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The cost of hatchery straying: an economic case study on Alaska pink salmon

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Abstract

Augmenting harvest using hatchery-produced salmon relies on fish returning to intended sites for capture. However, not all do—some stray, evading capture, and entering wild spawning grounds, thus representing foregone yield. Here we ask, "what is the theoretical loss to harvesters as a result of straying?" We applied existing stray estimates and ex-vessel values from the world's largest pink salmon hatchery-fishery program: Prince William Sound, Alaska, across three return years with full accounting of system-wide harvest, escapement, and straying, to examine the value of strays under a range of scenarios that varied the component of the harvesting sector that might catch strays. In this system, approximately 1%–5% of returning hatchery fish are estimated to stray away from release sites, which translates to approximate 0.8–4.5 million fish. We found that these strays were worth between $1 and $8 million per year, depending on the scenario and harvest year examined. While many important assumptions factor into this evaluation, our intention is for this work to spark dialogues about the economic tradeoffs associated with investing in stray reduction technologies, complementing the well-studied eco-evolutionary costs and benefits of straying.

Key words: straying, salmon, hatcheries, fisheries economics

Background

In the North Pacific Ocean, over 5 billion juvenile anadromous salmonids are released annually by hatcheries, primarily to augment commercial harvests by targeting returning adults (NPAFC 2022). While most hatchery-origin individuals are harvested as intended, a small proportion escape the fishery and "stray" into wild populations (Quinn 1993). This small proportion of very large numbers of fish can sum to millions of fish lost to fishing economies (Knudsen et al. 2021). Concerns over adverse effects of hatchery strays on wild conspecific populations and on marine ecosystems have motivated numerous studies of possible "ecological and evolutionary costs" of hatchery straying (Naish et al. 2007). As a result, many hatchery programs have reformed in attempts to reduce straying, for example, by artificially selecting for divergent run timing between hatchery and wild fish or by releasing hatchery juveniles far from natural populations (i.e., spatiotemporal buffering). Other straying reduction technologies are also being explored, such as using odorants that would improve embryonic and juvenile imprinting and subsequently increase adult homing (Dittman et al. 2015). If these emergent technologies prove effective, they will necessarily come at some financial cost but must be considered against the current costs of straying. Thus, studies that quantify the potential financial value of hatchery strays would help qualify the possible incentive of implementing additional stray reduction methods. However, no study has quantified the economic cost of hatchery straying.

The pink salmon (*Oncorhynchus gorbuscha*) hatchery program in Prince William Sound (PWS), Alaska has become a model for studies examining hatchery-wild interactions (Knudsen et al. 2021; Shedd et al. 2022) and presents an ideal system for a case study examining the financial value of hatchery strays. With three active pink salmon hatcheries releasing a combined ca. 700 million juveniles annually, PWS represents the largest pink salmon hatchery program in the world (NPAFC 2022). In these hatcheries, broodstock for the next generation are sourced exclusively from fish returning to the hatchery (assumed to be of hatchery origin), not from wild streams, representing a "segregated" hatchery system (Waters et al. 2015). Original broodstock were sourced from wild populations in the 1970–1980s (Habicht et al. 2000). Otoliths of all hatchery-origin individuals are thermally marked during incubation, to allow differentiation from natural-origin fish, and fish are released into the marine environment as fed fry. Pink salmon are thought to have naturally high stray propensity, relative to other Pacific salmon species (Quinn 1993) and are the most numerically abundant salmon; thus, unsurprisingly, the number of hatchery-origin strays in natural streams can be high, particularly those closest to hatchery release sites (Knudsen et al. 2021). In recognition of the high proportion of hatchery-origin ancestry in these naturally spawning populations, recent literature has begun to refer to fish born

Table 1. Number of adult pink salmon (in millions) returning to Prince William Sound, AK (i.e., total run size) and number of spawners (i.e., escapement) by origin (natural or hatchery).

Parameter	Origin	2013	2014	2015
Run size	Natural	34.95 (2.71)	6.75 (1.80)	63.94 (2.68)
	Hatchery	73.92 (0.69)	42.86 (0.67)	77.84 (2.96)
	Combined	108.87 (3.0)	49.61 (2.25)	141.78 (5.53)
Escapement	Natural	17.53 (2.74)	4.93 (1.80)	38.47 (2.73)
	Hatchery	0.83 (0.60)	0.85 (0.66)	4.51 (2.94)
	Combined	18.36 (3.01)	5.78 (2.25)	42.98 (5.53)

Note: Values were estimated by Knudsen et al. (2021) and include approximate standard error in parenthesis.

in natural streams as "natural-origin" as opposed to "wild" (i.e., May et al. 2024), and we adopt this terminology here.

In response to concerns over potential impacts to wild populations (e.g., Brenner et al. 2012), the Alaska Department of Fish and Game (ADF&G) initiated the Alaska Hatchery Research Program (AHRP), in collaboration with the fishing industry, academia, and nonprofit hatchery producers. The AHRP organized one of the most comprehensive spawning ground surveys ever conducted, generating detailed data on hatchery escapees across PWS for over a decade (Shedd et al. 2022; May et al. 2024). Knudsen et al. (2021) utilized these data in part to estimate both donor and recipient hatchery stray rates across PWS for 3 years of returns (2013–2015). Their study revealed significant variability in the number of hatchery strays recovered in different streams in PWS and provided estimates for the total number of strays across PWS. In addition, ADF&G collects detailed in-season catch and ex-vessel value data by species and region, presented in yearly technical reports (i.e., Wilson 2023). These publicly available reports provide yearly estimates of the potential value of uncaught fish. The data analyzed by Knudsen et al. (2021) and provided by ADF&G provide a rare opportunity to analyze the economic impact of hatchery strays. This analysis is particularly prudent given the significant role of pink salmon in the local and regional economies (Pinkerton 1994). As one of the most commercially valuable fish species given its high abundance, pink salmon support a substantial portion of the commercial fishing industry in Alaska (Wilson 2023). Therefore, quantifying the financial value of hatchery strays in PWS has practical implications for fisheries management and economic sustainability.

In this paper, we aimed to estimate theoretical annual financial losses to harvesters from current levels of straying. By estimating the potential monetary value to the fishery from harvesting strays, we aim to provide a resource for policymakers, fishery managers, and stakeholders in the region. While this analysis represents a case study of one specific system, we believe our logic regarding the financial opportunity cost of hatchery straying can be applied to much larger scales for global hatchery production.

Data sources and analysis

Here we used annual estimates of the total number of strays in PWS, provided in Knudsen et al. (2021). Briefly, they used a mixed modeling approach that combined data from longitudinal stream and ocean surveys of hatchery- and natural-origin fish with additional data from commercial fishery catches and hatchery returns. By combining multiple sources of data, Knudsen et al. (2021) provided robust estimates of total run size, total fisheries harvests, total stream escapements, and harvest rates for both hatchery- and natural-origin pink salmon in PWS for three return years (2013–2015). We used the numerical estimates of total escapement of hatchery-origin fish (Table 1) sourced from Knudsen et al. (2021), combined with ex-vessel value data from ADF&G PWS Area Finfish Management Reports (Botz et al. 2014; Wiese et al. 2015; Haught et al. 2016). These annual reports used fish ticket data from across each management area to estimate the total number of fish landed for each permit type used by the commercial fishery (i.e., purse seines, drift gillnets, and set gillnets) and for the hatchery cost-recovery fishery (Table 2). Hatchery cost recovery is the mechanism by which Alaska hatcheries recoup their operating costs. Annual reports provided the required data on weight of landed fish, ex-vessel value per pound, the total value of the fishery, and the number of permit holders for each gear type.

To estimate the value of uncaught hatchery strays, we multiplied the estimated number of strays in each year by the weight of the average fish and average ex-vessel value per pound reported from fish ticket data. The values for average fish weight and ex-vessel price were weighted according to the number of fish caught by each gear type (purse seines, drift gillnets, and set gillnets), and hatchery strays were assumed to be identical in weight and value to the mean reported catch. We estimated the total value of uncaught hatchery strays under three different scenarios: (1) all hatchery strays were caught by the commercial, common property fishery, (2) all hatchery strays were caught by the hatchery cost-recovery fishery, and (3) hatchery strays were caught by both the commercial fishery and the cost-recovery fishery. For the first scenario, we assumed that hatchery strays were caught by the three different gear types in proportion to the true catch, as these gear types had slightly different ex-vessel valuations and average weights. This also enabled us to estimate the value lost per permit holder from uncaught hatchery strays. In the second scenario, we assumed that hatchery strays were caught exclusively by the cost-recovery fishery, whose ex-vessel prices were substantially higher than the commercial fishery, because hatchery operators

Table 2. Commercial pink salmon harvest data for the Prince William Sound management area by permit type (purse seine, drift net, set net, or hatchery cost recovery) and year.

Year	Permit type	No. fish	Pounds	Price/lb	No. permits
2013	Seine	85 925 135	238 018 132	$0.42	211
	Drift	2605 952	7179 124	$0.34	522
	Set	19 114	52 786	$0.32	28
	Hatchery	4089 674	11 226 239	$0.78	–
2014	Seine	37 873 270	127 295 081	$0.29	222
	Drift	1298 075	4526 178	$0.30	525
	Set	35 681	119 268	$0.30	29
	Hatchery	5451 273	17 314 059	$0.61	–
2015	Seine	89 112 315	301 531 658	$0.20	222
	Drift	976 921	3572 099	$0.16	525
	Set	29 070	114 052	$0.13	29
	Hatchery	7214 635	21 656 411	$0.46	–

Note: Estimates of number of fish caught (No. fish), number of pounds landed (Pounds), and Price/lb were estimated by the Alaska Department of Fish and Game using fish ticket data; all values were sourced from PWS area finfish management reports (Botz et al. 2014; Wiese et al. 2015; Haught et al. 2016).

negotiate pricing with processors prior to the fishing season. In the third scenario, as in Scenario 1, we assumed that hatchery strays were caught by the three different gear types and by the cost-recovery fishery in proportion to that of the true catch.

Final values in each scenario were inflation-adjusted following the US Bureau of Labor Statistics Consumer Price Index (CPI) from August of the catch year to January 2024. To estimate the approximate standard error for the value of strays, we multiplied the approximate standard error associated with the estimated number of hatchery strays (Knudsen et al. 2021) by ex-vessel values. Notably, ex-vessel values reported by ADF&G did not include corresponding error estimates, so the standard error values reported here may underestimate error in our value estimates. Values and code used for all calculations are provided in the supplemental materials.

Results

We estimated the economic opportunity cost to the PWS fishing industry through the theoretical harvest of hatchery-origin pink salmon strays across three return years and under three distinct scenarios that made different assumptions of which harvesting sector catches the fish. Under a scenario where all hatchery strays were entirely caught by the common-property commercial fishery, the ex-vessel value of hatchery strays ranged from approximately $800 000 to over $3 million during the years 2013–2015 (Table 3). This was equivalent to 0.93%–5.01% of the total value of the common property fishery or $1–4 million in CPI-adjusted purchasing power. Divided by the number of commercial permits, the value to each permit holder ranged from $1000 to nearly $4000 across these years ($1296–5186 CPI-adjusted).

Under a second scenario, where all hatchery strays were caught by the cost-recovery fishery, the value of uncaught hatchery fish ranged from $1.6 to 6.2 million or 15.73%–63.04% of the total value of hatchery landings ($2.1–8 million CPI-adjusted). This monetary value is greater than under Scenario 1, because the ex-vessel values reported for cost-recovery fisheries are higher than the ex-vessel values for the common property fishery (Table 1). In reality, the nonprofit hatcheries may only fish until their operating costs have been recouped, and this scenario may be unlikely under current management practices.

Under a third scenario, all hatchery strays were assumed to be caught by both the commercial and cost-recovery fisheries in the same proportions as the true fisheries. The value of uncaught hatchery strays under this scenario ranged from $1.0 to 3.6 million or 0.92%–5.05% of the total value of the fishery ($1.3–4.6 million CPI-adjusted). This scenario likely represents the most realistic management scenario, whereby both common property fishers and hatchery cost-recovery fishers land a portion of would-be strays.

Discussion

This study quantified the theoretical economic value of pink salmon hatchery strays in PWS, Alaska over 3 years with unique full accounting of salmon returns. The ex-vessel value of hatchery strays ranged from $1 to 8 million in 2024's dollars, depending on scenario and return year. While straying is a natural part of salmon life history diversity (Quinn 1993), in an ideal management scenario, the stray rate of hatchery-produced salmon would be minimized to reduce potential human impacts on wild populations (Naish et al. 2007). Our findings highlight the tangible economic benefit incurred when straying is reduced, which we hope will facilitate a more informed evaluation of potential economic benefits of investing in stray reduction technologies. Managers are tasked with making difficult decisions that balance the economic objectives of hatcheries with the ecological well-being of wild salmon populations. Our brief study provides

Table 3. Estimating of the potential economic value of uncaught hatchery-origin pink salmon that strayed into wild streams in Prince William Sound, Alaska for return years 2013–2015.

		2013	2014	2015
Common property fishery (Scenario 1)	Price/lb	$0.42	$0.29	$0.20
	lbs/Fish	2.77	3.31	3.39
	Landed value	$102 816 600	$37 790 406	$60 891 010
	Value of strays (SE)	$961 040 ($694 728)	$816 119 ($633 693)	$3 048 967 ($1 987 575)
	Cost per permit	$1 263	$1 052	$3 929
	Percent of landed value	0.93%	1.75%	5.01%
	Inflation-adjusted value	**$1 267 338**	**$1 058 242**	**$3 945 825**
Cost recovery fishery (Scenario 2)	Price/lb	$0.78	$0.61	$0.46
	lbs/Fish	2.75	3.18	3.00
	Landed value	$8 765 309	$10 482 055	$9 873 200
	Value of strays (SE)	$1 780 350 ($1 287 000)	$1648 830 ($1 280 268)	$6223 800 ($4 057 200)
	Percent of landed value	15.86%	15.73%	63.04%
	Inflation-adjusted value	**$2 347 773**	**$2 137 998**	**$8 054 540**
Both fisheries (Scenario 3)	Price/lb	$0.45	$0.36	$0.24
	lbs/Fish	2.77	3.31	3.36
	Landed value	$111 581 909	$48 272 461	$70 764 210
	Value of strays (SE)	$1 025 996 ($741 684)	$1 011 201 ($785 168)	$3 573 528 ($2 329 528)
	Percent of landed value	0.92%	2.09%	5.05%
	Inflation-adjusted value	**$1 352 996**	**$1 311 201**	**$4 624 687**

Note: Estimates for Scenarios 1 and 3 represent a combined weighted average by permit type.

a quantified thought experiment that managers may use to facilitate long-term sustainability for the fishery and broader economy.

Our study, while providing useful insights, is built upon specific assumptions that require consideration before applying our cost estimates to management or applying our methods to other systems. First, all scenarios assumed that 100% of hatchery-origin strays in PWS were capable of being caught by the commercial fishery. Although straying is a key biological trait in salmon that is known to vary in magnitude among species, populations, and years (Westley et al. 2013) it is impossible in practice for harvesters to catch all returning hatchery-produced fish. While some such stray reduction technologies are being investigated (e.g., Dittman et al. 2015), the cost of implementing them remains uncertain; diminishing returns should be expected as money is spent on efforts to reduce straying to zero. We note that by assuming 100% were caught, we sought to provide a benchmark for comparison in future studies investigating the efficacy of stray reduction technologies. Second, we assumed that strays comprised the same average body weight as the rest of the fishery. Of note, many studies have shown significant differences between hatchery- and natural-origin fish in traits such as in body size, return timing, and spatial distribution (McConnell et al. 2018; Shedd et al. 2022; May et al. 2023). Similarly, we assume that hatchery strays would be caught by different permit types in the same proportions as the rest of the fishery. In reality, this may be subject to the spatial and temporal distribution of hatchery strays, which are also known to differ from the rest of the fishery (Brenner et al. 2012; McMahon 2021). A third assumption was in our treatment of market dynamics: our analysis did not account for the potential broader economic ramifications of an increased supply of fish, which could lead to a decrease in the price per pound, thereby reducing the potential economic benefit of reduced of straying. Accounting for more realistic supply and demand dynamics may be prudent in future applications. Additionally, our reliance on stray numbers reported by Knudsen et al. (2021) comes with its own set of uncertainties. These estimates, while the best available for PWS—or indeed any region to our knowledge—have somewhat large standard error estimates, presented in Tables 1 and 3. These uncertainties must be acknowledged and emphasize the need for cautious interpretation and application of our findings in policy decisions. Despite these caveats, we intend our study to serve as a proof-of-concept case study for a specific species and study system.

Beyond the direct economic opportunity costs quantified here, hatchery strays may impose significant indirect costs that should be considered. For example, the effect of hatchery strays on wild population recruitment is contentious, with many empirical and theoretical studies demonstrating how hatchery strays may have adverse, neutral, or beneficial effects on wild recruitment, diversity, and resilience (Naish et al. 2007). In PWS, natural-origin pink salmon can comprise a significant proportion of total harvest (Wilson 2023).

Thus, the effect of hatchery fish on wild recruitment could indirectly—and possibly much more severely—affect commercial harvests, compared to the approximately 1%–5% direct economic growth of catching all strays. A second indirect economic effect of potentially altering hatchery-origin stray rates has to do with the broader economic value associated with processing, distribution, and consumer sales sectors. While our study estimated the direct, ex-vessel value to fishers, the processing sector adds additional value to the raw product, while distribution and sales determine its eventual market price. Thus, by providing additional whole fish to processors, the multiplier effects to the broader economy would necessarily be much larger than the values estimated in this study. However, quantifying these types of indirect costs is logistically challenging, requiring proprietary information on downstream costs and profits. This makes it difficult to accurately assess the full economic impact of uncaught hatchery strays on downstream sectors. Therefore, while our study sheds light on the direct economic opportunity costs of hatchery strays, we also hope it catalyzes broader discussion about the multifaceted economic impacts that extend beyond the ex-vessel value of strays. Finally, we believe this work underscores a difficult reality regarding the large size of hatchery programs in PWS: a small rate (1%–5%) of straying away from release sites by such large numbers of returning adult salmon translates into millions of individual strays and millions of lost potential revenues for Alaska harvesters.

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All data used in this study are cited and presented in the text.

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Supplementary material

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