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EFFECT OF SIZE AT STOCKING ON HARVEST OF RAINBOW TROUT IN BAD MEDICINE LAKE

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EFFECT OF SIZE AT STOCKING ON HARVEST OF RAINBOW TROUT IN BAD MEDICINE LAKE[1]

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Abstract.--The effect of size at stocking on probability of harvest and on cost per harvested fish were examined in Bad Medicine Lake, a 323 hectare lake managed as a two-story fishery for rainbow trout and walleye. In 1990 and 1991, 16,000 age-1 rainbow trout (160-310 mm) were marked with oxytetracycline (OTC) before stocking. At stocking, vertebrae were removed from subsamples, and the circular bands formed by OTC were digitized to measure backbone mark area (BMA). The relationship established between BMA and stocking length was used to calculate stocking lengths from BMA of rainbow trout harvested by anglers. Stocking lengths of harvested trout were estimated monthly, and combined with traditional effort and harvest data to calculate total harvest by size group. The total first year return rate was 51.1% in 1990 and 58.6% in 1991. Return rates were strongly related to length at stocking. The three largest length groups (236-310 mm) contributed 78% of the harvest of age-1 trout in 1990, and 91.6% of the harvest of age-1 trout in 1991. Mortality associated with hauling and stocking stresses was only 1.6% and was not size-dependent. Size-selective predation by northern pike, burbot, and walleye likely accounted for the lower return rates among smaller sized trout.

Introduction

In Minnesota, much of the attention to management of rainbow trout *Oncorhynchus mykiss* in lakes has been directed toward establishing fisheries in small lakes (< 40 hectares) after the removal of existing fish populations (Johnson 1978), but little is understood about cost-effective management of rainbow trout in larger lakes where potential coolwater predators and competitors exist (two-story fisheries). When other fish species are present, predation related mortality is often size-selective (Nielsen 1980;

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Tonn and Paszkowski 1986; Post and Prankevicius 1987), and sizes of stocked individuals can determine the success or failure of many stockings (Johnson 1982; Carline et al. 1986; Hanson et al. 1986; Serns and Andrews 1986; Storck and Newman 1986). Fish losses following stocking have been attributed to handling (Pickering et al. 1982), confinement stresses (Carmichael et al. 1984; Williamson and Carmichael 1986), thermal shock (Mather et al. 1986), disease (Herting and Witt 1967), competition (Fraser 1978; Gunn et al. 1987), and predation (Stein et al. 1981; Carline et al. 1986). Mortality associated with handling, confinement, and temperature stressors can be minimized by careful handling practices without significant additional costs (Barton and Peter 1982; Wurtsbaugh 1986). Careful handling practices also may reduce predation on stocked fish by resident fish (Coutant 1973; Sigismondi and Weber 1988). Nonetheless, increased size of stocked fish appears most important for improving survival (Storck and Newman 1988; Wahl and Stein 1989).

Costs of creating and maintaining a rainbow trout fishery by stocking are strongly controlled by the number stocked, and by hatchery costs of growing fish to a given size. Hauling costs also increase with fish size (American Fisheries Society 1982; D. Bathel, Minnesota Department of Natural Resources, personal communication). Because costs increase indefinitely with size while survival rate cannot exceed one, the optimal size fish to stock should be explicitly defined and thereby minimize the cost per fish harvested. Fishery management has established a successful rainbow trout fishery on Bad Medicine Lake, MN (Olson and Cunningham 1989), but at considerable cost. Stocking individuals of larger size has generally produced better survival, but size-related differences in survivorship must be understood before fishery management can cost-effectively maximize stocking practices.

The objectives of this study were: 1) to show a simple method of marking fish and subsequently determining size at stocking; 2) to describe the rainbow trout fishery of Bad Medicine Lake; 3) to document the relationship between harvest return and size at stocking for yearling rainbow trout in Bad Medicine Lake; and 4) to describe the cost per harvested fish as a function of stocking size.

Study Area

Bad Medicine Lake (323 hectare), located 25 mi northwest of Park Rapids is currently managed as a two-story rainbow trout and walleye *Stizostedion vitreum* fishery. Bad Medicine is a hardwater lake (127 mg/L as $CaCO_3$) of low fertility (<0.005 mg/L of total phosphorous), with a steep shoreline that contains little littoral area. The lake has a maximum depth of 26 m, with midsummer oxygen levels suitable for trout at 17 m. During the 1960s, the crayfish *Orconectes virilis* became extremely abundant in Bad Medicine Lake. After the expansion of the crayfish population, dramatic reductions in abundance of submergent macrophytes, bluegill *Lepomis macrochirus*, and yellow perch *Perca flavescens* were noted (MNDNR, unpublished data). In an attempt to control the crayfish population, rainbow trout were first introduced in 1977. During the 1980s, yearling rainbow trout (130-300 mm TL) were typically stocked at a density of 37 fish/hectare each year. By 1982, a rainbow trout fishery was successfully established. Two-story management of Bad Medicine Lake has created trout fishing opportunities in a region where few such opportunities exist (D. Ash, MNDNR, personal communication 1991).

Methods

Stocking

Bad Medicine Lake was stocked with 16,000 Madison strain, age-1 rainbow trout on 2 May 1990. The following year on 30 April, 16,000 Wytheville strain, age-1 rainbow trout were stocked. At stocking, length-frequencies were estimated by measuring total lengths of 140 fish in 1990 and 181 fish in 1991. Rainbow trout were dip-netted directly from the chutes during stocking. Dip-netting consisted of two randomly timed net-passes per tank-compartment (7 tank compartments). Collected fish were held in a stocking tank and released after their total lengths were recorded. Initial stocking length-frequencies were calculated for six 25 mm length-groups (165-315 mm TL).

Post-stocking Mortality

In 1991, age-1 rainbow trout were held in holding nets to assess whether post-stocking mortality from hauling and stocking stresses were related to fish size. At stocking, 30-31 fish of random sizes were placed in each of 6 cylindrical holding nets (3.33 x 0.75 m, 13 mm stretch mesh, with five support hoops). Fish were not temperature acclimated from the truck (11°C) to the lake (9°C). The holding nets were set on the bottom of a nearby shoal (3.4-4.0 m), oriented similarly, and evenly spaced apart (approximately 10 m). Mortality was recorded after 48 h.

Estimation of Stocking Length From Harvested Trout

Oxytetracycline (OTC) labeling techniques have primarily been used as a temporal marker for age validation and growth studies. In this study, OTC was used to mark yearling rainbow trout so they would carry a record of length at stocking. Tetracycline incorporates into calcifying tissue and forms a fluorescent band that is visible under ultraviolet light. OTC marking is cheap, reduces cumulative effects of acute stress (Sigismondi and Weber 1988), and avoids potential problems of differing survival among pectoral, adipose, and pelvic fin-removed fish (Coble 1971; Nicola and Cordone 1973). In both 1990 and 1991, rainbow trout were marked using OTC before stocking. At the Lanesboro State Fish Hatchery, 16,000 rainbow trout were fed 13-14 days with OTC-labeled feeds (11 g of TM-50/kg of GR6-30, 4.76 mm pellets, double vitamin packed with Roxanthin), and were taken off OTC-labeled feed 12 days before stocking. To quantify a relation between the location of fluorescence and fish length at stocking, 75-80 fish were sacrificed at stocking. A broad range of fish were chosen so large and small fish would be well described by the mark-body length relation. Total lengths (mm) and weights (kg) were measured, and vertebrae numbers 2 through 4 removed. Vertebrae were boiled for two minutes to soften their cartilaginous discs. Cartilaginous discs were removed with a forceps and the middle (3rd) vertebra was gently cleaned with a dental brush. The tetracycline mark fluoresced under ultraviolet light, forming an easily recognized ring around the edge of the vertebra. Vertebrae are asymmetrical, so radius or diameter would be imprecise measures of size, therefore the area inside the fluorescent mark, termed backbone mark area (BMA), was measured. Anterior and posterior images of the backbone were photographed using a 35 mm camera attached to a stereomicroscope. Slide images were projected onto a digitizing tablet. The circular fluorescent rings were traced (3-5 repetitions) to measure BMA from both anterior and posterior planes. BMA values from anterior and posterior vertebral views were averaged for each fish. A least-squares linear regression of $\log_e$(total length) on $\log_e$(BMA) was used to quantify the relation between stocking length and BMA for each stocking year.

Regressions of stocking length on BMA were used to estimate stocking lengths of rainbow trout caught by anglers. Anglers were asked to donate vertebrae from rainbow trout in their catch. The creel census clerk removed vertebrae 2-4. Anglers also benefitted from the backbone collection process because their catches were cleaned (eviscerated) by the clerk, and they were offered free ice to keep their fish cold. Vertebrae were prepared as described above. Estimated stocking lengths were tabulated to construct a stocking length-frequency distribution for harvested trout.

Creel Survey

The creel survey design was a complete trip random two-stage sampling with unequal probabilities (Malvestuto et al. 1978). Two-week periods were stratified by weekday or weekend day with holidays treated as weekend days. The fishing day was divided into four 4 h time blocks in 1990. In 1991, time blocks were three, four, or five h, depending on time of day and month. The clerk examined the anglers' catch, recorded lengths (TL), and removed scales and vertebrae (2-4). Subsamples of rainbow trout were weighed (kg). Fishing effort was estimated using two random instantaneous boat counts per shift (4 h time block) (Malvestuto 1983) made while the creel clerk motored the length of the lake.

Fishing effort, catch rates, and harvest rates were estimated for every four-week period during the trout fishing season. Estimates from a four week period replicated each day-type/time-block, which permitted the estimation of fishing effort variance. Variance estimates for total fishing effort were calculated according to Cochran's (1977) equation 10.47. Harvest rates (fish/boat-hour), and catch rates (fish/boat-hour) were estimated for each four-week period using a total ratio estimator. Harvest and catch rates were calculated for yearling rainbow trout and for age-2 and older trout. Variance estimates for harvest rates and catch rates were calculated according to Cochran's (1977) equation 6.13. Harvest rates were also estimated for other species. Total fishing effort, expressed as hours (meaning angler-hours) and boat-hours (when specified), were estimated for every four-week period during the trout fishing season. Catch per unit effort (CPUE) and harvest per unit effort (HPUE) are fish/angler-hour (fish/h) unless specified as fish/boat-hour.

Monthly estimates of harvest rates and angling effort and their variances were combined to estimate monthly harvest (number) of yearling and older (age 2 and older) rainbow trout. Weights of all creeled fish were estimated as: $\log_e(W) = -17.408 + 2.843 \log_e(L)$, ($N=92$, $r^2=0.98$) in 1990; or $\log_e(W) = -20.481 + 3.358 \log_e(L)$, ($N=252$, $r^2=0.99$) in 1991. These equations were derived from length-weight regressions where W is weight (kg), and L is total length (mm). Estimated weights were then averaged by age-group and month of capture. Monthly harvest (number) was multiplied by monthly mean weight, and summed to estimate annual biomass of the harvested rainbow trout. Variance estimates for angling effort, harvest rates, and mean weight were combined to estimate biomass variance. Harvest (number) of other species that occurred in the creel survey was also estimated.

The effect of size at stocking on harvest of rainbow trout was evaluated by estimating harvest during the entire trout fishing season, as smaller fish were expected to "grow into the creel" later in the season. For this reason, the stocking length distributions of the annual harvest must be obtained by summing appropriately weighted monthly values. First, for each month, stocking lengths estimated from BMA were tallied into six 25-mm length-intervals (165-315), and expressed as a proportion. Then these proportions were multiplied by the monthly harvest to obtain monthly harvest by stocking size-interval. Finally, the resulting monthly values were summed to give annual return by stocking length-interval. Percent annual return was found for each length-interval by dividing annual harvest by number stocked within that length-interval. The relationship of return rate to stocking length was described by least-squares logistic regression of proportion harvested on length (after proportion harvested was set at 1.0 where higher return rates had been estimated).

Mean MNDNR rearing costs of yearling rainbow trout were estimated to be \$1.19-1.42 per fish (KPMG Peat Marwick 1990). Our MNDNR estimates of cost increased with fish size, but were slightly lower for the size stocked. To obtain conservative estimates of cost per harvested fish, the intercept of the MNDNR cost function was increased so the cost of a 300 mm fish matched the higher mean cost. The cost function used was cost \$ = 0.22 + 0.004 length. Cost per harvested fish was described by dividing the linear cost function by the logistic return rate function.

Results

Post-stocking Mortality

Post-stocking mortality associated with hauling and stocking stresses was 1.6% and was not size-dependent. After 48 hours, only three fish were dead. All three dead fish had puncture and laceration wounds, and one live fish also contained a large puncture-laceration. These wounds were probably caused by the common loon *Gavia immer* striking through the nets. The holding nets were not monitored during the 48 h period, but several pairs of common loons were observed on the lake.

Marking and Estimation of Stocking Length

BMA was easily measurable and closely related to stocking length. All fish sacrificed at stocking showed a narrow, bright, continuous, fluorescent ring near the edge of their vertebrae. BMA calculations were precise and objective, with coefficients of variation for the five repetitions per image $<1\%$. The regression equation $\log_e(\text{stocking length}) = 4.682 + 0.489 \log_e(\text{BMA})$, ($N=80$, $r^2=0.92$) was calculated from samples taken at stocking in 1990, and used to estimate stocking lengths of age-1 trout harvested in 1990 and of age-2 trout harvested in 1991. The regression equation $\log_e(\text{stocking length}) = 4.753 + 0.477 \log_e(\text{BMA})$ ($N=75$, $r^2=0.95$) was calculated for the 1991 stocking, and used to estimate stocking lengths of age-1 rainbow trout harvested in 1991. Mark fluorescence did not diminish during the two year study. Creel clerks collected vertebrae from 341 age-1 fish in 1990, and from 460 age-1 and age-2 fish in 1991. Of the 801 examined vertebrae, only one contained no recognizable mark.

Stocking length-frequencies of Madison strain trout differed by month of capture during 1990, declining through the season (Figure 1). Mean stocking lengths were 264, 256, 254, 245, and 236 mm, for fish caught in May, June, July, August, and fall of 1990, respectively. Rainbow trout of larger stocking lengths were harvested disproportionally earlier in the fishing season, while smaller stocked age-1 fish contributed more to the harvest in the fall and in the following year.

Stocking length-frequencies of Wytheville strain fish did not differ between capture months in 1991 (Figure 2). Mean stocking lengths were 266, 264, 260, 264, and 271 for fish caught in May, June, July, August, and fall of 1991, respectively.

Fishing Pressure

Anglers spent an estimated 39,091 h angling Bad Medicine Lake in 1990 (121 h/hectare) and 34,121 h in 1991 (105 h/hectare). Most anglers were seeking rainbow trout (86.9% in 1990 and 94% in 1991). Each year angling effort peaked during June and July. Over one-half of the season's fishing pressure occurred during these two months (Table 1). After July, fishing effort declined to 0.5-2.0 h/hectare for October.

Angling Success

Angling success for rainbow trout in Bad Medicine Lake was excellent. Catch rates of rainbow trout were 0.31 and 0.38 fish/h (weighted annual mean) in 1990 and 1991, respectively. Harvest rates of rainbow trout were 0.27 and 0.31 fish/h (weighted annual mean) in 1990 and 1991, respectively. Seasonal trends in catch and harvest rates were similar between years.

Catch rates ranged from 0.31 to 0.50 fish/h May through July. After July, catch

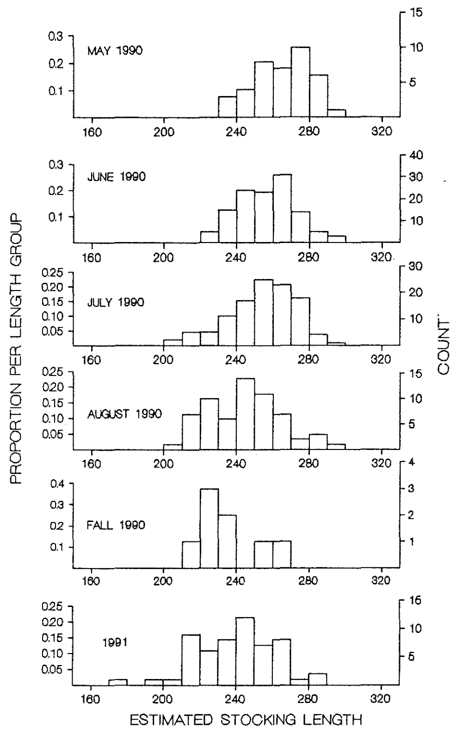

Figure 1. Estimated stocking lengths for trout stocked in 1990 and sampled in the harvest in 1990 and 1991. Yearlings harvested in 1990 are presented by month (September and October are combined.) Two-year-old trout harvested in 1991 are presented as one plot. Y-axes are scaled as proportion per standard unit and counts.

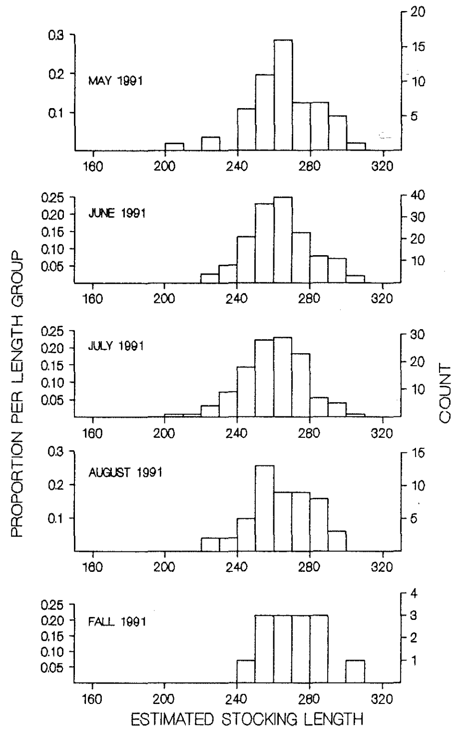

Figure 2. Estimated stocking lengths for yearling rainbow trout stocked in 1991 and sampled in the harvest in 1991. September and October samples were combined. Y-axes are scaled as proportion per standard unit and counts.

rates declined to lows of 0.14-0.20 fish/h by fall. For most months, angling success was markedly higher in 1991 than 1990. The catch was comprised mostly of age-1 rainbow trout (Tables 2,3). Age-2 and older fish provided anglers opportunities to catch larger rainbow trout during the months of May, June, and July. After July, however, catches of age-2 and older fish steadily declined (Tables 2,3).

Angling success for other species was low. Harvest rates for northern pike *Esox lucius*, walleye, burbot *Lota lota*, yellow perch, and white sucker *Catostomus commersoni* were typically less than 0.008 fish/h. For these species, no differences in angling success occurred in the study years. Harvest rates could not be estimated by species sought because too few anglers reported seeking the other species. Harvest rates, particularly for walleye, were underestimated because anglers seeking walleye were often seen arriving around 10 p.m., and creel clerks did not census night anglers.

Harvest

In 1990, anglers harvested 90% of the rainbow trout they caught, and in 1991, they harvested 84%. Trout that were released were almost exclusively age-1 fish. Only

Table 1. Amount of effort spent fishing Bad Medicine Lake during 1990 and 1991. Estimates of fishing effort are shown in boat-hours and angler-hours.

Year	Dates	Effort angler-hours	Effort boat-hours	Variance (boat hours)
1990	May 12-Jun 5	5,850	2,592	44,480
	Jun 6-Jul 3	10,545	4,712	55,831
	Jul 4-Jul 31	13,486	5,159	83,109
	Aug 1-Aug 28	7,026	2,796	93,634
	Aug 29-Sep 25	2,031	967	7,291
	Sep 26-Oct 31	153	73	940
	Total	39,091	16,299	285,285
1991	May 11-Jun 4	5,148	2,140	23,411
	Jun 5-Jul 2	9,256	3,580	116,294
	Jul 3-Jul 30	9,911	4,029	186,576
	Jul 31-Aug 27	6,673	2,738	25,267
	Aug 28-Sep 4	2,466	969	13,775
	Sep 25-Oct 31	667	349	3,076
	Total	34,121	13,805	368,399

Table 2. Monthly estimates of catch per unit effort (CPUE) and harvest rates (HPUE) for age-1 and age-2++ rainbow trout in Bad Medicine Lake, 1990. Data from September and October were combined.

Dates	CPUE (all ages) (fish/hr) Est.	Var.	HPUE age-1 (fish/hr) Est.	Var.	HPUE age-2++ (fish/hr) Est.	Var.
May 12-Jun 5	0.324	0.00369	0.203	0.00449	0.068	0.00088
Jun 6-Jul 3	0.402	0.00302	0.202	0.00208	0.115	0.00049
Jul 4-Jul 31	0.314	0.00153	0.253	0.00445	0.045	0.00014
Aug 1-Aug 28	0.162	0.00166	0.145	0.00252	0.017	0.00004
Aug 29-Oct 31	0.201	0.00491	0.115	0.00705	0.014	0.00024

Table 3. Monthly estimates of catch per unit effort (CPUE) and harvest rates (HPUE) and for three age-classes of rainbow trout in Bad Medicine Lake, 1991. Age-1 were Wytheville strain stocked in 1991. Age-2 and age-3, were Madison strain stocked in 1990 and 1989, respectively.

Dates	CPUE (all ages) Est.	Var.	HPUE age-1 Est.	Var.	HPUE age-2 Est.	Var.	HPUE age-3 Est.	Var.
May 11-Jun 4	0.382	0.0058	0.174	0.00180	0.095	0.00068	0.020	0.00015
Jun 5-Jul 2	0.504	0.0055	0.376	0.00314	0.044	0.00008	0.004	0.00007
Jul 3-Jul 30	0.387	0.0053	0.283	0.00232	0.011	0.00004	0.005	0.00009
Jul 31-Aug 27	0.287	0.0024	0.275	0.00228	0.007	0.00002	0.000	0.00000
Aug 28-Sep 24	0.167	0.0095	0.150	0.00897	0.018	0.00014	0.000	0.00000
Sep 25-Oct 31	0.137	0.0048	0.110	0.00387	0.000	0.00000	0.014	0.00015

one angler interviewed during the study reported releasing a rainbow trout larger than 380 mm (lengths of age-2 fish are typically 380-440 mm).

Anglers harvested an estimated 10,572 (95% CI=8,815-12,329)rainbow trout in 1990 (32.7 trout/hectare), totaling 4,988 kilograms (Table 4). In 1991, anglers harvested 10,673 (95% CI=8,710 - 12,636) rainbow trout (33.0 trout/hectare), totalling 4,625 kg (Table 5). Age-1 fish compromised 77.3% and 87.9% of the trout harvest by number in 1990 and 1991, respectively (Tables 4, 5).

Of the 16,000 (2,419 kg) fish stocked in 1990, 51.1% by number (95% CI=40.9-61.2%) and 127.0% by weight (95% CI=88.4-165.5%) were estimated to have been harvested in the first year (Table 4). The harvest of Madison strain during their second year totalled 1,090 fish weighing 942 kg (Table 5). Harvest return of the 1990 stocking over the two years was 57.9% by number (95% CI=47.5 - 58.2%), and 166.0% by weight (95% CI=125.0-206.8%). Of the 16,000 (2,502 kg) Wytheville strain fish stocked in 1991, 58.6% by number (95% CI=46.6-70.6%) and 137.6% by weight (95% CI=99.8-175.4%) were harvested in the first year (Table 5).

Annual harvests of species other than rainbow trout were negligible. Northern pike, walleye, burbot, yellow perch, and white sucker together comprised 1.9 and 2.1% of the total harvest (number) in 1990 and 1991, respectively (Table 6).

Effect of Size on Harvest Return

The probability that a stocked trout would return to the creel was related to its length at stocking; larger fish had a greater return than small ones (Figures 3,4). The initial stocking length-frequency included small rainbow trout that never appeared in the creel. In 1990, mean length at stocking was 235 mm, and the mean stocking length of harvested trout was 252 mm. In 1991, the mean stocking length was 246 mm, and the mean stocking length of harvested trout was 263 mm.

Among the six length-groups stocked, the three largest contributed most to the anglers' catch in the first year (78% in 1990 and 91.6% in 1991; Table 7). In 1991, the three smallest length-groups contributed 50.6% of the age-2 harvested trout, but harvest of age-two trout was only 11.8% of the total harvest of the cohort. Percent of rainbow trout returning to the creel as year-

Table 4. Monthly estimates of harvest (number), mean weight, and harvest weight, for age-1 rainbow trout in Bad Medicine Lake, 1990. Monthly harvest (number) for all rainbow trout (ages combined) are shown.

	Age-1						All Ages	
	Harvest (number)		Mean weight (kg)		Harvest weight (kg)		Harvest (number)	
Dates	Est.	Var.	Est.	Var.	Est.	Var.	Est.	Var.
May 12-Jun 5	1,205	80,406	0.274	0.0026	330.2	9,813	1,607	88,939
Jun 6-Jul 3	2,120	131,844	0.337	0.0028	714.4	27,598	3,331	215,725
Jul 4-Jul 31	3,544	337,999	0.417	0.0079	1477.8	158,261	4,174	364,885
Aug 1-Aug 28	1,040	84,297	0.422	0.0031	438.9	18,403	1,166	80,976
Aug 29-Sep 25[a]	243	20,399	0.424	0.0026	103.0	3,820	273	20,880
Sep 26-Oct 31[a]	18	177	0.424	0.0026	7.6	33	21	192
Annual total	8,170	655,122			3,071.9	217,928	10,572	771,597

[a] Weights from September and October were combined for a single estimate of mean weight.

lings was positively related to length at stocking, but percent return to the creel for the two largest length groups was over-estimated (Table 7). Logistic regressions described the relation between first year return and length at stocking (Figure 5). First year return rates were similar between years.

The rearing cost of a stocked rainbow trout was linearly related to length at stocking (Figure 6). When the rearing cost function was divided by the logistic function for proportion returned to the creel, a non-linear relation between cost per harvested fish and stocking length was found (Figure 6). For Bad Medicine Lake in 1990 and 1991, cost/return was lowest for fish stocked at approximately 280 mm.

Table 5. Monthly harvest of estimates for three age-classes of rainbow trout in Bad Medicine Lake, 1991. Age-1 fish were Wytheville strain stocked in 1991. Age-2 and age-3 fish were Madison strain stocked in 1990 and 1989, respectively.

Age	Dates	Harvest (number)		Mean weight (kg)		Harvest weight (kg)	
		Est.	Var.	Est.	Var.[a]	Est.	Var.
1	May 11-Jun 4	908	48,768	0.26	0.0032	238.6	5,987
	Jun 5-Jul 2	3,377	383,866	0.32	0.0030	1,090.4	74,469
	Jul 3-Jul 30	2,803	328,708	0.39	0.0065	1,091.7	100,957
	Jul 31-Aug 27	1,867	112,626	0.44	0.0024	816.9	29,833
	Aug 28-Sep 24	345	47,693	0.48	0.0046	166.8	11,695
	Sep 25-Oct 31	79	2,439	0.48	0.0046	38.0	598
	Annual total	9,379	924,100			3,442.4	223,539
2	May 11-Jun 4	499	20,219	0.82	0.0068	407.7	15,186
	Jun 5-Jul 2	395	6,900	0.88	0.0038	346.6	5,896
	Jul 3-Jul 30	106	4,282	0.96	0.0090	102.3	4,051
	Jul 31-Aug 27	49	769	0.96	0.0090	46.8	730
	Aug 28-Sep 24	41	702	0.90	0.0090	39.0	663
	Sep 25-Oct 31	0	0	0.96	0.0090	0.0	0
	Annual total	1,090	32,872			942.4	26,526
3	May 11-Jun 4	106	4,280	1.17	0.0336	124.1	6,244
	Jun 5-Jul 2	36	630	1.17	0.0336	42.1	906
	Jul 3-Jul 30	53	935	1.17	0.0336	62.3	1,378
	Jul 31-Aug 27	0	0	1.17	0.0336	0.0	0
	Aug 28-Sep 24	0	0	1.17	0.0336	0.0	0
	Sep 25-Oct 31	9	90	1.17	0.0336	11.5	124
	Annual total	204	5,935			240.0	8,652

[a] Weights were aggregated to calculate mean weight and variance for certain periods (age-1 for September-October, age-2 for July-October, and age-3 for May-October).

Table 6. Estimated monthly and annual harvest of other species occurring in the Bad Medicine fishery during 1990-1991.

		Number Harvested				
Year	Date	Burbot	Northern Pike	Walleye	White sucker	Yellow perch
1990	May 12-June 5	0	0	0	0	0
	Jun 6-Jul 3	0	66	14	0	0
	Jul 4-Jul 31	26	0	0	0	0
	Aug 1-Aug 28	0	17	62	0	17
	Aug 29-Sep 25	0	0	0	0	0
	Sep 26-Oct 31	0	0	0	0	0
1990 annual total		26	83	76	9	17
1991	May 11-Jun 4	15	15	0	0	0
	Jun 5-Jul 2	18	18	18	0	0
	Jul 3-Jul 30	0	18	53	18	0
	Jul 31-Aug 27	16	16	16	0	0
	Aug 28-Sep 24	0	0	0	0	0
	Sep 25-Oct 31	0	10	0	0	0
1991 annual total		49	77	87	18	0

Table 7. Estimated harvest of rainbow trout by length at stocking. Madison strain rainbow trout stocked in 1990 were sampled for two seasons. Wytheville strain rainbow trout stocked in 1991 were sampled for one season.

Year	Length (mm)	Number stocked	Harvest after 1 year	Return after 1 year(%)	Harvest after 2 years	Return after 2 years(%)
1990	165-190	1,257	0	0.0	20	1.6
	191-215	1,942	210	10.8	307	15.8
	216-240	5,486	1,577	28.7	1,966	35.8
	241-265	5,714	3,870	67.7	4,376	76.6
	266-290	1,485	2,380	160.3	2,457	165.4
	291-315	114	131	114.9	131	114.9
	Total	15,998	8,168	51.1	9,257	57.9
1991	165-190	87	0	0.0	-	-
	191-215	611	38	6.2	-	-
	216-240	5,147	748	14.5	-	-
	241-265	7,939	4,310	54.3	-	-
	266-290	1,919	3,609	188.1	-	-
	291-315	87	672	772.4	-	-
	Total	15,790				

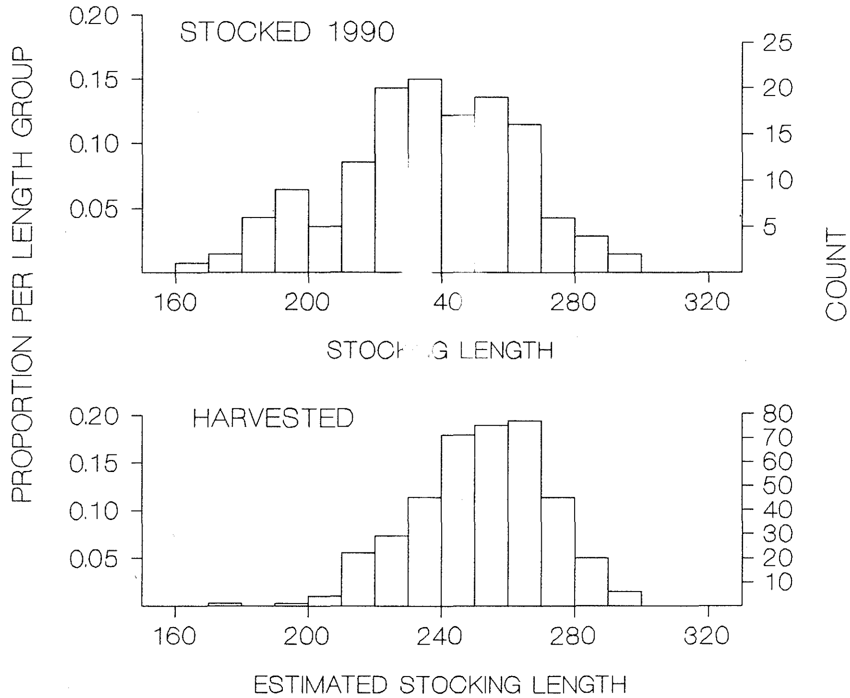

Figure 3. A comparison of the 1990 initial stocking length frequency to stocking lengths estimated from rainbow trout harvested during 1990 and 1991 (a two-year composite).

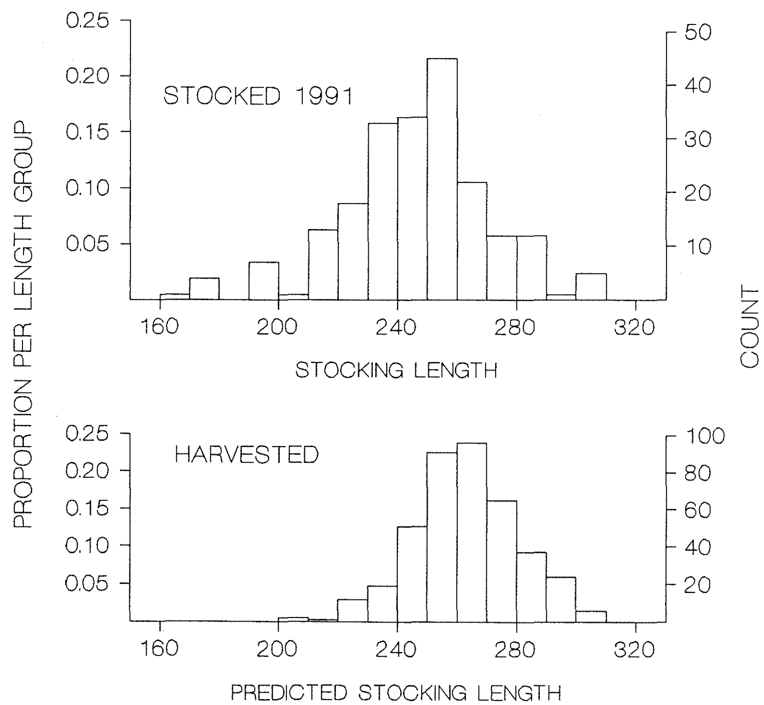

Figure 4. A comparison of the 1991 initial stocking length frequency to stocking lengths estimated from yearling rainbow trout harvested during 1991.

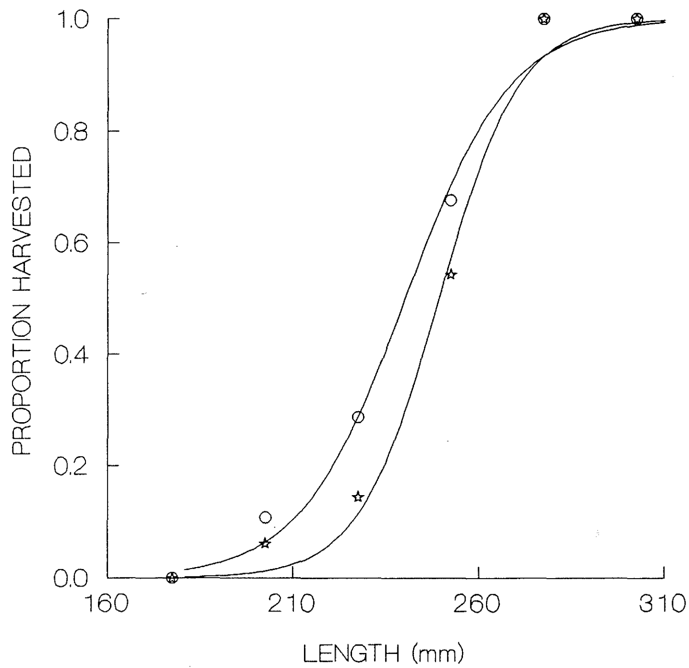

Figure 5. Proportion of stocked fish harvested as a logistic function of length at stocking (circles = 1990 stocking and stars = 1991 stocking).

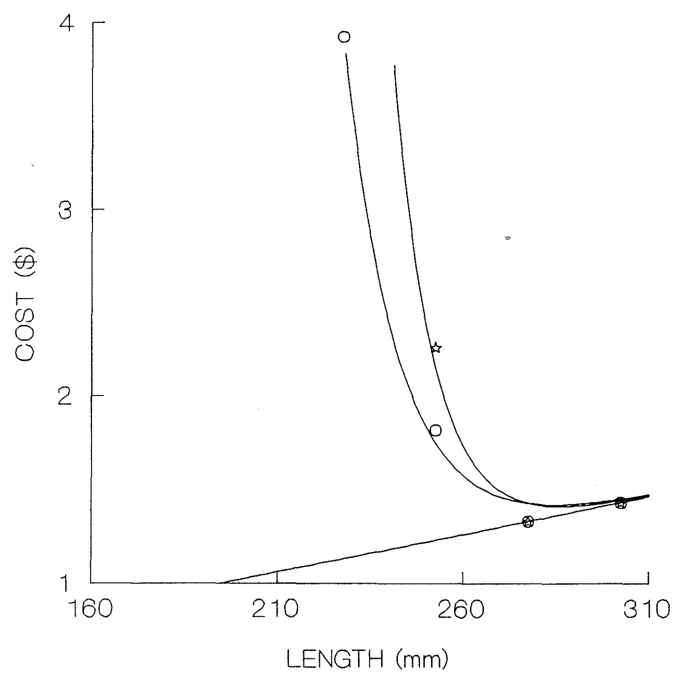

Figure 6. Rearing cost as a linear function and cost per harvested fish as a nonlinear function of rainbow trout length. Cost per harvested fish was calculated from rearing costs and the logistic functions for proportion harvested shown in Figure 5 (circles = 1990 stocking, stars = 1991 stocking).

Discussion

The method of marking fish at stocking so an individual's size at stocking can be determined much later is of particular value because it can be used to address several difficult problems, particularly the measurement of size-dependent growth rates, the magnitude and timing of size-selective mortality, and the monitoring of the cost-effectiveness of stocking programs. The tetracycline method used in this study is practical, having low cost and high measurement precision. Bone samples may be obtained inexpensively in conjunction with routine lake surveys, creel surveys, or by other collection techniques (Parsons et al. 1992). Rainbow trout vertebra did not require sectioning because subsequent bone growth appeared only on the outer margin of the vertebral centrum. Tetracycline marks were equally conspicuous for trout 1.5 years at liberty and probably permanent (McFarlane and Beamish 1987; Leaman and Nagtegaal 1987), however, other bony structures or older fish may require sectioning or grinding to measure their marks. The accuracy of measurements of mark areas of older fish therefore should be validated with individually tagged fish marked with oxytetracycline at known sizes and held for various periods before processing.

Characteristics of the Bad Medicine Lake fishery have changed dramatically since the early 1980s. Ash (1984) conducted a creel survey of Bad Medicine Lake from 14 May to 30 September 1983. Annual fishing pressure for 1983 was 44.7 h/hectare, and the annual harvest rate was 0.003 trout/h. Ash attributed poor fishing success during 1983 to poor spring weather and an unusually hot summer. Ash speculated that high mid-summer temperatures forced rainbow trout to occupy deeper water that anglers could not successfully fish. Since 1983, harvest rates have increased (0.27 trout/h in 1990 and 0.31 in 1991) and so has fishing pressure (121 h/hectare in 1990 and 105 in 1991). According to Johnson's (1978) tabulation of fishing pressure for much smaller single-story trout lakes (2.8-32 hectares), fishing pressure less than 250 hours per hectare would be light. In comparison to fishing pressure on other lakes in northwestern Minnesota, the 100-120 h/hectare observed was moderate to heavy.

The character of the rainbow trout population has also changed because of increased angling pressure. During the early 1980s, 1.2-4.0 kg rainbow trout were well represented in the fishery (Ash 1984; Olson and Cunningham 1989). High angling pressure and harvest rates no longer permit trout to attain sizes comparable to those of early 1980s, though growth conditions are still excellent (MNDNR, unpublished data). The largest censused rainbow trout weighed 1.4 kg. Rapid declines in catch and harvest rates of age-2 trout and a scarcity of age-3 fish show that a cohort is nearly removed from the fishery after two fishing seasons.

In comparison to other two-story fisheries, Bad Medicine Lake might be considered a benign environment allowing successful rainbow trout stocking. Northern pike abundance in Bad Medicine Lake is lower than in most lakes in Ecological Lake Class 22 (Schupp 1992). The median net-lift for Lake Class 22 is 4.9 northern pike/lift, while the 1986 Bad Medicine Lake survey found 0.6 northern pike/lift, and the 1991 lake survey 1.8 pike/lift. Northern pike prefer soft-rayed fishes (Wahl and Stein 1988), and do prey on rainbow trout (Finnel 1988). Common loons, burbot, and walleye are also common in Bad Medicine Lake, and may exert size-selective predation. Common loons prey on rainbow trout (Matkowski 1989), and during the spring and summer 3-6 pairs of common loons were observed foraging.

Greater returns of rainbow trout stocked at larger size are better explained by size-selective predation than by size-selective mortality due to stocking stresses or hooking mortality. Cage experiments showed negligible post-stocking mortality resulting from confinement, hauling, and handling stress. Hooking mortality was low, because the Bad

Medicine Lake fishery was principally a harvest fishery with release rates of 0% to 25%.

Analysis of harvested rainbow trout was used to test whether size-dependent mortality regulates survival of rainbow trout in Bad Medicine Lake. Rainbow trout stocking success was positively related to stocking length, but cost/harvested fish was lowest at about 280 mm (Figure 6). Yearling trout stocked at smaller sizes rarely contributed to the fishery during the two study years. Greater returns from stocking larger individuals were reported in several stocking evaluations (Hansen and Staufer 1971; Gunn et al. 1987).

The percent return of the largest two size groups (261-310 mm) of rainbow trout stocked was overestimated, as returns exceeding 100% were calculated. Large trout represented the tail of the length-frequency distribution, thus few were sampled at stocking and the precision with which the shape of the tails of the stocking distribution was described may be low. Monthly estimates of large trout harvested may also have large errors because they were based, in part, on the relatively few fish for which BMA was determined. Since percent return was estimated by dividing the sum of monthly harvest estimates by the number stocked, the division would compound any inaccuracy at the tails. Problematic return rates for the upper tails of the length-frequency distribution could have been improved by sorting fish into length groups of equal number before stocking, by measuring lengths of more fish at stocking and in the creel, or by using individually marked fish. Overestimates of returns of large fish also may result if backbone mark area was consistently overestimated for fish caught by anglers or underestimated for fish sampled at stocking, however, the precision of repeated measurements would suggest this source of error is small.

Madison and Wytheville strains may differ in their catchability, and this confounds comparisons of first-year returns. The Madison strain "grew into the creel" throughout their first season, thus smaller fish were exposed to risk of natural mortality for a longer period than larger fish, on average. Whether risk of natural mortality was size-dependent throughout the season cannot be determined, however, several studies have found losses to predation were high and size-dependent immediately after stocking (Hansen and Staufer 1971; Carline et al. 1986; Hanson et al. 1986; Gunn et al. 1987; Storck and Newman 1988; Wahl and Stein 1989). The Wytheville strain did not "grow into the creel," so natural losses must have been strongly size-dependent, probably immediately after stocking. In spite of this difference between strains or between years, the aggregate effects of stocking length on first year return rates were similar in 1990 and 1991, and the larger fish stocked in 1991 produced a somewhat greater harvest at age-1 (9,379 vs. 8,170; not statistically different).

Management Implications

The lack of spatial and temporal replication inherent in this experiment precludes general inferences about two-story fisheries, nevertheless, results of this study suggest that size-selective mortality may be an important factor limiting the success of two-story rainbow trout fisheries. In two-story fisheries, managers need to monitor predator populations and trout harvest, and adjust the size of rainbow trout they stock to minimize cost per harvested fish. Hatchery economic efficiency is increased if the variability in size of the stocked fish is reduced, but the risk of complete stocking failure is increased and the ability to detect a change in optimal sizes is reduced. In lakes similar to Bad Medicine, rainbow trout of about 280 mm provide optimum return.

This method of marking fish at stocking and subsequently finding their size can be used to evaluate the effect of stocking size on harvest rates and minimize cost per fish harvested. The optimal stocking size and return rates should be evaluated for lakes in various Ecological Lake Class categories, and reevaluated on important fisheries when predator populations have changed. The method will be valuable for strain evaluation studies where variation in mean stocking size may obscure differences in vulnerability among strains.

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