Since its inception, the National Park Service (NPS) has operated under a mandate to preserve the resources under their stewardship such that they represent ‘vignettes of primitive America’. For natural resources, this mandate equates to a management target of maintaining abundances within a ‘natural range of variation’. Pursuant to this, park managers are often confronted with either the scarcity of endemic plant or animal species or an abundance of non-native (exotic, invasive) species that may damage park ecosystems. However, harm to ecosystems can also be driven by a hyperabundance of an endemic species, due either to shifting regional trends in habitat suitability, to direct (and often anthropogenic) intervention, or to a combination of the two.

For example, in Yellowstone National Park endemic mountain pine beetles have recently decimated coniferous forests due to a lack of cold winter temperatures which have traditionally limited the insects’ numbers and, by extension, their impacts on forests (Gibson et al. 2008). Likewise, in many Midwestern and Eastern NPS units, habitat alterations and the extirpation of natural predators outside park boundaries has led to unprecedented densities of endemic white-tailed deer, capable of intense foraging on vegetation and the depletion of resources on which other endemic species depend (Miller et al. 2023).

While there is little debate that these issues generate a need for management action, the question of when a hyperabundance of some endemic species exceeds the natural range of variation, thereby triggering a need for management action, can be difficult to ascertain. In the case of the mountain pine beetle, numbers of the insects are on the rise throughout the Rocky Mountains due to shifting climate patterns (Gibson et al. 2008). Is this then an ‘unnatural’ overabundance or is it representative of a new natural state? Park managers across the NPS are confronted with these issues as they seek to interpret and implement the mandate to preserve resources in a natural condition. These ideas are central to the research question presented in this article which focuses on a river in a small National Historical Park in Sitka, Alaska.

Sitka National Historical Park is a small 112-acre coastal park located in the southern panhandle of Alaska. The site was designated a national monument in 1910 and a national park in 1972, to conserve the area where a battle occurred in 1804 between native Tlingit and Russian colonizers. The park is visited by tens of thousands of tourists each year who learn about the history of Sitka and Tlingit culture. The park features a series of totem poles along designated trails and active traditional totem carving activities. While its foundational purpose is the preservation of a historical event, the park is also managed to preserve the spruce-hemlock forest, riparian ecosystem, and the Indian River, which includes a section of the main reach and the intertidal area which falls within the park boundaries (CITE PARK WEBSITE).

Since time immemorial Kaasda Héen (the Indian River) has been the location of a fishing camp and harvesting site for the Kiks.ádi clan. The river was particularly valued for its proximity to the clan’s winter villages, as well as for hosting runs of Pacific salmon species, including chum (*Oncorhynchus keta,* Gaynii, téel), coho (*O. kisutch*, ÜÜx, l’ook), Chinook (*O. tshawytscha*, Yee, t’á) and pink salmon (*O. gorbuscha*, Sti’moon, cháas’) (Thornton 1998), the latter which is the most numerically abundant species. Pink salmon typically return to spawn in late summer. When the eggs hatch in the spring juvenile pink salmon emerge from the river gravel and immediately migrate to the ocean, with all members of a brood returning to spawn as adults two years later. This leads to two genetically distinct runs in even numbered and odd numbered years, although unlike regions further north or south, the rivers in this area see little variation in the even/odd year abundances (Alaska Department of Fish and Game 2024a).

Pink salmon are an important food resource for predators and scavenging wildlife, a source of ‘marine-derived’ nutrients and energy for river and riparian ecosystems, and a coveted viewing experience for visitors to the park who observe the spawning and migrating fish from a footbridge that spans the river. Although pink salmon have always been abundant in the Indian River, their numbers have increased rapidly in the last thirty years. The Alaska Department of Fish and Game (ADFG) peak escapement surveys (numbers of fish that have ‘escaped’ the fishery and successfully returned to spawn in the river) demonstrate that, since 1980, pink salmon abundance has increased from several thousand to regularly exceeding 100,000 fish annually (Stopha 2015). What’s more, several locals have anecdotally noted the presence of pink salmon spawning, which used to be limited to August and September, now regularly spans July through October.

High salmon densities in the river are not necessarily a cause for management concern because as it’s a naturally occurring phenomena across influenced by variation in including in-stream conditions, ocean productivity, predation intensity, and commercial harvests, among others (REFs).

However, salmon hatcheries can also influence abundances of wild salmon (REF). As part of typical hatchery operations, juvenile salmon are reared in raceways and net pens and released into the ocean after they acquire a certain size. The hatchery utilizes the natural homing ability of salmon who imprint on the chemical cues in the water in which they are reared to return to the hatchery as adults, not unlike what occurs naturally in stream and river systems. If all salmon that in adjacent systems would be independent of the hatchery operations. However, homing by salmon isn’t perfect, and some fish produced in the hatchery will ‘stray’ into a nearby freshwater stream or river when returning as adults. While it is difficult to infer whether straying is more or less likely in hatchery origin fish, homing imperfection is likely an evolved trait as it allows a few fish to colonize new habitats when they become suitable for spawning (Quinn 2018). Nevertheless, hatchery and fishery managers typically want to minimize straying rates, in part to maximize the returns to the hatchery and in part to reduce the chance that hybridizing between hatchery and wild occurs as . Hybridization can produce offspring that are less adapted to local conditions and thus have lower fitness

For the Indian River, the possibility of hatchery pink salmon straying into the river is particularly high owing to several factors. First, the not-for-profit Sitka Sound Science Center operates a hatchery immediately adjacent to the park boundary, less than a mile from the Indian River estuary. In general, the rate of straying is influenced by spatial proximity (Knudsen et al. 2021) as the closer the hatchery is to a stream, the greater the chance hatchery fish will stray into that stream. The hatchery has been in operation since 1975, and since 2010 has reared up to 3 million pink salmon annually, producing fish that would return just meters from the Indian River.

Second, and perhaps more importantly, the hatchery utilizes water from the Indian river, via a diversion upriver of the park’s boundary, as the source of water for operations. Since its inception, the hatchery was granted water rights from the Indian River (originally granted to Sheldon Jackson College which operated the hatchery until it closed in 19XX). Indian River water is used to rear salmon fry, which imprint on its chemical signature, and is also released into the bay near the hatchery in order to attract returning adult fish.

Not surprisingly, surveying efforts in Indian river have at times unusually high numbers of stray pink salmon from the hatchery, making up one third of all individuals sampled in a given year, although rates vary depending upon sampling period (Gende and Carter 2015). Managers can identify adults that were produced in the hatchery because all pink salmon released by the hatchery are subject to a process called otolith marking, in which small carbonate bodies located in the inner ‘ears’ of fish are marked with a distinct pattern. This pattern is produced during incubation when salmon eggs are exposed to a carefully controlled regime of dry periods and periods submerged in water, leaving a pattern on the otoliths of each fish (Alaska Department of Fish and Game 2024b; Stopha 2015). When salmon return to spawn as adults, the otoliths from the carcasses can be collected and sent to a lab (OTOLITH IMAGE) to determine whether the adult fish sampled in the Indian River are of hatchery or wild origin.

While it is possible that fish originating from the hatchery are contributing to the abundance of pink salmon observed in recent decades at Indian River, it is also possible that the relatively low numbers of spawning pink salmon observed before 1980 may themselves have been historically atypical. During World War II, US Navy contractors began dredging sand and gravel from the river bed, as well as from a wooded island at the river’s mouth, in order to build fortifications on nearby Japonski Island. Park service officials at the time believed that the removal of gravel contributed to several severe floods between 1940 and 1960 (Antonson and Hanable 1987). Even with the completion of said military fortifications, gravel removal would continue in the Indian River delta intermittently until 1960. This gravel removal and the accompanying floods had profound effects on the geomorphology of the reaches of Indian River located in what is now Sitka National Historical Park, shifting the mouth of the river and stripping away lowlands near the river’s banks, impacting the quality of riparian habitat. Kiks.ádi elders have recalled that, prior to these dredging operations, the pink salmon runs at Indian River were so numerous that “it seemed like you should just be able to walk across the river on the humpies [pink salmon]” (Thornton 1998). It is altogether possible that high pink salmon abundances observed in recent years are not an exception but a return to historic levels.

Nevertheless,

The Indian River hatchery strays are also somewhat unique in that the original brood stock of pink salmon, i.e., the original adults used for egg extraction and rearing, utilized by the hatchery were, in part, Indian river pink salmon. Given that the hatchery and Indian River fish have been straying for decades, but that these ‘hybrids are mostly Indian River fish spawning with Indian River hatchery fish, there is less (if any) molecular concern about preserving the ‘pure’ line of salmon that are adapted to the conditions of the Indian River. Instead, the concen is that the abundance of pink salmon, assuming the rates of straying from the hatchery to the river exceeds the river to the hatchery, is ‘unnaturally’ high.

Unnaturally high densities of salmon also increase the chance that the salmon deleteriously impacts the river’s ecosystem. When salmon spawn, they remove dissolved oxygen from the water through the direct consumption of O2 while alive and through the release of carbon during decomposition of the carcasses following death (Sergeant et al. 2023). When high abundances occur during a period of low river flows (creating very high densities), in-stream dissolved oxygen concentrations can drop to levels below what is needed for resident fish to survive. In streams systems free of hatchery influence, there are natural regulators (density-dependence) that bring the population back into balance when the number of returning spawners exceeds a stream’s carrying capacity. For example, in very high densities, females arriving later will dig up the eggs (redds) of early arriving females, and the ‘recruit-per-spawner’ ratios (number of returning adults based on the number of adults that spawned 2 years prior) will drop precipitously. And in some instances ovigerous females, i.e., those still carrying eggs, will die before spawning. For river systems strongly influenced by hatcheries, the number of spawning fish will always be elevated because the hatchery will annually produce a consistent number of fish regardless of density-dependent factors in the stream.

Coincident with the initial increases in pink salmon observed in the 1980s was the commencement of operations at Sheldon Jackson Hatchery (SJH), Today, In recent years the hatchery has been permitted to propagate 3 million eggs, which equate to releasing millions of fry to the ocean each year. While these eggs are extracted from adults that return to the hatchery, the original stock of eggs was taken primarily from pink salmon from the Indian River (even years) and nearby Starrigavan Creek (odd years).

[[DO we want to put the data in here that was collected on strays…?]]

It is possible to distinguish hatchery-origin fish at Indian River

With all this in mind, how might park mangers determine whether the abundances of pink salmon observed in recent years at Indian River are within some natural range of variation? The implications include impacts to the entire Indian River.

Building a baseline picture of pink salmon abundance in the wider region could provide a useful basis of comparison. ADFG has monitored pink salmon streams in southeast Alaska as far back as 1960, for the purpose of managing escapement and regulating the fishery. This monitoring effort surveys 714 pink salmon index streams throughout the Alaska panhandle via fixed wing aircraft, with a randomly selected subset of those streams surveyed subject to foot counts for validation (A. Dupuis, personal communication, August 19, 2024). Of these 714 index streams, ADFG places 35 within the “Northern Southeast – Outside” subregion, the neighborhood of Sitka and the Indian River which includes the ocean-facing coasts of Baranof and Chicagof Islands, as well as a few smaller islands in the vicinity.

In 2023, the NPS entered into a partnership with USGS and the University of Washington to explore how the Indian River pink salmon populations may be ;Using statistical modeling, the objective is to utilize all sources of data to to evaluate the range of natural variation in in Indian River pink salmon, given recent trends in the species’ abundance throughout Southeast Alaska. Multivariate autoregressive state-space (MARSS) models are particularly well suited for parsing long running time series data like ADFG’s pink salmon surveys for two reasons. First, MARSS models are designed to mathematically distinguish inconsistencies in observations from variation in the underlying state of a system (in this case the underlying state refers to the actual population of pink salmon in a stream). This is useful when parsing data collected by different observers operating in differing conditions (weather, time of day, time of year, etc.), where those conditions likely bias the observations being made. Second, MARSS models allow for gaps in the time series of observations to occur, while retaining the ability to make inferences about the underlying state (Holmes et al. 2012). While ADFG’s surveys of pink salmon index streams are consistent from 1960 onward, records of pink salmon at Indian River contain some years with no observations, making this second feature of MARSS models especially valuable to this research. MARSS models make it possible to estimate the annual abundance of pink salmon at Indian River and to then compare those estimates to pink salmon abundance in neighboring streams. These models also allow the year-to-year variation in pink salmon returning to spawn at Indian River to be likewise compared to the variation seen elsewhere in the area. MARSS models also make it possible to explore the Indian River system in greater detail, the goal being to identify what measurable impact hatchery releases have on abundance of spawning pink salmon entering the stream each year. Controlling for stream level characteristics (temperature and flow rate) and ocean climate allows these statistical models to isolate the effect of hatchery straying on pink salmon populations.

Part of the management challenge when confronted with hyperabundant endemic species is assessing whether or not the abundances observed occur within some natural range of variation. The cases of the pine mountain beetle and white-tailed deer illustrate that many factors both local and global may drive the proliferation of endemic species within a national park. Pink salmon have returned to Indian River in large numbers every summer since time immemorial, but whether the density of spawning salmon observed recently is exceptional requires understanding both the general behavior of pink salmon in the region as well as the potential impact of direct influences such as hatchery releases. Taken together, we hope to provide context and clarity to park officials regarding the pink salmon population in the Indian River and the ability to maintain the healthy riverine ecosystem on which so many other resident species depend.

References

Alaska Department of Fish and Game. 2024a. Commercial Salmon Fisheries – Southeast Alaska & Yakutat Research: Pink Salmon. Available at: <https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareasoutheast.salmon_research_pink> (accessed December 14, 2024)

Alaska Department of Fish and Game. 2024b. Mark Recovery Laboratory – Otolith Marking. Available at: <https://mtalab.adfg.alaska.gov/OTO/marking.aspx> (accessed December 14, 2024)

Antonson, J. M. and W. S. Hanable. 1987. *An Administrative History of Sitka National Historical Park*. National Park Service. Available at: <https://www.nps.gov/parkhistory/online_books/sitk/adhi/index.htm> (accessed December 17, 2024).

Gende, S. and B. Carter. 2015. *Straying rates of pink salmon into the Indian River, Sitka National Historical Park. Final Report – ADF&G Permit # SF2015-225.* National Park Service, 11 pp.

Gibson, K., K. Skov, S. Kegley, C. Jorgensen, S. Smith, and J. Witcosky. 2008. *Mountain Pine Beetle Impacts in High-Elevation Five-Needle Pines: Current Trends and Challenges.* USDA Forest Service – Forest Health Protection, 40 pp.

Holmes, E. E., E. J. Ward, and K. Wills. 2012. MARSS: Multivariate Autoregressive State-space Models for Analyzing Time-series Data. *The R Journal* 4(1): 11-19.

Knudsen, E. E., P. S. Rand, K. B. Gorman, D. R. Bernard, and W. D. Templin. 2021. Hatchery-Origin Stray Rates and Total Run Characteristics for Pink Salmon and Chum Salmon Returning to Prince William Sound, Alaska in 2013-2015. *Marine and Coastal Fisheries* 13(1): 41-68.

Miller, K. M., S. J. Perles, J. P. Schmit, E. R. Matthews, A. S. Weed, J. A. Comiskey, M. R. Marshall, P. Nelson, N. A. Fisichelli. 2023. Overabundant deer and invasive plants drive widespread regeneration debt in eastern United States national parks. *Ecological Applications* 33: 24pp.

Quinn, T. P. 2018. *The Behavior and Ecology of Pacific Salmon and Trout, Second Edition.* University of Washington Press, 547 pp.

Sergeant, C. J., J. R. Bellmore, C. McConnell, J. W. Moore. 2017. High salmon density and low discharge create periodic hypoxia in coastal rivers. *Ecosphere* 8(6).

Sergeant, C. J., J. R. Bellmore, R. A. Bellmore, J. A. Falke, F. J. Mueter, and P. A. H. Westley. 2023. Hypoxia vulnerability in the salmon watersheds of Southeast Alaska. *Science of the Total Environment* 896.

Stopha, M. 2015. *An Evaluation of the Sheldon Jackson Salmon Hatchery for Consistency with Statewide Policies and Prescribed Management Practices.* Alaska Department of Fish and Game, Division of Commercial Fisheries, 42 pp.

Thornton, T. F. 1998. *Traditional Tlingit Use of Sitka National Historical Park*. National Park Service, 170 pp.

Tillotson, M. D., T. P. Quinn. 2017. Climate and conspecific density trigger pre-spawning mortality in sockeye salmon (Onchorhynchus nerka). *Fisheries Research* 188: 138-148.