as private nonprofit entities to benefit the entire state of Alaska, its fisheries, and user groups.

The Alaska hatchery program is designed to increase salmon abundance and enhance fisheries while protecting wild stocks. Fisheries enhancement projects are not permitted by the Department of Fish & Game if they are anticipated to have a significant negative effect on natural production. The fisheries enhancement program is designed to supplement natural production, not replace or displace it. The Alaska salmon hatchery program, in place for over 40 years, is one of the most successful public-private partnership models in Alaska's history. Alaska's hatcheries are important infrastructure across the state and benefit our communities, economy, and harvesters.

Alaska's hatcheries provide measurable economic impacts to the region by providing additional salmon for harvest by all user groups, reducing harvest pressure on returning wild runs in years of low abundance. These significant positive impacts are applied to the economies of coastal communities through the direct benefit of hatchery operations, increased landings, and raw fish taxes of salmon at local ports.

Alaska's salmon hatcheries account for the annual equivalent of 4,700 jobs and $218 million in total labor income, including all direct, indirect, and induced economic impacts. A total of $600 million in annual economic output is connected to Alaska salmon hatchery production. The economic footprint of Alaska's hatcheries includes $95 million in labor income associated with commercial fishing, $82 million in labor income associated with processing, and $25 million connected to hatchery operations.

Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Nelly Hand

Submitted By
Mark Palmer
Submitted On
3/1/2022 1:51:30 PM
Affiliation
OBI Seafoods LLC

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2067695634
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mark.palmer@obiseafoods.com
Address
1100 W Ewing St
Seattle, Washington 98127

Dear Chair Carlson-Van Dort and Members of the Alaska Board of Fisheries,

OBI Seafoods appreciates the Alaska Board of Fisheries (BOF) holding an annual Hatchery Committee meeting on March 23, 2022. OBI Seafoods supports the practice of BOF sponsored Hatchery Committee meetings on an annual basis to keep the BOF, stakeholders, and members of the public updated on Alaska's state salmon enhancement programs. Providing a platform to factually educate and update the state on enhancement practices helps alleviate speculation and misconceptions surrounding Alaska's hatchery programs. Additionally, holding annual committee meetings in conjunction with already scheduled meetings helps curb excessive costs and participant time associated with addressing hatchery issues out of cycle.

OBI Seafoods operates ten shore-based processing plants across Alaska. Our company has over 110 years of history in Alaska seafood processing. Sustainable salmon stocks are the single most important issue to the long-term viability of our company and the ability to maintain our industry's contribution to the state economy. We are thankful for the boost Alaska's hatchery programs have provided for Alaska's fisheries for nearly fifty years and appreciate their mission to coincide without adversely affecting salmon stocks.

We ask that the BOF continue to utilize annual hatchery committee meetings as way to distribute factual and scientific information regarding Alaska's salmon enhancement programs in a transparent and productive manner. Thank you for your dedication and service to the Alaska Board of Fisheries.

Thank you,

Mark Palmer

President/CEO

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

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I live in Cordova, Alaska, and I participate in commercial fishing and public use fisheries in Alaska.

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Thank you for your consideration. Please continue to support Alaska’s hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Patricia Kallander

Submitted By
Patrick P McCormick
Submitted On
3/7/2022 2:34:09 PM
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It is increasingly clear that industrial scale hatchery production of pink and chum salmon is negitively affecting wild fish populations throughout the state. As an area E drift gillnetter I am very concerned about the state of the hatchery system in the sound. Hatchery fish are clearly inferior to wild fish are increasingly small, and are very low quality meaning we have lower quality fish. Furthermore poor hatchery returns have lead to overescapement and lack of fishing time on wild stocks.

Hatcheries and enhancement should be a part of Alaskan fisheries and have a place in this state however I urge the board and the hatchery systems throughout the state to seriously consider stocking fewer higher value salmon. I also would support a cap on the number of fish released, especially with pink salmon, which hardly need help from hatcheries to be insanely numerous and are very aggressive feeders and are likely leading to the limiting factor in salmon production in this state going from freshwater and near shore issues to ocean productivity.

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

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I live in Kalifornsky, Alaska, and I participate in subsistence and commercial fishing in Alaska. I am Vice-Chair of Kenai-Soldotna Fish & Game Advisory Committee. Salmon fishing in Alaska is a sentinel and identity species for my family and myself.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

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Alaska's hatcheries provide measurable economic impacts to the region by providing additional salmon for harvest by all user groups, reducing harvest pressure on returning wild runs in years of low abundance. These significant positive impacts are applied to the economies of coastal communities through the direct benefit of hatchery operations, increased landings, and raw fish taxes of salmon at local ports.

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Paul A. Shadura II

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Cordova, Alaska, and I participate in subsistence fishing, commercial fishing, and sport fishing in Alaska. I was born and raised in Cordova. I have been in multiple fisheries in the last 40 years and I have served on boards and councils in my community. Salmon fishing in Alaska is tremendously important to me and my community and is a very important economic engine for the region I live in.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC), Cook Inlet Aquaculture Association (CIAA), and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Robert Beedle

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Ketchikan, Alaska, and I'm retired and enjoy fishing with my grandkids for the king salmon in Alaska. Salmon fishing is one of the most enjoyable pastime things to do with your family when you get sunshine.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Robert Nedzwecky

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Ninilchik, Alaska, and I participate in commercial fishing, sport fishing, and public use fisheries in Alaska. Over the last 32 years I have worked in many aspects of commercial and sport fishing for salmon. These range from guiding, processing, seining, setnetting, offloading, marketing, and more. Salmon fishing is important to my family for a livelihood through my current job as a seiner. We also take part in sport fishing. We cherish the amazing blessing of having fresh and frozen salmon to eat.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Rod Van Saun

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Ninilchik, Alaska, and I participate in subsistence fishing, commercial fishing, sport fishing, public use fisheries, and as a board member of Cook Inlet Aquaculture Association and original member of the RPT in Alaska. As a member of the RPT, we (the RPT) have always supported the idea of more fish for all Alaskans. Hatcheries are an important component to accomplish this goal.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Stephen Vanek

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game
P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska’s private non profit salmon hatchery program.

I live in Homer, Alaska, and I participate in commercial fishing and sport fishing in Alaska. Our families came to Alaska in the early 1930’s looking for a better life post Depression. Commercial fishing, construction, and other business ventures have sustained our hard working families for five generations so far. Sport fishing has always been a part of our lives. We enjoy and put fresh fish on the table as well as sharing with others. Our collective families invest financially in fisheries, real estate exceeds and local vendor. I started commercial fishing with my dad 51 years ago, my three sons and daughter all have their own com fish operations and represent the fourth generation in our family to make their living in Alaska in this industry.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Sincerely,

Steve Tutt

Submitted By
Thomas Dunagan
Submitted On
12/15/2020 9:56:31 AM
Affiliation
resident of Seldovia

Phone
907-2299894
Email
tom.dunagan@gmail.com
Address
Box 838
Seldovia , Alaska 99669

It is the intent Statewide Stocking Plan - Sport Fish, Alaska Department of Fish and Game page 11-8 third paragraph to stop stocking Seldovia king Salmon.

https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareacookinlet.contacts

This apparently came about as a result of a dispute between Seldovia Native Association wanting more red salmon subsistence permits. Area Management Biologist **Glenn Hollowell** Phone: (907) 235-8191 Email: glenn.hollowell@alaska.gov. is the person mainly responsible for this situation. Correspondence with Michael Mopheim Environmental Coordinator Seldovia Native Association says the following:

It was during our AC meeting last year when Glenn Hollowell (LCI Area Finfish Management Biologist for the Division of Commercial Fisheries, ADF&G) came over. At the meeting he did say that if the proposals that the Seldovia Village Tribe (SVT) not Seldovia Native Association Incorporated (SNAI) was putting forward to the Board of Fish were to go through he may have to pull the king salmon from Seldovia. Even with the extended fishing time there was nowhere near 200 kings caught during the subsistence fishery. The initial report was 26 kings had been caught but not all subsistence reports were in yet at that time. So there could have been a few more kings caught but probably not the 200 kings it would need to say the subsistence fishers were overharvesting them. Just for some clarification. Vivian if you have any questions please feel free to call, e-mail or stop by my office.

Thank you,

Michael

My response to this is as follows:

Andrew Garry
William Jack Hernandez Sport Fish Hatchery
941 N. Reeve Blvd.
Anchorage, Alaska 99501

andrew.garry@alaska.gov

Re: King salmon stocking in Seldovia Lagoon

Dear Mr. Garry,

I have just become aware the stocking of king salmon smolt in Seldovia will be terminated under the proposed Statewide Stocking Plan - Sport Fish, Alaska Department of Fish and Game.

With the exception of one year where the water was too warm, since stocking directly in the lagoon began, returns have been very good. Stocking in the lagoon was my suggestion to Carol Kerkvliet at the time, as funds for a pen were not available. It is my opinion that even though the smolt release is less than in Homer spit lagoon, we have a significantly better return. Costs for delivering and releasing the smolt is only about $500, according to Michael Booz, the area biologist. Many of the people in town, including myself, help with the release by laying the pipe and using our skiffs to make sure everything goes as planned.

Not restocking the king salmon smolt in Seldovia is shortsighted. This is a very good fishery in which many in the local community participate and depend on, in part, for their winter supply of fish. Many cannot even afford a boat.

Seldovia is struggling economically. Since the return has substantially improved, tourism has increased to the benefit of the town. The exception has been this year 2020, due to the impacts of Covid 19. Even then there were a considerable number of 'outsiders' fishing. They are spending money in the restaurants, bars, bed and breakfasts, and local inns. I have seen more people fishing in this lagoon, off the bridge and along the channel than in Homer. I suspect this is due to the lower Homer return.

Please do not terminated this run.

Sincerely

Thomas R. Dunagan

Box 838

Seldovia, Alaska

tom.dunagan@gmail.com

Submitted By
Thomas Upah
Submitted On
9/5/2021 5:04:18 PM
Affiliation

Phone
9072011455
Email
Upaht1@gmail.com
Address
8621 Solar dr
Anchoragr, Alaska 99507

There comes a time when the health of the ecosystems become more urgent then financial gain. Commerical fishing of all salmon is continually decreasing salmon numbers. It is true that banning all salmon fishing for at least one season maybe longer would devastate an industry and cause difficulties. If Commerical fishing of salmon is allowed to continue the salmon may not be able to recover. Certainly any people losing income or jobs will most likely recover. In my mind the choice is simple but unpopular. Thanks for listening

March 8, 2022

Board of Fisheries
Alaska Dept. of Fish and Game P.O. Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526

Dear Members of the Board of Fisheries,

I am writing in regards to the upcoming Hatchery Committee Board of Fisheries meeting taking place in Anchorage, Alaska and wish to submit this public comment of support for Alaska's private non profit salmon hatchery program.

I live in Craig, Alaska, and I participate in subsistence fishing, commercial fishing, sport fishing, and public use fisheries in Alaska. I am the Mayor of Craig, a troller, a longliner, and logger VP of ATA. Salmon fishing in Alaska provides food for our subsistence, tribes, commercial fishing families and revenue for our communities. It also feeds my family and elders, grandbabies, earns part of my income, and feeds my community.

I wish to extend my support on the record for Alaska's hatchery program and the hatcheries of the state, Kodiak Regional Aquaculture Association (KRAA), Southern Southeast Regional Aquaculture Association (SSRAA), Northern Southeast Regional Aquaculture Association (NSRAA), Douglas Island Pink and Chum, Inc. (DIPAC), Armstrong-Keta Inc (AKI), Prince William Sound Aquaculture Corporation (PWSAC) and Valdez Fisheries Development Association (VFDA).

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Thank you for your consideration. Please continue to support Alaska's hatchery program at the upcoming Board of Fisheries meetings in Anchorage, including the 2022 Hatchery Committee Meeting.

Sincerely,

Tim O'Connor

VALDEZ FISHERIES DEVELOPMENT ASSOCIATION, INC.
SOLOMON GULCH HATCHERY

P.O. Box 125 Valdez, AK. 99686 1815 Mineral Creek Loop Road Valdez, AK 99686
(907) 835-4874 Fax (907) 835-4831 Mike.Wells@valdezfisheries.com

PC35
1 of 1

March 8, 2022

Alaska Dept. of Fish & Game
Alaska Board of Fisheries
PO Box 115526
1255 W. 8th Street
Juneau, AK 99811-5526
dfg.bof.comments@alaska.gov

RE: On Time Comments for 2022 Hatchery Committee Meeting

Chair Carlson-Van Dort, Members of the Alaska Board of Fisheries,

The Valdez Fisheries Development Association Inc., (VFDA) submits these comments in continued support of the Alaska Board of Fisheries Hatchery Committee meeting process.

The adoption of the Joint Protocol on Salmon Enhancement and the establishment of the Hatchery Committee provides a beneficial forum for the reporting of new information related to hatchery management and ongoing research of Alaska's enhancement programs. VFDA supports these annual efforts to update the board and to provide the public an opportunity to benefit from such shared knowledge.

Over the years, there has been significant analysis of the contributions hatcheries make to Alaska's fisheries. In addition, presentations have been made on regulatory structure, permitting and operations and hatchery/wild interactions. Topics that bring both perspective and scientific insight to the discussions surrounding hatchery policy on a regular basis and we hope that continues.

Alaska's hatchery programs are a vital economic engine for coastal Alaska and our sport, commercial, subsistence, and personal use fisheries. The benefit of these enhancement programs transcend the regions and fisheries from which they are located.

Thank you for the opportunity to provide comment in support for this important meeting.

Sincerely,

Mike H. Wells
Executive Director

Western Interior Alaska Subsistence Regional Advisory Councils
c/o United States Fish and Wildlife Service
Office of Subsistence Management
1011 East Tudor Road, MS 121
Anchorage, Alaska 99503-6199

In Reply Refer To:
RAC/WI.22029.NBP

MAR 08 2022

Simon Kinneen, Chair
North Pacific Fishery Management Council
1007 West Third, Suite 400
Anchorage, Alaska 99501

Dear Chairman Kinneen,

The Western Interior Alaska Subsistence Regional Advisory Council (Council) writes to you seeking immediate regulations be put in place to reduce all salmon bycatch in the Bering Sea/Aleutian Islands commercial fisheries and to request restrictions be instituted in domestic hatchery salmon production and conversations started with international countries that have hatcheries on the North Pacific to do the same.

This Council collectively represents 38 subsistence communities along the Yukon and Kuskokwim Rivers that all depend on salmon as their primary food, life, and livelihood. This Council was established by the authority in Title VIII of the Alaska National Interest Lands Conservation Act (ANILCA) and is chartered under the Federal Advisory Committee Act. Section 805 of ANILCA and the Council charter establish its authority to initiate, review and evaluate proposals for regulations, policies, management plans, and other matters related to subsistence uses of fish and wildlife within our Council's region. This Council also reviews resource management actions occurring outside its region that may impact subsistence resources critical to communities served by the Council. The Council provides a forum for the expression of opinions and recommendations regarding any matter related to the subsistence uses of fish and wildlife across our region.

The Council met in February 2022 and elected to write this letter to address ongoing concerns about the impact of salmon bycatch and unsustainable effects that salmon hatchery practices have on our subsistence communities.

Subsistence Salmon Fishing on the Yukon and Kuskokwim Rivers was Catastrophic This Year

The Chinook and Chum salmon run failures in 2021 resulted in the complete closure or severe restriction of subsistence salmon fishing for all communities along the Yukon and Kuskokwim rivers, tributaries, and coastal areas. This was the lowest ever Yukon River Coho and Chum salmon returns on record, for the second year in a row. The crash of the Chinook and Chum salmon populations will likely result in severe restrictions or complete closure to subsistence fishing across western Alaska again this year. There was no opportunity for cultural and traditional practices to be taught to the younger people. Instead of being able to fish for salmon, we instead relied on whitefish and Sheefish, and we are unsure of if their population will be able to sustain this increase in fishing pressure. The salmon in our rivers are keystone species; brown bears that rely on the salmon runs had to rely on other food sources – foods we also depend on – such as moose. The Council has serious concerns about the food security for the people that live on these rivers and depend on these different species, as well as the long- and short-term environmental impacts that is created when these important species fail to appear.

This is a huge discrepancy between what is occurring in our rivers and our lack of opportunity to fish, and what is occurring in the trawl fleet industry, which is to be allowed to harvest fish commercially with very few restrictions. While the Council acknowledges that the North Pacific Fisheries Management Council (NPFMC) has been trying to limit Chinook bycatch in the trawl fleet, it is not enough. Salmon stocks are currently so depressed that there is not enough salmon to allow any prohibited species bycatch. It is becoming increasingly apparent to this Council that the NPFMC is more concerned with commercial fisheries making money and is failing to give adequate consideration to other users that depend on these fish. Nearly all current policy on limiting bycatch has been focused on Chinook Salmon, and, as the 2021 subsistence fishing season on the Kuskokwim and Yukon rivers clearly demonstrated, the people of the river depend on the other salmon species that migrate up our rivers as well.

Even with the NPFMC taking steps to reduce Chinook Salmon bycatch for well over a decade, this salmon species still has not come back. To date, the total regulatory measures taken by the NPFMC have not been enough to reverse or even stabilize the downward trend in Chinook Salmon abundance. This violates the following National Standards:
National Standard 1: *"management measures shall prevent overfishing".*
National Standard 2: *Bycatch has been and continues to be a KNOWN cause of salmon mortality.*
National Standard 4: *Allowing Prohibited Species Bycatch to occur up to 10 months a year while in river subsistence fisheries are closed and salmon escapement goals chronically not achieved is discrimination to residents of rural Alaska.*
National Standard 8: *"...take into account the importance of fishery resources to fishing communities."*

The Bering Sea and Aleutian Islands trawl fleet said that they would regulate themselves to avoid salmon bycatch, but this is clearly not happening. The fleet has little incentive to do so – there are no bycatch caps on depressed Chum Salmon stocks, and other than for Chinook Salmon there are no Savings Area closures to protect the summer migration passage areas for Chum Salmon other species. Those Savings Areas were in Amendment 91. Since the fleet will not control themselves, as demonstrated, the NPFMC needs to again do it for them.

Institute Regulations on Hatchery-Raised Salmon to Mitigate Effects on Wild Stocks

The current model of domestic salmon hatchery production is not sustainable to the continuation of healthy wild salmon stocks. The NPFMC needs to start thinking about this in a dynamic way to address salmon survival amid changing ocean conditions. Currently, there is no cap on the number of smolt that hatcheries are allowed to release. Billions of hatchery salmon smolt are being released into the Pacific Ocean from Washington, Oregon, British Columbia, and Alaska on top of the unknown amounts from Asia. These fish are released annually with no regard for what oceanic anomalies or changes, such as a marine cycle downturn, are occurring. These fish are released with one goal: to be harvested by the commercial fishing fleet. The hatchery salmon are outcompeting native stocks in the ocean by sheer number.

The NPFMC must start addressing how to get US hatcheries to limit the amount of smolt being released into the Pacific Ocean, as well as the timing of these releases to not be a detriment to the wild stocks, and to direct NOAA to start conversations with Canada and Asia to do the same. Policy must be instituted that will take changing oceanic conditions into consideration on an annual basis regarding how many hatchery salmon smolt are allowed to be released into ecosystems. This would allow for a more sustainable hatchery model, so that when the Pacific Ocean is modulating in temperature and productivity, the hatcheries are not dumping millions of salmon into an already strained ecosystem.

The Council hopes the NPFMC reads this letter and understands the lack of salmon getting to subsistence users in Western Alaska is a crucial issue for the people of this region in terms of food security, the ability to conduct and teach our customary and traditional practices, as well as an environmental concern. We request the NPFMC to take appropriate and expedited steps to begin addressing this issue now through immediate bycatch caps and Amendment 91 Savings Area closures, with follow up in policy to cement these changes through the appropriate channels. This Council also requests the NPFMC direct NOAA to establish sustainable and appropriate ocean productivity biomass models specifically to assist with regulating hatcheries on the smolt release numbers and timing so they are not outcompeting wild stocks, and begin holding discussions with other countries who release hatchery salmon into the Pacific to do the same.

Thank you for the opportunity to provide these recommendations the NPFMC. We look forward to continuing discussions about the issues and concerns of subsistence users of the Western Interior Alaska subsistence region. If you have questions about this letter, please contact me through Nissa Bates Pilcher, Subsistence Council Coordinator with the Office of Subsistence Management, at 1-800-478-1456 or (907) 786-3888 or nissa_batespilcher@fws.gov.

Sincerely,

Jack Reakoff, Chair
Western Interior Alaska
Subsistence Regional Advisory Council

cc Federal Subsistence Board
Interagency Staff Committee
Office of Subsistence Management
Western Interior Subsistence Regional Advisory Council
Douglas Vincent-Lang, Commissioner, Alaska Department of Fish and Game
Märit Carlson-Van Dort, Chair, Alaska Board of Fisheries
Glenn Haight, Executive Director, Alaska Board of Fisheries
Kelly Susewind, Director, Washington Department of Fish and Game
Curt Melcher, Director, Oregon Department of Fish and Wildlife
Regional Administrator for the National Marine Fisheries Service, Alaska Region
Tanana Chiefs Conference Hunting and Fishing Task Force

Association of Village Council Presidents
Kuskokwim Intertribal Fish Commission
Yukon Intertribal Fish Commission
Benjamin Mulligan, Deputy Commissioner, Alaska Department of Fish and Game
Mark Burch, Special Projects Coordinator, Alaska Department of Fish and Game
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