FISHERY RESEARCH

PROJECT 4: HATCHERY TROUT EVALUATIONS

Grant # F-73-R-42

Report Period July 1, 2019 to June 30, 2020

Phil Branigan
Senior Fisheries Research Biologist

Emily Washburn
Fisheries Technician

Kevin A. Meyer
Principal Fisheries Research Biologist

John Cassinelli
Anadromous Fisheries Manager

IDFG Report Number 22-02
January 2022

Annual Performance Report

July 1, 2019 to June 30, 2020

Grant # F-73-R-42

Project 4: Hatchery Trout Evaluations

Subproject #1: Relative Performance of Triploid Kokanee Salmon in Idaho Lakes and Reservoirs

Subproject #2: Effects of Moon Phase on Indices of Kokanee Size and Abundance as Measured Through Gill Net Surveys

Subproject #3: Effects of Baffles on Raceway Cleaning, Fin Erosion, In-Hatchery Survival, and Post-Release Angler Catch of Catchable-Sized Hatchery Rainbow Trout

By

Phil Branigan
Emily Washburn
Kevin A. Meyer
John Cassinelli

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83712

IDFG Report Number 22-02
January 2022

TABLE ON CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

ANNUAL PERFORMANCE REPORT

SUBPROJECT #1: RELATIVE PERFORMANCE OF TRIPLOID KOKANEE SALMON IN IDAHO LAKES AND RESERVOIRS

State of: Idaho

Grant No.: F-73-R-42 Fishery Research

Project No.: 4

Title: Hatchery Trout Evaluations

Subproject #1: Relative Performance of Triploid Kokanee Salmon in Idaho Lakes and Reservoirs

Contract Period: July 1, 2019 to June 30, 2020

ABSTRACT

Kokanee *Oncorhynchus nerka* mature earlier than most other salmonids, typically spawning and dying between age-2 and age-4. Due to short lifespan and semelparity, kokanee are often only exploited by anglers for a short period of time during their last year of life. Use of triploid (i.e., sterile) salmonids in hatchery-supported freshwater fisheries protects native stocks from genetic introgression with hatchery fish, but other benefits may include increased longevity, survival, and growth—all of which might enhance kokanee fisheries. The objective of this study was to evaluate the response of switching hatchery-supported kokanee populations from diploid (i.e., fertile) to triploid stocking as measured through changes in age-structure, annual growth, and average length. Annual gill net samples were collected in June 2012-2018 to characterize baseline population metrics and to evaluate changes after switching to triploid fish stocking. Increased longevity was achieved at both treatment populations, whereby an additional age class established after switching to triploid fish. However, despite living an additional year, no size benefit was observed for those older fish. Annual growth remained relatively unchanged between stocking periods across all water bodies. After transitioning to triploid stocking, average length of kokanee sampled each year increased in one population and decreased in the other, emulating the patterns observed in nearby control populations. Unmarked (i.e., wild) fish were abundant throughout the study at both treatment populations, which may have confounded the effects of triploid stocking, but marked fish (i.e., recaptured triploids) were larger on average than unmarked conspecifics. Taken collectively, the effects of triploid stocking appeared to be population-specific, and was likely regulated by underlying system-level growth and recruitment conditions. However, even in the absence of a size benefit, increased longevity resulting from triploidy could be useful by extending the availability of older age classes to the sport fishery. Nevertheless, our results suggest that in general anglers will not experience an increase in kokanee abundance or size structure if triploid fish are stocked.

Author:

Phil Branigan
Senior Fisheries Research Biologist

INTRODUCTION

Kokanee *Oncorhynchus nerka* are an important recreational fish species found in many reservoirs and lakes across the western United States and Canada (Rieman and Myers 1992). In Idaho, hatchery-reared diploid kokanee are stocked to supplement wild populations and to provide put-grow-take fisheries. Kokanee are often managed to support high yield fisheries or provide a forage base for large piscivores (Wydoski and Bennett 1981). While kokanee are important to harvest-oriented anglers and for providing trophy fisheries, managing for healthy kokanee populations can be difficult. In general, kokanee population structure is influenced by the interplay between population density, annual growth rate, and fish size, which are largely associated with complex and dynamic food-web interactions (Beattie and Clancey 1991; Corsi et al. 2019). Since the majority of kokanee populations in Idaho are found in oligotrophic lakes or reservoirs, growth rates can be relatively low, especially when population densities exceed 50 fish/ha (Rieman and Myers 1992). Additionally, kokanee mature early and typically spawn and die between age-2 and age-4 (Johnston et al. 1993). Due to short life span and angler's preference for larger fish, kokanee are often only exploited for a short period of time during their last year of life.

The use of triploid salmonids has become increasingly common in hatchery-supported freshwater fisheries. Since triploids are functionally sterile, one obvious benefit of stocking triploid fish is genetic protection of wild stocks (Rohrer and Thorgaard 1986). However, it is often asserted that sterility may provide a fisheries or aquaculture benefit (Teuscher et al. 2003), such as increased survival (Ihssen et al. 1990) or growth (Habicht et al. 1994; Sheehan et al. 1999). In kokanee fisheries, enhanced longevity may provide additional sportfishing opportunity in subsequent years after semelparous diploids have perished. Indeed, increased longevity could ultimately result in larger size due to a longer growth period, and thus increase yield. However, there are drawbacks to stocking triploids, which may include higher mortality and reduced growth during early life-history stages (Myers and Hershberger 1991). Additionally, survival to eye-up for triploid kokanee eggs may be lower than diploid control groups (Koenig 2011), requiring more eggs to be collected to meet stocking requests.

Post-release performance of sterile kokanee compared to fertile conspecifics has been seldom investigated. Parkinson and Tsumura (1988) and Johnston et al. (1993) both reported increased longevity but no growth advantage for sterilized fish, and the longevity benefit could not overcome the much poorer survival of younger age classes of sterile fish compared to control fish. The overall result of these studies was reduced catch of sterile fish. Although these studies provide insight into the utility of sterile kokanee fisheries, the scope of the results are limited because each study was performed with no definitive marks to differentiate sterile and fertile fish, making comparisons of catch between groups difficult. In addition, Parkinson and Tsumura (1988) and Johnston et al. (1993) stocked treatment and control fish into the same lakes, where intraspecific competition could have affected results. Both studies used kokanee that were sterilized through hormone treatment, and it is unclear if alternative sterilization methods—such as triploid induction—would produce different results.

OBJECTIVE

1. Evaluate if switching hatchery-supported kokanee populations from diploid to triploid would result in greater longevity and better size structure (i.e., more larger fish) in the fishery.

METHODS

Study Sites

Since this evaluation compared kokanee populations after converting to triploid-only stocking, study sites were chosen from those currently stocked with kokanee. Few locations were suitable for research purposes; popular sport fisheries were not considered to avoid negative fishery consequences, and systems had to be of manageable size for cost and sampling efficiency. In addition, efforts were made to select populations with minimal natural reproduction to reduce confounding effects that may be associated with population density. Based on these selection criteria, two lakes in southeast Idaho and two from north Idaho were selected for this study. Waters in each geographic region of the state were paired, such that one water served as a control and the other served as a treatment. Consequently, Mirror Lake and Montpelier Reservoir were randomly selected as treatment populations, whereas Lower Twin Lake and Devils Creek Reservoir served as control populations. All populations were stocked with diploid fish in 2012; beginning in 2013, treatment populations were stocked with triploid fish, whereas control populations continued to receive diploids.

Egg Collection and Triploidy Induction

Triploid (i.e., treatment) and diploid (i.e., control) groups were spawned in September 2011-2016 during normally scheduled weir operations on the Deadwood River. Triploidy was induced by applying pressure treatment to eggs on site. Eggs were subjected to 9500 psi at 350 Celsius-minutes after fertilization for five minutes. Kokanee from normal production were used for the diploid control groups.

Hatchery Rearing and Stocking

Fertilized eggs were flown to Cabinet Gorge Fish Hatchery where they were reared until the eyed egg stage. Year-specific otolith thermal marks were applied to both diploid and triploid test groups to distinguish them from naturally produced diploid kokanee, and from subsequent year classes to ensure accurate age identification. Kokanee destined for Devils Creek and Montpelier reservoirs were transferred to Mackay Fish Hatchery to complete rearing, while Cabinet Gorge Fish Hatchery continued rearing kokanee for Mirror and Lower Twin lakes.

Fish Sampling

Kokanee populations were first sampled in 2012 using experimental gill nets, and annual samples were collected from each water body through 2018. Net locations were initially randomly assigned at each waterbody and repeated in subsequent years. The limnetic zone of each water body was divided into numbered squares and a random number generator was used to select three squares to serve as the monitoring locations. One net was fished overnight at each of the three locations on each water body, for a total annual fishing effort of three net-nights per water body.

Each kokanee population was sampled once annually in June (during thermal stratification) around the timing of the new moon phase. Fish were collected by suspending the experimental gill nets at the depth of the thermocline. Each gill net measured 55 m long by 6 m deep. Two of the three nets were “small” mesh composed of panels ranging from 19 to 64 mm bar mesh monofilament; the third net was “medium” mesh composed of panels ranging from 64 to 152 mm bar mesh monofilament. Panels were randomly positioned on nets during manufacturing. Captured kokanee were enumerated and measured individually for total length (mm). In addition, otoliths from all kokanee were extracted and later analyzed in the laboratory to identify ages of each individual fish.

Data Analysis

Standing stocks of kokanee were described in terms of catch rates, age distribution, and size distribution before and after switching to triploid-only stocking. Devils Creek Reservoir and Lower Twin Lake received diploid fish throughout the entire evaluation period. As such, catch data from these systems were collected and analyzed to serve as reference populations for describing any large-scale effects that may be associated with the environment (e.g., drought) or hatchery rearing (e.g., disease). Mean catch-per-unit-effort (CPUE) was calculated each year by summing the catch from each net and dividing by the total number of net-hours fished to generate an average catch rate (fish/net-hour). Beginning in 2014, sagittal otoliths were examined for year-specific thermal marks to determine age of each captured kokanee by grinding whole otoliths to their nucleus and viewing under 200x magnification; unmarked kokanee were presumed to be unmarked stocked diploid fish or of wild origin, depending on which year an individual unmarked fish was sampled. Individual ages of unmarked fish were estimated by enumerating annuli on sectioned otoliths viewed at 40x magnification. The proportion of unmarked fish was determined each year to explain patterns in catch that may be related to population density. Mean length-at-age was calculated each year to characterize stock structure in each lake.

Annual growth for each population was modeled using a von Bertalanffy growth function applied to data collected before and after switching to triploid-only stocking. Three parameters were estimated for both stocking periods using the following model parameterization:

$$L_t = L_\infty[1 - e^{-K(t-t_0)}],$$

where L_t is the estimated length at time *t*, L_∞ is the asymptotic and theoretical maximum length, *K* is the growth coefficient, and t_0 is the theoretical age when length equal zero. Since test fish were first stocked in 2013 at age 0 and were not recruited to the sampling gear, catch data from 2012 and 2013 were pooled to serve as baseline data before switching to triploid-only stocking. Data from 2014-2018 were pooled to evaluate population-level changes in annual growth after switching to triploid-only stocking. Confidence intervals (α = 0.05) were generated for L_∞ and *K* estimates during both stocking periods to determine if significant changes in annual growth were evident as a result of stocking triploid fish.

Linear regression models were fit to evaluate the effects of switching to triploid-only stocking on the average length of kokanee sampled from each population. Each captured kokanee served as the unit of observation and total length (mm) was related to subsequent years after switching to triploid stocking (i.e., “years post-switch”; YPS). As such, catch data from 2012 and 2013 were pooled to serve as reference for the YPS parameter. Water body was included as an interactive term with YPS to evaluate population-specific changes in average length since switching to triploid-only stocking. Two linear models were fit to evaluate changes in each population: one using all data, and another using data truncated at sample year 2015 to determine differences in average length between marked and unmarked fish. Truncating the dataset at 2015 minimized the chances of including older, unmarked diploids (i.e., non-study fish) in the analysis that may confound the effect observed between marked and unmarked individuals.

RESULTS

Catch composition of kokanee varied among annual samples at each water body. However, there was no noticeable pattern of increasing or decreasing CPUE at treatment (i.e., triploid) waters compared to control (diploid) waters (Figure 1), nor was there a pattern of increased growth through time at treatment or control waters (Figure 2). The proportion of unmarked kokanee collected in each annual sample was lowest at diploid waters and highest at triploid waters throughout the entire evaluation. The proportion of unmarked (i.e., wild or unmarked stocked diploid) fish remained relatively high at Mirror Lake throughout the evaluation period, whereas fewer unmarked fish were sampled at Montpelier Reservoir as the study progressed (Figure 3).

Age distribution varied among populations and among triploid and diploid waters, but both triploid populations experienced an increase in longevity. After switching to triploid-only stocking, kokanee populations at Montpelier Reservoir and Mirror Lake produced an additional age class that was previously undocumented (Table 1). However, despite the increase in longevity in both populations, no size benefit was observed because age-4 kokanee in Montpelier Reservoir and age-5 kokanee in Mirror Lake were not larger (on average) than the preceding age classes (Table 1).

With regard to annual growth models, we observed no differences between diploid and triploid stocking periods (Figure 4). Parameter estimates of the von Bertalanffy growth models did not differ significantly between stocking periods, except for *K* estimates at Mirror Lake (Figure 5). Despite *K* increasing significantly between stocking periods, the average length of kokanee sampled from Mirror Lake decreased 11 mm each year since switching to triploid-only stocking. Conversely, the average length of kokanee in Montpelier Reservoir increased by 9 mm since switching to triploid stocking (Table 2). The average length of kokanee sampled from treatment populations reflected the same pattern observed in nearby control populations. Beginning in year 2015, when marked fish comprised the majority of all sampled kokanee, the average length of kokanee with a confirmed thermal mark increased by 9 mm compared to unmarked fish across all populations (Table 3).

DISCUSSION

Although triploid populations in this study produced an additional age-class that was absent in baseline samples, no size benefit was observed during the additional year of life, and no benefit in fish growth was evident for triploid fish. Previous evaluations have demonstrated that sterile kokanee reared in captivity can achieve larger sizes with age (Robertson 1961), but size benefits have not been observed when sterile kokanee have been released into lacustrine environments (Parkinson and Tsumura 1988; Johnston et al. 1993). The lack of any population-level benefit (in terms of metrics anglers would notice) to the slight increase we observed in longevity was primarily due to the fact that the additional age class comprised a very minor proportion of the total catch.

The proportion of unmarked (wild) fish sampled during this study was substantial, especially in both treatment (triploid) study waters. Consequently, it is difficult to ascertain whether any density-dependent interactions between stocked triploid and wild diploid kokanee may have obscured our conclusions regarding triploid stocking. Nevertheless, our results suggest that stocking either diploid or triploid kokanee will produce similar fisheries in terms of growth and size structure. As such, any switch in hatchery-supported kokanee populations from diploid to triploid fish stocking will likely have little impact on the fishery except that, over time, such a change may diminish the number of spawners in the population, which could alter natural reproduction output. In places like Warm Lake, where genetic introgression between stocked and wild kokanee is a concern, our results suggest that stocking triploid fish will produce a similar fishery as would stocking diploid fish.

MANAGEMENT RECOMMENDATION

1. Stock triploid kokanee in hatchery-supported populations if genetic introgression with the sympatric wild stock of kokanee is a potential management concern. Otherwise, stocking either triploid or diploid kokanee will likely produce similar fisheries.

ACKNOWLEDGEMENTS

I would like to acknowledge John Cassinelli, Joe Thiessen, Liz Mamer, Kristi Stevenson, Kevin Nelson, Dennis Daw, Kyle Gatt, Jordan Everson, Hamish Stevenson, and Garrett Hensley for assisting with sample collection. I would like to thank Steve Elle, Kristi Stevenson, Dennis Daw, Liz Mamer, and Kyle Gatt for their help with processing otoliths. I would also like to thank Bob Becker and the staff at Nampa Fish Hatchery for their assistance collecting and pressure treating kokanee eggs at Deadwood Reservoir. Additionally, I would like to thank John Rankin and the staff at Cabinet Gorge Fish Hatchery and Pat Moore and the staff at Mackay Fish Hatchery for their work rearing and releasing fish. I also thank Tim D'Amico for editing this report. Funding for this work was provided by anglers and boaters through their purchase of Idaho fishing licenses, tags, and permits, and from federal excise taxes on fishing equipment and boat fuel through the Sport Fish Restoration Program.

LITERATURE CITED

Beattie, W. D., and P. T. Clancey. 1991. Effects of *Mysis relicta* on the zooplankton community and Kokanee Salmon population of Flathead Lake, Montana. American Fisheries Society Symposium 9:39-48.

Corsi, M. P., M. J. Hansen, M. C. Quist, D. J. Schill, and A. M. Dux. 2019. Influences of Lake Trout (*Salvelinus namaycush*) and *Mysis Diluviana* on kokanee (*Oncorhynchus nerka*) in Lake Pend Oreille, Idaho. Hydrobiologia 840:351-362.

Habicht, C., J. E. Seeb, R. B. Gates, I. R. Brock, and C. A. Olito. 1994. Triploid Coho Salmon outperform diploid and triploid hybrids between Coho Salmon and Chinook Salmon during their first year. Canadian Journal of Fisheries and Aquatic Sciences 51:31-37.

Ihssen, P. E., L. R. McKay, I. McMillan, and R. B. Phillips. 1990. Ploidy manipulation and gynogenesis in fishes: cytogenetic and fisheries applications. Transactions of the American Fisheries Society 119:698-717.

Johnston, N. T., E. A. Parkinson, and K. Tsumura. 1993. Longevity and growth of hormone-sterilized Kokanee Salmon. North American Journal of Fisheries Management 13:284-290.

Koenig, M. K. 2011. Idaho Department of Fish and Game. Annual performance report number 11-07. Boise.

Myers, J. M., and W. K. Hershberger. 1991. Early growth and survival of heat shocked and tetraploid-derived triploid Rainbow Trout. Aquaculture 96:97-101.

Parkinson, E. A., and K. Tsumura. 1988. Growth and survival of hormone-sterilized Coho *Oncorhynchus kisutch* and Kokanee Salmon *O. nerka* in a lacustrine environment. Canadian Journal of Fisheries and Aquatic Sciences 45:1490-1494.

Rieman, B. E., and D. Myers. 1992. Influence of fish density and relative productivity on growth of Kokanee Salmon in ten oligotrophic lake and reservoirs in Idaho. Transactions of the American Fisheries Society 121:178-191.

Robertson, O. H. 1961. Prolongation of the life span of Kokanee Salmon (*Oncorhynchus Nerka* Kennerlyi) by castration before beginning of gonad development. Proceedings of the National Academy of Sciences of the Unites States of America 47:609-621.

Rohrer, R. L., and G. H. Thorgaard. 1986. Evaluation of two hybrid trout strains in Henry's Lake, Idaho, and comments on the potential use of sterile triploid hybrids. North American Journal of Fisheries Management 6:367-371.

Sheehan, R. J., S. P. Shasteen, A. V. Suresh, A. R. Kapuscinski, and J. E. Seeb. 1999. Better growth in all-female diploid and triploid Rainbow Trout. Transactions of the American Fisheries Society 128:491-498.

Teuscher, D. M., D. J. Schill, D. J. Megargle, and J. C. Dillon. 2003. Relative survival and growth of triploid and diploid Rainbow Trout in two Idaho reservoirs. North American Journal of Fisheries Management 23:983-988.

Wydoski, R. S., and D. H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transaction of the American Fisheries Society 110:764-771.

Table 1. Net-hours, CPUE, age distribution, and mean-length-at-age estimates of diploid (2N) and triploid (3N) kokanee sampled from two control and two treatment populations in June 2012-2018. Gray shaded values represent age classes that are triploid. NA refers to not applicable.

Water Body	Sample Year	Treatment	Net-Hours	CPUE	Mean-Length-At-Age (mm)					
					Age-0	Age-1	Age-2	Age-3	Age-4	Age-5
Montpelier Res.	2012	3N	105.8	1.63	109	271	330	338	NA	NA
	2013		54.5	1.27	112	220	274	NA	NA	NA
	2014		40.0	0.65	105	228	282	314	NA	NA
	2015		41.3	0.58	NA	247	NA	NA	NA	NA
	2016		41.3	0.84	96	163	267	301	NA	NA
	2017		45.6	0.66	96	238	275	323	NA	NA
	2018		40.3	1.19	162	272	354	361	313	NA
Mirror Lake	2012	3N	46.5	4.10	100	160	204	245	NA	NA
	2013		45.5	4.37	104	159	205	235	270	NA
	2014		47.3	1.27	103	185	200	240	NA	NA
	2015		47.1	1.74	125	186	224	237	NA	NA
	2016		43.7	3.43	112	211	253	255	NA	NA
	2017		48.8	3.43	102	158	238	274	252	NA
	2018		49.1	3.40	NA	172	207	242	256	268
Devils Creek Res.	2012	2N	49.1	3.60	121	317	459	NA	NA	NA
	2013		47.0	4.68	115	317	467	500	NA	NA
	2014		45.3	1.08	103	277	449	NA	NA	NA
	2015		44.5	1.87	102	283	NA	NA	NA	NA
	2016		41.3	0.34	116	NA	NA	NA	NA	NA
	2017		46.3	1.12	97	311	NA	NA	NA	NA
	2018		44.3	1.51	NA	298	448	NA	NA	NA
Lower Twin Lake	2012	2N	89.8	3.00	106	293	389	NA	NA	NA
	2013		45.0	1.82	104	289	393	NA	NA	NA
	2014		48.5	0.72	97	263	387	NA	NA	NA
	2015		47.9	7.62	136	320	380	NA	NA	NA
	2016		45.3	1.81	NA	254	332	312	NA	NA
	2017		48.2	1.70	96	266	333	NA	NA	NA
	2018		45.3	0.42	NA	272	393	389	NA	NA

Table 2. Parameter estimates and 95% confidence intervals (CIs) for a linear model that quantified changes in average total length (mm) of kokanee sampled from two treatment (triploid) and two control (diploid) populations since switching to triploid-only stocking (treatment populations only). “Years post switch” (YPS) is a numeric integer variable that reflects 5 subsequent years since switching to triploid fish.

Variable	Ploidy	Estimate	Lower 95% CI	Upper 95% CI
Intercept	--	224.5	220.4	228.7
YPS × Devils Creek Reservoir	Control	9.2	6.0	12.5
YPS × Lower Twin Lake	Control	-4.9	-8.0	-1.8
YPS × Mirror Lake	Treatment	-10.5	-12.3	-8.7
YPS × Montpelier Reservoir	Treatment	8.8	5.0	12.7

Table 3. Parameter estimates and 95% confidence intervals (CIs) for a linear model that quantified changes in average total length (mm) between marked and unmarked kokanee sampled from two treatment (triploid) and two control (diploid) populations since switching to triploid-only stocking (treatment populations only). “Years post switch” (YPS) is a numeric integer variable that reflects 5 subsequent years since switching to triploid fish.

Variable	Ploidy	Estimate	Lower 95% CI	Upper 95% CI
Intercept	--	219.5	204.3	234.7
Thermal mark	--	9.4	-0.3	19.0
YPS × Devils Creek Reservoir	Control	10.7	6.5	14.9
YPS × Lower Twin Lake	Control	11.5	6.8	16.2
YPS × Mirror Lake	Treatment	-6.3	-10.1	-2.5
YPS × Montpelier Reservoir	Treatment	8.0	3.6	12.4

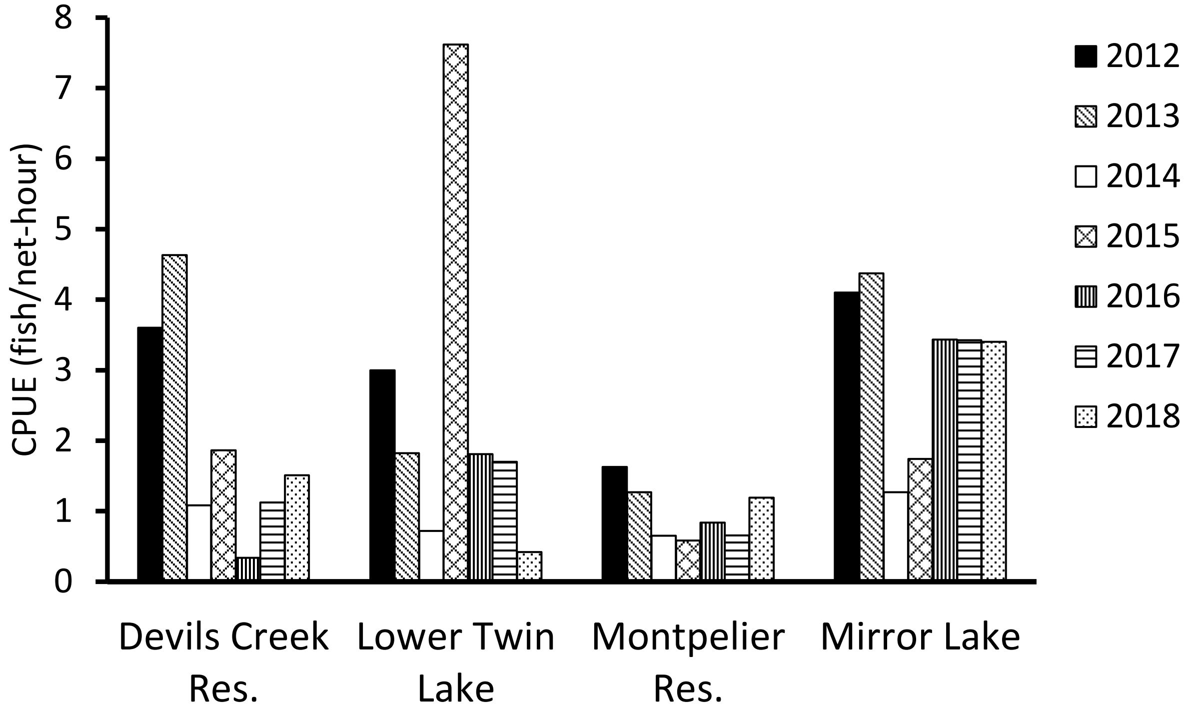

Figure 1. Catch-per-unit-effort (CPUE; fish/net-hour) of kokanee sampled from 2012-2018 among four study waters.

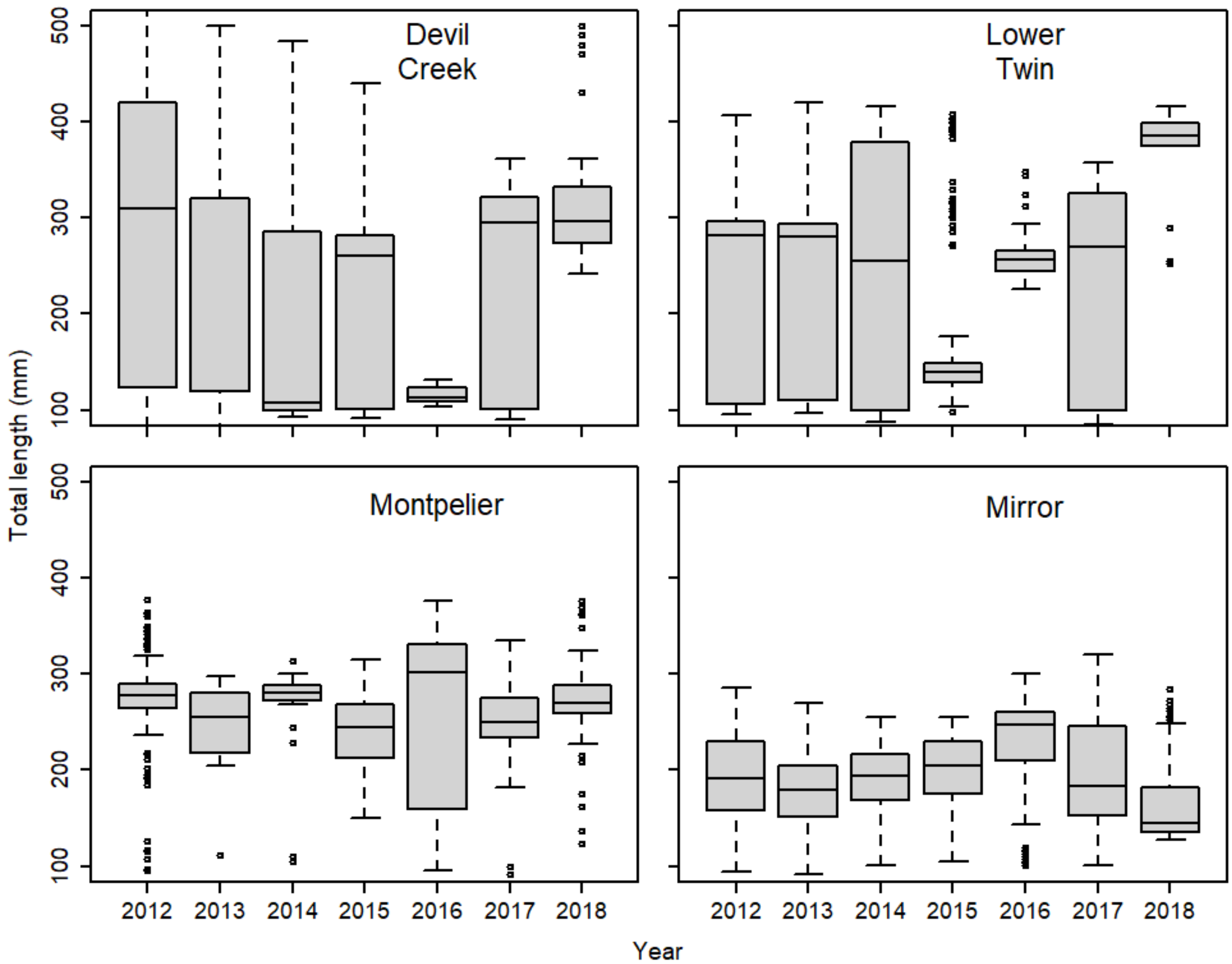

Figure 2. Length distribution of kokanee captured during annual gill net surveys across four populations during the summers of 2012-2018.

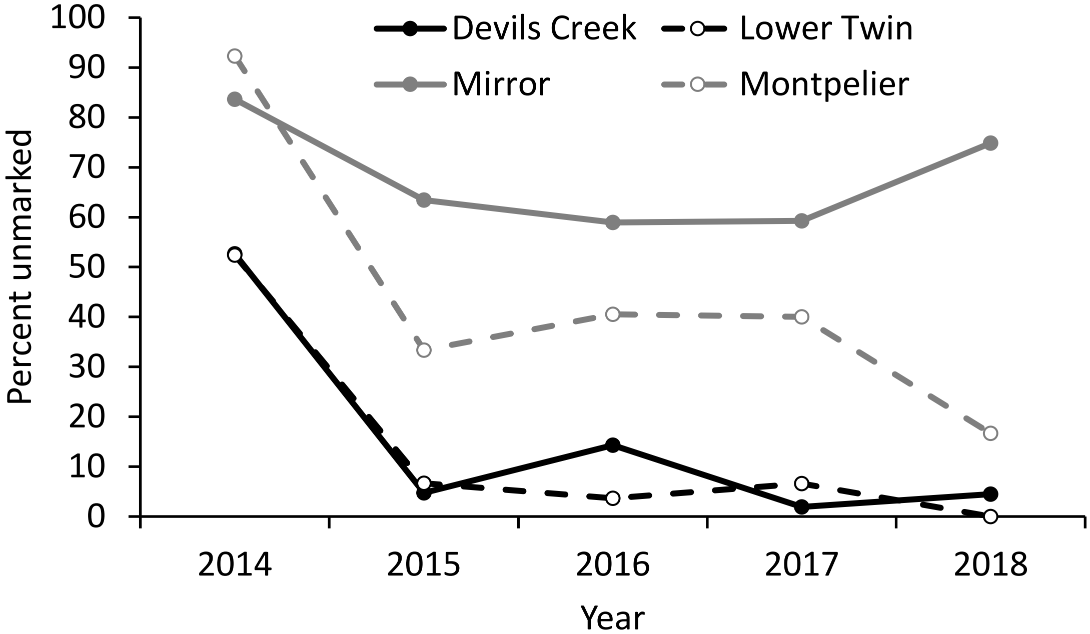

Figure 3. Proportion of unmarked kokanee sampled during annual gill net surveys across 4 water bodies. Data rendered in gray represent water bodies that switched to triploid-only stocking beginning in 2013.

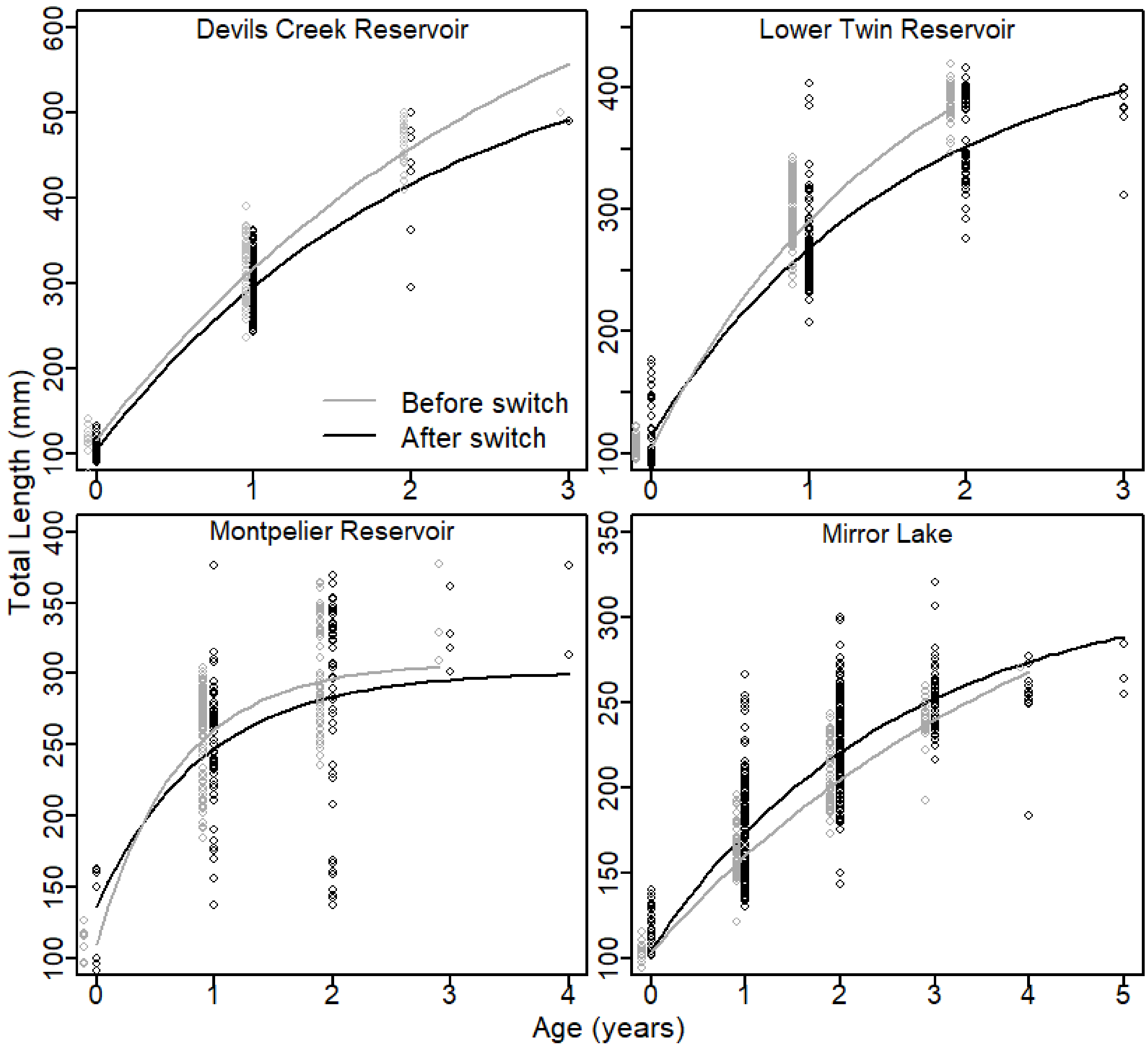

Figure 4. von Bertalanffy growth models applied to kokanee catch data collected before (gray) and after (black) switching to triploid-only stocking. Note: Devils Creek and Lower Twin reservoirs continued to receive diploid kokanee throughout the evaluation, but are included here for reference.

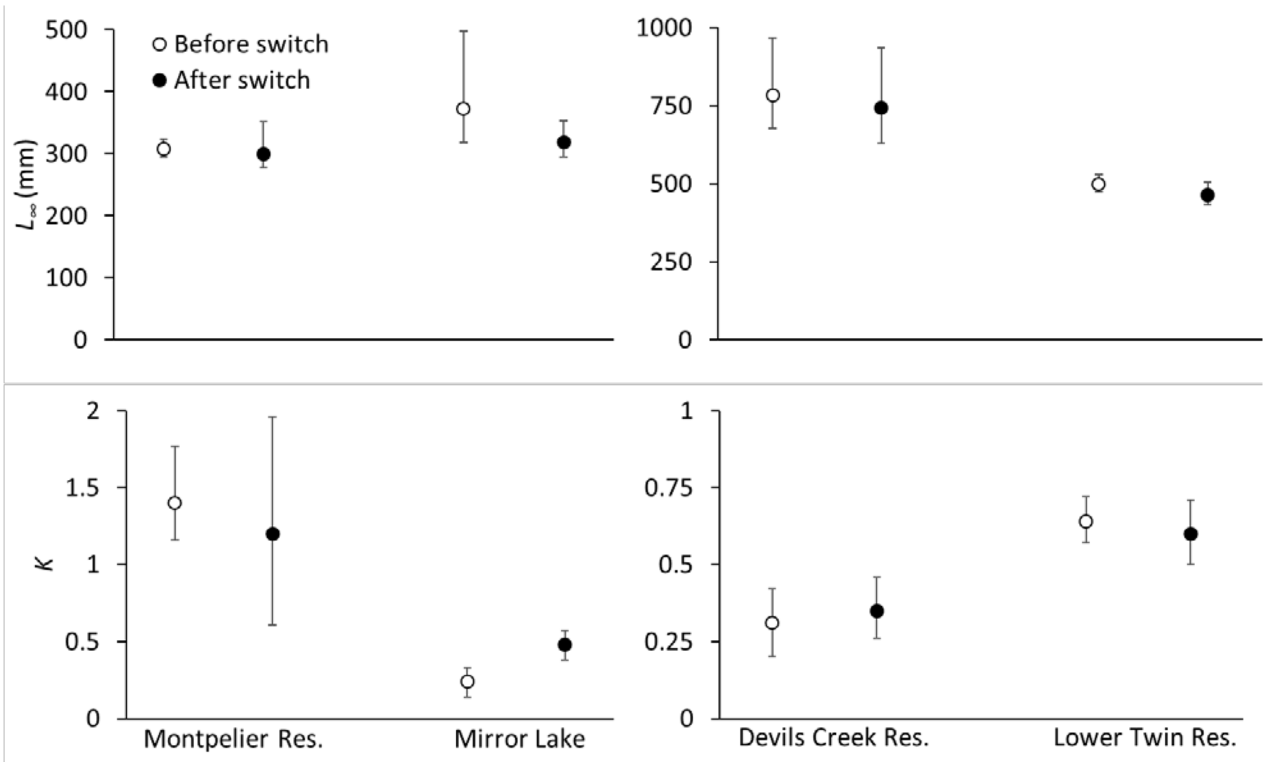

Figure 5. Parameter estimates and 95% confidence intervals (CIs) for two parameters of the von Bertalanffy growth function, L_∞ (top row) and K (bottom row), applied to catch data collected before (white circles) and after (black circles) switching to triploid-only stocking. Note: Devils Creek and Lower Twin reservoirs (right column) continued to receive diploid kokanee throughout the evaluation, but are included here for reference.

ANNUAL PERFORMANCE REPORT

SUBPROJECT #2: EFFECTS OF MOON PHASE ON INDICES OF KOKANEE SIZE AND ABUNDANCE AS MEASURED THROUGH GILL NET CATCH

State of: Idaho

Grant No.: F-73-R-42 Fishery Research

Project No.: 4

Title: Hatchery Trout Evaluations

Subproject #2: Effects of moon phase on indices of kokanee size and abundance as measured through gill net catch

Contract Period: July 1, 2019 to June 30, 2020

ABSTRACT

Many pelagic fish species such as kokanee *Oncorhynchus nerka* undertake diel vertical migration in response to dynamic interactions between ambient light, foraging opportunity, and predation risk. Consequently, kokanee populations are almost universally sampled during the dark phase of the moon (i.e., the new moon), presumably to optimize capture efficiency. However, it is unclear if this sampling precaution is necessary to avoid bias in kokanee catch data related to moon phase. We sampled kokanee populations using experimental gill nets in two thermally stratified reservoirs during three distinct moon phases (i.e., new, first quarter, full) to understand the relative effects of moon phase and other ambient light variables on total catch and average size of captured kokanee. Total catch of kokanee differed significantly between populations, but was not significantly affected by moon phase, secchi depth, or net depth. The average size of kokanee sampled from both populations increased significantly with moon illuminance and likely reflects behavior associated with predator-prey dynamics. Taken collectively, our results suggest that the effect of moon phase and other ambient light variables on gill net catch composition of kokanee is likely population-specific and is governed in part by population parameters such as abundance, growth rate, and size-structure. As such, investigators should be cognizant of—or perhaps standardize gill net samples to—ambient light variables when indexing populations of kokanee and other pelagic fishes that undertake diel vertical migrations, especially when size indices are examined.

Authors:

Phil Branigan
Senior Fisheries Research Biologist

Emily Washburne
Fisheries Technician

Kevin A. Meyer
Principal Fisheries Research Biologist

INTRODUCTION

Kokanee *Oncorhynchus nerka* are the non-anadromous form of Sockeye Salmon that serve as an important fishery resource throughout many oligotrophic freshwater systems in western North America. Like other species of pacific salmon, kokanee achieve maximum ages of 3-4 years in most populations and are capable of providing robust, harvest-oriented sport fisheries that generate high levels of angling effort. In addition, kokanee may also serve as an important forage base for other popular sport fishes that can achieve trophy size, such as Lake Trout *Salvelinus namaycush,* Bull Trout *S. confluentus*, and Rainbow Trout *O. mykiss* (Wydoski and Bennett 1981; Pate et al. 2014).

Due to their ecological and recreational value, many kokanee populations are actively managed to monitor and forecast recreational fisheries. For example, hatchery supplementation is often used to benefit trophy fisheries and (or) enhance fishing and harvest opportunities for kokanee angling. Most stocking programs follow a put-grow-take model, where age-0 fish are stocked as fry or fingerlings that are expected to achieve sizes exploitable by recreational anglers 1-4 years later. However, kokanee growth can be influenced by population density (Rieman and Myers 1992; Luecke et al. 1996), which may affect the size of exploited age classes (Rieman and Maiolie 1995; Grover 2005). Many fisheries management agencies index kokanee populations to evaluate responses to environmental or management perturbations such as changes in reservoir operations, angling regulations, or stocking densities.

Kokanee typically congregate in the pelagic zone of lakes and reservoirs and are susceptible to capture using a variety of sampling gears. In particular, gill net surveys are a relatively inexpensive sampling method that can effectively index population abundance and characterize age and size structure of exploitable size classes of kokanee (Klein et al. 2019). As a passive sampling gear, gill nets rely on movement of fishes to encounter the net and become entangled. Therefore, investigators must be cognizant of the ecology and behavior (e.g., migration patterns) of pelagic fish when conducting population surveys and drawing inferences used to manage and forecast recreational fisheries. In addition, kokanee populations are usually sampled overnight during the dark phase of the moon (i.e., the new moon), presumably to optimize capture efficiency (e.g., Rieman and Myers 1992; Paragamian and Bowles 1995, Stockwell and Johnson 1999; Hardiman et al. 2004; Klein et al. 2019). However, it is unclear if moon phase and other ambient light variables (e.g., secchi depth) significantly affects catch of kokanee sampled during gill net surveys.

OBJECTIVE

1. Sample kokanee populations using gill nets during three distinct moon phases (i.e., new, first quarter, full) to understand the relative effects of ambient light variables on total catch and size structure.

METHODS

<u>Study Sites</u>

Kokanee were captured using monofilament, multi-panel gill nets at two reservoirs located in southern Idaho; Anderson Ranch and Mackay reservoirs. Anderson Ranch Reservoir has a storage capacity of 474,900 acre-feet and surface area of 1,918 hectares. It typically supports a harvest-oriented recreational kokanee fishery, self-sustaining populations of piscivores like Smallmouth Bass *Micropterus dolomieu* and Northern Pikeminnow *Ptychocheilus oregonensis*, as well as a hatchery-supported population of landlocked Chinook Salmon *Oncorhynchus tshawytscha* that may also exert predatory pressure on kokanee behavior. Kokanee have been stocked into Anderson Ranch Reservoir during the spring for decades, with releases varying from 50,000-200,000 individuals, but no kokanee were stocked in 2019. An unknown portion of the kokanee population stems from wild production.

Mackay Reservoir has a storage capacity of 45,000 acre-feet and surface area of 461 hectares. Kokanee and Rainbow Trout comprise the sport fishery, and there are no notable predator populations. Some Rainbow Trout may grow large enough to exhibit piscivory, but their effect on the overall composition of the kokanee population is presumed to be negligible. The kokanee population is largely self-sustaining but in 2019, 95,000 age-0 kokanee were stocked due to production surplus at a nearby hatchery, marking the first stocking event in 10 years.

Field Sampling

Surveys occurred in June and July of 2019 when both reservoirs were thermally stratified and before mature kokanee began spawning emigrations. The vertical distribution of kokanee and other pelagic fish in lentic systems is thought to be governed by complex interactions between fish size, thermal stratification, and predator-prey dynamics (Luecke and Wurtsbaugh 1993; Stockwell and Johnson 1997, 1999; Hardiman et al. 2004.). As such, we limited this evaluation to periods when both reservoirs were thermally stratified. Secchi depth (m) was measured at the beginning of each sampling event to quantify turbidity, which affects light attenuation (Kirk 1985). Both populations were sampled three times each month during each occurrence of the new, first quarter, and full moon phases (± 2 days).

Pairs of gill nets were positioned at unique depths and oriented in parallel (within 50 m) to sample a localized two-dimensional area. This approach afforded the opportunity to account for the progressive absorption of light through the water column while minimizing any differences in ambient light conditions experienced in other relative space (i.e., positions in the reservoir, proximity to shoreline, etc.). One net in each pair was positioned immediately beneath the water surface (hereafter “surface net”) and the other was suspended at a depth that intersected the thermocline (hereafter “thermocline net”). Both reservoirs experience high levels of angling and boating traffic, so the float line of all surface nets was positioned 1.5 m below the surface of the water. We identified the depth of the thermocline by slowly lowering a thermometer (Vernier Software & Technology; Beaverton, OR, USA) in 0.5-m increments and observing changes in the temperature profile. Thermocline depth varied throughout the sampling period and thermocline nets were positioned such that the horizontal center line of the net aligned with the depth of the thermocline.

Each net measured 54 m wide, 6 m deep, and was constructed with 4.5 m-wide sections of monofilament mesh panels consisting of 20-, 25-, 32-, 38-, 51-, and 64-mm bar measure mesh (2 panels per net). Monofilament diameter size was 0.15 mm for 20-, 25-, and 32-mm mesh and 0.28 mm for 38-, 51-, and 64-mm mesh. Sampling locations were randomly selected for each water body initially, and those same locations were repeated during each sampling event (i.e., moon phase). Two sets of net pairs (i.e., 4 total nets) were deployed at Anderson Ranch Reservoir, whereas one pair (2 nets) was deployed at Mackay Reservoir due to elevated catch. All gill nets were positioned at respective depths in the evening and retrieved the following morning in the order that they were deployed. Fish captured from each net were identified and measured for total length (TL) to the nearest millimeter. Kokanee comprised the vast majority (~85%) of the catch, and all other species were removed from further analysis for this study.

Data Analysis

Catch and environmental data were summarized by moon phase, net depth, and fishery to describe patterns in catch and evaluate differences among samples. Means were calculated to describe patterns in catch and inform regression models. Relative abundance (catch-per-unit-effort; CPUE) was estimated as the total number of fish caught in surface and thermocline nets divided by the total number of nets fished at each depth (i.e., fish/net night) during each lunar phase.

Negative binomial regression models were fit to evaluate the relative effects of ambient light variables on total catch of kokanee. A suite of candidate models were developed *a priori* using moon phase (i.e., light intensity), secchi depth (i.e., light penetration), and net depth (surface or thermocline) as predictor variables, whereby each gill net served as the sampling unit. Each candidate model included a fixed term for fishery and an offset term for gill net fishing effort (measured to the nearest minute) to account for inherent differences between the populations (e.g., stocking regimes, angler harvest, reservoir operation) and the amount of time that each net fished. In addition, a null model that contained only an offset term for fishing effort was included in the candidate set to evaluate the relative effects of ambient light variables versus random chance. Moon phase and secchi depth could not be included as additive or interactive terms in any single model due to lack of replication between the range of secchi depths measured and lunar phases sampled. Instead, moon phase and secchi depth were isolated among models to determine the relative importance of light intensity versus light penetration on gill net catch. Interactions between moon phase × net depth and secchi depth × net depth were included in the candidate suite to account for variation associated with the progressive attenuation of light that occurs through the water column.

Another suite of linear regression models were fit to evaluate the relative effects of ambient light variables on the average size of kokanee captured. Total length (mm) of each captured kokanee was used as the unit of observation, and candidate models were developed using the same *a priori* combinations of predictor terms that were included in the negative binomial suite, including a null model (see above). Moon phase and secchi depth remained segregated among candidate models, and each model in the candidate set included a fixed term for fishery (except the null).

Akaike's Information Criterion (AIC) was used to determine the relative likelihood of each model in the negative binomial and linear regression model suites. Any models within 2.0 AIC units of that with the lowest AIC value (i.e., the top model) were selected as plausible alternates to explain patterns in gill net catch (Burnham and Anderson 2002). Regression coefficients for the top negative binomial models were exponentiated to interpret the effect of each parameter on the odds scale. All regression coefficients were deemed statistically significant if their 95% confidence interval (CI) excluded one.

RESULTS

In total, 36 nets were fished overnight during the course of two lunar cycles (Table 4). Secchi depth differed between reservoirs throughout the sampling period, varying from 2.5 to 5.2 m (mean = 3.5 m; SD = 1.0) at Anderson Ranch Reservoir and from 1.5 to 2.7 m (mean = 2.2 m;

SD = 0.4) at Mackay Reservoir. Thermocline depths ranged from 3.7 to 9.1 m (mean = 6.0; SD = 1.7) at Anderson Ranch Reservoir and from 3.7 to 7.9 m (mean = 5.6 m; SD = 1.6) at Mackay Reservoir. Net soak times varied from 11 hours and 50 minutes to 15 hours and 31 minutes.

A total of 3,242 fish was captured during the study period, with kokanee comprising the vast majority of the catch at both reservoirs (*n* = 2,729). In general, kokanee CPUE varied between nets (i.e., surface or thermocline nets) and fishery (Figure 6). Mean length (± SD) of kokanee sampled from Anderson Ranch Reservoir was 367 mm (± 111), whereas the mean length in Mackay Reservoir was 233 mm (± 51).

The most plausible negative binomial regression models explaining variation in kokanee gill net catch contained factors associated with ambient light variables. The top negative binomial model associated with kokanee CPUE included secchi depth and net depth, which represented 49% of the AIC weight (i.e., relative likelihood) of all models in the candidate suite (Table 5). An alternate model included moon phase and net depth, and accounted for 36% of the relative AIC weight in the negative binomial suite. However, the 95% CIs associated with parameters in both models indicated that fishery was the only significant variable associated with total catch of kokanee during this study (Table 6).

Length-frequency distributions were similar among moon phases in both populations, but an appreciable decline in catch was observed for the largest mode during the full moon at Mackay Reservoir (Figure 7). The top linear regression model explaining variation in mean size of kokanee in the gill net catch accounted for 80% of AIC weight, and included moon phase, net depth, and fishery for predictive factors (Table 7). The 95% CIs associated with the parameter estimates indicated that average length of kokanee was significantly greater in nets set during the first quarter and full moon than during the new moon, but did not differ significantly between the surface and thermocline nets (Table 8). In addition, the average length of kokanee sampled from Mackay Reservoir was significantly smaller than those sampled from Anderson Ranch Reservoir. There was virtually no support for any other plausible models.

DISCUSSION

Anderson Ranch and Mackay reservoirs support kokanee populations that differ in relative abundance, and overnight gill net catch used to characterize abundance at these waters was apparently unaffected by nighttime ambient light. Although the results of the negative binomial model selection process suggest that secchi depth, net depth, and moon phase served as better predictors of total catch than random chance, the only parameter that was considered significant in any of the most plausible models was the fishery being sampled. The lack of evidence that moon phase affected kokanee gill net catch contrasts results from the commercial gill net fishery of Lake Huron, where average CPUE of Lake Whitefish *Coregonus clupeaformis* declined appreciably during the full moon (Collins 1979). As noted earlier, kokanee fisheries are generally monitored overnight during the new moon due to a perceived moon phase influence on catch (e.g., Rieman and Myers 1992; Paragamian and Bowles 1995, Stockwell and Johnson 1999; Hardiman et al. 2004; Klein et al. 2019). Such a sampling scheme greatly restricts when kokanee population monitoring can be conducted on a monthly basis, and our results suggest that perhaps the practice of restricting kokanee gill net sampling to the new moon phase can be relaxed with respect to indices of abundance. However, our inference related to kokanee CPUE is admittedly not robust with respect to sample size, and we caution against such relaxation until future research can be conducted to qualify the current findings.

In contrast to indices of kokanee abundance, indices of kokanee size structure were influenced by moon phase, whereby the average size of kokanee sampled increased with moon illuminance. *O. nerka* diel vertical migration patterns are well-linked to the dynamics between predator-prey interactions and ambient light conditions (Narver 1970; Levy 1990; Beauchamp et al. 1995; Scheuerell and Schindler 2003; Hardiman et al. 2004). As such, indices of size structure in kokanee populations gleaned through gill net catch may be disparate if samples are not standardized by moon phase. Despite this finding, the effect size of Mackay Reservoir in the top linear regression model was an order of magnitude larger than moon phase and net depth, indicating that moon phase and net depth had a much smaller effect on fish size than the effect of waterbody.

Tradeoffs between foraging opportunities and predation risk likely drive a species' propensity to undertake diel vertical migrations, and although the proximate causes and mechanisms may be unknown, vertical migration unquestionably influences the visual environment. Feeding rates of planktivorous fish are substantially higher in well-lit conditions than in the dark (Ryer and Olla 1999), but feeding efficiency is reduced in turbid environments (De Robertis et al. 2003). Turbidity has a light-scattering affect that impairs visual clarity and is associated with increases in the magnitude and duration of diel vertical migrations in freshwater systems (Hansen and Beauchamp 2015). The lack of replication among secchi depths measured and moon phases sampled precluded our ability to include both variables in the same model and evaluate their interactive effects. For instance, the interaction between moon light intensity and secchi depth can account for up to 84% of the variation in diel vertical migration amplitude for zooplankton in freshwater systems (Dodson 1990). Diel patterns of kokanee and Bonneville Cisco *Prosopium gemmifer* populations in Bear Lake, Utah-Idaho border have demonstrated that diel vertical migrations and other foraging movements (e.g., schooling) are minimized in response to increased moon illuminance (Luecke and Wurtsbaugh 1993). Interestingly, angler catch of high-profile piscivores like Northern Pike *Esox Lucius* and Muskellunge *E. masquinongy* is maximized during the full moon as well as the new moon (Kuparinen et al. 2010; Vinson and Angradi 2014), suggesting that predator populations will capitalize on the overall effects of the entire lunar cycle as it relates to foraging opportunity.

As a passive sampling technique, the catchability of kokanee in gill nets is directly related to their movement and eventual entanglement. In light of current study and previous empirical evaluations, it seems prudent to measure ambient light variables such as moon phase, net depth, and secchi depth when indexing pelagic fish populations with gill nets to account for factors that may affect their movement and associated capture. Accounting for these ambient light variables may serve to explain differences in catch composition among sampling events. Considering the significant effect of waterbody related to total catch and average size of kokanee sampled, gill net catch metrics for some populations may respond differently to ambient light variables due to inherent population-level differences in abundance, growth rate, and size-structure. We encourage future studies to further evaluate the interactive effects of moon phase and secchi depth as it relates to sampling pelagic fish populations with passive sampling gears over a broader temporal distribution (i.e., multiple years). Such inquiry may further elucidate sources of variation related to gill net CPUE and improve the precision of annual population indices that are used to forecast recreational fisheries or measure changes in management strategies.

MANAGEMENT RECOMMENDATIONS

1. If evaluating size-structure, conduct annual kokanee gill net surveys around the timing of the new moon to maximize representation of all relevant size-classes.

2. More thoroughly investigate moon phase impacts on kokanee gill net catch with a larger sample size (more waters sampled over more than one year) to more conclusively determine whether sampling on the new moon is needed in Idaho waters for consistent characterization of kokanee populations.

ACKNOWLEDGEMENTS

A special thanks goes B. Marciniak, J. Besson. J. Unsworth, J. Valdez, H. Reynolds, K. Ballinger, and others who assisted with field sampling. We also thank J. McCormick and L. Chiaramonte for providing assistance with the development of our analytical approach. I also thank Tim D'Amico for editing this report. Funding for this work was provided by anglers and boaters through their purchase of Idaho fishing licenses, tags, and permits, and from federal excise taxes on fishing equipment and boat fuel through the Sport Fish Restoration Program.

LITERATURE CITED

Beauchamp, D. A., M. G. LaRiviere, and G. L. Thomas. 1995. Evaluation of competition and predation as limits to juvenile kokanee and sockeye salmon production in Lake Ozette, Washington. North American Journal of Fisheries Management 15:193–207.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer-Verlag, New York.

Collins, J. J. 1979. Relative efficiency of multifilament and monofilament nylon gill net towards Lake Whitefish (*Coregonus clupeaformis*) in Lake Huron. Journal of the Fisheries Research Board of Canada 36:1180-1185.

De Robertis, A., C. H. Ryer, A. Veloza, and R. D. Brodeur. 2003. Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. Canadian Journal of Fisheries and Aquatic Sciences 60:1517-1526.

Dodson, S. 1990. Predicting diel vertical migration of zooplankton. American Society of Limnology and Oceanography 35(5):1995-2000.

Grover, M. C., 2005. Changes in size and age at maturity in a population of kokanee *Oncorhynchus nerka* during a period of declining growth conditions. Journal of Fish Biology 66: 122–134

Hansen, A. G., and D. A. Beauchamp. 2015. Latitudinal and photic effects on diel foraging and predation risk in freshwater pelagic ecosystems. Journal of Animal Ecology 84:532-544.

Hardiman, J. M., B. M. Johnson, and P. J. Martinez. 2004. Do predators influence the distribution of age-0 kokanee in a Colorado reservoir? Transactions of the American Fisheries Society 133:1366–1378.

Kirk, J. T. O. 1985. Effects of suspensoids (turbidity) on penetration of solar radiation in aquatic ecosystems. Hydrobiologia 125:195-208.

Klein, Z. B., M. C. Quist, A. M. Dux, and M. P. Corsi. 2019. Size selectivity of sampling gears used to sample kokanee. North American Journal of Fisheries Management 39:343–352.

Kuparinen, A., T. Klefoth, and R. Arlinghaus. 2010. Abiotic and fishing-related correlates of angling catch rates in pike (*Esox Lucius*). Fisheries Research 105:111-117.

Levy, D. A. 1990. Sensory mechanism and selective advantage for diel vertical migration in juvenile sockeye salmon *Oncorhynchus nerka*. Canadian Journal of Fisheries and Aquatic Sciences 47:1796– 1802.

Luecke, C., and W. A. Wurtsbaugh. 1993. Effects of moonlight and daylight on hydroacoustic estimates of pelagic fish abundance. Transactions of the American Fisheries Society 122:112-120.

Luecke, C., W. A. Wurtsbaugh, P. Budy, H. P. Gross, and G. Steinhart. 1996. Simulated growth and production of endangered Snake River Sockeye Salmon: assessing management strategies for the nursery lakes. Fisheries 21:18-25.

Narver, D. W. 1970. Diel vertical movement and feeding of underyearling sockeye salmon and limnetic zooplankton in Babine Lake, British Columbia. Journal of the Fisheries Research Board of Canada 27:281–316.

Paragamian, V. L., and E. C. Bowles. 1995. Factors affecting survival of kokanees stocking in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 15:208-219.

Pate, W. M., B. M. Johnson, J. M. Lepak, and D. Brauch. 2014. Managing for coexistence of kokanee and trophy Lake Trout in a montane reservoir. North American Journal of Fisheries Management 34:908–922.

Rieman, B. E., and M. A. Maiolie. 1995. Kokanee population density and resulting fisheries. North American Journal of Fisheries Management 15:229–237.

Rieman, B. E., and D. L. Myers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society 121:178–191.

Ryer, C. H., and B. L. Olla. 1999. Light-induced changes in the prey consumption and behavior of two juvenile planktivorous fish. Marine Ecology Progress Series 181:41-51.

Scheuerell, M. D., and D. E. Schindler. 2003. Diel vertical migration by juvenile sockeye salmon: empirical evidence for the antipredation window. Ecology 84:1713–1720.

Stockwell, J. D., and B. M. Johnson. 1997. Refinement and calibration of a bioenergetics-based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 54:2659-2676.

Stockwell, J. D., and B. M. Johnson. 1999. Field evaluation of a bioenergetics-based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 56(Supplement 1):140–151.

Vinson, M. R., and T. R. Angradi. 2014. Muskie lunacy: does the lunar cycle influence angler catch of Muskellunge (*Esox masquinongy*)? PLoS ONE 9: e98046. doi:10.1371/journal.pone.0098046

Wydoski, R. S., and D. H. Bennett. 1981. Forage species in lakes and reservoirs of the western United States. Transactions of the American Fisheries Society 110:764–771.

Table 4. Data type and means (± SD) for variables measured during three distinct moon phases in June and July 2019 at Anderson Ranch and Mackay reservoirs. Data informed negative binomial and linear models developed to describe patterns in total catch and average size of kokanee sampled during gill net surveys.

		Anderson Ranch Reservoir			Mackay Reservoir		
Variable	Data type	New	First quarter	Full	New	First quarter	Full
Surface net depth (m)	Categorical	1.5 (± 0.0)	1.5 (± 0.0)	1.5 (± 0.0)	1.5 (± 0.0)	1.5 (± 0.0)	1.5 (± 0.0)
Thermocline net depth (m)	Categorical	6.4 (± 2.9)	5.6 (± 0.5)	6.1 (± 0.0)	5.8 (± 0.4)	5.8 (± 2.5)	5.2 (± 1.8)
Secchi depth (m)	Continuous	3.3 (± 0.8)	3.9 (± 1.4)	3.3 (± 0.7)	2.6 (± 0.1)	1.8 (± 0.4)	2.3 (± 0.3)
Effort (hours)	Continuous	13.4 (± 1.1)	14.5 (± 0.5)	14.7(± 0.5)	12.9 (± 0.6)	14.3 (± 1.4)	13.2 (± 0.8)

Table 5. Comparison of negative binomial models used to assess the relative effects of ambient light variables on total catch of kokanee sampled with gill nets. Number of parameters (*k*), Akaike's Information Criterion (AIC), change in AIC value (ΔAIC), and relative model weight (w_i) was used to select top models from the candidate set.

Model	***k***	**AIC**	**ΔAIC**	w_i
Catch ~ Secchi depth + Net depth + Fishery	3	326.8	0.0	0.49
Catch ~ Moon phase + Net depth + Fishery	3	327.4	0.6	0.36
Catch ~ Secchi depth × Net depth + Fishery	4	329.5	2.7	0.13
Catch ~ Moon phase × Net depth + Fishery	4	332.9	6.1	0.02
Intercept only	0	389.3	62.5	0.00

Table 6. Coefficient estimates (i.e., odds) and 95% CIs for the most highly supported negative binomial regression models used to estimate total catch of kokanee sampled with experimental gill nets from Anderson Ranch and Mackay reservoirs. Nets were positioned 1.5 m below the surface or at the depth of the thermocline and fished overnight during three distinct moon phases. Thermocline net, New moon, and Anderson Ranch Reservoir serve as the reference categories for net depth, moon phase, and fishery.

Coefficient	**Estimate**	**95% CI**
Catch ~ Secchi depth + Net depth + Fishery		
Intercept	1.35	0.66–2.79
Secchi depth	1.01	0.83–1.22
Surface net	0.95	0.68–1.33
Mackay reservoir	10.62	6.81-16.59
Catch ~ Moon phase + Net depth + Fishery		
Intercept	1.42	1.01–2.03
First quarter moon	1.12	0.76–1.66
Full moon	0.82	0.55–1.22
Surface net	0.97	0.70–1.33
Mackay reservoir	10.14	7.30–14.22

Table 7. Comparison of linear regression models used to assess the relative effects of ambient light variables on average length of kokanee sampled with gill nets. Number of parameters (*k*), Akaike's Information Criterion (AIC), change in AIC value (ΔAIC), and relative model weight (w_i) was used to select top models from the candidate set.

Model	***k***	**AIC**	**ΔAIC**	$\boldsymbol{w_i}$
Length ~ Moon phase + Net depth + Fishery	3	30,469.6	0.0	0.80
Length ~ Moon phase × Net depth + Fishery	4	30,530.4	3.0	0.20
Length ~ Secchi depth + Net depth + Fishery	3	30,466.7	61.7	0.00
Length ~ Secchi depth × Net depth + Fishery	4	30,528.4	63.7	0.00
Intercept only	0	31,800.3	1,333.6	0.00

Table 8. Coefficient estimates and 95% CIs for a linear model used to evaluate the effect of moon phase (new, first quarter, full) and net depth on average length of kokanee sampled from Anderson Ranch and Mackay Reservoirs, Idaho. Experimental gill nets were positioned 1.5 m below the surface or at the depth of the thermocline and fished overnight during three distinct moon phases. New moon, thermocline net, and Anderson Ranch Reservoir serve as the reference categories for moon phase, net depth, and fishery.

Coefficient	**Estimate**	**95% CI**
Total length ~ Moon + Net depth + Fishery		
Intercept	350.25	342.88 – 357.61
First quarter moon	17.55	12.04 – 23.07
Full moon	27.35	20.75 – 33.94
Surface net	2.14	-2.73 – 7.01
Mackay Reservoir	-131.50	-137.97 – -125.02

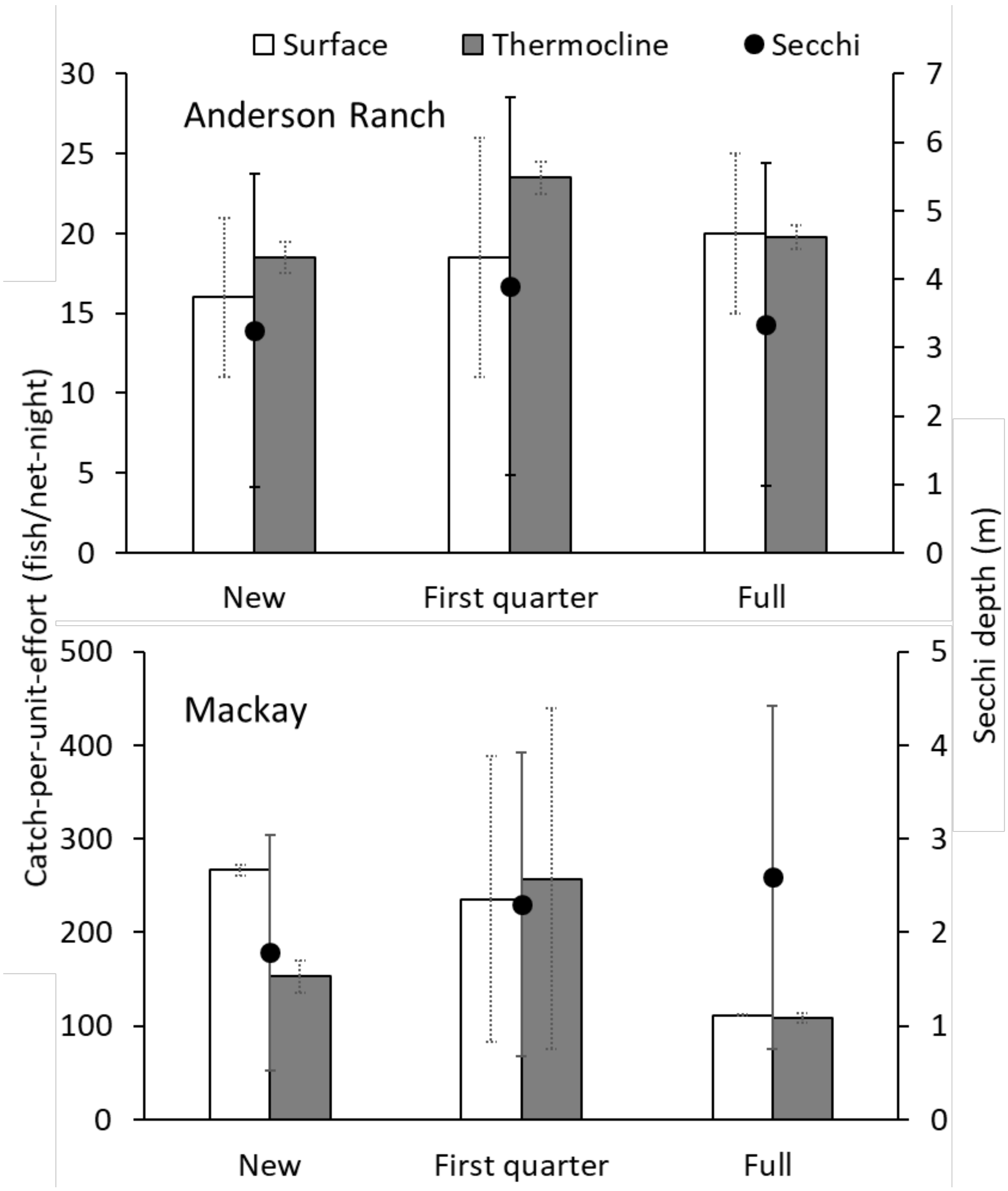

Figure 6. Mean catch-per-unit-effort (± SE) of kokanee and mean secchi depth sampled from Anderson Ranch and Mackay reservoirs in June and July 2019 during the new, first quarter, and full moon phases. Nets were positioned at 1.5m below the water's surface (i.e., white bars) or at the depth of the thermocline (i.e., gray bars) and fished overnight.

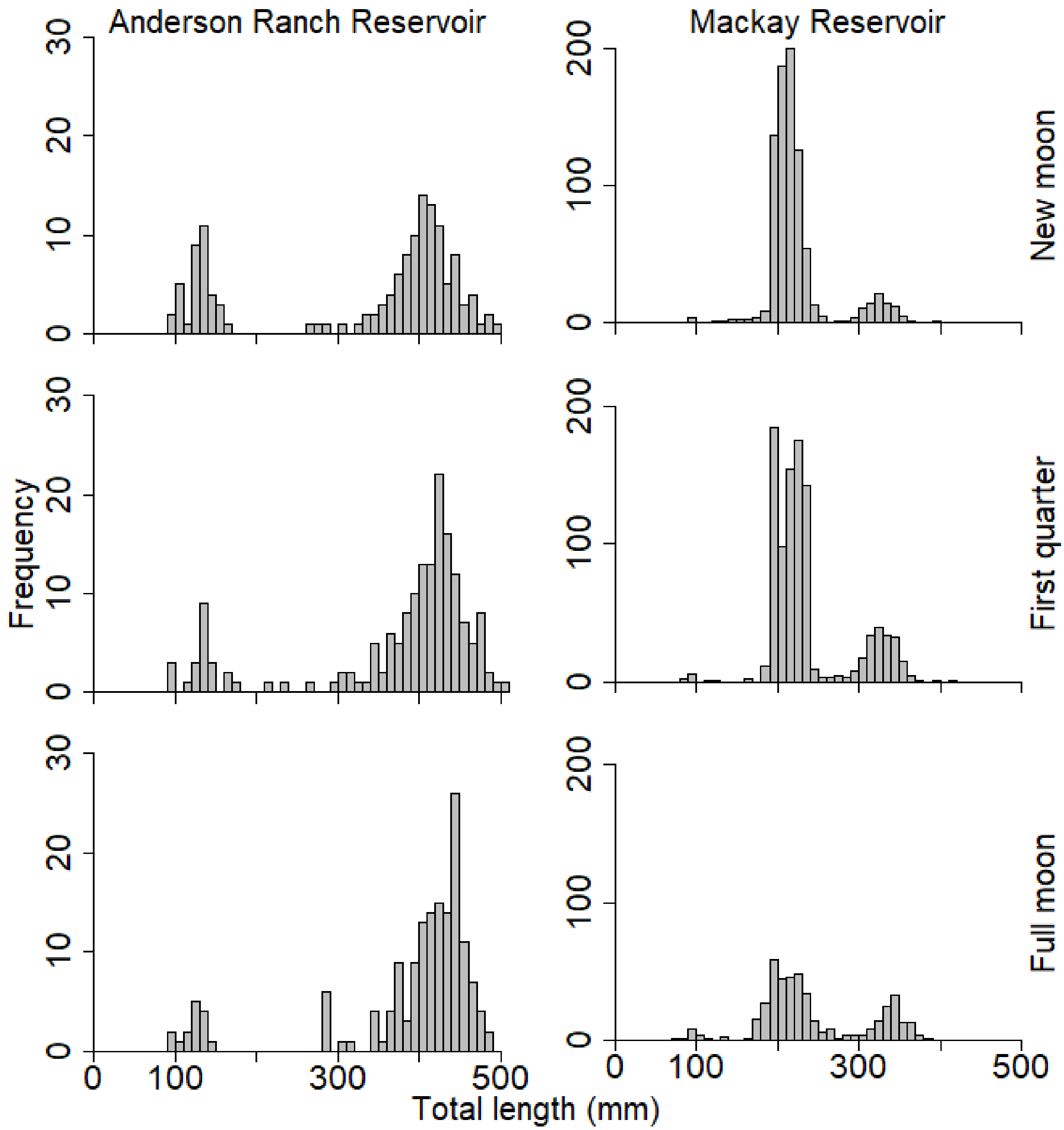

Figure 7. Length-frequency histograms for kokanee sampled from Anderson Ranch and Mackay reservoirs using experimental gill nets in June and July 2019 during the new, first quarter, and full moon phases.

ANNUAL PERFORMANCE REPORT

SUBPROJECT #3: EFFECTS OF BAFFLES ON RACEWAY CLEANING, FIN EROSION, IN-HATCHERY SURVIVAL, AND POST-RELEASE ANGLER CATCH OF CATCHABLE-SIZED HATCHERY RAINBOW TROUT

State of: Idaho

Grant No.: F-73-R-42 Fishery Research

Project No.: 4

Title: Hatchery Trout Evaluations

Subproject #3: Effects of baffles on raceway cleaning, fin erosion, in-hatchery survival, and post-release angler catch of catchable-sized hatchery Rainbow Trout

Contract Period: July 1, 2019 to June 30, 2020

ABSTRACT

Hatchery fish exposed to exercise training often exhibit physiological and behavioral benefits compared to unexercised fish, but results from previous studies have been equivocal, and have rarely examined post-release performance of stocked fish. We evaluated various in-hatchery and post-release consequences of rearing catchable-sized (~254 mm) Rainbow Trout *Oncorhynchus mykiss* in a raceway installed with baffles, the intent being to self-clean the raceway and exercise fish. Installing baffles increased water velocities experienced by fish, with some velocities exceeding 0.26 m/s (1.0 body-lengths-per-second [BLS]). In contrast, the maximum velocity experienced by fish in the control raceway was 0.07 m/s (0.27 BLS). Prior to stocking, fin erosion (as measured by relative dorsal and pectoral fin lengths) did not differ between the baffled and unbaffled raceways, but surprisingly, survival was reduced for baffled fish. Catch by anglers and mean time-to-capture did not differ between raceways, but did differ by water type (i.e., lentic, lotic, and community pond waters). While the augmented velocities along the bottom of the baffled raceway assisted with clearing some fish waste, they were not entirely effective and still required some raceway sweeping. Taken collectively, our results suggest that installing baffles in production-scale raceways rearing catchable-sized trout is not advantageous.

Authors:

Kevin A. Meyer
Principal Fisheries Research Biologist

Phil Branigan
Senior Fisheries Research Biologist

John Cassinelli
Regional Fisheries Manager

INTRODUCTION

Catchable-sized hatchery trout (~254 mm total length; henceforth, “catchables”) are an important component of many fisheries management programs in North America because they instantly provide fisheries once they are stocked. This is especially important in habitats such as impounded reservoirs and community fishing ponds, which typically do not support self-sustaining trout populations, and often do not provide adequate conditions over a sufficient time period for put-and-grow fisheries to develop (Trushenski et al. 2010). In lotic waters, stocking may be needed to meet public demands and political pressures exerted on government agencies to provide sportfish harvest opportunity above the levels that self-sustaining fish populations can provide. However, while catchable stocking programs are popular among anglers, hatchery operation and transport costs associated with catchable rearing and stocking are nevertheless expensive (Losee and Phillips 2017; Hunt et al. 2017; Branigan et al. 2021). Consequently, numerous hatchery rearing and stocking practices associated with catchable programs have been investigated for decades as a means of maximizing program efficiencies (e.g., Mullan 1956; Larmoyeux and Piper 1973; Elrod et al. 1989; Banks and LaMotte 2002; Barnes et al. 2009; Cassinelli et al. 2016; Cassinelli and Meyer 2018). One such practice is exercising fish during rearing, which has been widely studied (see reviews in Davison 1989, 1997; Hammer 1995; Kieffer 2000).

Prior studies have suggested that exercising salmonids can provide several benefits to the fish being cultured. For example, hatchery trout exposed to continuous velocities of 1-2 body lengths per second (BLS) for several weeks had higher growth and lower feed conversion ratios than fish reared under normal conditions (Leon 1986; Houlihan and Laurent 1987; Christiansen et al. 1989, 1992; Christiansen and Jobling 1990; Nielsen et al. 2000; Azuma 2001). Exercising hatchery salmonids may also increase post-release swimming performance relative to unexercised fish (Besner and Smith 1983; Farrell et al. 1990; McDonald et al. 1998), making them better able to escape predators as well as pursue prey. Additionally, exercise training may reduce aggressive behavior as fish form schools at higher swimming velocities (Davison 1997), which may reduce fin nipping and therefore curb fin erosion (Kindschi et al. 1991; but see Barnes et al. 1996). Finally, sustained exercise training may lower lactate and cortisol levels in fish both at rest (Young and Cech 1994a) and after stressful events (Lackner et al. 1988; Young and Cech 1993a). While these and other studies have demonstrated benefits to hatchery fish from exercise training, some studies have shown no such benefit. For example, Gamperl and Stevens (1991) and Gamperl et al. (1991) found no difference between the swimming ability or muscle composition of exercised Rainbow Trout *Oncorhynchus mykiss* and control fish. However, the training regimen in these latter two studies differed from most other investigations in that fish were forced to sprint to total exhaustion for 30 sec every other day (for 4-12 weeks) rather than exercising fish with slower velocities (i.e., 1-2 BLS) for longer periods of time.

Although the effects of exercise training on various behavioral and physiological parameters have been well studied, fewer investigations have examined the effect that exercise training has on the post-release survival or angler catch of stocked fish. In one such study, fall Chinook Salmon *O. tshawytscha* fingerlings subjected to an exercise period of unrecorded duration and speed increased their swimming performance by 35% compared to control fish, and adult returns from the ocean were 62% higher for exercised fish compared to control fish (Burrows 1969). Similar results from exercise training have been observed for juvenile Atlantic Salmon *Salmo salar* (Wendt and Saunders 1973) and catchable Brown Trout *S. trutta* (Cresswell and Williams 1983) but not for Coho Salmon *O. kisutch* (Lagasse et al. 1980) or juvenile steelhead *O. mykiss* (Evenson and Ewing 1993). However, the latter study exercised fish via raceway drawdown, which may be a poor way to train fish and instead may act as a stressor to fish

(Davison 1997). We are aware of only one study investigating post-release performance of exercise-trained catchable-sized trout (i.e., Cresswell and Williams 1983), which demonstrated that ~200 mm Brown Trout exercised at 0.1 m/s (or 0.5 BLS) and stocked in small streams were caught by anglers at ~20% higher rate than unexercised fish, but those exercised at velocities of 0.24 m/s (1.2 BLS) were caught at the same rate as unexercised fish.

Besides potential physical and physiological benefits for catchables held in raceways with elevated water velocities, an additional benefit of raceway baffles is the potential to remove solid waste from the raceway floor, which could reduce or negate the need for manual cleaning. Indeed, baffles installed throughout the length of a raceway, that are spaced approximately equal to the width of the raceway and that contain a small gap between the bottom of the baffle and raceway floor, will inherently increase water velocity along the bottom of the raceway (Boersen and Westers 1986). Under such conditions, the bulk of any waste products may be washed towards the outflow, reducing the volume of waste remaining in the raceway that hatchery personnel must periodically mobilize manually (Kindschi et al. 1991).

The variable water velocities and microhabitats potentially created by raceway baffles may therefore not only reduce the need for manual cleaning, but the baffles may also provide a rearing environment more similar to that of natural conditions. However, few studies have been conducted to evaluate whether such benefits are realized at a production scale.

OBJECTIVE

1. Determine whether the use of baffles in a production raceway rearing catchable Rainbow Trout for sportfish stocking programs would: increase the average and variation in water velocities within the raceway; reduce in-hatchery fin erosion; improve in-hatchery survival; increase post-release angler catch of stocked catchables; prolong the fishery by increasing the number of days stocked fish were at-large before being caught by anglers; curtail the effort needed to clean the raceway (a desired by-product of increasing water velocity).

METHODS

Catchable Rainbow Trout from the Idaho Department of Fish and Game’s (IDFG) Hayspur Hatchery broodstock strain (mixed-sex triploids) were raised in two consecutive years. Eyed-eggs were shipped to Nampa Fish Hatchery in April of 2016 and 2017, surface-disinfected in an iodophor bath, and transferred into upwelling incubators to hatch. Hatching occurred 14-16 days after arrival, and exogenous feeding was initiated about 9 days later. All of the water supply at Nampa Fish Hatchery is spring-fed at 15°C and is not recirculated.

Hatched fish were first reared in small concrete outdoor raceways (7.6 × 1.5 × 0.6-m sections) and fed using a combination of hand-feeding and belt feeders on a 12-h timer. After reaching approximately 80 mm in total length (TL; in early October of each year), fish were inventoried and moved to large outdoor concrete raceways (30 × 3.7 × 1.1-m sections) and fed with a tractor-pulled feed cart three times per day. We used commercial floating extruded pellet feed, which consisted of a formula of 55% protein and 17% fat from hatching until fish reached 80 mm, after which the formula was changed to 45% protein and 16% fat until stocking occurred. The feeding rate was approximately 4% body weight/d in the early stages and gradually decreased to 1.5% body weight/d as the fish approached the targeted size for stocking. The fish were reared to a mean target size of 254 mm at the time of stocking initiation (April of the following year). At that time, the raceways were at a density index of approximately 1.89 kg m^{-3} cm^{-1} (0.30 lb ft^{-3} in^{-1} in English units); this target was based on both the recommendations in Piper et al. (1982) and past fish culture experience (cf. Cassinelli et al. 2016). Once fish reached catchable size, they were held on a maintenance diet of about 0.3% of body weight/d until all stocking was completed.

Prior to fish being moved to the larger raceways (i.e., about 26 weeks prior to reaching target stocking size), nine aluminum baffles, spaced 3.7 m apart, were installed perpendicular to the flow in one raceway (Figure 1). The baffles were positioned with the bottom facing slightly upstream, creating a 70° angle to the raceway floor. The sides of each baffle were positioned tight against the raceway walls, the top of each baffle extended above the water surface, and a 13-mm gap was maintained between the bottom edge of each baffle and the raceway floor, all of which concentrated water velocity at the bottom of the raceway to transport waste material downstream. In addition, two 15 × 61 cm windows were designed along the bottom edge of each baffle to allow fish to move more freely within the raceway and to create more variable water velocities. The design and positioning of the baffles was determined prior to the experiment by testing the effect that baffle angles, window openings, and bottom gap had on maximum and variation in velocities created in an experimental 20 m long × 2 m wide × 1.2 m deep flume at the University of Idaho Water Center (R. Budwig, University of Idaho, unpublished data). In the adjacent raceway, no baffles were installed, which served as the control.

Water velocities were measured in the treatment (i.e., baffled) raceway and control raceway to characterize the rearing conditions experienced by fish in both test groups. Because water volume and flow in the raceways were invariable, velocity measurements were made only once and were assumed to be constant throughout the study. Seven transects—spaced 0.6 m apart and oriented perpendicular to the flow—were created between the two most downstream baffles. At each transect, water velocities were measured at six equidistant points across the raceway and at six equidistant points in the water column, creating 36 velocity measurements at each transect (or 252 velocity measurements per raceway). Velocities were measured with an electromagnetic flow meter (Marsh-McBirney Model 2000) with the sensor always facing directly upstream relative to the raceway. Scaffolding above the raceways allowed data recorders to stay out of the water during these measurements to avoid influencing water velocities. Velocities were converted to BLS (in absolute values) and compared between raceways using a t-test.

Once fish reached catchable size but prior to any stocking events, fin quality was determined from a subsample of fish in both the treatment (n = 101) and control (n = 152) raceway. Fin measurements were made by sedating the subsample of fish and measuring the length (in mm) of the dorsal fin as well as the right and left pectoral fins following the methods of Kindschi (1987). Relative fin length ([fin length × 100]/total body length) was calculated for each fin. Differences in relative fin length between baffled and unbaffled fish were compared using multivariate analysis of variance with three response variables (i.e., the three relative fin lengths) and one predictor variable (i.e., the baffle treatment).

In-hatchery mortality was recorded daily for both raceways in both years, from the time that baffles were installed to the time at which fish reached catchable size. Ninety-five percent confidence intervals (CIs) were calculated for each estimate of mortality, following the formulas of Fleiss (1981); we considered non-overlapping CIs to indicate statistical differences between baffled and unbaffled fish for each year.

All catchables used for post-release performance analyses were tagged prior to stocking with 70 mm fluorescent orange T-bar anchor tags. Fish were collected for tagging by randomly dip netting them from each raceway. Netted fish were sedated, measured to the nearest mm (total length), and tagged just under the dorsal fin following the methods of Guy et al. (1996). After tagging, fish were placed in holding pens (1.5 × 1.5 × 1.5 m metal-framed enclosure) in the raceway for at least 12 hours. Within 48 hours of tagging, tagged fish were loaded by dip net onto stocking trucks and transported to stocking locations. Tags were implanted into fish at no more than 10% of the total number of catchables stocked at a particular water body, and no more than 1,000 tagged fish were stocked in any release group. Untagged fish were loaded from adjacent production raceways not associated with this study to complete each stocking event. Mortalities associated with tagging, and shed tags prior to stocking, were rare (both <1%), but they were monitored and accounted for prior to loading fish for transport. Stocking events occurred from mid-April to early August in 2017 and early April to the end of June in 2018.

Return-to-creel and days-at-large data were obtained using information provided by anglers who reported their catch. Anglers could report tags using the IDFG (Tag! You're It!) phone system or website, as well as at regional IDFG offices or by mail. To facilitate angler reporting of tagged fish, anchor tags were labeled with "IDFG", a tag reporting phone number, the website address, and a unique tag number. While it is well understood that anglers do not report every tagged fish that they catch (Pollock et al. 2001; Meyer et al. 2012), for this study the relative raw angler tag return rates between baffle and control groups provided a measure of post-release performance differences (cf. Meyer and Cassinelli 2020; Branigan et al. 2021).

The effect of baffle installation on both angler tag return rate and days-at-large of tagged fish was evaluated with the use of generalized linear mixed-effects models using Proc GLIMMIX in the SAS statistical software package (SAS Institute 2009). For both models, each stocked fish was considered the unit of observation. The dependent variable in the model was a dummy variable of either 1 or 0, which represented tagged fish that either were or were not caught and reported by anglers, respectively. In addition to the effect of raceway baffles, fish length was included as a predictor variable because larger trout are better able to escape predators and have higher energy reserves, improving their post-release survival, and they may be more aggressive in foraging, all of which makes them more vulnerable to angler catch (Wiley et al. 1993; Yule et al. 2000; Cassinelli et al. 2016). The water type being stocked (lentic, lotic, or community pond) was also included as a predictive variable because angler catch of stocked catchables can vary between these water types (Wiley et al. 1993). A treatment × water type interaction term was included to assess whether any effect of baffle installation on tag returns was mediated by the type of water being stocked. The above effects were all considered to be fixed effects, whereas water body being stocked was included as a random effect in the models.

Candidate models included all combinations of predictive factors. Models were ranked using Akaike's information criterion (AIC; Burnham and Anderson 2002), and we considered the most plausible models to be those with AIC scores within 2.0 of the best model (Burnham and Anderson 2004). We used AIC weights (w_i) to assess the relative plausibility of each model. Coefficients were estimated and reported only for the most plausible angler tag return model and days-at-large model (i.e., the model with the lowest AIC score). However, coefficients were only considered influential if their 95% CIs did not overlap zero. For all statistical analyses, we used SAS (SAS Institute 2009) with $\alpha = 0.05$.

RESULTS

Installing baffles greatly increased the velocities that fish experienced in the raceways (*t* = 5.67; *P* <0.001), and increased velocity variability (Table 9). When converted to BLS (in absolute values), 11.5% of the cell velocities in the baffled raceway exceeded 0.5 BLS, though only 0.3% exceeded 1.0 BLS. All of the cells in the baffled raceway where velocities exceeded 0.5 BLS occurred in the bottom third of the water column. Whereas the baffled raceway produced velocities up to 0.41 m/s (1.58 BLS), the maximum velocity experienced by fish in the control raceway was 0.07 m/s (0.27 BLS).

A total of 9,862 non-reward tags were implanted in catchables that were stocked into 19 lentic, 10 lotic, and 17 community pond waters in 61 total stocking events. Fish averaged 258.9 mm in total length (SD = 27.8 mm) at the time of stocking, and ranged from a low of 126 mm to a high of 380 mm. Fish size differed little between baffled ($\bar{X}$ = 255.2 mm; SD = 27.8 mm) and unbaffled ($\bar{X}$= 262.5 mm; SD = 27.6 mm) raceways. Relative fin length prior to stocking averaged 9.5% (SD = 3.9%) and 9.1% (SD = 3.8%) for the left and right pectoral fins, respectively, and 5.0% (SD = 2.9%) for the dorsal fin. Relative fin length did not differ between the baffled and unbaffled raceways (Wilk's Lambda = 0.98; *F* = 1.97; *P* = 0.12).

In-hatchery mortality from the time that baffles were installed to the time at first stocking was higher in both years for fish reared in the baffled raceway compared to fish in the unbaffled raceway. In 2017, in-hatchery mortality rate (± 95% CIs) was 3.0% ± 0.2% for fish in the baffled raceway compared to 2.0% ± 0.2% in the unbaffled raceway. In 2018, mortality was 7.8% ± 0.3% for fish in the baffled raceway compared to 3.3% ± 0.2% in the unbaffled raceway.

A total of 987 tagged fish was subsequently caught and reported by anglers, for an overall angler tag return rate of 10.0%. Mean angler tag return rate (± 95% CIs) was 9.5% (± 8.7 – 10.4%) for fish from the baffled raceway compared to 10.4% (9.6–11.3%) for fish from the unbaffled raceway. For water types, mean angler tag return rate was 12.6% (10.7–14.5%) for community ponds, 8.6% (7.5–9.8%) for lotic waters, and 10.1% (9.3–10.8%) for lentic waters. The best logistic regression model associated with angler tag return data included fish length and water type, but not treatment, and indicated that tag return rate increased as fish length increased, and was highest for community ponds (Tables 10 and 11). There was essentially no support for any other tag return model (Table 10).

Mean time-to-capture for fish caught and reported by anglers was 70 days, but days-at-large for individually tagged fish ranged from a low of zero to a high of 935 days. Mean days-at-large (± 95% CIs) was 65 days (56–75 days) for fish reared in the baffled raceway compared to 74 days (65–83 days) for fish from the unbaffled raceway. For water types, mean days-at-large was 91 days (81-100 days) for lentic waters, 36 days (28–44 days) for lotic waters, and 25 days (18.9–31.5 days) for community ponds. The best logistic regression model associated with days-at-large data indicated that tagged fish were at-large for a longer period of time prior to being caught when they were shorter in length, stocked in lakes and reservoirs, and stocked earlier in the year (Tables 10 and 11). While treatment (i.e., baffled vs unbaffled raceway) was included in the top model, 95% CIs around the coefficient estimate overlapped zero (Table 11), indicating this effect was not influential. There was little support for any other competing model (Table 10).

Raceway cleaning time needed to sweep waste from baffled and unbaffled raceways was monitored anecdotally throughout the study. Such observations revealed that the augmented velocities along the bottom of the baffled raceway were effective at clearing fish waste in the upper third of each raceway segment (with the space between baffles considered a segment), but some waste accumulated in the lower portion of each raceway segment, requiring as much cleaning in the lower 2/3 of each segment as was needed throughout the unbaffled raceway. Thus, the baffled raceway required about 33% less cleaning time. However, if waste was manually cleared too quickly from the lower 2/3 of each raceway segment, pressure on the baffles increased, sometimes causing them to buckle and even move downstream slightly. Thus cleaning in the baffled raceway had to be done carefully, and baffles sometimes had to be repositioned if they moved during cleaning.

DISCUSSION

In the present study, while the baffles did increase water velocities in the raceway, this increase did not provide any benefit to in-hatchery or post-release performance of catchable-sized Rainbow Trout. Previous studies investigating exercise training have typically focused on in-hatchery or laboratory performance, and have demonstrated improvements in growth, feed conversion, swimming performance, and stress response when various species have been exercised at >1-2 BLS (Besner and Smith 1983; Leon 1986; Houlihan and Laurent 1987; Young and Cech 1993b, 1994b; Farrell et al. 1990). However, considering the cost of rearing catchable-sized trout for recreational fisheries (Losee and Phillips 2017; Branigan et al. 2021), in-hatchery survival and post-release performance are arguably the two most relevant measures of program efficiency. Our finding that baffle installation reduced in-hatchery survival was unexpected, considering that, while not all studies have demonstrated positive benefits for exercised fish, none have demonstrated negative results. However, for most prior research, baffle installation was not the mechanism used to exercise fish. In the present study, the baffles may have created a more stressful rearing environment, separating fish into small compartments of water that were cumbersome to navigate and that may have increased chronic stress levels, regardless of the lack of external signs of injury, disease, or other perturbation.

To our knowledge, the present study is the first to evaluate post-release catch of catchable-sized trout reared in hatchery raceways installed with baffles. Our results suggest that in hatcheries where available water is already being used to maximize catchable trout rearing capacity, installing baffles will not increase the number of stocked fish caught by anglers, nor will it prolong the fishery. However, the increase in water velocities created by baffles in our study may have been better suited to ‘exercise’ fry or fingerling-sized fish (i.e., 75-125 mm TL) had they been the target size for stocking. This may be an avenue of future research, considering that many state agencies have fry, fingerling, and catchable stocking programs. However, we would encourage any such study to also measure in-hatchery mortality rates, considering the negative effect that baffle installation had in the present study on catchable trout survival prior to release.

While baffle installation did not affect angler catch of catchables in our study, we found that fish length and the type of water being stocked affected both the percentage of catchables caught by anglers and how long the fish persisted in the fishery. The effect of fish length on post-release performance of catchable trout has been well established in aquaculture literature (Wiley et al. 1993; Yule et al. 2000; Cassinelli et al. 2016; Cassinelli and Meyer 2018). Similarly, previous studies have demonstrated that days-at-large for catchables in lentic waters (Cassinelli and Meyer 2018) are typically much longer than in lotic waters (Dillon et al. 2000; also see Branigan et al. 2021) or community ponds (Schultz and Dodd 2008). In the present study, we controlled for these factors in order to focus our analyses on the effect of baffles on angler catch and longevity of stocked catchables.

Relative fin length for the catchable-sized hatchery Rainbow Trout in our study was shorter than has been observed for wild Rainbow Trout (Bosakowski and Wagner 1994) for both dorsal fins (5.0% for this study vs. 13.9% for wild) and pectoral fins (9.3% vs. 14.9%). This was expected considering that fin erosion in cultured fish is commonplace (Latremouille 2003). Fin erosion in hatchery fish is typically attributed to bacterial infection, nutrition, abrasion, or fin nipping (Latremouille 2003). Baffle installation has also been shown to cause fin erosion in some studies (e.g., Barnes et al. 1996; but see Kindschi 1991), presumably due to increased abrasion caused by restricted space when moving along the raceway. However, in the present study, 26 weeks of rearing in a baffled raceway had no impact on fin erosion. The dual windows installed at the bottom of each of our baffles apparently provided enough space to prevent fin damage due to abrasion from swimming underneath the baffles.

Despite the small but significant difference we observed in in-hatchery survival, baffles may still be advantageous if there is an overall cost benefit associated with installing and maintaining them. In the present study, the baffles were only partially effective at mobilizing fish waste along the bottom of the raceway, thus some cleaning by hatchery personnel was still required. The baffles were made out of aluminum and the total cost to build nine baffles for the 30-m section of raceway was $7,650. Considering there are 36 total raceway sections at Nampa Hatchery, it would have cost over $275,000 to outfit the entire hatchery with baffles. In comparison, roughly $60,000 is needed annually for labor costs to sweep all the occupied raceways once per week, with baffles potentially saving about 1/3 of that cost since they were not completely effective at self-cleaning the raceways. Moreover, this does not account for the fact that baffle installation and removal each year also requires labor, especially if baffles have to be removed and re-installed more than once to empty the raceway for stocking. Taken collectively, baffles as installed in this study provided no long-term cost savings, especially after factoring in the apparent difference in in-hatchery mortality as noted above.

MANAGEMENT RECOMMENDATION

1. Consider evaluating whether the baffles built for the present study might be better suited to ‘exercise’ Rainbow Trout fingerlings (i.e., 75-125 mm TL) in IDFG production hatcheries prior to release, since water velocities of 1-2 BLS necessary to exercise fish can be better achieved for smaller fish.

ACKNOWLEDGEMENTS

We thank Bob Becker and the staff at Nampa Fish Hatchery for all their assistance tagging, rearing, and releasing fish, and monitoring in-hatchery mortality. Tony Lamansky and Kristi Stevenson were instrumental in managing tag return data. And thanks are due to Jeff Dillon, Jennifer Vincent, and Beau Gunter for reviewing earlier versions of the manuscript. Funding for this work was provided by anglers and boaters through their purchase of Idaho fishing licenses, tags, and permits, and from federal excise taxes on fishing equipment and boat fuel through the Sport Fish Restoration Program.

LITERATURE CITED

Azuma, T. 2001. Can water-flow induce an excellent growth of fish; effects of water flow on the growth of juvenile Masu Salmon, *Oncorhynchus masou*. World Aquaculture 32:26-29.

Banks, J. L., and E. M. LaMotte. 2002. Effects of four density levels on Tule fall Chinook Salmon during hatchery rearing and after release. North American Journal of Fisheries Management 64:24–33.

Barnes, M. E., W. A. Sayler, and R. J. Cordes. 1996. Baffle usage in covered raceways. The Progressive Fish-Culturist 58:286-288.

Barnes, M. E., G. Simpson, and D. J. Durben. 2009. Post-stocking harvest of catchable-sized Rainbow Trout enhanced by dietary supplementation with a fully fermented commercial yeast culture during hatchery rearing. North American Journal of Fisheries Management 29:1287–1295.

Besner, M., and L. S. Smith. 1983. Modification of swimming mode and stamina in two stocks of Coho Salmon (*Oncorhynchus kisutch*) by differing levels of long-term continuous exercise. Canadian Journal of Fisheries and Aquatic Sciences 40:933-939.

Boersen, G., and H. Westers. 1986. Waste solids control in hatchery raceways. The Progressive Fish Culturist 48:151-154.

Bosakowski, T., and E. J. Wagner. 1994. Assessment of fin erosion by comparison of relative fin length in hatchery and wild trout in Utah. Canadian Journal of Fisheries and Aquatic Sciences 51:636-641.

Branigan, P. R., K. A. Meyer, and J. D. Cassinelli. 2021. Relative cost and post-release performance of hatchery catchable Rainbow Trout grown to two target sizes. Fisheries. In Press.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer Verlag, New York.

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociological Methods and Research 33:261-304.

Burrows, R. E. 1969. The influence of fingerling quality on adult salmon survivals. Transactions of the American Fisheries Society 98:777-784.

Cassinelli, J. D., and K. A. Meyer. 2018. Factors influencing return-to-creel of hatchery catchable-sized Rainbow Trout stocked in Idaho lentic waters. Fisheries Research 204:316-323.

Cassinelli, J. D., K. A. Meyer, and M. K. Koenig. 2016. Effects of rearing density on return-to-creel of hatchery catchable Rainbow Trout stocked in Idaho lentic waters. North American Journal of Aquaculture. In Press.

Christiansen, J. S., and M. Jobling. 1990. The behaviour and the relationship between food intake and growth of juvenile Artic Charr, *Salvelinus alpinus* L., subjected to sustained exercise. Canadian Journal of Zoology 68:2185-2191.

Christiansen, J., E. Ringø, and M. Jobling. 1989. Effects of sustained exercise on growth and body composition of first-feeding fry of Artic Charr, *Salvelinus alpinus* (L.). Aquaculture 79:329-335.

Christiansen, J. S., Y. S. Svendsen, and M. Jobling. 1992. The combined effects of stocking density and sustained exercise on the behaviour, food intake, and growth of juvenile Artic Charr (*Salvelinus alpinus* L.). Canadian Journal of Zoology 70:115-122.

Cresswell, R. C., and R. Williams. 1983. Post-stocking movements and recapture of hatchery-reared trout released into flowing waters—effect of prior acclimation to flow. Journal of Fish Biology 23:265-276.

Davison, W. 1997. The effects of exercise training on teleost fish, a review of recent literature. Comparative Biochemical Physiology 117A:67-75.

Davison, W. 1989. Training and its effects on teleost fish. Comparative Biochemical Physiology 94A:1-10.

Dillon, J. C., D. J. Schill, and D. M. Teuscher. 2000. Relative return to creel of triploid and diploid Rainbow Trout stocked in eighteen Idaho streams. North American Journal of Fisheries Management 20:1-9.

Elrod, J. H., D. E. Ostergaard, and C. P. Schneider. 1989. Effect of rearing density on post-stocking survival of Lake Trout in Lake Ontario. Progressive Fish Culturist 51:189–193.

Evenson, M. D., and R. D. Ewing. 1993. Effect of exercise of juvenile winter steelhead on adult returns to Cole Rivers Hatchery, Oregon. The Progressive Fish-Culturist 55:180-183.

Farrell, A. P., J. A. Johansen, J. F. Steffensen, C. D. Moyes, T. G. West, and R. K. Suarez. 1990. Effects of exercise training and coronary ablation on swimming performance, heart size, and cardiac enzymes in Rainbow Trout, *Oncorhynchus mykiss*. Canadian Journal of Zoology 68:1174-1179.

Fleiss, J. L. 1981. Statistical methods for rates and proportions. New York: John Wiley and Sons.

Gamperl, A. K., D. L. Schnurr, and E. D. Stevens. 1991. Effect of a sprint-training protocol on acceleration performance in Rainbow Trout (*Salmo gairdneri*). Canadian Journal of Zoology 69:578-582.

Gamperl, A. K., and E. D. Stevens. 1991. Sprint-training effects on Rainbow Trout (Oncorhynchus mykiss) white muscle structure. Canadian Journal of Zoology 69:2786-2790.

Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 19 96. Tagging and marking. Pages 353–383 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Hammer, C. 1995. Fatigue and exercise tests with fish. Comparative Biochemical Physiology 112A:1-20.

Houlihan, D. F., and P. Laurent. 1987. Effects of exercise training on the performance, growth, and protein turnover of Rainbow Trout (*Salmo gairdneri*). Canadian Journal of Fisheries and Aquatic Sciences 44:1614-1621.

Hunt, T. L., H. Scarborough, K. Giri, J. W. Douglas, and P. Jones. 2017. Assessing the cost-effectiveness of a fish stocking program in a culture-based recreational fishery. Fisheries Research 186:468–477.

Kieffer, J. D. 2000. Limits to exhaustive exercise in fish. Comparative Biochemistry and Physiology 126A:161-179.

Kindschi, G. A. 1987. Method for quantifying degree of fin erosion. Progressive Fish-Culturist 49:314-315.

Kindschi, G. A., R. G. Thompson, and A. P. Mendoza. 1991. Use of raceway baffles in Rainbow Trout culture. The Progressive Fish Culturist 53:97-101.

Lackner, R., Wieser, W., Huber, M., and J. Dalla Via. 1988. Responses of intermediary metabolism to acute handling stress and recovery in untrained and trained *Leuciscus cephalus* (Cyprinidae, Teleostei). Journal of Experimental Biology 140:393-404.

Lagasse, J. P., D. A. Leith, D. B. Romey, and O. F. Dahrens. 1980. Stamina and survival of Coho Salmon reared in rectangular circulating ponds and conventional raceways. The Progressive Fish-Culturist 42:153-156.

Larmoyeux, J. D., and R. G. Piper. 1973. Effects of water reuse on Rainbow Trout in hatcheries. Progressive Fish-Culturist 35:2–8.

Latremouille, D. N. 2003. Fin erosion in aquaculture and natural environments. Reviews in Fisheries Science 11:315-335.

Leon, K. A. 1986. Effect of exercise on feed consumption, growth, food conversion, and stamina of Brook Trout. The Progressive Fish-Culturist 48:43-46.

Losee, J. P., and L. Phillips. 2017. Bigger is better: optimizing trout stocking in western Washington lakes. North American Journal of Fisheries Management 37:489–496.

McDonald, D. G., D. L. Milligan, W. J. McFarlane, S. Croke, S. Currie, B. Hooke, R. B. Angus, B. L. Tufts, and K. Davidson. 1998. Condition and performance of juvenile Atlantic Salmon (*Salmo salar*): effects of rearing practice on hatchery fish and comparison with wild fish. Canadian Journal of Fisheries and Aquatic Sciences 55:1208-1219.

Meyer, K. A., F. S. Elle, T. Lamansky, E. R. J. M. Mamer, and A. E. Butts. 2012. A reward-recovery study to estimate tagged-fish reporting rates by Idaho anglers. North American Journal of Fisheries Management 32:696-703.

Meyer, K. A., and J. D. Cassinelli. 2020. The effect of raceway grading on return to creel for catchable-sized hatchery Rainbow Trout. North American Journal of Aquaculture 82:224–234.

Mullan, J. W. 1956. The comparative returns of various sizes of trout stocked in Massachusetts streams. Progressive Fish-Culturist 18:35–38.

Nielsen, M. E., L. Boesgaard, R. M. Sweeting, B. A. McKeown, P. Rosenkilde. 2000. Physiological and endocrinological responses during prolonged exercise in hatchery reared Rainbow Trout (*Oncorhynchus mykiss*). Acta Veterinaria Scandinavica 41:173-184.

Piper, R. G., I. B. McElwain, L. E. Orne, J. P. McCraren, L. G. Fowler, and J. R. Leonard. 1982. Fish Hatchery Management. U. S. Department of the Interior, Fish and Wildlife Service. Washington, D.C.

Pollock, K. H., J. M. Hoenig, W. S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation: 1. An evaluation of the high-reward tagging method. North American Journal of Fisheries Management 21:521-532.

SAS Institute Inc. 2009. SAS/STAT ® 9.2 User’s Guide, Second Edition. Cary, NC: SAS Institute Inc.

Schultz, R. D., and B. J. Dodd. 2008. Characteristics of an Iowa put-and-take Rainbow Trout fishery and associated economic benefits. Pages 391-401 in R. T. Eades, J. W. Neal, T. J. Lang, K. M. Hunt, and P. Pajak, editors. Urban and community fisheries programs: development, management, and evaluation. American Fisheries Society, Symposium 67, Bethesda, MD.

Trushenski, J. T., T. Flagg, and C. C. Kohler. 2010. Use of hatchery fish for conservation, restoration, and enhancement of fisheries. Pages 261–293 in W. Hubert and M. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Wendt, C. A. G., and R. L. Saunders. 1973. Changes in carbohydrate metabolism in young salmon response to various forms of stress. International Atlantic Salmon Foundation. Special Publication 4:55-82.

Wiley, R. W., R. A. Whaley, J. B. Satake, and M. Fowden. 1993. Assessment of stocking hatchery trout: a Wyoming perspective. North American Journal of Fisheries Management 13(1):160-170.

Young, P. S., and J. J. Cech, Jr. 1993a. Effects of exercise conditioning on stress responses and recovery in cultured and wild young-of-the-year Striped Bass, *Morone saxatilis*. Canadian Journal of Fisheries and Aquatic Sciences 50:2094-2099.

Young, P. S., and J. J. Cech, Jr. 1993b. Improved growth, swimming performance, and muscular development in exercise-conditioned young-of-the-year Striped Bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 50: 703-707.

Young, P. S., and J. J. Cech, Jr. 1994a. Effects of different exercise conditioning velocities on the energy reserves and swimming stress responses in young-of-the-year Striped Bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 1528-1534.

Young, P. S., and J. J. Cech, Jr. 1994b. Optimum exercise conditioning velocity for growth, muscular development, and swimming performance in young-of-the-year Striped Bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 51:1519-1527.

Yule, D. L., R. A. Whaley, P. H. Mavrakis, D. D. Miller, and S. A. Flickinger. 2000. Use of strain, season of stocking, and size at stocking to improve fisheries for Rainbow Trout in reservoirs with walleyes. North American Journal of Fisheries Management 20:10-18.

Table 9. Raceway velocities (in m/s and body lengths per second [BLS]) as measured in baffled and unbaffled (i.e., control) raceways where catchable-sized hatchery Rainbow Trout were reared prior to tagging and stocking in Idaho recreational fisheries.

	m/s		BLS	
Metric	**Baffle**	**Control**	**Baffle**	**Control**
Absolute mean	0.061	0.0221	0.237	0.0854
Absolute SD	0.071	0.0159	0.276	0.0616
Minimum	-0.110	-0.050	-0.425	-0.193
Maximum	0.410	0.070	1.583	0.270

Table 10. The most plausible models relating angler tag returns and days-at-large for catchable-sized hatchery Rainbow Trout tagged in baffled and unbaffled raceways and stocked in Idaho recreational fisheries. Akaike's information criterion (AIC), AIC difference (ΔAIC), and AIC weights (w_i) were used to select the most plausible models (see text for details). Water body was included as a random effect in all models.

Model	**AIC**	**ΔAIC**	w_i
Angler tag return models			
Fish length + water type	3798.85	0.00	0.97
Fish length + water type + treatment	3807.21	8.36	0.01
Days-at-large models			
Water type + fish length + tagging month + treatment	11805.91	0.00	0.86
Water type + fish length + tagging month	11810.70	4.79	0.08

Table 11. Coefficient estimates and 95% confidence intervals (CIs) for the most plausible models relating angler tag returns and days-at-large for catchable-sized hatchery Rainbow Trout tagged in baffled and unbaffled raceways and stocked in Idaho recreational fisheries. Water body was included as a random effect in both models.

		95% CIs	
Coefficient	**Estimate**	**Lower**	**Upper**
Most plausible angler tag return model			
Intercept	-0.3104	-0.3792	-0.2416
Fish length	0.0014	0.0012	0.0017
Water type - pond	0.1258	0.0689	0.1827
Water type - river	0.0273	-0.0474	0.1019
Most plausible days-at-large model			
Intercept	141.0100	56.5759	225.4441
Water type - pond	-87.1930	-120.2143	-54.1717
Water type - river	-32.9020	-70.9262	5.1222
Tagging month - April	79.6143	36.3114	122.9172
Tagging month - May	58.1229	17.1901	99.0557
Tagging month - June	25.0517	-5.8842	55.9876
Fish length	-0.3784	-0.6616	-0.0952
No baffles	2.2172	-9.9174	14.3518

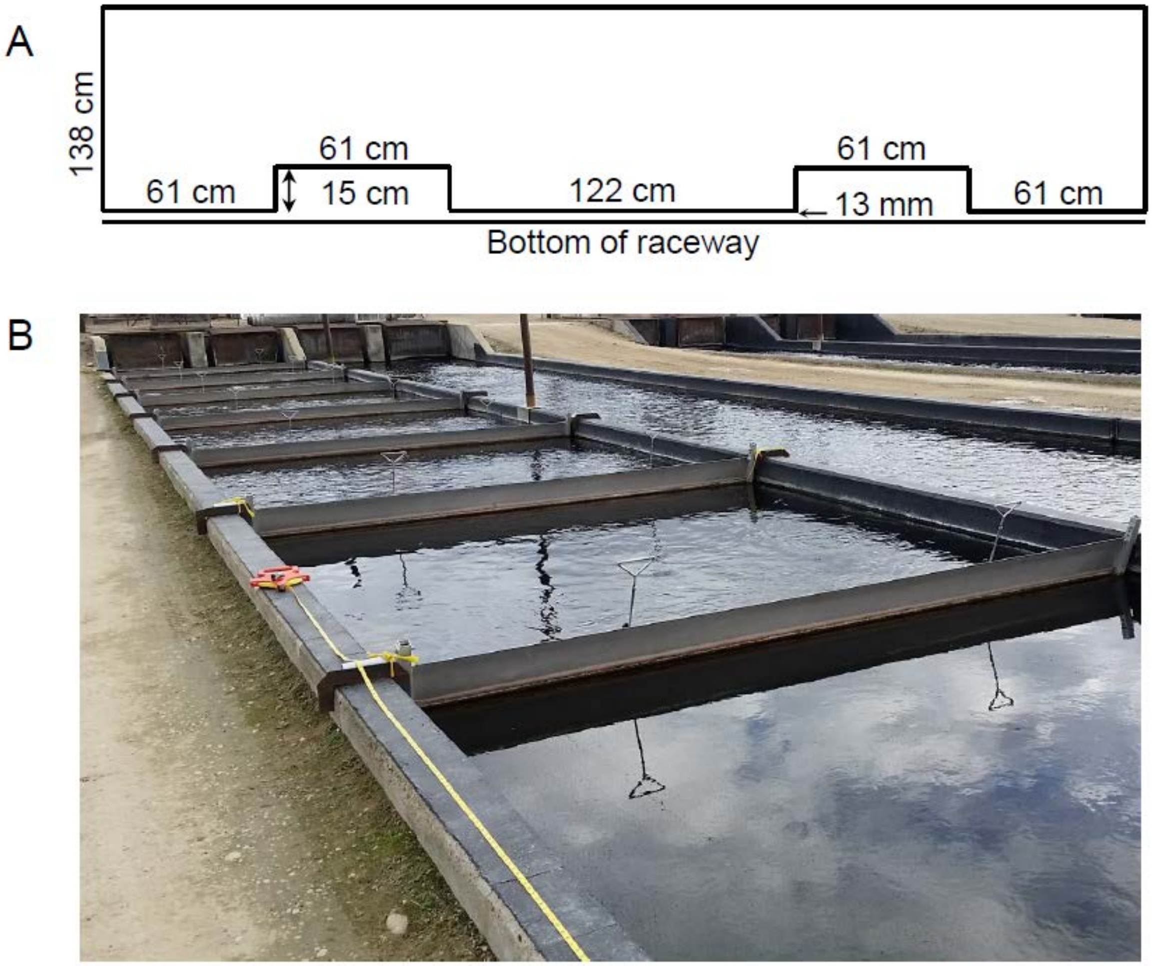

Figure 8. One of nine 3.6-m wide aluminum baffles installed at equidistance throughout a 30.0 × 3.7 × 1.1-m hatchery raceway used to rear catchable-sized Rainbow Trout destined for Idaho recreational fisheries, showing (A) the dimensions of the baffle and (B) placement in the raceway.

Prepared by:

Phil Branigan
Regional Fisheries Biologist

Emily Washburn
Fisheries Technician

Kevin A. Meyer
Principal Fisheries Research Biologist

John Cassinelli
Anadromous Fisheries Manager

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Matthew P. Corsi
Fisheries Research Manager

J. Lance Hebdon
Bureau of Fisheries