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Research Article

Lake Elevation Drives Stocking Success of Chinook Salmon in Lake Oahe, South Dakota, a Large Midwest Reservoir

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Abstract: Landlocked Chinook salmon (*Oncorhynchus tshawytscha*) are a popular sport fish in Missouri River, USA, reservoirs. These fisheries are maintained through stocking, but few studies have examined specific factors at the time of stocking that may influence post-stocking survival of Chinook salmon. In this study, we used an information theoretic approach to evaluate the ability of candidate models to explain variability in the return of stocked Chinook salmon to a spawning station in Lake Oahe, a large Missouri River reservoir in central South Dakota. The best candidate models to explain adult Chinook salmon returns included the lake elevation in May and, to a lesser extent, the number of Chinook salmon stocked. Surprisingly, recruitment of Chinook salmon exhibited an inverse relationship to lake elevation. Models that included measures of predator and prey abundance showed little support. Thus, it appears that Lake Oahe's fish assemblage at the time of stocking plays less of role in the return of Chinook salmon to the spawning stock compared to the lake characteristics at the time of stocking.

Keywords: Lake Oahe; Missouri River; *Oncorhynchus tshawytscha*; smolt stocking; South Dakota

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Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) are native to the Pacific Ocean but were introduced into the Laurentian Great Lakes (Parsons 1973; hereafter Great Lakes) and northeast USA states in the late 1800s (Hoover 1936), and into the Missouri River reservoirs of North and South Dakota, USA, in the late 1900s (Warnick 1987). In 1982, a Chinook salmon stocking program began in Lake Oahe, South Dakota, and was well received by sport fishermen. Economic models suggest between $107,000 and $2,500,000 is generated annually by the Chinook salmon sportfishery on Lake Oahe (Fincel et al. 2012). These economic estimates are substantially less than salmon fisheries in the Pacific Northwest or Great Lakes; however, they provide substantial monetary inputs to local communities in the central Dakotas. Similar to other sportfish populations, increased angling effort is observed when angler harvest success is high (Goedde and Coble 1981, Moring 1993). Thus, when many Chinook salmon are being caught and harvested per angler, more anglers target this species. This, coupled with the economic impact estimated for the fishery, stresses the importance of maintaining a high harvest Chinook salmon fishery in central South Dakota.

A variety of hatchery rearing practices have been shown to increase recruitment of Chinook salmon to Lake Oahe spawning operations (Wipf and Barnes 2012, Barnes et al. 2013), but no research has examined relationships between recruitment of Chinook salmon and other biotic or abiotic factors at the time of stocking. These include factors such as predator densities, water temperature, lake elevation, or prey availability when Chinook salmon smolts are stocked. These factors could impact initial Chinook salmon survival and subsequent recruitment to the spawning stock. For instance, in the Great Lakes, alewives (*Alosa pseudoharengus*) appear to buffer predation of stocked brown trout (*Salmo trutta*) by walleye (*Sander vitreus*) by acting as an alternative prey resource (Johnson and Rakoczy 2004).

The objective of this study was to identify factors that impact recruitment of Chinook salmon to the spawning operations in Lake Oahe. We hypothesized that Chinook salmon recruitment would be 1) positively related to numbers and/or size of Chinook salmon smolts stocked, 2) negatively related to the abundance of predators in Lake Oahe, 3) positively related to the abundance of prey species in Lake Oahe, and/or 4) positively related to lake elevation and negatively related to reservoir water temperature at the time of stocking. Revealing the relationship(s) between these factors and Chinook salmon recruitment to spawning operations will allow fish managers to adjust stocking strategies in order to maximize returns from stocking efforts in inland systems that contain Chinook salmon.

Study Site

Lake Oahe extends from Riverdale, ND to Pierre, SD, USA. At average lake elevation, the South Dakota portion of Lake Oahe has a surface area of approximately 145,000 ha, with a mean and maximum depth of approximately 19 and 67 m, respectively. Lake Oahe is characterized by numerous embayments and many large tributaries, including the Grand, Moreau, and Cheyenne Rivers. Lake Oahe supports recreational fisheries primarily for Walleye (*Sander vitreus*) and to a lesser extent, northern pike (*Esox lucius*). In recent years, Smallmouth Bass (*Micropterus dolomieu*) abundance has increased on Lake Oahe; however, their numbers remain lower than that of Walleye, the most abundant piscivore in the system (Fincel et al. 2019). The lower third of the reservoir thermally stratifies in July through September and maintains an oxygenated hypolimnion providing approximately 48,000 ha of coldwater habitat (less than 20°C thermal tolerance for Chinook salmon; Keefer et al. 2018) at normal operating pool. Thus, Chinook salmon are concentrated in the lower third of the reservoir for the majority of the open-water angling season (May through October).

The Lake Oahe Chinook salmon sport fishery is important to South Dakota. From 1988 through 2017, estimated yearly Chinook salmon harvest has ranged from 55 to 33,077 fish. Anglers harvest a range of Chinook salmon age classes. Most of the sportfish harvest consist of age-2 and age-3 Chinook salmon with fewer age-4 and age-5 fish. Angler harvest and returns to the Chinook Salmon spawning operations show a strong positive relationship **(Figure 1)** suggesting angler exploitation is not a limiting factor for returns of adult Chinook salmon to the spawning operations.

Whitlock Bay Spawning Station was constructed in

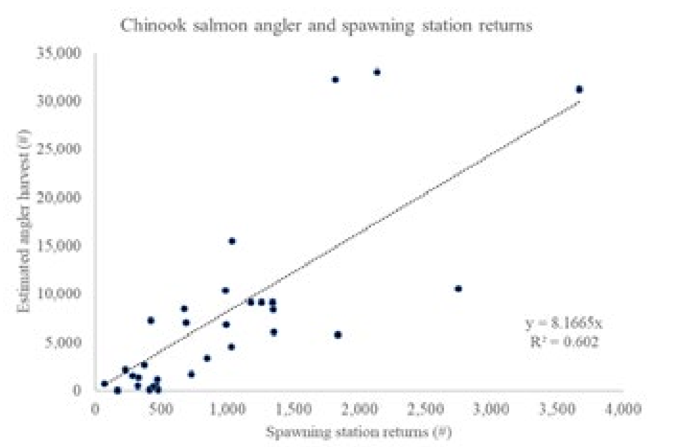

Figure 1: Mean yearly Chinook salmon spawning station returns by estimated Chinook salmon angler harvest from 1988 to 2017 in Lake Oahe, South Dakota, USA.

1984 and consists of an artificial stream fish ladder, four concrete holding ponds, one crowding raceway and a spawning building. Two deep-water intake pumps draw water from an adjacent bay and deliver up to 9,800 L per minute to pressurize Whitlock Bay Spawning Station and gravity feed lake water through the raceways and down the artificial stream fish ladder. Whitlock Bay Spawning Station typically operates from the 15th of September through the first week of November (dependent on weather and fish returns).

Since construction, between 69 to 3,664 Chinook salmon have ascended the fish ladder annually. Additionally, in four of the years examined, SDGFP crews used boat electrofishing to bolster numbers for the Chinook salmon propagation program. These fish were added to the raceways and spawned in the same manner as those that ascended the fish ladder. Chinook salmon begin returning to the spawning station as age-2 males (jacks), though most returns are from age-3 and age-4 fish. Additionally, few age-5 fish ascend the Whitlock Bay Spawning Station fish ladder, but generally these fish are exceedingly rare.

Materials and Methods

Chinook salmon stocking

South Dakota Department of Game, Fish, and Parks began stocking Chinook salmon in the spring of 1982. From 1984 through 2015, as many as 1,127,529 Chinook salmon smolts were stocked in Lake Oahe yearly with up to 130,364 tagged yearly with a coded-wire tag (CWT). Chinook salmon smolts were stocked at sizes ranging from 5.8 to 21.2 g. In 1986, SDGFP began marking approximately 10% of the Chinook salmon smolts with coded wire-tags (batch tagging to delineate stocking year; CWT), and tags are collected for age validation via annual spawning operations. Starting in 1990, SDGFP began stocking Chinook salmon in the fall. However, these stockings were infrequent until the mid-2000's, and all stocking groups had corresponding CWT; thus, only the spring-stocked Chinook salmon were used in this analysis. Spring stocked Chinook salmon are stocked in April, May, or early June dependent on hatchery space and lake conditions at the time of stocking. No Chinook salmon were stocked in Lake Oahe in 2000 through 2002.

Chinook salmon recruitment

To evaluate variables that potentially impact the success of a cohort of stocked Chinook salmon, we defined a response variable as the total number of Chinook salmon to return to the spawning station from a single stocked cohort. Thus, these returning fish have recruited to the spawning stock. To derive this response variable, we used the percentage of known age Chinook salmon (from CWT), adjusted for the total number of fish that had been CWT, to assign ages to untagged Chinook salmon that returned to the spawning station in a given year. We then summed the total returns (tagged and untagged) of a specific year class for the duration that year class was at large. We termed this variable total year class returns.

Prey fish and sport fish collection

Diet studies in 1994, 2001, and 2008 through 2010 identified gizzard shad (*Dorosoma cepedianum*) and rainbow smelt (*Osmerus mordax*) as the dominant prey resources in Lake Oahe through the duration of this study (Fincel et al. 2014, Fincel et al. 2016a). Additionally, SDGFP began stocking adult, pre-spawn gizzard shad in Lake Oahe in 2012 to bolster this prey resource (Fincel et al. 2017). Estimates of abundance of gizzard shad (1988 through 2015) and rainbow smelt (1996 through 2015) were taken from standard surveys conducted by SDGFP each year. Gizzard shad were sampled in July each year using 31 m by 2 m bag seine of 6 mm bar mesh. Four quarter-arc hauls were completed at each of nine fixed sites equidistant from one another on Lake Oahe. Gizzard shad abundance is reported as number per seine haul (catch per unit effort [CPUE]). We estimated rainbow smelt abundance in July using dual beam, down looking, mobile hydroacoustic sonar at twenty fixed transects throughout Lake Oahe. Transects were approximately 2.5 km in length and only targets at or below the thermocline were used for the analysis. We enumerated hydro-acoustic targets using single target detection when possible; however, when rainbow smelt abundance was high, echo-integration was used to determine fish density. Density estimates (i.e., # rainbow smelt per 100 m^3) for each transect were extrapolated to the total cold-water volume of Lake Oahe at the time of the survey. Rainbow smelt abundance is reported as the estimated number of rainbow smelt in Lake Oahe at the time of the survey.

We estimated walleye abundance every August with bottom-set experimental mesh gill nets set overnight (approximately 20 h) in depth zones of 0–30 m (n=3) and 30–60 m (n=3) for a total of six net nights per location at 9 locations in Lake Oahe. Gill nets were multifilament nylon 91-m long by 2-m deep, with 15 m panels of 12, 19, 25, 32, 38, and 51 mm bar mesh. Upon capture, walleye were weighed (g) and measured (mm, total length). Beamesderfer (2000) documented walleye as small as 200 mm to be Chinook salmon smolt predators on the Columbia River; thus, all walleye age-1 and older were included in measures of abundance.

Abiotic variables

We obtained long-term weather data (www.weatherunderground.com; Pierre, SD station) to determine characteristics of Lake Oahe at the time Chinook salmon smolts were stocked. These included monthly average high air temperatures (as a proxy for water temperature) and total precipitation for the month of May (runoff into the lake). We obtained lake elevation characteristics from the US Army Corps of Engineers including average May lake elevation, quantified a "spring rise" as the change in lake elevation from April 1st to May 31st, and a longer term change in lake elevation from May 31st of the previous year to May 31st of the year Chinook salmon were stocked.

Analysis

We used multiple linear models to examine the variation observed in Chinook salmon recruitment. Four main effects categories were hypothesized to impact Chinook salmon recruitment. These include characteristics of the 1) stocked Chinook salmon, 2) prey fish in the system at the time of stocking, 3) the abundance of the dominant predator in the system when Chinook salmon are stocked, and 4) environmental variables on Lake Oahe at the time of Chinook salmon stocking.

Ten single parameter candidate models were developed to encompass these four main categories **(Table 1)**. We then combined logical parameters to create 13 additional multi-parameter candidate models **(Table 1)** and used Akaike's Information Criterion (AIC_c; Burnham and Anderson 2002) to determine which model(s) best supported trends in Chinook salmon recruitment to the spawning stock. For 1988 – 2015, we evaluated only models that excluded a measure of rainbow smelt abundance because rainbow

Table 1: Model names and terms for candidate models used to explain recruitment of Chinook salmon to the Lake Oahe spawning stock from 1988 through 2015 (asterisks denote models used for reduced data set of 1996 through 2015).

Model Name	Model definition
Spr#	Number of Chinook salmon smolts stocked (Spr#)
SprSz	Size of Chinook salmon stocked (SprSz)
WAE	Walleye abundance (WAE)
GZD	Gizzard shad abundance (GZD)
** RBS	Rainbow smelt abundance (RBS)
MayE	Average lake elevation for the month of May (MayE)
May-May	Change in elevation from May 31st the year prior to the May 31st when the Chinook salmon smolts were stocked (May-May)
SprR	Difference in lake elevation from April 1st to May 31st (SprR)
MayP	Total May precipitation (MayP)
MayT	Average May high temperature (MayT)
MayT + MayP	Average May high temperature (MayT), total May precipitation (MayP)
Spr# + MayE	Number of Chinook salmon smolts stocked (Spr#), average lake elevation for the month of May (MayE)
Spr# + SprSz	Number of Chinook salmon smolts stocked (Spr#), size of Chinook salmon stocked (SprSz)
Spr# + WAE	Size of Chinook salmon smolts stocked (Spr#), walleye abundance (WAE)
SprSz + WAE	Number of Chinook salmon smolts stocked (Spr#), walleye abundance (WAE)
WAE + GZD	Walleye abundance (WAE), gizzard shad abundance (GZD)
Spr# + SprSz + WAE	Number of Chinook salmon smolts stocked (Spr#), size of Chinook salmon stocked (SprSz), walleye abundance (WAE)
Spr# + WAE + GZD	Number of Chinook salmon smolts stocked (Spr#), walleye abundance (WAE), gizzard shad abundance (GZD)
Spr# + MayT + MayP	Number of Chinook salmon smolts stocked (Spr#), average May high temperature (MayT), total May precipitation (MayP)
** Spr# + RBS	Number of Chinook salmon smolts stocked (Spr#), rainbow smelt abundance (RBS)
** WAE + RBS	Walleye abundance (WAE), rainbow smelt abundance (RBS)
** WAE + RBS + GZD	Walleye abundance (WAE), rainbow smelt abundance (RBS), gizzard shad abundance (GZD)
** Spr# + WAE + GZD + RBS	Number of Chinook salmon smolts stocked (Spr#), walleye abundance (WAE), gizzard shad abundance (GZD), rainbow smelt abundance (RBS)

smelt surveys were only run after 1995. Thus, we also ran a truncated Akaike's Information Criterion for the time period 1996-2015 to evaluate all variables including those measures of rainbow smelt abundance. Hence, we performed two different model selection analyses; 1) 18 models from 1988 to 2015 that excluded all rainbow smelt parameters and 2) 23 models from 1996 to 2015 that included rainbow smelt parameters.

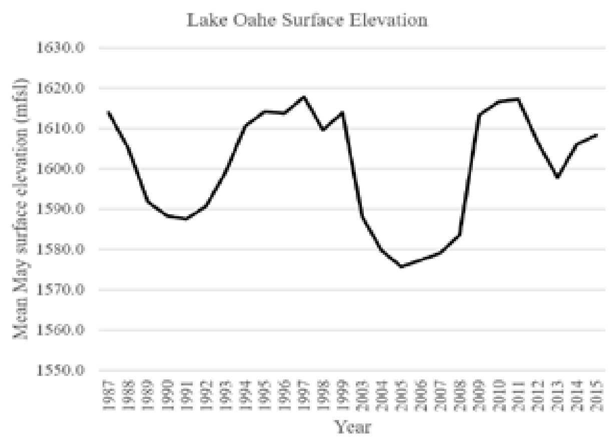

Figure 2: Mean May surface elevation (mfsl) from 1987 to 2015 in Lake Oahe, South Dakota, USA.

Results

From 1988 to 2015, returns of a single year class to the Whitlock Bay Spawning Station ranged from 31 to 6,035. Yearly rainbow smelt abundance varied appreciably (range 11,869,570 to 1,167,490,370) during the study particularly after a high discharge year of 2011 during the Missouri River flood (Fincel et al. 2016b). Gizzard shad abundance also fluctuated substantially and ranged from 0 to 840.9 fish per seine haul. Throughout the study walleye were the most abundant piscivore in Lake Oahe with CPUE ranging from 8.7 to 31.0 fish per net night from 1988 through 2015.

From 1988 to 2015, mean May high temperatures ranged from 18 to 27 C, and cumulative May precipitation ranged from 20 to 295 mm. Average May lake elevation ranged from 1575.7 to 1617.2 mfsl **(Figure 2)**, change in lake elevation from April 1st to May 31st (spring rise) ranged from -1.1 to 3.0 m, and May to May elevation change ranged from -4.2 to 8.9 m.

The most supported model for explaining Chinook salmon recruitment to the spawning stock was average May surface elevation (mfsl) for both time periods, 1988 to 2015 and 1996 to 2015 **(Table 2)**, **(Table 3)**. Additionally, adding the number of Chinook salmon smolts stocked to the model was well supported in the model that evaluated all years. All other models carried less than 0.3 weight and were deemed

Table 2: Model selection results for eighteen candidate models evaluating recruitment of Chinook salmon to the Lake Oahe spawning stock from 1988 to 2015 in Lake Oahe, South Dakota, USA. Included are the top 5 models in the analyses with the number of estimated parameters (K), residual sums of squares (RSS), Akaike's Information Criterion (AIC), 2nd order Akaike's Information Criterion (AICc), difference in AIC values relative to the best model (Δ AICC), and Aikaike weights (Weights). Model parameters include the average lake elevation for the month of May (MayE), the number of Chinook salmon smolts stocked (Spr#), average May high temperature (MayT), and total May precipitation (MayP).

Model	K	RSS	AIC	AICc	Δ AICc	Weights
MayE	3	9,858,874	328.13	329.27	0.000	0.623
Spr# + MayE	4	9,556,635	329.35	331.35	2.079	0.22
Spr#	3	12,631,009	334.32	335.46	6.195	0.028
MayT	3	12,796,982	334.65	335.79	6.521	0.024
Spr# + MayT + MayP	5	10,311,560	333.25	336.41	7.137	0.018

Table 3: Model selection results for twenty-three candidate models evaluating recruitment of Chinook salmon to the Lake Oahe spawning stock from 1996 to 2015 in Lake Oahe, South Dakota, USA. Included are the top 5 models in the analyses with the number of estimated parameters (K), residual sums of squares (RSS), Akaike's Information Criterion (AIC), 2nd order Akaike's Information Criterion (AICc), difference in AIC values relative to the best model (Δ AICC), and Aikaike weights (Weights). Model parameters include the average lake elevation for the month of May (MayE), the number of Chinook salmon smolts stocked (Spr#), walleye abundance (WAE), and the change in elevation from May 31st the year prior to the May 31st when the Chinook salmon were stocked (May-May).

Model	K	RSS	AIC	AICc	Δ AICc	Weights
MayE	3	1,395,192	301.77	303.77	0.000	0.837
Spr# + MayE	4	1,436,645	304.54	308.17	4.398	0.093
WAE	3	1,851,315	309.13	311.13	7.354	0.021
May-May	3	2,050,442	311.79	313.79	10.011	0.006
Spr#	3	2,058,932	311.89	313.89	10.118	0.005

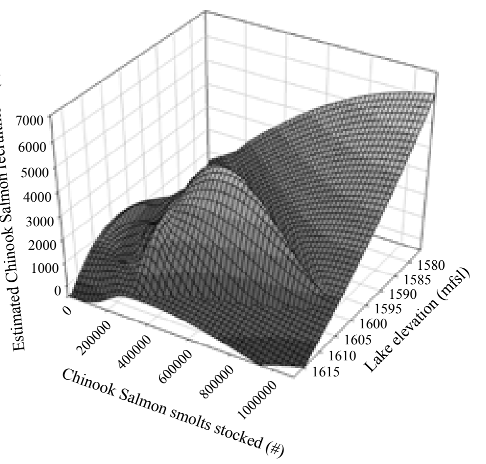

Figure 3: Estimated Chinook salmon recruitment to the spawning stock (#) as a function of lake elevation (mfsl) and the number of Chinook salmon smolts stocked (#) from 1988 to 2015 in Lake Oahe, South Dakota, USA.

unimportant in predicting Chinook salmon recruitment to the spawning stock. In both models, an inverse relationship was observed between lake elevation and Chinook salmon returns **(Figure 3)**. Additionally, a positive relationship was observed between the number of Chinook salmon smolts stocked, and the recruitment of that year class to the Whitlock Bay Spawning Station.

Discussion

It was unexpected to find that Lake Oahe surface elevation showed the most support in predicting recruitment of Chinook salmon to the spawning stock. Even more puzzling was the fact that Chinook salmon recruitment increased with decreasing surface elevation. Thus, as the lake level drops, recruitment of Chinook salmon to the spawning stock increases. It is likely that Lake Oahe surface elevation envelopes multiple biotic and abiotic factors into a single variable. In the Puget Sound, Chinook salmon experienced a shift in mortality following the El Nino years of 1982-1983 (Ruggerone and Goetz 2004). Although specific mechanisms for this shift were difficult to elucidate, it was hypothesized that this time period represents a shift from predation to competition-based mortality in response to local predator, prey, and competitor abundances. Thus, it was not the impacts of the El Nino itself that drove the change in Chinook salmon mortality, but associated linkages with the weather event. In Lake Oahe, it is plausible that changes in lake elevation can be used as a surrogate for relationships between Chinook salmon recruitment and predators, prey, and/or lake productivity in Lake Oahe. Thus, further research may reveal the specific mechanisms that influence recruitment of Chinook salmon to the spawning stock that are linked solely or in combination with Lake Oahe surface elevation.

Drastic elevation changes in reservoirs can dramatically alter lake morphology, which in-turn influences in-lake nutrient cycling, thermal regimes, and primary productivity (Rounsefell 1946, Rawson 1952, Fee 1979, Ryder 1982) all of which may impact survival of newly stocked fish. We believe decreasing water elevation in Lake Oahe increases primary productivity in the reservoir. Reservoir tributaries are a major source for nutrient additions and subsequent primary productivity in reservoirs (Bott et al. 2006, Fincel 2011). Lake Oahe has multiple tributaries, each of which supply nutrients to the reservoir. Moreover, lake elevation is dictated by hydropower need and water supply for downstream navigation, not inputs from local tributaries. As the reservoir elevation drops, the volume of water stored in the reservoir also decreases while, theoretically, nutrient inputs remain constant. It is possible that this results in a higher concentration of nutrients within the reservoir increasing potential primary productivity when the reservoir elevation is low. Many fish species show a positive relationship in growth and/or survival with increased productivity (Martinez and Wiltzius 1995, Bremigan and Stein 2001, Perrin et al. 2006, Fincel et al. 2013), including Chinook salmon (Hard 1986, Sommer et al. 2001). Hence, it is plausible that during periods of low surface elevation, primary productivity is higher, and growth and survival of Chinook salmon smolts is higher compared to when the reservoir is at a higher elevation. Unfortunately, SDGFP does not have long-term productivity estimates for Lake Oahe to directly evaluate this hypothesis.

Environmental conditions can also mediate predator-prey interactions, thereby influencing aquatic community structure (Carpenter et al. 1985, DeVries and Stein 1992). In a review by Swales (2006), surface area, mean and maximum depth, and lake volume are all correlated with surface elevation and all have shown negative correlations with rainbow trout production. Thus, as surface area, depth and volume decrease, rainbow trout production increases. Being similar coldwater species, it is logical to see the same trends in Chinook salmon even though the exact causal agents remain unknown.

We found a modest relationship between the number of Chinook salmon smolts stocked and subsequent total year class return to the spawning station. The common perception suggests that increased numbers of fish stocked should equate to higher recruitment, which we found (Fielder 1992, Fincel et al. 2017). However, the Lake Oahe surface elevation impacts recruitment of Chinook salmon to the spawning stock more so than the number of Chinook salmon smolts stocked. Thus, Chinook salmon recruitment in Lake Oahe appears to follow an inverse Biotic-Abiotic Constraining Hypothesis model (BACH; Quist et al. 2003, Quist and Hubert 2005) where the abiotic controlling factor is lake elevation and the secondary biotic controlling factor is the number of Chinook salmon smolts stocked. Under a traditional BACH framework, the influence of biotic factors (e.g. predator or prey abundance, number or size of fish stocked, etc.) can have an "overriding influence" on a fish population. However, in the case of Lake Oahe Chinook salmon it appears that an abiotic factor (or linkage of biotic and abiotic factors falling under the "lake elevation" metric) overrides the influence of prey availability, predator density, and number and/or size of Chinook salmon stocked.

We were surprised that models including rainbow smelt abundance did not carry weight in our analyses. Inland (i.e. non-anadromous) rainbow smelt typically move into shallow water habitats in April to spawn, are highly fecund, and can produce a strong year class with few spawning stock (Luey and Adelman 1984, Fincel et al. 2012). We suspected prey buffering, or the act of providing alternative food to increase initial survival of a sought-after species, is possibly taking place whereby strong rainbow smelt year classes buffer walleye predation on stocked Chinook salmon smolts. In the Great Lakes, alewives appear to buffer predation of stocked brown trout by walleye by acting as an alternative prey resource (Johnson and Rakoczy 2004). As a result, Johnson et al. (2009) recommended stocking windows of brown trout to coincide with peak abundance of alewives. In several rivers in Maine, a suite of prey fish has been recognized as having various prey buffering effects on Atlantic salmon (*Salmo salar*). Consequently, restoration of these prey species has been viewed as a crucial aspect of the recovery of the Atlantic salmon (Saunders et al. 2006). In Lake Oahe, prey buffering by rainbow smelt may be taking place, but does not appear to be driving recruitment of Chinook salmon to the spawning stock.

None of the top models in our analysis showed a relationship between size of fish stocked and recruitment of Chinook salmon. This contradicts much of the current literature that suggests survival increases as the size at stocking increases. For instance, Beckman et al. (1999) suggest pre-stocking growth and size increased return rate of adult Pacific Chinook salmon in Oregon streams. In the Simojoki River of the Baltic Sea, Atlantic salmon smolt survival increased as a function of size (Saloniemi et al. 2004) and Baldwin et al. (2003) recommended increasing the size of stocked salmonids in Lake Roosevelt, WA, to combat initial walleye predation post stocking. In Lake Oahe, it appears more beneficial to focus on stocking large numbers of Chinook salmon while sacrificing larger sizes which could benefit hatchery operations. If sizes can remain small, more fish can be grown in a finite area freeing up hatchery space. Moreover, if a smaller sized product is acceptable, hatchery managers could raise more fish but stock them earlier thereby saving on food and labor costs associated with growing smolts to a larger size.

Small stocking size also provides an indication of the time of year when stocking occurred with smaller smolts generally being stocked earlier in the year. This fact may shroud the impact of size alone on Chinook salmon recruitment to the spawning stock. A smaller stocking size may have corresponded to a time when localized predator abundance was low due to spawning movements of walleye. In early spring, walleye move to tributaries to spawn (Crowe 1962, Ferguson and Derksen 1971). In Lake Oahe, these walleye spawning movements overlap with early Chinook salmon smolt stockings in April. In Lake Oahe, Chinook salmon are stocked in a small embayment adjacent to the main lake. Thus, it is plausible that walleye spawning movements into local tributaries reduce walleye densities at Chinook salmon stocking locations early in the year. However, post-spawn walleye likely return in early summer and thus, local predator abundance increases for these later Chinook salmon smolt stockings. These declines in local predator abundance could reduce initial post-stocking mortality of Chinook salmon stocked in early to mid-April and explain the poor relationship between Chinook salmon smolt size and later recruitment of Chinook salmon to the spawning stock.

Pacific Chinook salmon evolved in systems very different than Missouri River impoundments and likely lack predator avoidance mechanisms for species common in the Missouri River impoundments, especially walleye. Walleye can have high predation rates on salmonids including Chinook salmon (Rieman et al. 1991, Vigg et al. 1991, Baldwin et al. 2003, Sanderson et al. 2009). In Lake Oahe, walleye stomach contents collected post Chinook salmon stocking suggest high consumption of this naïve prey resource; however, Chinook salmon smolts were only found in diets of walleye collected when the smolts where stocked in June (Fincel et al. 2014). Hence, we were surprised when models that included either or both numbers of rainbow smelt and walleye abundance showed little support when determining recruitment of Chinook salmon to the spawning stock.

Post-stocking survival could also be linked to various learned behaviors that are lacking from hatchery products. These behaviors could include predator detection, predator recognition, optimal foraging behaviors, and/or naivety to new habitat characteristics (Fincel et al. 2010, Brown et al. 2013). For Chinook salmon, predator detection and avoidance can be "taught" prior to stocking; however, no increased survival has been attributed to the endeavor (Berejikian et al. 1999). Additionally, habitat characteristics of the release environment also need to be considered for hatchery products that are likely naïve to the new habitats that they will encounter (Gazdewich and Chivers 2002).

In Lake Oahe, rearing density has shown to increase post-stocking survival of Chinook salmon (Barnes et al. 2013). However, like raising Chinook salmon smolts to a larger size, this stresses hatchery operations (M. Barnes SDGFP personal communication).

Conclusion

Management implications

While the exact mechanism(s) remain unclear, our results provide evidence for a relationship between Chinook salmon recruitment and lake elevation in a large Midwest reservoir. We recommend maintaining the reservoir elevation at relatively lower levels which should increase recruitment of Chinook salmon in Lake Oahe. Moreover, in years of low reservoir elevation, we recommend stocking fewer Chinook salmon smolts which could result in acceptable levels of recruitment to the spawning population saving the state precious resources and hatchery space. However, Lake Oahe has many designated purposes and we realize surface elevation manipulation is unlikely. Nevertheless, our results show that in years of high lake surface elevation, managers should expect to stock more Chinook salmon smolts to achieve similar levels of recruitment. We did find a weak relationship between Chinook salmon recruitment and predator abundance at the time of stocking. Thus, we also recommend stocking Chinook salmon smolts earlier in the spring at a time when local predator abundances are low. We did not find a relationship between prey abundance and Chinook salmon recruitment. Thus, adjusting stockings based on the relative abundance of prey in the lake appears to be ill-advised.

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