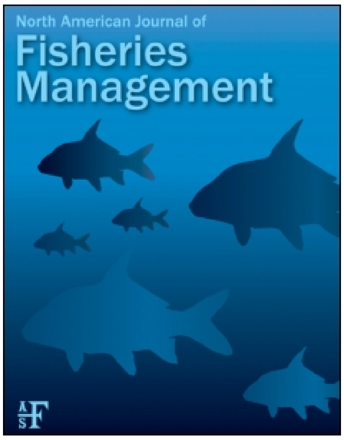

North American Journal of Fisheries Management
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t927035357

Performance of Diploid and Triploid Rainbow Trout Stocked in Idaho Alpine Lakes

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First published on: 11 March 2011

To cite this Article Koenig, Martin K. , Kozfkay, Joseph R. , Meyer, Kevin A. and Schill, Daniel J.(2011) 'Performance of Diploid and Triploid Rainbow Trout Stocked in Idaho Alpine Lakes', North American Journal of Fisheries Management, 31: 1, 124 — 133, First published on: 11 March 2011 (iFirst)

To link to this Article: DOI: 10.1080/02755947.2011.561163

URL: http://dx.doi.org/10.1080/02755947.2011.561163

North American Journal of Fisheries Management 31:124–133, 2011

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2011.561163

ARTICLE

Performance of Diploid and Triploid Rainbow Trout Stocked in Idaho Alpine Lakes

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Abstract
Increased growth, improved survival, and genetic protection of wild stocks have been suggested as benefits of stocking triploid (i.e., sterile) salmonids for recreational fisheries. We examined the return rates and growth of mixed-sex diploid (2N), mixed-sex triploid (3N), and all-female triploid (AF3N) rainbow trout *Oncorhynchus mykiss* across 28 alpine lakes. Equal numbers of each treatment group were stocked in 2001 and 2003 and sampled 3–4 years later. During 2004 and 2005, a total of 75 2N and 36 3N marked rainbow trout were recaptured. Taken together, the 2N fish accounted for an average of 0.68 of the total marked fish caught, and the combined proportions of test fish (including netting and angling) differed significantly between the test groups and were consistent across survey years. During 2006 and 2007, a total of 60 2N, 31 3N, and 208 AF3N marked rainbow trout were recaptured. The mean length of the test fish was similar between test groups within sampling years. Overall, the return of 3N rainbow trout to alpine lakes in Idaho was low compared with that of 2N trout, whereas AF3N trout appeared to return in higher proportions than both of the other groups. The triploid stocks studied in this evaluation did not show any growth advantages over the duration of the study. Study design limitations may have contributed in part to some of the differences in the number of 2N and 3N rainbow trout captured. However, our results suggest that fisheries managers should consider all-female triploid rainbow trout as a low-risk option for maintaining alpine lake fisheries while minimizing the impact on native stocks.

Idaho contains approximately 3,000 alpine lakes, ranging from small seasonal ponds to lakes over 1.6 km long (IDFG 2007a). Of these lakes, approximately 1,355 are stocked by the Idaho Department of Fish and Game (IDFG) or have self-sustaining fish populations. Fishing opportunities in alpine lakes are highly rewarding, offering solitude, dramatic scenery, and a backcountry experience seldom found in other fisheries. Not surprisingly, anglers visiting alpine lakes typically express high levels of satisfaction with their fishing experience (WGF 2002; IDFG 2007a). Alpine lake fisheries can provide a high quality angling experience at relatively little investment in stocking costs to management agencies (Wiley 2003; IDFG 2007b). In Idaho, alpine lakes make a significant contribution to Idaho's recreational economy, garnering visits from over 40,000 anglers annually (IDFG 2007a).

Managing alpine lake fisheries presents a challenge, as managers must balance the conflicting mandates of providing recreational fishing opportunities with minimizing the impacts on wilderness ecosystems and native fish communities (Knapp et al. 2001; Wiley 2003). The IDFG Fisheries Management Plan (IDFG 2007a) outlines guidelines regarding the management of alpine lakes, with genetic conservation of wild trout populations being a priority. Triploid salmonids (created by heat or pressure shock) are functionally sterile and may be a useful tool for managing alpine lake fisheries. Sterility can help avoid genetic introgression with native wild stocks and may provide a fishery benefit such as increased growth (Thorgaard 1986; Boulanger 1991; Teuscher et al. 2003) or longevity (Parkinson and Tsumura 1988; Johnston et al. 1993; Warrillow et al. 1997). Because of these attributes, the IDFG in 2001 established a policy to stock only triploid rainbow trout *Oncorhynchus mykiss* in stocked fisheries in which diploid hatchery fish could pose a genetic risk to native trout populations (IDFG 2007a, 2007b).

The survival, longevity, and growth of triploid salmonids in natural environments have been inconsistent relative to those for diploid fish (Parkinson and Tsumura 1988; Simon et al. 1993;

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Received January 27, 2010; accepted November 16, 2010

Brock et al. 1994; Warrillow et al. 1997) and may be species or strain dependent (Ihssen et al. 1990). Studies describing the survival and return to creel of triploid rainbow trout have been performed in ponds, streams, and reservoirs (Simon et al. 1993; Dillon et al. 2000; Teuscher et al. 2003), but literature describing their performance in alpine lakes is sparse. In such lakes, rainbow trout may experience low temperatures and severe hypoxia in winter (Gruber and Wieser 1983; Rahel and Kolar 1990), and some authors have suggested that triploid salmonids may suffer higher mortality under stressful conditions (see Benfey 1999 and Piferrer et al. 2009 for reviews). Before using sterile fish as a common management tool in alpine lakes, it is important to determine whether triploid rainbow trout produce satisfactory fisheries in these habitats. If not, managers may need to adjust stocking strategies rather than rely on historical stocking levels, as is often practiced (Meyer and Schill 2007). Our objective was to compare mean size and return rates of diploid and triploid rainbow trout stocked in Idaho alpine lakes 3 and 4 years after stocking—at which time rainbow trout would normally have reached sexual maturity and a desirable size for anglers.

STUDY SITE

The majority of alpine lakes in Idaho were historically fishless, lying in cirque basins formed by receding glaciers (Bahls 1992). Study locations occurred across the Idaho Batholith ecological subregion of central Idaho, which is composed of underlying Tertiary and Mesozoic granite. The Idaho Batholith ranges in elevation from 425 to 3,400 m, and contains extensive alpine terrain, cirques, and large U-shaped valleys. Soil and vegetation patterns include shallow to moderately deep loam, sand, or rock with Douglas-fir *Pseudotsuga menziesii*, ponderosa pine *Pinus ponderosa*, and lodgepole pine *Pinus contorta*. We chose 28 lakes in central Idaho representing the range of sizes and elevations of alpine lakes typically stocked with rainbow trout by IDFG (Table 1). Lake elevation ranged from 2,138 to 3,157 m, surface area ranged from 0.7 to 23.5 ha, and maximum depth ranged from 2.8 to 26.6 m. Lakes were selected from those having a history of rainbow trout stocking and were scheduled to receive plants in the given study year. Additionally, past surveys indicated that these lakes were capable of supporting rainbow trout populations. Most study lakes were managed under the "general" trout regulation of six fish per day with no length restrictions; two lakes, however, had a 508-mm minimum length and a two-fish bag limit.

METHODS

2001 stocking.—Rainbow trout were obtained from mixed-sex rainbow trout eggs produced from 1:1 pairings at IDFG's Hayspur Fish Hatchery. One-half of the eggs were thermally shocked (26°C water bath at 20 min after fertilization for 20 min) to produce the triploid (hereafter 3N) stock (Teuscher et al. 1998); the other half were untreated and used as a mixed-sex diploid stock. The triploid induction rate was estimated at 98% ($n = 40$) by analyzing blood samples by means of flow cytometry (Thorgaard et al. 1982). Diploid (hereafter 2N) and 3N stocks were marked with adipose fin clips and either green or red fluorescent grit dye, respectively. Three hundred fry from each group were then stocked into 16 alpine lakes by fixed-wing aircraft from August 30 to September 15, 2001. Accordingly, lakes were initially surveyed 3 years after stocking, between July 16 and August 24, 2004, and half of the lakes sampled again between July 6 and August 16, 2005.

2003 stocking.—Rainbow trout were obtained from mixed-sex eggs produced from 1:1 pairings at Hayspur Fish Hatchery. One-half of the eggs were thermal-shocked (using the methods described above) to produce a mixed-sex triploid stock (3N), while the other half were untreated and used as a mixed-sex diploid stock (2N). In addition, all-female triploid Kamloops stock rainbow trout (hereafter AF3N) eggs were purchased from Troutlodge, Inc. (Sumner, Washington). Fry from the 2N, 3N, and AF3N stocks were marked with left ventral, right ventral, and adipose fin clips, respectively. Triploid induction rates were estimated as 100% for the 3N stock ($n = 25$) and the AF3N stock ($n = 60$) by analyzing blood samples by means of flow cytometry (Thorgaard et al. 1982). Marked rainbow trout were stocked in 14 lakes from August 14 to 22, 2003, using fixed-wing aircraft or all-terrain vehicles. Each of the lakes received 500 fry from each treatment group except Blue Lake, which received 400 3N fry and 500 fry from each of the other two groups. As in the 2001 stocking, lakes were initially surveyed 3 years after stocking, between July 7 and October 2, 2006, and half of the lakes were sampled again from July 30 to September 26, 2007.

Sampling.—Lakes were sampled using a combination of angling and gill nets. Floating experimental gill nets were 46 m long and 1.5 m deep, consisting of multifilament nylon mesh panels of 19, 25, 30, 33, 38, and 48 mm bar mesh. Typically, three to six gill nets were set perpendicular to the shoreline around the lake and set overnight. In 2004, gill nets were set at each lake, for an average of 56 h per lake. Angling was conducted at 12 of the 16 lakes, for an average of 4.9 h per lake (Table 2). In 2005, gill nets were set at eight lakes, for an average of 63 h per lake. Angling in 2005 was conducted at six of the eight lakes for an average of 4.3 h per lake (Table 2). Gill-net and angling effort in 2006 averaged 32 h and 2.3 h per lake, respectively. Gill-net effort in 2007 included eight lakes for an average of 23 h per lake, whereas angling averaged 3.5 h per lake (Table 3).

Rainbow trout captured were measured to the nearest millimeter (total length), weighed to the nearest gram, and examined for fin clips and the presence of grit marking (when applicable) using a portable fluorescent lantern (Model UVL-4; UVP, Inc.). Visual examination for grit dye was conducted in the absence of light within an industrial-strength black plastic bag.

Bathymetric and water quality data were collected along three transects placed at equal distances perpendicular to the

TABLE 1. Names and select habitat characteristics for 28 alpine lakes in Idaho stocked with diploid, triploid, and all-female triploid rainbow trout in 2001 or 2003.

Lake	Elevation (m)	Stocking density (fish/ha)	Area (ha)	Average depth (m)	Maximum depth (m)	Mean pH	Mean conductivity (μS/cm)	Mean temperature (°C)	Maximum temperature (°C)	Secchi depth (m)
2001										
Blackwell	2,151	41	14.5	7.3	10.8	7.4	14.3			2.8
Blue 1	2,222	95	6.3	4.3	5.2	7.5	9.0			4.2
Blue Jay	2,610	250	2.4	9.4	17.5	7.8	5.0	16.0	17.7	6.0
Brush	2,179	58	10.4	4.3	8.7	7.3	4.0	15.1	16.0	5.5
Cache Creek 1	2,370	273	2.2	4.5	8.3	7.7	17.0	12.3	14.6	2.1
Cache Creek 2	2,334	857	0.7	1.6	7.1	7.6	20.0	16.3	18.4	3.1
Josephine 2	2,262	109	5.5	7.5	17.3	7.6	8.0	16.3	17.5	4.5
Ingeborg	2,723	58	10.4	8.7	14.2	7.6	1.7	14.2	17.1	6.0
Long	2,907	113	5.3	1.6	2.8	8.7	41.3	15.4	17.7	5.8
North Fork 20 Mile Long	2,388	90	6.7	6.1	7.8	7.2	10.3	15.9	17.5	5.0
North Fork 20 Mile South	2,400	171	3.6	4.5	7.8	7.3	18.3	15.5	16.8	3.3
Queens River 5	2,561	176	3.4	6.6	14.4	7.8	3.0	12.3	14.1	4.2
Raft	2,138	214	2.8	5.2	8.6	6.9	8.3	20.1	22.3	2.7
Shaw Twins 1	2,213	250	2.4	8.0	10.3	7.0	6.7	15.5	17.0	7.0
Squaw	2,150	353	1.7	4.5	6.6	7.2	6.0	16.4	18.0	4.5
Washington	3,157	231	2.6	12.5	20.2	7.9	14.0			3.9
2003										
Big	2,958	224	6.7	6.0	10.5	7.7		16.2	18.0	7.6
Blackwell	2,151	103	14.5	7.3	10.8	7.2	12.0			2.8
Blue–Secesh	2,332	203	6.9	12.8	19.8	7.8	11.0	17.9	19.2	4.9
Edna 2	2,563	64	23.5	13.2	21.2	6.2	5.0			
Heart 3B	2,617	250	6.0	3.6	7.5	7	3.0	17.6	18.2	
Heart 4	2,542	385	3.9	13.7	26.6	8.9	13.7			
Kane Canyon	2,813	254	5.9	2.8	4.7	7.7	22.0	11.1	13.0	2.2
Ingeborg	2,723	144	10.4	8.7	14.2	7.2	2.0	16.9	17.6	6
Leggit	2,600	200	7.5	5.3	10.2	8.2	4.0	12.8	14.2	
Lynx Creek	2,569	294	5.1	7.4	10.3	8	12.0			
Perkons	2,653	395	3.8	5.8	13.8	7.9	217.0	16.2	18.0	
Rough	2,925	366	4.1	4.4	5.9	7.5	13.4	16.1	17.6	5.7
South Buckhorn	2,123	221	6.8	9.5	11.9	7.1	3.4			
West Fork Buckhorn 1	2,122	123	12.2	12.6	21.9	7.2	3.3			

long axis of the lake, as determined with the aid of a laser rangefinder. Three sampling points were equally spaced along each transect, where several measurements were made. Depth (m), specific conductivity (μS/cm), pH, and temperature (°C) were collected with a handheld sonar unit and Hanna HI98127 and DiST 3 instruments. Water transparency was determined based on Secchi depth (m). In addition, lake temperature was recorded hourly for 1 year using a thermograph placed in each lake approximately 0.6 m below the water's surface and 2–3 m from shore. Lake area was determined with ArcGIS 9.2 software.

Data analysis.—Mean total length and weight of test groups before stocking were compared by using one-way analysis of variance (ANOVA) and Tukey's multiple comparisons (Zar 1999). Catch per unit effort (CPUE) was calculated for each test group by lake, survey year, and gear type by dividing the total number of fish caught by the total hours of netting or angling effort. Because of the different combinations of fish strains used in the years of stocking, catch data from each stocking year (2001 or 2003) were examined separately. Mean total length and weight at the time of sampling were compared between groups within each sampling year using mixed-model ANOVA

TABLE 2. Catch per unit effort (fish per total hours of effort netting or angling) of diploid (2N) and triploid (3N) rainbow trout in 28 Idaho alpine lakes stocked in 2001 and surveyed in 2004, 2005 or both. Proportion refers to the proportion caught of each group from the total marked fish (adjusted for the 98% triploid-induction rate). Blanks indicate lakes where angling was not conducted.

	Total		Nets			Angling			Proportion	
Lake	3N	2N	3N	2N	Effort	3N	2N	Effort	3N	2N
2004										
Blackwell	0	1	0.00	0.17	6.0	0.00	0.00	9.0	0.00	1.00
Blue 1	4	8	0.09	0.15	33.5	0.22	0.67	4.5	0.33	0.67
Blue Jay	1	1	0.05	0.05	21.5	0.00	0.00	5.5	0.50	0.50
Brush	0	0	0.00	0.00	78.9			0.0	0.00	0.00
Cache Creek 1	0	1	0.00	0.03	34.3	0.00	0.00	6.5	0.00	1.00
Cache Creek 2	0	0	0.00	0.00	45.8			0.0	0.00	0.00
Josephine 2	0	0	0.00	0.00	58.0	0.00	0.00	4.5	0.00	0.00
Ingeborg	2	6	0.05	0.15	41.0	0.00	0.00	7.5	0.25	0.75
Long	2	6	0.04	0.07	54.0			0.0	0.25	0.75
North Fork 20 Mile Long	0	3	0.00	0.04	55.5	0.00	0.15	6.5	0.00	1.00
North Fork 20 Mile South	1	1	0.01	0.01	89.5			0.0	0.50	0.50
Queens River 5	0	1	0.00	0.02	59.5	0.00	0.00	3.0	0.00	1.00
Raft	19	24	0.23	0.29	81.5	0.00	0.00	3.5	0.44	0.56
Shaw Twins 1	0	2	0.00	0.01	134.5	0.00	0.00	6.0	0.00	1.00
Squaw Lake	0	0	0.00	0.00	49.0	0.00	0.00	1.5	0.00	0.00
Washington	0	2	0.00	0.04	55.0	0.00	0.00	1.0	0.00	1.00
Mean	2	4	0.03	0.06	56.1	0.02	0.07	4.9	0.19	0.81
2005										
Cache Creek 1	0	0	0.00	0.00	33.5	0.00	0.00	2.0	0.00	0.00
Josephine 2	0	3	0.00	0.04	75.5	0.00	0.00	1.3	0.00	1.00
Ingeborg	3	6	0.05	0.11	56.0	0.00	0.00	5.5	0.33	0.67
North Fork 20 Mile Long	1	1	0.01	0.01	85.0	0.00	0.00	5.5	0.50	0.50
Queens River 5	0	0	0.00	0.00	80.5	0.00	0.00	8.5	0.00	0.00
Raft	1	5	0.02	0.10	48.0			0.0	0.17	0.83
Shaw Twins 1	0	1	0.00	0.01	70.0	0.00	0.00	3.0	0.00	1.00
Washington	2	3	0.04	0.06	53.0			0.0	0.40	0.60
Mean	1	2	0.02	0.04	62.7	0.00	0.00	4.3	0.24	0.76

and Tukey's multiple comparisons. We used the total marked rainbow trout caught by both angling and gill nets for analysis, letting each lake serve as one independent observation. To compare return rates, we expressed the total number captured from each group as a proportion of the total combined marked trout caught within each lake. Before analysis, catch data were transformed using a $\log_{10} + 1$ transformation to approximate the assumptions of identical, independent, and normally distributed errors. The mean proportion captured was compared between groups by using mixed-model ANOVA and Tukey's multiple comparisons with repeated measures to account for multiple survey years at some lakes. Stock and survey year were treated as categorical fixed effects, whereas Lakes were treated as random effects. All statistical tests were performed with $\alpha = 0.05$ using Statistical Analysis Software 9.1 (SAS 2003).

Relationships between lake habitat variables (Table 1) and the catch of marked fish captured across study lakes were examined to assess whether they explained any differences in catch between test groups. Relationships were examined using a correlation matrix (Pearson correlation coefficients) and scatter plots for the 2001 and 2003 data sets separately.

RESULTS

2001 Stocking

Initial mark retention in the hatchery 2 weeks postmarking was estimated as 94% for the diploid stock (green) and 98% for the triploid stock (red). At the time of stocking, the mean ± SD lengths of the 2N (65 ± 0.62 mm) and 3N (67 ± 0.62 mm) stocks were not statistically different (ANOVA: $F_{1,198} = 2.64$, $P = 0.1059$). The weights for the 2N (3.0 ± 0.07 g) and 3N

TABLE 3. Catch per unit effort (fish per total hours of effort netting and angling) of all-female triploid, diploid (2N), and triploid (3N) rainbow trout in Idaho alpine lakes stocked in 2003 by survey year. Proportion refers to the proportion caught of each group from the total marked fish. Blanks indicate lakes where angling was not conducted.

	Total			Nets				Angling				Proportion		
Lake	AF3N	3N	2N	AF3N	3N	2N	Effort	AF3N	3N	2N	Effort	AF3N	3N	2N
2006														
Big	4	0	0	0.09	0.00	0.00	43.1	0.00	0.00	0.00	0.6	1.00	0.00	0.00
Blackwell	2	0	0	0.04	0.00	0.00	27.1	0.33	0.00	0.00	3.0	1.00	0.00	0.00
Blue–Secesh	1	0	0	0.04	0.00	0.00	27.8				0.0	1.00	0.00	0.00
Edna 2	4	1	2	0.10	0.00	0.07	29.5	0.33	0.33	0.00	3.0	0.57	0.14	0.29
Heart 3B	6	1	6	0.11	0.02	0.11	54.7	0.00	0.00	0.00	3.6	0.46	0.08	0.46
Heart 4	40	4	14	1.47	0.04	0.31	25.9	0.73	1.09	2.18	2.8	0.69	0.07	0.24
Kane Canyon	9	0	4	0.33	0.00	0.15	27.5	0.00	0.00	0.00	0.8	0.69	0.00	0.31
Ingeborg	0	0	0	0.00	0.00	0.00	27.4	0.00	0.00	0.00	2.5	0.00	0.00	0.00
Leggit	12	1	0	0.36	0.04	0.00	27.6	1.33	0.00	0.00	1.5	0.92	0.08	0.00
Lynx Creek	10	4	2	0.35	0.12	0.00	26.0	1.00	1.00	2.00	1.0	0.63	0.25	0.13
Perkons	3	0	1	0.11	0.00	0.04	28.2				0.0	0.75	0.00	0.25
Rough	44	3	7	0.83	0.06	0.15	47.2	1.67	0.00	0.00	3.0	0.81	0.06	0.13
South Buckhorn	23	5	12	0.49	0.16	0.41	24.6	2.75	0.25	0.50	4.0	0.58	0.13	0.30
WF Buckhorn 1	0	0	1	0.00	0.00	0.04	25.5				0.0	0.00	0.00	1.00
Mean	11	1	4	0.29	0.03	0.08	31.6	0.68	0.22	0.39	2.3	0.70	0.06	0.24
2007														
Blackwell	1	0	0	0.04	0.00	0.00	25.7	0.00	0.00	0.00	1.5	1.00	0.00	0.00
Blue–Secesh	3	0	0	0.10	0.00	0.00	29.6	0.00	0.00	0.00	3.2	1.00	0.00	0.00
Heart 3B	2	1	4	0.00	0.00	0.11	9.3	0.20	0.10	0.30	10.0	0.29	0.14	0.57
Heart 4	18	9	2	0.57	0.16	0.00	24.5	1.74	2.17	0.87	2.3	0.62	0.31	0.07
Ingeborg	0	0	0	0.00	0.00	0.00	14.6	0.00	0.00	0.00	4.0	0.00	0.00	0.00
Leggit	12	0	2	0.47	0.00	0.08	25.8	0.00	0.00	0.00	0.5	0.86	0.00	0.14
Lynx Creek	10	1	2	0.41	0.04	0.08	24.4				0.0	0.77	0.08	0.15
Rough	4	1	1	0.04	0.04	0.04	25.3	0.49	0.00	0.00	6.2	0.67	0.17	0.17
Mean	6	2	1	0.23	0.03	0.04	22.4	0.40	0.38	0.19	3.9	0.74	0.10	0.16

stocks (3.0 ± 0.07 g) were equal (ANOVA: $F_{1,\,198} = 0.00$, $P >$ 0.9782).

The catch per unit effort of marked fish caught in 2004 and 2005 was variable across lakes and treatment groups (Table 2). During 2004, 779 rainbow trout were captured, including 56 diploid and 29 triploid marked rainbow trout; the remainder consisted of unmarked previously stocked or wild trout. In 2004, the 3N and 2N stocks were caught on average at 0.03 and 0.06 fish/h of gill netting, respectively, whereas angling produced catch rates of 0.03 and 0.07 fish/h, respectively. However, angling was successful at capturing marked fish in only 2 of the 12 lakes where it was used (Table 2). During 2005, 329 rainbow trout were sampled, including 19 diploid and 7 triploid marked rainbow trout. The mean CPUE in 2005 using gill nets for the 3N and 2N stocks was 0.02 and 0.04 fish/h, respectively (Table 2); no marked fish were captured by angling in six of the lakes where it was used.

Overall, the 2N stock returned in higher proportions in both years surveyed. In 2004, the 2N stock made up 0.81 of the total marked fish caught on average, whereas the 3N stock made up only 0.19 (Table 2). The results were similar in 2005, the 2N stock composing an average of 0.76 of the total marked fish caught (Table 2). Considered across both survey years, the combined proportions of marked test fish captured (including netting and angling) differed significantly between the test stocks (ANOVA: $F_{1,\,30} = 29.68$, $P < 0.0001$; Table 4), the 2N fish being over twice as likely to be recaptured. Survey year and the interaction of survey year and stock did not have significant effects (ANOVA: $F_{1,\,14} = 0.06$, $P = 0.81$; and $F_{1,\,14} = 0.01$, $P = 0.93$, respectively).

Despite apparent differences, the mean lengths of 2N and 3N stocks were not statistically different in 2004 (ANOVA: $F_{1,\,83} =$ 1.80, $P = 0.18$) or in 2005 (ANOVA: $F_{1,\,24} = 0.65$, $P = 0.43$), as shown in Table 5. This was probably the result of large variation in sizes and low numbers of recovered fish for the 3N stock. The mean weight of the 2N rainbow trout captured in 2004, 376 g, was significantly greater than that of the 3N trout, 305 g (ANOVA: $F_{1,\,83} = 7.04$, $P = 0.01$). Similar to comparisons

TABLE 4. Mean relative proportions captured (from both angling and netting) of diploid (2N), triploid (3N), and all-female triploid (AF3N) rainbow trout by stocking year. $\text{Log}_{10} + 1$ transformed values derived from the ANOVA analysis and associated standard errors are shown. Within stocking years, treatments with the same letter are not statistically different at $\alpha = 0.05$.

Stock	Estimate	SE
	2001 Stocking	
2N	0.453 z	0.043
3N	0.125 y	0.043
	2003 Stocking	
AF3N	0.468 z	0.047
2N	0.183 y	0.047
3N	0.062 y	0.047
	2003 Stocking with AF3N removed	
2N	0.385 z	0.052
3N	0.182 y	0.052

of length, differences in weight were not significant in 2005 (ANOVA: $F_{1,24} = 1.22$, $P = 0.28$) despite the apparent disparity in mean weight between stocks (Table 5).

2003 Stocking

At the time of stocking, there were minor differences in mean length between stocks (ANOVA: $F_{2,327} = 9.85$, $P < 0.001$). Based on Tukey's multiple comparisons, the mean ± SD lengths of the 2N (62 ± 4.6 mm) and 3N stocks (62 ± 5.2 mm) were similar; the AF3N stock was slightly longer (65 ± 6.0 mm). There were slight differences in mean weight between the stocking groups (ANOVA: $F_{2,327} = 3.26$, $P = 0.0396$). The mean ± SD weight of the AF3N stock (2.0 ± 0.7 g) was slightly heavier than that of the 2N stock (1.8 ± 0.5 g), but the 2N and 3N (1.8 ± 0.5 g) groups were not statistically different.

TABLE 5. Total lengths (mm) and weights (g) of marked diploid (2N), triploid (3N), and all-female triploid (AF3N) rainbow trout recaptured in Idaho alpine lakes, by sampling year. Within sample years, stocks with the same letter are not statistically different.

			Length		Weight	
Stocking year	Stock	*n*	Mean	(SD)	Mean	(SD)
			2004 Sample			
2001	2N	56	332 z	(39)	376 z	(133)
	3N	29	322 z	(23)	305 y	(73)
			2005 Sample			
	2N	19	348 z	(62)	464 z	(253)
	3N	7	327 z	(46)	351 z	(143)
			2006 Sample			
2003	AF3N	157	295 z	(35)	275 z	(88)
	2N	43[a]	290 z	(31)	274 z	(85)
	3N	19	280 z	(35)	233 z	(83)
			2007 Sample			
	AF3N	50	336 z	(31)	357 z	(107)
	2N	11	340 z	(39)	391 z	(162)
	3N	12	321 z	(28)	338 z	(100)

[a]While 49 2N fish were captured, only 43 were actually measured.

In the first year of sampling (2006), 983 rainbow trout were sampled, including 230 marked rainbow trout (49 2N, 19 3N, and 158 AF3N). Mean gill-net CPUE was highest for the AF3N (0.29 fish/h), followed by the 2N and 3N stocks (0.08 and 0.03 fish/h, respectively; Table 3). Angling in 2006 paralleled the same pattern as netting, but resulted in higher mean catch rates, catch rates being highest in the AF3N rainbow trout (0.68 fish/h), followed by the 2N and then 3N stocks (0.39 and 0.22 fish/h, respectively). In 2007, 202 rainbow trout were captured, including 50 AF3N, 11 2N, and 12 3N trout. The mean gill-net catch rate in 2007 again was highest for the AF3N stock (0.23 fish/h), the 2N and 3N stocks being caught at 0.04 and 0.03 fish/h, respectively. Mean angling catch rates in 2007 were higher, ranging from 0.19 fish/h for the 2N stock to 0.40 fish/h for the AF3N stock (Table 3).

The AF3N stock had the highest return rate of the three groups, followed by the 2N stock. During the 2006 sample, the AF3N female stock on average made up 0.70 of the total marked fish captured, followed by the 2N stock and the 3N stock (0.24 and 0.06, respectively Table 3). Results in 2007 were similar, the AF3N stock making up 0.74 of the total marked fish caught on average, followed by the 2N stock and the 3N stock (0.16 and 0.10, respectively). Stock had a significant effect on the proportion of fish captured (ANOVA: $F_{2,39} = 19.23$, $P < 0.0001$), but survey year and the interaction of survey year and stock did not have significant effects in the analysis (ANOVA: $F_{1,21} = 0.01$, $P = 0.98$; and $F_{2,21} = 0.49$, $P = 0.62$, respectively). Results from Tukey's multiple comparisons indicated that the AF3N stock was caught in significantly higher proportions than both the 2N and 3N stocks, but the proportions of the two Hayspur stocks could not be statistically distinguished, despite the seemingly large disparity in the results (Table 4).

The mean length of marked fish captured in 2006 was similar among stocks and ranged from 280 to 295 mm (ANOVA: $F_{2,216} = 1.62$, $P = 0.20$; Table 5). As with length, the mean weight of marked rainbow trout in 2006 was not significantly different between test stocks (ANOVA: $F_{2,214} = 2.00$, $P = 0.14$; Table 5). In 2007, the mean length and weight was similar between stocks (ANOVA: $F_{2,70} = 1.33$, $P = 0.27$ and ANOVA: $F_{2,69} = 0.62$, $P = 0.54$, respectively), as shown in Table 5.

On the basis of these results, we repeated the ANOVA analysis but removed the AF3N treatment and found differences between the 3N and 2N stocks as to the mean proportion caught (ANOVA: $F_{1,26} = 7.46$, $P = 0.01$), the 2N stock making up a greater proportion of the catch. Survey year had a significant effect in the this model (ANOVA: $F_{1,14} = 6.66$, $P = 0.02$), suggesting that proportions of the two stocks caught changed between years. However, the interaction of survey year and stock did not have a significant effect ($F_{1,14} = 2.87$, $P = 0.11$), indicating that differences in catch among stocks remained consistent (Table 4).

The habitat characteristics we measured did not help explain the differences in catch between test groups. From the 2001 stocking, there were no significant correlations between the total catch or the proportions caught of any of the test groups and any of the habitat variables, including stocking density. From the 2003 stocking, stocking density was positively correlated with the catch of 3N ($r^2 = 0.53$, $P = 0.012$), 2N ($r^2 = 0.41$, $P = 0.056$), and AF3N ($r^2 = 0.57$, $P = 0.006$) rainbow trout. None of the other variables we measured were significantly correlated to the catch of any of the test groups.

DISCUSSION

The performance of triploid salmonids outside of aquaculture settings sympatric with diploids appears to be highly variable and often species specific (Ihssen et al. 1990). For example, Brock et al. (1994) found that AF3N rainbow trout survived 34% and 39% less than did mixed-sex 2N rainbow trout at age 0 and age 1, respectively, in five Alaskan lakes. Rutz and Baer (1996) reported similar results for coho salmon, diploids being caught at three times the proportion of triploids by 16 months after stocking. In contrast, Teuscher et al. (2003), who conducted a long-term fingerling evaluation in two productive reservoirs, found that AF3N rainbow trout had higher cumulative catch over 4 years than did 2N rainbow trout planted simultaneously. Results of our study suggest that catch of 2N rainbow trout far exceeded that of 3N rainbow trout in alpine lakes. On average, 2N rainbow trout made up 3.6 times the proportion of 3N trout across both stocking events. Moreover, the catch of the AF3N stock far exceeded that of both the 2N and 3N rainbow trout groups from the 2003 planting. On average, the AF3N group made up 3.6 times and 9.0 times the proportion of the 2N group and 3N groups, respectively, far exceeding the catch of either of the Hayspur stocking groups (Table 3). Not only was the AF3N group captured in higher numbers, but also these fish were caught in more locations. For example, in 2006, rainbow trout from the AF3N stock were the only test fish recovered in five of the study waters. This suggests not only better survival relative to Hayspur-stock rainbow trout, but also more consistent survival across various alpine lakes in general.

Triploid rainbow trout groups did not present any growth advantage over 2N rainbow trout during this study. In fact, the 2N stock attained the largest ultimate mean lengths and weights in both stocking events, but we were unable to statistically distinguish significant differences in mean lengths and weight between groups because of the small sample sizes of 3N rainbow trout recaptured (Table 5). Previous studies suggested that benefits of sterile salmonids in terms of growth and longevity are not realized until after the species normally reaches sexual maturity (Simon et al. 1993; Teuscher et al. 2003). For example, Teuscher et al. (2003) found all-female diploid rainbow trout grew faster than triploids through age 3. However, as diploid fish reached sexual maturity at age 4, the growth of triploid fish exceeded that of diploids. Similar results have been noted for brook trout *Salvelinus fontinalis* and rainbow trout, where triploids showed growth advantages over diploids after reaching 600–700 g (Thorgaard 1986; Boulanger 1991). Sheehan et al. (1999) found that all-female triploid rainbow trout grew faster than their diploid and mixed-sex counterparts over a 265-d trial in an aquaculture setting. Much of the growth advantage was attributed to low gonad development and the lack of males present, which matured earlier and at smaller sizes. In this respect, our results differ from much of the literature reporting growth of triploid salmonids exceeding that of diploids, because the diploid stock attained the largest ultimate lengths and weights in both stocking events. However, we recommend caution when comparing growth rates of different strains of rainbow trout; some strains may reach sexual maturity at small sizes, which may increase the disparity in growth rates between diploids and triploids (Sheehan et al. 1999). Perhaps if our study had continued for several more years, larger ultimate sizes of triploid rainbow trout may have become apparent. However, although triploid trout may hold some potential for improved managing of trophy fisheries, their low survival relative to diploid trout is a disadvantage in situations where higher catch rates are more desirable.

Although triploids may perform as well as or better than diploids when grown separately, such growth advantages often disappear when triploids and diploids are sympatric (Thorgaard et al. 1982; Lincoln and Bye 1987; Ojolick et al. 1995; Sheehan et al. 1999). For example, triploid Atlantic salmon *Salmo salar* grew more rapidly than diploids when reared separately, but grew more slowly than diploids when reared together (Galbreath et al. 1994), apparently a result of competition with diploids. In one respect, the results of our study differ from those of Galbreath et al. (1994): all-female triploids achieved similar size but greater numbers than their diploid competitors. However, when only Hayspur-stock fish were compared, diploids did outperform triploids, as Galbreath et al. (1994) would have predicted. The poor returns and smaller sizes of Hayspur triploid test fish may be indicative of poor competitive ability against their diploid counterparts. If so, poor returns of Hayspur triploid fingerlings stocked in lakes with established populations of diploid rainbow trout could be expected.

Alpine lakes are usually oligotrophic habitats, with short growing seasons, cold temperatures, inconsistent food sources, and low dissolved oxygen during winter months (Donald and Anderson 1982; Bailey and Hubert 2003). Some authors have reported poor performance of triploid rainbow trout under chronically stressful conditions such as high temperatures or low dissolved oxygen (Simon et al. 1993; Ojolick et al. 1995). Other research has shown that triploid brook trout, rainbow trout, and Atlantic salmon do not differ from diploids in their stress responses in terms of increased blood hematocrit, plasma cortisol, and glucose levels (Benfey and Biron 2000; Sadler et al. 2000). Benfey et al. (1997) found no differences in critical thermal maxima of diploid and triploid brook trout. Triploid fish have lower hemoglobin–oxygen ratios than diploid fish do, yet maintain equal hematocrit volume. As a result, triploid fish have a lower maximum blood oxygen capacity, which is hypothesized to reduce their overall aerobic capacity and susceptibility to chronic stress (Graham et al. 1985; Ojolick et al. 1995). However, Stillwell and Benfey (1997) found no difference in critical swimming velocity of diploid and triploid brook trout, suggesting that triploidy does not necessarily result in lower aerobic capacity. In fact, some have concluded that triploid trout should not be limited by blood-oxygen carrying capacity (Stillwell and Benfey 1998) and should be equivalent to diploids during acute hypoxia (Benfey and Sutterlin 1984). Unlike other studies, we found no correlation between habitat variables such as maximum temperature, elevation, pH, conductivity, and Secchi depth and the catch of triploid rainbow trout (or other test groups for that matter). In fact, catch of each of the marked test group was positively correlated only with stocking density, and this only for the 2003 stocking. Since catch of all three groups increased with stocking density, we interpret this as a reflection of higher capture probability, probably as a function of lake size. Therefore, we were unable to make any conclusions about the effect of stocking density on the catch of any one particular test group. These results make it difficult to conclude whether the habitat conditions in these alpine lakes might have affected triploid trout performance.

Given the lack of a definitive physiological mechanism to explain the lower survival of triploid fishes, the reduced competitive ability of triploids may be a more likely explanation of poor returns. Poor competitive ability of triploid fishes has been demonstrated for Atlantic salmon (Galbreath et al. 1994) and saugeyes (sauger *Sander canadensis* × walleye *S. vitreus*; Czesny 2000). If competition were indeed a key factor affecting return rate of the various stocking stocks in our study, we might anticipate higher returns of triploid rainbow trout when stocked separately from diploids.

It is unknown whether spawning-related emigration might account for some of the differences in return rates between the test stocks. Spawning-related emigration by adult brook trout, well documented in Adirondack lakes, can result in significant losses to stocked fisheries (Josephson and Youngs 1996; Warrillow et al. 1997; Josephson et al. 2001). Consequently, sex ratios in lakes with mixed-sex triploid stocks may shift towards higher proportions of females as the males emigrate or die as a result of spawning behavior (Warrillow et al. 1997; Josephson et al. 2001). This behavior could present an advantage to planting all-female triploid stocks. Such stocks could provide greater angling opportunity, because few triploid females would be lost to spawning-related emigration and mortality. Additionally, triploid females do not develop mature gonads as do triploid males, and do not divert energy resources into secondary sexual characteristics and reproductive behavior. As a result, triploid females are thought to have higher dress-out weights and better flesh quality than their triploid male counterparts (Sheehan et al. 1999). Unfortunately, the small number of mixed-sex triploid trout captured makes it impossible to draw meaningful conclusions about how spawning behavior might affect long-term persistence of mixed-sex triploid rainbow trout in these mountain lake fisheries. However, the current data indicate that the return rate of triploid Hayspur rainbow trout is so low that emigration of males is probably an insignificant factor in terms of contributing to low catches of Hayspur triploids. Spawning-related emigration would be associated with reaching sexual maturity, which we expected would have occurred by the time sampling began. Differences in returns related to emigration of diploids and triploid males should have been accounted for.

Confounding factors in this study include differences in fin clips and size at stocking. The AF3N stock was marked with adipose fin clips, while the 2N and 3N stocks were given ventral fin clips. Mortality in salmonids associated with ventral fin clips is variable but is generally higher than in adipose-clipped and unmarked salmonids of the same stock (Jacobs 1990; PSC 1995; PSC 1997). For example, the catch of ventral-clipped rainbow trout was only 81% of that of adipose-clipped trout in an alpine lake (Nicola and Cordone 1973), 43% of that of brook trout in reclaimed ponds (Mears and Hatch 1976), and 55–61% of that of coho salmon in Bear Lake, Alaska (Vincent-Lang 1993). Compared with reported values, the differences in return rates we found between adipose- and ventral-clipped trout in this study are considerably higher. Even considering increased mortality attributable to ventral fin clips (compared with adipose fin clips), the differences in catch between our test stocks remains considerable. Although expecting lower survival rates in ventral-clipped stocks is reasonable, the differences in performance between our test stocks are large enough that they are unlikely to be attributable to fin clips alone.

For the 2003 stocking group, the mean length of the AF3N fish (65 mm) was slightly greater than that of the 2N and 3N groups (62 mm) at the time of stocking. Winter mortality of young salmonids can be significant and is often size-dependent. Increased size has been shown to confer a survival advantage during the first winter for young fish (Hunt 1969; Meyer and Griffith 1997; Biro et al. 2004; Justice et al. 2009). Despite these studies, data describing survival differences at the scale of a 1- or 2-mm difference in length are sparse. Biro et al. (2004) studied overwinter mortality of rainbow trout fry in two small, shallow British Columbia lakes. From the plots presented in their study, we might expect to see roughly 3% lower survival of the 2N and 3N groups over the first winter because of a 3-mm difference in length. While the AF3N group may have had a slight survival advantage based on length, we conclude it is unlikely to explain the large differences in returns during the sampling years later.

Previous long-term evaluations indicate that the field performance of triploid salmonids can be highly variable (Simon et al. 1993; Brock et al. 1994; Warrillow et al. 1997; Dillon et al. 2000). Our study presents similar findings, two triploid stocks exhibiting large differences in return rates. The catch of 3N Hayspur-stock rainbow trout in alpine lakes in Idaho was very low relative to that of 2N trout, while AF3N rainbow trout from Troutlodge, Inc., appeared to return in higher proportions than either Hayspur stocks when stocked concurrently. Unfortunately, we were unable to produce all-female fish of the Hayspur stock for this evaluation and were unable to separate the effects of stock and ploidy-level. Given these limitations, we recommend future studies should confirm our results by using a multi-lake design that eliminates the stock effect.

The triploid stocks studied in this evaluation did not show any growth advantages over the duration of the study, and their ultimate sizes were similar to those of diploids. In this respect, triploid rainbow trout (especially all-female stocks) could be expected to return to anglers at sizes similar to that of diploid trout. Fisheries managers concerned with maintaining consistent alpine lake fisheries while minimizing natural reproduction or impact to native stocks should consider all-female triploid salmonids as a viable alternative to fertile fish.

ACKNOWLEDGMENTS

We thank John Cassinelli, Lars Alsager, Mike Biggs, Matt Wilson, Brett High, Art Butts, Sarah Nelson, Matt Kreizenbeck, Travis Parrill, Dan Garren, Carl Stiefel, Alan Sievers, and Bob Esselman for their assistance during high mountain lake surveys. This research would not have been possible without the generous contributions of our resident hatchery personnel. Gene McPherson, Steve Kammeyer, and Joel Patterson reared and stocked the high mountain lake test groups in 2001. Dan Baker, Jeff Heindel, and Jeremy Redding reared the three test groups for stocking in 2003. Brett High, Lance Hebdon, and three anonymous reviewers provided helpful reviews and commentary that greatly improved the quality of this manuscript.

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