FEATURE

Relative Cost and Post-Release Performance of Hatchery Catchable Rainbow Trout Grown to Two Target Sizes

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Rainbow Trout *Oncorhynchus mykiss*.
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Catchable-sized hatchery trout (hereafter, catchables) have become a staple component of many fisheries management programs throughout North America. Due to their size, catchables create immediate fisheries once they are stocked, and fisheries managers have gradually shifted towards stocking fewer, larger trout. However, the cost of growing larger fish may reduce the efficiencies of catchable stocking programs overall. We grew catchable-sized Rainbow Trout *Oncorhynchus mykiss* to two target average sizes (254 and 305 mm total length) at a production scale, while tracking feed expenditures to examine the costs and benefits associated with increased size-at-stocking. Although larger catchables cost 31% more in feed expenditures than those reared to a smaller average size, catch (by anglers) of larger fish increased by 100% relative to smaller fish. Consequently, if target stocking size was changed from 254 to 305 mm and feed costs were held constant by reducing the total number of fish stocked, anglers would benefit by catching larger and more fish, despite the reduction in number of fish stocked. In lentic systems, larger catchables were reported by anglers more quickly than smaller fish, so managers must consider interactions between stocking size and residence time for lentic systems supported by catchables. In lotic systems, overall catch by anglers was much lower than catch at lentic waterbodies, and all catchables were either reported by anglers quickly or failed to be reported at all regardless of size-at-stocking. Producing larger catchables for hatchery-supported fisheries serves to benefit angling and would likely increase angler satisfaction while improving efficiencies associated with hatchery catchable stocking programs.

INTRODUCTION

Catchable-sized hatchery trout (hereafter, catchables) serve as an important component of many coldwater fisheries management programs throughout North America. In 2004 alone, nearly 60% of the ~80 million non-anadromous Rainbow Trout *Oncorhynchus mykiss* stocked by state and federal management agencies across the United States were released as catchables (>152 mm TL; Halverson 2008). While the overall number of trout stocked in the United States has declined since 1973, the total weight of stocked trout has increased (Halverson 2008), indicating that fisheries management agencies have shifted their stocking programs by providing anglers with fewer, larger trout. Due to their size, catchables provide immediate fisheries once they are stocked and are especially important for coldwater fisheries that cannot support wild trout populations or where wild trout catch rates are low. In many fisheries, stocking catchables allows resource managers to provide harvest opportunity to the public. In Idaho, the Idaho Department of Fish and Game (IDFG) produces catchables specifically for put-and-take fisheries to provide opportunities for anglers to catch or harvest stocked fish.

Angler catch of hatchery fish can be influenced by a variety of factors, some of which are associated with decisions made prior to stocking. In-hatchery conditions such as diet formulation (Barnes et al. 2009), water quality (Larmoyeux and Piper 1973), and rearing density (Elrod et al. 1989; Banks and LaMotte 2002) have been shown to affect post-stocking performance of salmonids. In addition, stocking density (Moring 1985; Miko et al. 1995) and size-at-stocking (Mullan 1956; Walters et al. 1997; Losee and Phillips 2017) can influence angler catch of stocked trout. However, growing catchables to a larger size in fixed-space rearing units naturally results in fewer individuals to be stocked, which may reduce overall catch by recreational anglers (Moring 1985). Accordingly, resource managers are tasked with optimizing the number and size of catchables produced while maximizing angler catch when evaluating the effectiveness of a hatchery catchable stocking program.

Return-to-creel of catchable trout may also be influenced by the conditions at receiving water bodies where fish are stocked. Post-stocking survival of hatchery catchables is often low (Shetter 1947; Walters et al. 1997; Dillon et al. 2000; High and Meyer 2009), thus catchables are generally not expected to reproduce, survive long-term, or otherwise fully recruit to a fishery (Patterson and Sullivan 2013). Angling effort is generally highest immediately following a stocking event (e.g., Baer et al. 2007; Hyman et al. 2016), and removal of catchables through angler harvest will reduce average residence time of stocked fish, highlighting the need to consider stocking frequency when managing put-and-take fisheries. Depending on management objectives, multiple stocking events may be warranted in select fisheries to maintain adequate catch rates throughout the angling season. Catch rates of Rainbow Trout by recreational anglers may also be affected by the abundance of aquatic predators (Baldwin et al. 2003), the presence and abundance of avian predators (Walters et al. 1997; Chiaramonte et al. 2019), and prey availability (Haddix and Budy 2005). In general, larger trout are better suited to avoid predation by piscivorous fish (e. g. Yule et al. 2000), but growing hatchery fish to a larger size is accompanied with increased rearing costs (e.g., feed expenditures). As such, resource managers must strike a balance between rearing costs, the number and size of fish produced, and angler catch to maximize the efficiency of a catchable stocking program.

Despite the popularity of catchable stocking programs throughout North America, current programmatic assessments of catchable stocking programs are lacking (Jackson et al. 2004). The paucity of literature devoted to the economics of catchable stocking programs warrants further inquiry, and management agencies may benefit financially from reducing the number of stocked catchables (Johnson et al. 1995). A recent evaluation reported that larger catchables can provide economic and angling benefits (Losee and Phillips 2017), however, those results were limited to two relatively small lakes that were sampled within 3 days of stocking. Many fishery management agencies release catchables across multiple waterbodies throughout the stocking season to satisfy angler demand. As such, it is unclear if the benefits associated stocking larger catchables scales up at the programmatic level. Since larger hatchery trout typically return-to-creel more frequently than smaller conspecifics (e.g., Wiley et al. 1993; Walters et al. 1997; Yule et al. 2000; Losee and Phillips 2017), we evaluated two target sizes of catchable Rainbow Trout to determine if size-at-stocking influences angler catch. Fish were stocked into many lentic and lotic systems that varied considerably with regard to general site characteristics. In addition, feed expenditures associated with growing catchables at a production scale were compared between target length groups to evaluate the relative cost effectiveness of stocking trout at a larger size. Although feed expenditures alone likely do not reflect all cost increases associated with stocking larger trout, they serve as a primary expense that is generally unrelated to hatchery infrastructure limitations (e.g., water delivery systems) or facility operations (e.g., overhead and personnel costs, transportation constraints). As such, this evaluation provided a relatively comprehensive (though not exhaustive) framework to quantify the cost-effectiveness of catchable stocking at a programmatic level.

METHODS

Catchable Rainbow Trout were raised from eggs that were sourced from Troutlodge (Sumner, Washington) and from the IDFG internal "Hayspur" broodstock. All eggs were pressure-treated to induce triploidy and maintain accordance with the statewide policy of stocking sterile fish (Kozfkay et al. 2006) to reduce the risk of genetic introgression with native trout populations. Fish were reared during 2014–2016 at two IDFG fish hatcheries (American Falls and Nampa) that produce most of the catchables stocked throughout Idaho. Catchables were grown to two target sizes for this evaluation, one being the 254 mm (TL) average length target for catchable trout normally produced in Idaho (hereafter, standards), the other being larger fish that were grown to a target average length of 305 mm (hereafter, magnums). Given that two different sizes of catchables were grown for this evaluation, eggs were hatched approximately two months apart to allow both size groups to achieve the targeted lengths concurrently. All fish were reared under typical conditions associated with each facility using standard production-level culturing practices; only hatch timing was different between standards and magnums.

At American Falls Fish Hatchery, study fish were reared in 13°C single-pass spring water. Initial rearing occurred in indoor concrete vats (5.3 × 1.2 × 0.8-m units) and fish were fed via hand and belt feeders. Upon reaching approximately 55 mm, fish were inventoried and moved to outdoor concrete raceways (30 × 2.4 × 0.6-m rearing units) and were hand-fed for the remainder of the rearing period. A maximum flow index of 0.80 lb/gal/min/ft was targeted for standards, whereas targeted maximum flow index for magnums was 1.0 lb/gal/min/ft throughout the rearing cycle (English units used as industry standard).

At Nampa Fish Hatchery, study fish were reared in 15°C single-pass spring water. All fish were hatched into small concrete outdoor raceways (7.6 × 1.5 × 0.6-m rearing units) and fed via hand feeding and belt feeders set on a 12-hour timer. Upon reaching approximately 80 mm, fish were inventoried and moved to large outdoor concrete raceways (30 × 3.7 × 0.6-m rearing units) and fed with a tractor-pulled broadcasting feeder for the remainder of the rearing period. A maximum flow index of 2.06 lb/gal/min/ft was targeted for standards, and a maximum flow index of 2.26 lb/gal/min/ft was targeted for magnums throughout the rearing cycle.

At both hatcheries, a single large outdoor raceway was used to rear fish for each targeted length group; both test raceways at each facility were identical in volume. Rearing densities were equivalent between length groups, and a maximum density index of 0.30 lb/ft^3/in was targeted for both groups once fish in each raceway achieved their target length. This approach provided the maximum number of individuals to be grown in each raceway while keeping biomass equivalent among length groups and maintaining the typical density index value targeted across all IDFG resident trout hatcheries. All fish were fed a floating commercial trout diet (EXTR450; Rangen, Buhl, Idaho); rations, feed formula, and pellet size were adjusted according to guidelines provided by the manufacturer as a function of fish size. Fish from all raceways were sampled and weighed monthly to refine feed rations and target 25 mm of growth per month. Since standards and magnums were grown in separate raceways at both hatcheries, feed costs were tracked separately throughout the rearing process.

Post-release performance (i.e., catch and harvest) of study fish was assessed via angler reporting of tagged fish. Prior to each stocking event, all catchables were crowded in their respective raceways and a sample was collected with a dip net at random. Individual fish were sedated, measured for TL (mm) and tagged using a uniquely numbered 70-mm fluorescent orange T-bar anchor tag that was implanted into the dorsal musculature. Tagged fish were placed in enclosures and allowed to recover overnight. Within 48 hours of tagging, tagged catchables were loaded onto stocking trucks by dip net and transported to stocking locations. During most stocking events, an equal number of tagged standards and magnums were released concurrently alongside equal proportions of untagged fish (Tables 1 and 2). Each water body received 44–795 tagged fish, depending on the total number of fish being released, and no more than 10% of the total number of fish released were tagged. A subset of randomly selected waterbodies received US $50 reward tags or double-tagged fish in addition to standard non-reward tags to estimate angler reporting rate and tag loss. Reward-tagged or double-tagged fish were apportioned equally between standards and magnums at a constant rate of 10% of the total number of tagged fish stocked. All tagged fish were stocked between April and October, and were at-large for a maximum of 2 years to allow ample time for anglers to catch and report individual fish. Mortalities and shed tags were recorded when loading fish for transport, and truck tanks were checked again for shed tags after stocking.

All anchor tags were marked IDFG and included a unique identification number and web URL on one side of the tag, and a phone number on the other side of the tag to facilitate tag reporting by anglers. In addition, anglers could report their catch by visiting a regional IDFG office or by mail. Anglers reported the date and disposition of their catch (i.e., harvested or released), and were asked if they removed the tag(s) from fish that were released to ensure accurate record keeping for subsequent recapture. Reward tags were identical to non-reward tags in size and color, but contained the text "$50 reward." All anglers who reported a tagged fish were asked if their catch had one or two tags. Tag return data from each waterbody were accrued for a maximum of 2 years post-stocking; all tag return data presented herein reflect "total catch" by anglers, which consists of all fish reported by anglers, including those harvested and released within 2 years of stocking. Subsequent recaptures of previously reported individual fish were rare throughout this 3-year evaluation (n = 6), therefore, all summaries and analyses used data associated only with the first instance of capture by an angler.

To estimate angler reporting rate (λ) of non-reward tags, we used the high-reward method (Pollock et al. 2001) and following equation:

$$\lambda = \frac{R_r/R_t}{N_r/N_t}$$

Table 1. Rainbow Trout stocking, tag release, and tag return summaries for 28 lentic systems stocked with tagged catchables during 2014–2015. Magnum catchables were grown to target 305 mm (average TL) and standards were grown to 254 mm. Proportion of tags returned and days-at-large (number of days between stocking date and reported capture date) were determined through information submitted by anglers who reported tagged catch. Proportions reflect the number of non-reward tags returned by anglers to the number released within 2 years of tag release date, and do not include corrections for reporting rate, tag loss, or tagging mortality.

Water body	Surface area (ha)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion returned	Mean days-at-large (± SE)
Alexander Reservoir	409	2014	3	5,396	21-Oct	American Falls	Magnums	180	313	175	365	0.01	233
							Standards	177	255	170	309	--	--
Alturas Lake	338	2015	4	5,185	17-Aug	Nampa	Magnums	74	274	199	342	--	--
							Standards	74	269	183	371	--	--
American Falls Reservoir	22,376	2014	8	97,021	21-Oct	American Falls	Magnums	180	319	232	388	0.12	358 (15.25)
							Standards	356	257	125	371	0.01	251 (2.82)
Ashton Reservoir	150	2014	4	42,171	22-Oct	American Falls	Magnums	200	315	199	365	0.12	132 (6.56)
						American Falls	Standards	198	257	119	354	0.01	81 (0.50)
Blackfoot Reservoir	6,834	2014	8	40,200	23-Oct	American Falls	Magnums	180	310	178	397	0.13	492 (18.88)
						American Falls	Standards	358	255	130	336	0.02	614 (20.88)
Bull Trout Lake	29	2015	5	3,292	17-Aug	Nampa	Magnums	67	259	164	337	0.01	19
						Nampa	Standards	67	263	147	312	0.03	34 (5.44)
Cascade Reservoir	10,988	2014	7	61,888	14-May	Nampa	Magnums	397	309	218	395	0.04	173 (14.03)
						Nampa	Standards	398	269	194	341	0.02	50 (2.19)
Chesterfield Reservoir	504	2014	8	56,490	18-Jun	American Falls	Magnums	200	326	221	379	0.17	138 (9.43)
							Standards	200	256	195	335	0.14	301 (17.76)
Deep Creek Reservoir	66	2014	4	14,298	18-Jun	American Falls	Magnums	200	326	222	366	0.24	116 (6.43)
							Standards	200	261	200	350	0.22	192 (7.70)
Foster Reservoir	52	2014	6	8,833	18-Jun	American Falls	Magnums	200	328	211	381	0.21	61 (4.25)
							Standards	198	260	178	385	0.03	81 (5.42)
Glendale Reservoir	87	2014	5	9,970	18-Jun	American Falls	Magnums	179	328	282	375	0.33	99 (8.2)
							Standards	182	260	190	326	0.17	136 (9.06)
					22-Oct	American Falls	Magnums	199	315	163	369	0.21	164 (7.41)
							Standards	199	260	163	355	0.09	183 (14.06)

(Continues)

Table 1. (Continued)

Water body	Surface area (ha)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion returned	Mean days-at-large (± SE)
Horsethief Reservoir	105	2014	8	35,102	12-May	Nampa	Magnums	300	312	236	389	0.24	44 (7.77)
							Standards	299	271	160	361	0.16	69 (5.12)
Island Park Reservoir	2,946	2014	9	28,394	18-Jun	American Falls	Magnums	200	324	232	374	0.16	226 (18.72)
							Standards	200	258	195	350	0.06	278 (18.25)
					22-Oct	American Falls	Magnums	200	315	240	385	0.02	342 (14.48)
							Standards	200	255	140	319	0.01	786 (51.95)
		2015	5	23,250	25-Jun	Nampa	Magnums	250	315	182	386	0.13	41 (5.09)
							Standards	250	236	137	336	0.01	25 (2.21)
Lake Walcott	3,338	2014	5	39,804	22-Oct	American Falls	Magnums	201	314	172	399	0.13	363 (12.15)
							Standards	200	250	130	313	0.07	403 (21.05)
Lamont Reservoir	34	2014	1	4,997	18-Jun	American Falls	Magnums	200	324	225	404	0.18	83 (5.55)
							Standards	199	260	166	388	0.09	171 (9.75)
Little Wood Reservoir	212	2014	6	10,753	7-Jun	Nampa	Magnums	200	314	255	372	0.04	81 (7.83)
							Standards	200	270	160	343	0.04	129 (12.19)
Lost Valley Reservoir	211	2014	5	15,052	7-Jun	Nampa	Magnums	300	313	226	397	0.16	47 (4.30)
							Standards	298	268	183	331	0.13	58 (5.38)
		2015	3	8,958	9-Jun	Nampa	Magnums	170	331	206	396	0.22	40 (4.26)
							Standards	169	251	166	340	0.05	52 (1.68)
Lucky Peak Reservoir	211	2014	5	35,309	17-Apr	Nampa	Magnums	296	314	235	378	0.17	62 (3.84)
							Standards	290	257	92	332	0.09	146 (7.93)
		2015	6	15,811	7-Apr	Nampa	Magnums	270	323	216	393	0.30	62 (5.25)
							Standards	270	275	188	358	0.11	71 (4.99)
Mackay Reservoir	461	2014	8	21,403	18-Jun	American Falls	Magnums	200	326	111	365	0.18	21 (1.48)
							Standards	200	256	185	338	0.10	20 (1.64)
Magic Reservoir	1,449	2014	3	5,040	16-Apr	Nampa	Magnums	149	309	221	364	0.03	49 (2.26)
							Standards	149	260	172	344	0.02	127 (10.92)

(Continues)

Table 1. (Continued)

Water body	Surface area (ha)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion returned	Mean days-at-large (± SE)
Manns Creek Reservoir	109	2014	10	9,095	16-Apr	Nampa	Magnums	111	301	231	381	0.13	25 (2.02)
							Standards	110	261	90	319	0.10	100 (12.88)
					14-May	Nampa	Magnums	150	311	205	369	0.24	30 (2.57)
							Standards	149	270	180	323	0.15	59 (7.47)
		2015	5	5,797	18-May	Nampa	Magnums	150	317	225	376	0.20	70 (2.88)
							Standards	150	251	189	308	0.03	109 (2.02)
					24-Sep	Nampa	Magnums	50	303	225	360	0.14	32.71 (7.41)
							Standards	50	261	182	359	0.20	57 (8.42)
Oakley Reservoir	407	2014	2	10,795	18-Jun	American Falls	Magnums	198	328	244	375	0.25	233 (15.24)
							Standards	196	260	181	336	0.12	244 (9.94)
Sage Hen Reservoir	94	2014	5	11,972	14-May	Nampa	Magnums	135	309	210	396	0.30	46 (10.45)
							Standards	135	271	211	364	0.16	145 (13.75)
		2015	5	7,197	18-May	Nampa	Magnums	125	312	205	362	0.19	67 (6.63)
							Standards	125	250	164	332	0.06	220 (16.28)
Salmon Falls Creek Reservoir	1,114	2014	6	39,909	21-Oct	American Falls	Magnums	180	314	206	393	0.13	229 (13.65)
							Standards	180	258	134	324	--	--
		2015	9	57,541	24-Sep	Nampa	Magnums	170	306	215	379	0.13	358 (22.76)
							Standards	170	262	186	345	0.08	313 (19.10)
Spring Valley Reservoir	20	2015	9	32,547	24-Sep	Nampa	Magnums	250	311	200	380	0.20	180 (3.91)
							Standards	246	260	165	350	0.09	162 (5.64)
Stanley Lake	75	2014	9	14,326	6-Jun	Nampa	Magnums	90	318	266	370	0.21	19 (1.22)
							Standards	88	264	200	326	0.06	22 (1.75)
		2015	5	8,440	17-Aug	Nampa	Magnums	100	269	121	349	0.04	35 (2.43)
							Standards	100	275	232	352	0.05	31 (1.30)
Twin Lakes Reservoir	177	2014	3	11,460	18-Jun	American Falls	Magnums	179	324	205	367	0.24	146 (10.24)
							Standards	179	258	160	338	0.17	173 (12.44)
Warm Lake	167	2014	5	24,057	7-Jun	Nampa	Magnums	298	313	216	382	0.22	42 (2.08)
							Standards	300	269	194	344	0.15	56 (4.22)
		2015	3	14,414	25-Jun	Nampa	Magnums	200	326	210	394	0.16	84 (9.62)
							Standards	200	240	140	315	0.08	148 (12.59)

where R_t and R_r are the number of non-reward tags stocked and reported, respectively, and N_t and N_r at the number of reward tags stocked and reported, respectively. Tag reporting rate was estimated separately for standards (0.47) and magnums (0.49), however, the difference between the two estimates (i.e., proportions) was not significant at the $\alpha = 0.05$ level ($P = 0.50$), so reward tag data from all fish were pooled to estimate an overall tag reporting rate by anglers.

All double-tagged fish that were returned by anglers with one or two tags were used to calculate tag loss rates using the following tag loss estimator (McCormick and Meyer 2018):

$$tag_l = \frac{n_A^{AA}}{n_A^{AA} + 2n_{AA}^{AA}}$$

where n_A^{AA} is the number of fish that were double tagged when stocked, but were reported by anglers as having only one tag at the time of capture, and n_{AA}^{AA} is the number of fish that were reported as having two tags at the time of capture. Similar to reward-tagged fish, tag loss rates were calculated separately for standards (0.0025) and magnums (0.0015), but the difference between the estimates was not significant at the $\alpha = 0.05$ level ($P = 0.64$), so double tag data were pooled across targeted length groups to estimate an overall tag loss rate.

In-hatchery tagging data were summarized using magnum-specific, standard-specific, and pooled data to describe the length distribution of fish released by IDFG and the length distribution of fish reported by anglers. Because standards and magnums were grown in independent raceways with unique feed regimens, we evaluated the difference between the proportion of magnums and standards caught and reported by anglers at $\alpha = 0.05$ level to determine if tag return rates differed between length groups. "Total catch" (u), which included fish that were harvested as well as those released within 2 years post-stocking, was estimated as the number of non-reward-tagged fish caught and reported by anglers divided by the number of non-reward tags stocked. Total catch was adjusted (u') to account for angler reporting rate (λ), tag loss (Tag_l), and tagging mortality ($Tag_m = 0.008$; Meyer and Schill 2014), and was estimated for standards and magnums separately using the formula:

$$u' = \frac{u}{\lambda\left(1 - Tag_l\right)\left(1 - Tag_m\right)}$$

Feed cost data from each rearing facility were summarized to estimate and compare average cost/fish grown for standard and magnum raceways. Average cost estimates for standards and magnums were then multiplied by the inverse of all plausible u' values (i.e., 0–100%) to model cost/fish caught by anglers for each target length group. Observed u' estimates were referenced to estimate cost/fish caught for standards and magnums. We define the relationship between the observed u' estimates and the associated cost/fish caught values for standards and magnums as the "effective" cost or benefit of growing and stocking larger catchables.

Mixed-effects logistic regression and accelerated failure time (AFT) models were fitted to tagging data to further characterize the effect of fish length (in mm) on angler catch of tagged fish. Targeted length categories (i.e., standard or magnum) are useful and necessary for large-scale fish production where rearing costs are incurred, but integer length of fish (in mm) was used for all models in lieu of targeted length category due to correlation between integer values and categorical values of length.

We estimated the probability of capture of tagged fish as a function of fish length (TL; mm), water body type (i.e., lotic or lentic), and their interaction using a mixed-effects logistic regression model. Fish length data were scaled to improve model convergence. Each tagged fish served as the unit of observation and catch of individuals was determined by angler reports. The specific water bodies where tagged fish were stocked served as a random effect in the model. Statistical significance of each parameter in the model was inferred by assessing if the associated 95% confidence interval (CI) excluded zero.

A suite of AFT models were fitted to tag return data to evaluate the effect of fish length on average time-to-capture (i.e., residence time) of catchable trout. Residence time (number of days between stocking date and reported catch date) of an individual was modeled as a function of fish length, waterbody type, and their interaction using six plausible error distributions. Akaike's Information Criterion was used to select the top, most plausible model (Burnham and Anderson 2002). The error distribution associated with the top model was then used to fit a null model, and all models (including the null) were ranked again using Akaike's Information Criterion to understand whether the longevity of a catchable fishery is better explained by measured variables or by random chance. As noted earlier, if the 95% CI associated with each parameter did not contain zero, then the effect of that parameter was considered statistically significant.

RESULTS

Across 3 years, 20,077 non-reward tagged catchables were released into 28 lentic and 17 lotic systems (Tables 1 and 2). Mean length (at tagging) for fish reared in standard raceways was 258 mm (±29; SD), compared to 313 mm (± 30) in magnum raceways, though substantial variation and overlap in size was observed for both target length groups (Figure 1).

In total, 2,314 non-reward tagged fish were returned by anglers within a maximum of 2 years from their tagging date. Anglers caught larger catchables more frequently than smaller catchables (Figure 2), reporting 15.1% of all tagged magnums and 7.5% of all tagged standards. The difference between the proportions of tagged catchables returned by anglers was 7.6%, which was statistically significant ($P < 0.05$). Estimated tag reporting rate was 48.6% and tag loss was 0.2% for all tagged fish. Adjusted total catch (u') for magnums was 31.4%, whereas adjusted total catch for standards was 15.5%.

Results from the mixed-effects logistic regression model corroborated the importance of fish length, indicating that the probability of return for individual fish was positively related to length at release (Table 3). Although individual fish stocked into lotic systems had a slightly higher mean probability of return compared to fish stocked into lentic systems, the effect of water body type in the model was not significant. Only integer length of tagged fish served as a statistically significant variable in the model.

The AFT model containing fish length, waterbody type, and their interaction using the lognormal error distribution served as the top model associated with time-to-capture (i.e., residence time) of catchables (Table 4). All model parameters were significant, and the individual effects of fish length and lotic systems were negatively related to residence time of an individual. In general, fish stocked into lotic systems were

Table 2. Rainbow Trout stocking, tag release, and tag return summaries for 17 lotic systems stocked with tagged catchables during 2015–2016. Magnum catchables were grown to target 305 mm (average TL) and standards were grown to 254 mm. Proportion of tags returned and days-at-large (number of days between stocking date and reported capture date) were determined through information submitted by anglers who reported tagged catch. Proportions reflect the number of non-reward tags returned by anglers to the number released within 2 years of tag release date, and do not include corrections for reporting rate, tag loss, or tagging mortality.

Water body	River length (km)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion of tags returned	Mean days-at-large (± SE)
Crooked River	47.8	2015	5	3,514	18-May	Nampa	Magnums	50	307	183	351	0.08	26 (1)
							Standards	50	247	219	291	0.08	41 (8)
		2016	4	1,999	13-Jun	Nampa	Magnums	44	304	213	368	0.02	26
							Standards	45	254	209	384	--	--
Gold Fork River	26.2	2015	2	1,150	17-Jun	Nampa	Magnums	50	332	256	377	0.14	34 (3)
							Standards	50	236	136	294	0.02	95
		2016	2	787	3-Aug	Nampa	Magnums	30	315	240	371	0.07	2 (0)
							Standards	35	256	177	350	--	--
Grimes Creek	69.0	2015	6	4,022	18-May	Nampa	Magnums	44	324	234	390	0.16	19 (3)
							Standards	45	259	190	311	0.09	6 (1)
					9-Jun	Nampa	Magnums	50	329	228	376	0.14	9 (1)
							Standards	50	252	191	287	0.02	4
		2016	5	3,027	20-May	Nampa	Magnums	49	300	211	345	0.14	39 (4)
							Standards	50	262	190	320	0.06	19 (1)
					15-Jun	Nampa	Magnums	49	307	194	364	0.20	48 (8)
							Standards	38	248	180	297	0.16	15 (3)
Indian Creek	107.0	2015	4	525	7-May	Nampa	Magnums	25	322	276	372	0.24	58 (9)
							Standards	25	272	215	322	0.21	27 (1)
					25-Sep	Nampa	Magnums	24	315	274	359	--	--
							Standards	25	269	205	322	0.12	54 (15)
		2016	12	2,588	19-May	Nampa	Magnums	25	292	178	340	0.12	110 (6)
							Standards	25	247	142	320	0.04	50
Middle Fork Boise River	84.3	2015	5	5,839	25-Jun	Nampa	Magnums	100	324	211	372	0.17	32 (2)
							Standards	100	241	142	325	0.06	42 (1)
					13-Aug	Nampa	Magnums	90	288	185	360	0.02	20 (1)
							Standards	90	254	170	306	0.02	49 (0)
		2016	5	6,196	22-Jun	Nampa	Magnums	91	315	220	396	0.19	38 (3)
							Standards	87	269	201	333	0.05	33 (5)
					6-Aug	Nampa	Magnums	99	322	260	394	0.17	37 (8)
							Standards	100	257	190	304	0.03	39 (4)

(Continues)

Table 2. (Continued)

Water body	River length (km)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion of tags returned	Mean days-at-large (± SE)
Middle Fork Payette River	77.6	2015	8	5,485	18-May	Nampa	Magnums	45	323	220	375	0.31	31 (4)
							Standards	45	252	202	325	0.07	40 (2)
		2016	15	5,745	25-May	Nampa	Magnums	50	278	190	352	0.14	15 (1)
							Standards	50	242	151	300	0.08	29 (3)
					14-Jun	Nampa	Magnums	36	306	217	359	0.17	38 (3)
							Standards	36	253	180	288	0.03	54
					27-Jun	Nampa	Magnums	36	301	226	362	0.19	14 (2)
							Standards	36	264	203	297	0.11	38 (4)
					3-Aug	Nampa	Magnums	40	312	248	405	0.12	17 (2)
							Standards	40	245	180	300	--	--
Mores Creek	64.4	2015	6	3,965	18-May	Nampa	Magnums	50	309	245	370	0.08	25 (2)
							Standards	50	250	213	296	0.08	21 (2)
					9-Jun	Nampa	Magnums	45	331	245	386	0.13	7 (1)
							Standards	45	253	159	297	0.11	12 (2)
		2016	6	3,005	20-May	Nampa	Magnums	45	301	181	352	0.04	20 (1)
							Standards	45	247	170	298	--	--
					15-Jun	Nampa	Magnums	50	315	214	404	0.06	6 (0)
							Standards	50	250	213	298	0.02	95
North Fork Boise River	81.0	2015	7	10,037	25-Jun	Nampa	Magnums	100	324	217	391	0.13	28 (3)
							Standards	100	236	145	300	0.08	42 (2)
					13-Aug	Nampa	Magnums	100	288	210	367	0.03	16 (0)
							Standards	100	259	174	310	0.12	35 (2)
		2016	4	5,804	27-Jun	Nampa	Magnums	100	311	226	397	0.14	47 (4)
							Standards	100	257	184	313	0.07	144 (29)
North Fork Payette River	169.8	2015	2	1,460	17-Jun	Nampa	Magnums	67	315	175	369	0.06	7 (1)
							Standards	67	247	142	304	0.03	21 (3)
		2016	2	979	22-Jun	Nampa	Magnums	50	308	245	370	0.04	254 (29)
							Standards	50	267	201	324	0.12	69 (6)
Rock Creek East Fork	19.3	2015	6	3,750	18-Aug	American Falls	Magnums	74	278	204	324	0.12	27 (1)
							Standards	75	249	197	283	0.07	61 (10)
		2016	6	3,750	30-Aug	American Falls	Magnums	75	291	262	334	0.05	25 (1)
							Standards	75	259	210	293	0.13	13 (1)

(Continues)

Table 2. (Continued)

Water body	River length (km)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion of tags returned	Mean days-at-large (± SE)
Silver Creek	20.6	2015	9	5,488	18-May	Nampa	Magnums	44	321	246	396	0.20	32 (6)
							Standards	45	253	225	296	0.18	28 (3)
					13-Aug	Nampa	Magnums	37	299	252	395	0.03	2
							Standards	46	258	192	320	0.04	23 (0)
		2016	15	5,670	25-May	Nampa	Magnums	50	284	200	347	0.22	30 (3)
							Standards	50	250	145	306	0.10	35 (5)
					14-Jun	Nampa	Magnums	40	315	256	367	0.12	28 (4)
							Standards	40	246	150	281	0.05	26 (1)
					27-Jun	Nampa	Magnums	40	316	260	386	0.12	5 (0)
							Standards	40	259	189	321	0.15	17 (3)
					2-Aug	Nampa	Magnums	67	313	221	390	0.09	21 (3)
							Standards	67	252	201	335	--	--
Snake River (Upper)	91.7	2015	3	6,200	22-Sep	American Falls	Magnums	50	289	252	366	0.10	58 (10)
							Standards	50	258	119	302	0.04	197 (3)
					31-Aug	American Falls	Magnums	100	293	261	335	0.07	84 (8)
							Standards	100	257	116	365	0.03	83 (5)
Snake River Gem State	4.2	2015	6	12,700	22-Sep	American Falls	Magnums	75	286	232	356	0.08	135 (15)
							Standards	75	257	200	298	0.05	134 (11)
					31-Aug	American Falls	Magnums	149	293	265	329	0.13	209 (12)
							Standards	148	256	166	300	0.02	323 (2)
Snake River Henry's Fork	181.1	2015	7	12,325	18-Aug	American Falls	Magnums	25	281	224	329	0.12	14 (1)
							Standards	25	257	178	304	0.08	18 (0)
					31-Aug	American Falls	Magnums	90	292	264	324	0.09	21 (1)
							Standards	89	257	155	300	0.06	18 (1)
Snake River (Lower)	49.9	2016	3	12,000	31-Aug	American Falls	Magnums	24	291	271	331	0.29	22 (2)
							Standards	25	251	176	290	0.28	22 (1)
Weiser River	165.9	2015	2	584	17-Jun	Nampa	Magnums	35	321	222	368	--	--
							Standards	35	247	165	314	--	--

(Contiunes)

Table 2. (Continued)

Water body	River length (km)	Year	Total number of stocking events	Total number of catchables stocked	Tag release date	Stocking hatchery	Length group	Number of tagged fish stocked	Mean TL	Min TL	Max TL	Proportion of tags returned	Mean days-at-large (± SE)
Wilson Creek	18.5	2015	15	3,421	7-May	Nampa	Magnums	25	314	247	355	0.20	8 (1)
							Standards	25	263	223	297	0.24	19 (8)
					13-Aug	Nampa	Magnums	25	285	215	325	0.08	41 (4)
							Standards	25	249	175	311	0.20	19 (4)
					17-Sep	Nampa	Magnums	25	313	200	354	0.36	23 (7)
							Standards	25	275	200	322	0.20	12 (4)
		2016	24	5,623	19-May	Nampa	Magnums	22	289	166	332	0.18	20 (3)
							Standards	22	235	169	300	0.27	12 (2)

returned by anglers much quicker than those stocked into lentic waterbodies at any particular length (Figure 3). Average residence time differed significantly between magnums and standards across all water bodies; magnums were at-large for 93 days (95% CI, ± 6 days) on average, whereas standards were at-large for an average of 112 days (± 10 days).

Though biomass and rearing volume were equivalent throughout the rearing cycle, feed costs were higher for raceways where fish were grown to larger target size. Feed costs increased 31% when growing fish to larger size; production-scale costs for standards was \$0.30/fish, whereas magnums cost \$0.43/fish on average. However, because the relative catch of magnums was double that of standards, the average cost/fish caught was \$0.55 less for magnums (Figure 4).

DISCUSSION

The need for more post-release evaluations of hatchery trout catchable stocking programs was identified over 30 years ago (Hartzler 1988), yet such evaluations remain relatively scarce. One exception to this scarcity is the growing body of literature indicating that larger catchables are more likely to be caught by an angler than smaller catchables (Mullan 1956; Yule et al. 2000; Cassinelli et al. 2016; Losee and Phillips 2017; Cassinelli and Meyer 2018; Meyer and Cassinelli 2020). However, all of these studies evaluated size of catchables as a secondary objective or tested size-at-release across small geographic and temporal scales. The results of the current study concur with previous work in demonstrating that anglers catch higher proportions of catchables when larger fish are stocked. To provide a programmatic-level benefit, however, the increase in average catch across all systems cannot be exceeded by the cost increase associated with growing larger fish. Whereas feed costs associated with raising magnums increased by 31% compared to standards in this study, angler returns of magnums increased by 100% compared to standards. Although feed costs do not account for all expenditures associated with fish rearing, they do serve as a primary expense (Westers 2001), especially when growing fish to larger sizes. Other expenses such as personnel, general operating, and overhead costs were not included in this analysis because those expenditures are relatively fixed, though they do vary considerably among hatcheries and agencies due to differences in hatchery operations (e.g., budget allocation, pay rate) and infrastructure limitations (e.g., water supply, transport constraints). Nevertheless, the current study indicates that producing and stocking catchables that were 313 mm on average would improve put-and-take program efficiencies overall compared to stocking catchables at an average length of 258 mm.

The observed difference in angler catch between standard and magnum catchables was unlikely to have been caused by other confounding factors. For example, individuals from both target length groups tested were presumed to be invulnerable to predation by piscivorous fishes (Yule et al. 2000), and any effect of predation by avian predators was assumed to be equal between length groups (Walters et al. 1997; Chiaramonte et al. 2019). We found no difference in tag reporting rate between length groups, indicating that the difference in angler catch can be attributed to the angling process itself. Although total catch by anglers was seemingly low in the present study (15.5% for standards, 31.4% for magnums), these results are consistent with other catchable post-release evaluations in Idaho (Meyer and Schill 2014; Cassinelli et al. 2016; Cassinelli et al. 2018) and other catchable evaluations

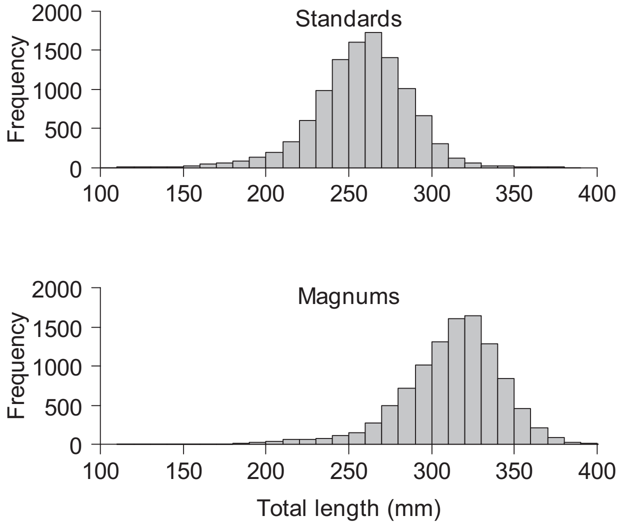

Figure 1. Length distributions at stocking for hatchery Rainbow Trout reared in respective raceways as "standards" (target average length = 254 mm) and "magnums" (target average length = 305 mm).

Table 3. Parameter estimates (i.e., log-odds) and 95% confidence intervals (CI) for a mixed-effects logistic regression model that evaluated the effect of fish length (mm) and waterbody type (lentic or lotic) on the probability of an angler catching and reporting a tagged fish. Specific water bodies where tagged fish were stocked served as a random effect in the model. Length data of all tagged fish were scaled to ensure model convergence.

Parameter	Estimate	95% CI
Intercept	−2.46	−2.77 – −2.16
Length (mm)	0.59	0.53 – 0.64
Lotic	0.09	−0.40 – 0.59
Length × Lotic	−0.08	−0.20 – 0.03

Table 4. Parameter estimates and 95% confidence intervals (CI) for an accelerated failure time model (lognormal error distribution) evaluating the effect of fish length (mm) and waterbody type (lentic or lotic) on time-until-capture by an angler.

Parameter	Estimate	95% CI
Intercept	5.33	4.82 – 5.85
Length (mm)	−0.004	−0.006 – −0.003
Lotic	−2.30	−3.37 – −1.23
Length × Lotic	0.0040	0.0009 – 0.0080

dating back 80 years (e.g., Shetter and Hazzard 1941; Walters et al. 1997). Catchability is of paramount importance for put-and-take fisheries, given that the impetus behind such programs is to create immediate fisheries. However, the fact that most stocked fish are never caught by anglers highlights the importance of making management decisions that maximize catch of hatchery fish at put-and-take fisheries. Size-selectivity associated with angling is well-documented for many species (Miranda and Dorr 2000; Pope et al. 2005), and the data presented herein suggest that anglers catch the largest of stocked trout at put-and-take fisheries. Despite increases in rearing costs associated with growing catchables to a larger size, it cost $0.55 less on average for every magnum caught by an angler than for every standard caught. This result-based outcome summarizes the effective programmatic benefit of producing and stocking larger catchables across a variety of lentic and lotic systems.

Preliminary analyses applied to the data herein indicated that integer length of individual fish served as a better predictor of angler tag returns than did the raceway-specific effect of "magnum" or "standard," likely due to overlapping lengths among test groups. A significant difference was observed between the proportions of standards and magnums caught by anglers, but not every individual fish achieved or maintained its targeted length. Efforts such as size grading can be used to select larger fish for stocking, allowing more time for smaller catchables to remain on-station to achieve a larger size. However, at the hatchery-production scale, size grading of catchables has not been shown to increase mean size-at-release compared to ungraded fish over the entirety

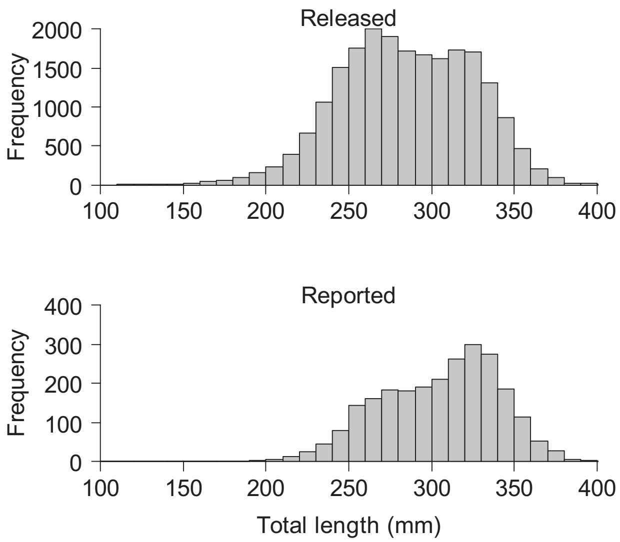

Figure 2. Length distributions for all tagged hatchery Rainbow Trout that were released into lotic and lentic waterbodies from 2014—2016 and those that were caught and reported by anglers.

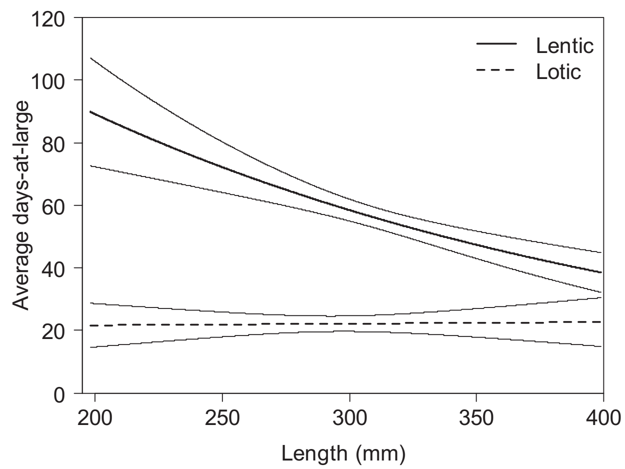

Figure 3. Predicted probabilities of an accelerated failure time model (lognormal error distribution) where time-to-capture (i.e., days-at-large) of tagged hatchery Rainbow Trout was related to fish length (mm) and waterbody type. Thin lines represent 95% confidence intervals.

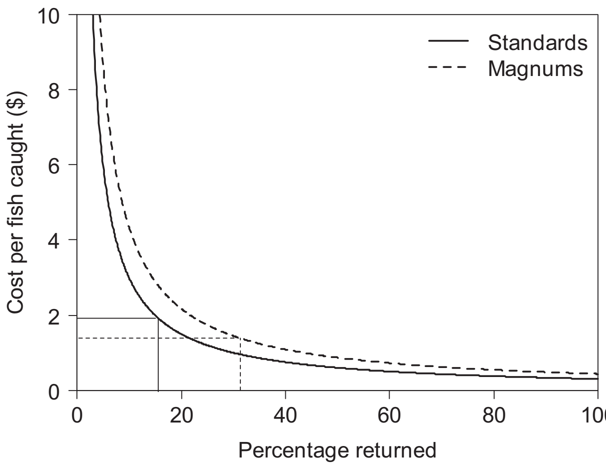

Figure 4. Cost/fish caught by anglers for catchables released as "standards" (average target length = 254 mm) and "magnums" (average target length = 305 mm). Adjusted total catch (*u′*) for fish grown in standard raceways was 15.5% (thin vertical solid line), whereas *u′* for fish grown in magnum raceways was 31.4% (thin vertical dashed line). The realized effective cost difference for fish caught by anglers was $0.55 less for magnums.

of a stocking period, and catch of size-graded fish by anglers is equivalent to that of ungraded fish (Meyer and Cassinelli 2020). Consequently, increasing the target length during production may be the most effective method of maximizing the proportion of stocked catchables that are caught by anglers.

The effective cost benefit observed when stocking magnum-sized catchables compared to standard-sized catchables raises questions relating to targeted length; specifically, what length should be targeted during production before rearing costs exceed the benefits of improved angler returns? Perhaps 305 mm serves as the apex of this cost-benefit relationship, but evaluating the post-release performance of catchables raised at production scale to an even larger target size would seem prudent. Catchables reared to 300 mm have been shown to be the most cost-effective length for catchable trout stocking in Washington Lakes (Losee and Phillips 2017), but that result is limited to fish that were harvested on opening day of the trout fishing season and may not reflect the lowest cost when considering catch-and-release or when evaluated throughout the season and across numerous waterbodies. Feed costs represent only a portion of the cost associated with rearing a group of fish at a production scale, but they are a useful metric when evaluating the post-release performance of two size groups when other important variables (e.g., rearing density, total number stocked) are held constant. However, ingredients used in commercial feeds are subject to market pricing, so fluctuations in commodity markets could influence the effective benefit of stocking larger fish.

Although waterbody type did not have a significant effect on probability of catch by an angler, the effect of fish length on residence time of catchables varied significantly between lentic and lotic systems. In lentic waterbodies, the largest of catchables were caught more quickly by anglers than smaller conspecifics. Therefore, stocking larger catchables in lentic waterbodies might serve to increase return-to-creel, but reduce the average residence time of the population, highlighting the need to consider stocking frequency to maintain desirable angler catch rates throughout the angling season. In contrast, residence time of stocked fish was much shorter in lotic systems, and individual fish length had little effect on the residence time of hatchery catchables in lotic fisheries. Previous studies in lotic systems have reported that most catchables are caught by anglers shortly after stocking (Fay and Pardue 1986; Dillon et al. 2000), presumably because survival is low (Bettinger and Bettoli 2002; High and Meyer 2009). In addition, hatchery catchables can disperse several kilometers from their stream stocking locations (Cresswell 1981), which may contribute to lower returns observed in lotic systems. In light of the results of the current study and others, catchables stocked into lotic systems seem to be caught and reported by anglers quickly or fail to be reported at all—regardless of size-at-stocking.

Considering the number of tagged fish and water bodies evaluated, the results presented here present a strong case that shifting trout stocking programs to larger size-at-stocking can improve the overall efficiency of a catchable hatchery trout program. However, not all fishery types were included in our evaluation. For example, urban and community ponds are quintessential examples of put-and-take fisheries (Eades et al. 2008), but we omitted them from the study due to inherently high levels of angling pressure and harvest rates that can exceed 90% (Brader 2008). Given such high catch rates, it may not be cost-effective to stock larger catchables in urban and community pond fisheries. However, community pond anglers have shown preference towards catching larger fish rather than more fish (Schramm and Dennis 1993), and the results of the current study suggest that an empirical evaluation of relative catch between standards and magnums at urban and community ponds would be useful.

Fishery-specific metrics such as angler catch rate and average length of catch could be used to adjust catchable production targets and further increase programmatic efficiencies. Angler satisfaction can be influenced by a suite of catch-related variables, such as stocking density, catch rates, and fish size (Miko et al. 1995; McCormick and Porter 2014). For Rainbow Trout anglers in general, average length of catch, as well as the number of fish caught per hour, are important predictors of angler satisfaction (McCormick and Porter 2014). Providing larger catchables for hatchery-supported fisheries would likely result in increased angler satisfaction and serve to increase efficiencies in agency operations. However, rearing space at production facilities in general is finite, and the average size-at-stocking has a direct effect on the number of individuals that may be reared and stocked. For instance, growing fish to magnum size in this study resulted in a 35–40% reduction in the total number of fish typically grown to standard size in the same rearing space. Total biomass in standard and magnum raceways were held constant during this evaluation to simplify the cost–benefit analysis. However, fish density can be increased as larger sizes are achieved (Piper et al. 1982), thereby increasing biomass and total number of fish produced. Fisheries managers must be cognizant of the interactions between stocking size, stocking frequency, total number of catchables produced (and stocked), and longevity of fisheries (i.e., residence time of stocked trout) when maintaining or supplementing populations with hatchery-reared catchables. Such considerations can improve the efficiencies of a catchable stocking program overall and provide an immediate benefit to recreational anglers.

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