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A Summary of Abundance and Density Estimates for Selected Lake Trout Populations in the Alaska Range, and an Examination of Trends in Yield

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ABSTRACT

Estimates of abundance of lake trout *Salvelinus namaycush* from seven lakes in interior Alaska varied from 96 to 5,066 mature fish. Estimated densities of lake trout of mature size varied from 0.6 fish per hectare (1.2 kilograms per hectare) to 31.9 fish per hectare (24.8 kilograms per hectare) with the highest densities in the smallest lakes and lower densities with increasing lake size. Densities of lake trout in the Alaskan lakes studied are high compared with densities reported in other studies. The relatively high density of lake trout in the lakes in Alaska is likely related to the small surface area of the lakes studied, the small average size of the fish, and the small size at maturity of lake trout in these populations. Sampling difficulties and bias in estimation of abundance and density are discussed. Increasing harvest and yield has occurred in the Paxson Lake lake trout population in spite of restrictive bag and length regulations.

KEY WORDS: abundance, density, yield, lake trout, *Salvelinus namaycush*, Paxson, Sevenmile, Twobit, Glacier, Tangle Lakes, Butte.

INTRODUCTION

Lake trout *Salvelinus namaycush* populations are generally sparse, have low productivity, and have low reproductive rates. As a result, lake trout stocks may be easily overharvested. In 1986, the state of Alaska altered sport fish regulations for lake trout based on recommendations by Healey (1978) to not exceed an average yield of more than 0.5 kg of lake trout per surface hectare per year. Based on harvest estimates and the average size of lake trout obtained from creel sampling and test netting in 1986, it was estimated that this guideline harvest rate was being exceeded for all populations in interior Alaska for which harvest estimates were available.

Because knowledge of population abundance, size structure, population dynamic rates, and harvest levels for Alaska lake trout populations was limited, a lake trout research program was initiated in 1986. Since then, abundance has been estimated for populations of lake trout from seven lakes in central Alaska: Paxson Lake of the Copper River drainage, Butte Lake of the Susitna River drainage, and Twobit, Sevenmile, Glacier, Landlocked Tangle, and Upper Tangle lakes in the Tanana River drainage. The lakes range widely in size from Sevenmile Lake (surface area 33 ha) to Paxson Lake (surface area 1,575 ha) with most of the lakes 300 ha or less (Figure 1). All lakes are located in the Alaska Mountain Range at elevations ranging from 778 to 1,006 m.

Estimates of abundance and density which have been obtained since 1986 are summarized in this paper and trends in yield are examined. The purpose of the paper is to lay a foundation upon which the applicability of the 0.5 kg/ha/yr yield guideline for managing lake trout populations in interior Alaska can be evaluated. Sampling difficulties, biases associated with estimation, and alternative yield criteria are also discussed.

MEASURES OF ABUNDANCE AND DENSITY

Data Collection and Analysis

The primary method of capture was with 3 m x 46 m x 51 mm (stretch measure) sinking gill nets. Lake trout were generally entangled in these nets rather than gilled. Gill nets were generally checked at one half hour intervals to minimize netting mortality. Other gear included 2.4 m x 0.6 m hoop nets baited with cut herring, and fyke nets with 1.2 m square frames and 50 m center leads. Hoop and fyke nets were checked on a daily basis. Fish at Paxson Lake were captured with a 3 m x 100 m x 25 mm beach seine at night while on spawning sites. Fork length (FL) of all lake trout was recorded to the nearest millimeter. Lake trout greater than 250 mm FL which were captured in good condition were marked with individually numbered Floy t-bar tags. The adipose fin was removed from all tagged fish as a second mark.

For Glacier Lake, Sevenmile Lake, Landlocked Tangle Lake and Upper Tangle Lake, a modified Petersen mark-recapture estimator was utilized (Chapman 1951) to estimate population abundance of lake trout greater than 250 mm FL, with both sampling events conducted during a single year (Table 1). Growth recruitment in these lake trout populations was assumed to be minimal when

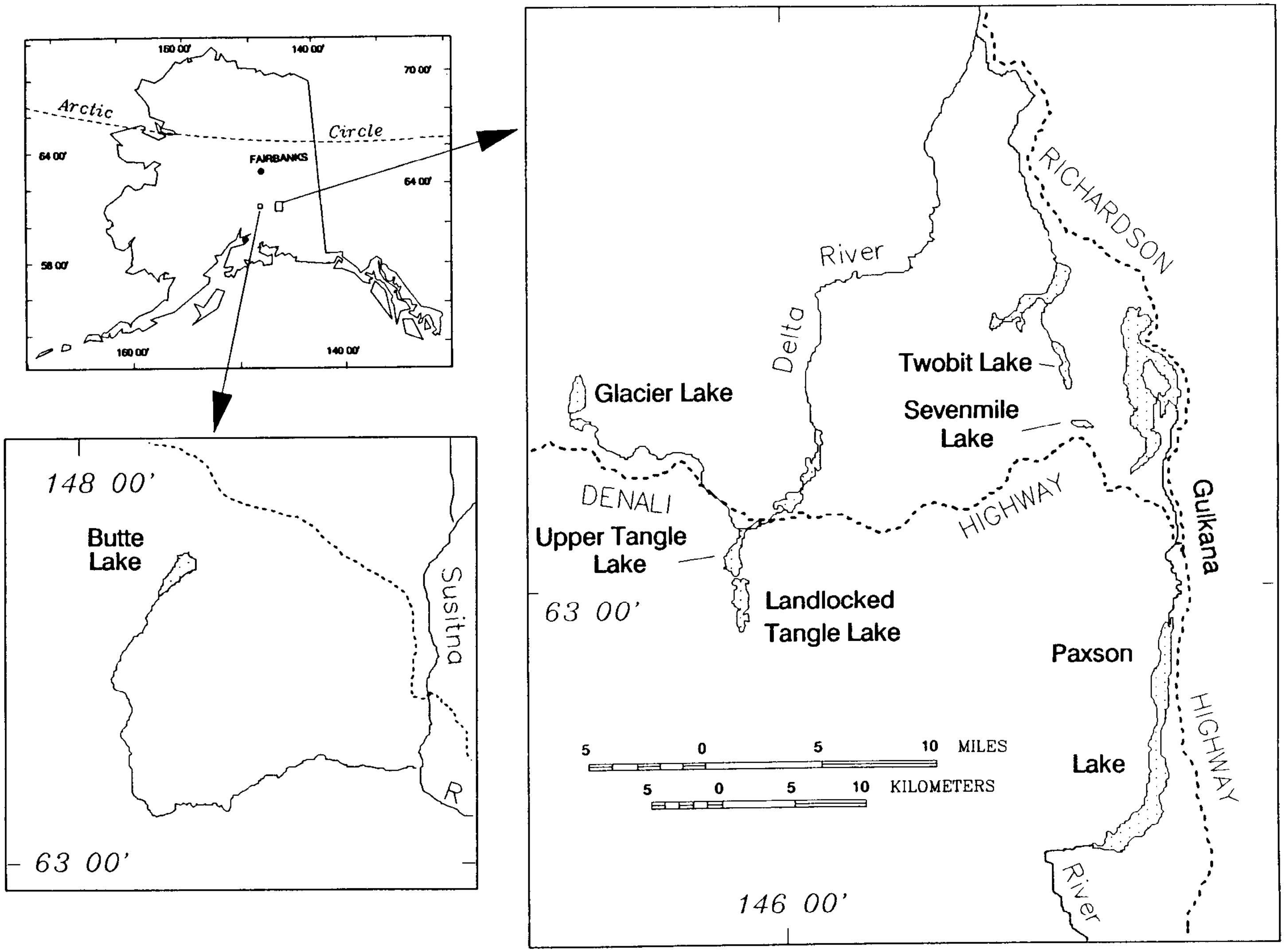

Figure 1. Study lakes in Alaska Mountain Range of Central Alaska.

Table 1. Sampling periods, gear types and estimators used for mark-recapture experiments of lake trout from seven lakes in Alaska.

Lake	Marking Period	Recapture Period	Estimator[a]	Gear[b] Type
Sevenmile	Jun 87	Jul 87	Ps	GNv, HN, FN, PS
	88	Jul 89	Pm	GNt, HN, FN
	89	Jul 90	Pm	GNt, HN, FN
Twobit	Jun 87			GNv, GNt, HN
	Aug 87	Jul 88	Pm	GNt, HN
Upper Tangle	Jun 88	Aug 88	Ps	GNt, HN, S
Glacier	Jun 86	Aug 86	Ps	GNv, HN, FN
	Jun 89			
	Aug 89	Aug 90	Pm	GNt, HN
Landlocked Tangle	Jun 87	Aug 87	Ps	GNv, HN, FN, PS
Butte	Jun 88	Jun 89		
	Aug 88	Aug 89	Pm	GNt
Paxson	Sept 87	Sept 88	JS	S
Paxson	Sept 88, 89	Sept 89, 90	JS	S

[a] Ps-Petersen performed during a single season, Pm-Petersen performed over two seasons, JS-Jolly-Seber.

[b] GNv-variable mesh sinking gill net, GNt-single mesh (51 mm) sinking gill net, HN-baited hoop net, FN-fyke net, PS- purse seine, S-seine.

marking and recapture events were performed within a season. Abundance of lake trout in Twobit Lake, Butte Lake, Sevenmile Lake and Glacier Lake was estimated with marking events and recapture events performed in separate years (Seber 1982; Table 1). To evaluate recruitment through growth between the marking period and the recapture period a year later, a nonparametric method for detecting and culling recruitment was used (Robson and Flick 1965). The abundance of spawning lake trout in Paxson Lake was estimated using the Jolly-Seber model (Seber 1982; Table 1). The Jolly-Seber estimator was selected since growth recruitment and mortality undoubtedly occurred between annual sampling events. This model allowed for recruitment and mortality and the multi-year design provided for adequate mixing of marked and unmarked fish. See Burr 1987, 1988, 1989, 1990, 1991 for further details regarding data analysis procedures.

Density of mature lake trout in the study populations was calculated by reducing the abundance estimate for fish 250 mm and larger by the proportion of fish which were less than the estimated length at 50% maturity (LM_{50}) for the population. The LM_{50}'s were estimated with probit analysis (Finley 1971).

The total weight (kg) of lake trout of mature size was estimated from the lengths of the lake trout captured for estimating population abundance and from the predicted weights of these fish. Length specific weights were derived for each population (Appendix A).

The surface area of each lake was estimated from scale 1:63,000 aerial photographs with a computerized digitizing table. Density in terms of numbers was calculated directly from the abundance estimates and the estimated surface area. Density in terms of weight (kg) was calculated from the estimated total weight of lake trout of mature size and the lake surface area.

Summary of Abundance Estimates, 1986-1990

Abundance estimates from the seven study lakes varied from 211 lake trout in Upper Tangle Lake to 1,665 lake trout in Sevenmile Lake. For four lakes, only one estimate of abundance is available. For two lakes, two abundance estimates each have been calculated. The greatest number of annual abundance estimates (three) have been completed for Sevenmile Lake.

In 1987, an experiment was conducted to estimate abundance in Twobit Lake. However, too few fish were recaptured, particularly those fish less than 350 mm, to yield a meaningful estimate. In 1988, this population was again sampled and abundance was calculated from lake trout marked in 1987 and captured in 1988 (Burr 1989). The estimated abundance after adjustment for growth recruitment was 1,621 fish 250 mm and larger.

Abundance of lake trout 250 mm and larger in Landlocked Tangle Lake during 1987 was estimated to be 3,433. Both mark and recapture events occurred within the same season (Table 1). In 1988, lake trout abundance in Upper Tangle Lake was estimated to be 211 fish 250 mm and larger, with both sampling periods occurring within a single season (Burr 1989; Table 2).

Table 2. Estimated abundance and density of lake trout ($\geq$ 250 mm FL except as noted) from seven populations in Alaska.

Lake (area)	Applicable Year	Estimated Abundance	SE	Density (fish/ha)	Reference
Sevenmile	1987	647	118	19.6	Burr 1988
(33 ha)	1988	942[a]	186	28.5[a]	Burr 1989
	1989	1,665[b]	210	50.5[a]	Burr 1990
Twobit (109 ha)	1987	1,621	226	14.9	Burr 1988
Upper Tangle (150 ha)	1988	211	33	1.4	Burr 1989
Glacier	1986	2,686	621	15.2	Burr 1987
(177 ha)	1989	3,142	669	17.8	Burr 1990
Landlocked Tangle (241 ha)	1987	3,433	801	15.7	Burr 1988
Butte (318 ha)	1988	4,440	710	14.0	Burr 1988
Paxson	1988	4,895[c]	955	3.1[c]	Burr 1989
(1,575 ha)	1989	5,066[c]	318	3.2[c]	Burr 1990

[a] For lake trout 345 mm and larger.
[b] For lake trout 275 mm and larger.
[c] For spawning lake trout.

An estimate of abundance of lake trout in Butte Lake was calculated from sampling conducted in 1988 and 1989 (Table 1). After adjustment for growth recruitment, there were an estimated 4,440 lake trout 250 mm and larger in Butte Lake in 1988 (Table 2).

Lake trout abundance (>250 mm FL) in Glacier Lake was estimated in 1986 and again in 1989. In 1986, both sampling events occurred within one season; estimated abundance was 2,686 (Table 2). In 1989, a mark recapture experiment with both sampling events within one season was conducted but too few fish were captured to provide a useful estimate of abundance. This population was again sampled in 1990 to obtain an estimate of abundance in 1989. With growth recruitment removed, the estimated abundance of lake trout in Glacier Lake in 1989 was 3,142 (Table 2).

The abundance of spawning lake trout in Paxson Lake has been estimated annually beginning in 1988 using the Jolly-Seber estimator. For 1988, the estimate was 4,895 spawning lake trout. For 1989, the estimate was 5,066 spawning lake trout (Table 2).

Lake trout abundance has been estimated annually at Sevenmile Lake since 1987. In 1987, the marking and recapture sampling periods occurred within the same season. The estimated abundance was 647 lake trout 250 mm FL and larger (Table 2). Since 1988, mark and recapture sampling events have been separated by one year. In 1988, abundance of lake trout 345 mm FL and larger was estimated to be 942. In 1989, there were estimated to be 1,665 lake trout 275 mm and larger. In the 1988 estimate, fish between 250 and 344 mm were not recaptured. Hence to avoid bias, only lake trout 345 mm and larger were used to calculate abundance (Burr 1989). A similar but less severe situation occurred in 1989 yielding an estimate for lake trout 275 mm and greater.

Fish of lengths 250 mm and larger were included in the population abundance estimates because 250 mm is the size of full recruitment to the capture gear. Some mark-recapture experiments failed to include fish in the smaller size classes and the experiment at Paxson Lake was designed to sample only spawning fish. Hence, to facilitate comparison of abundance between different years and between populations, abundance estimates of lake trout of mature size (LM_{50} and larger) were calculated. For the remainder of this paper, only estimates of abundance and density of lake trout of mature size are discussed.

There were an estimated 1,112 mature lake trout in Twobit Lake (Table 3). The estimated abundance of mature fish for the other three populations for which only one estimate was calculated were: Landlocked Tangle Lake, 1,645; Upper Tangle Lake, 96; Butte Lake, 2,124. The estimates of the number of mature fish in Sevenmile Lake in 1987, 1988, and 1989 were 459, 791, and 1,054 fish, respectively (Table 3). The estimates from 1987 and 1988 were significantly different ($P = 0.03$) while the 1988 and 1989 estimates were only marginally different ($P = 0.11$). The estimates of abundance of mature fish in Glacier Lake were 1,724 in 1986 and 1,474 in 1989 (Table 3). The difference in the two estimates was not significant ($P = 0.3$). For Paxson Lake, the abundance estimates were for spawning fish only, so no adjustment was needed. Estimates for 1988 and 1989 were 4,895 and 5,066; the estimates were not different ($P = 0.4$).

Table 3. Estimated abundance and density of lake trout of mature size ($\geq LM_{50}$) for seven populations in Alaska.

Lake (area)	Year Estimated	LM_{50}	Estimated Abundance	SE	Density (fish/ha)	Estimated Weight(kg)	Density (kg/ha)
Sevenmile	1987	367	459	85	13.9	469	14.2
(33 ha)	1988	368	791[b]	158	23.9	808	24.5
	1989	386[a]	1,054[c]	138	31.9	1,077	32.6
Twobit (109 ha)	1987	343	1,112	171	10.2	569	5.2
Upper Tangle (150 ha)	1988	402	96	17	0.6	179	1.2
Glacier	1986	373	1,724	403	9.7	1,750	9.9
(177 ha)	1989	375	1,474[d]	324	8.3	1,496	8.5
Landlocked Tangle (241 ha)	1987	357	1,645	359	6.8	1,038	4.3
Butte (318 ha)	1988	369	2,124	347	6.7	2,131	6.7
Paxson	1988	362	4,895	955	3.1	7,940	5.0
(1,575 ha)	1989	362	5,066[e]	318	3.2	8,217	5.2

[a] Difference in LM_{50} not significant ($a = 0.5$).
[b] Difference from previous estimate significant ($P = 0.03$).
[c] Difference from previous estimate significant ($P = 0.11$).
[d] Difference from previous estimate not significant ($P = 0.3$).
[e] Difference from previous estimate not significant ($P = 0.4$).

Using weight-length relationships calculated for lake trout from each lake (Appendix A), total weight (biomass) of lake trout of mature size was estimated directly from the abundance estimates. Estimates of biomass of mature fish from the seven lakes varied from 179 to more than 8,000 kg (Table 3).

Summary of Density Estimates, 1986-1990

Estimates of the density of lake trout of mature size varied from 0.6 fish/ha (1.2 kg/ha) to 31.9 fish/ha (24.8 kg/ha) with the highest densities in the smallest lakes (Table 3, Figure 2 a,b). The estimated density of lake trout in Upper Tangle Lake (0.6 fish/ha) was very low relative to estimates of other populations. The low density of lake trout in this lake is likely the result of suboptimal habitat for lake trout (little deep cooler water is available during mid summer) and a history of high fishing effort (Burr 1989). A significant inverse relationship between lake surface area and density both in terms of fish/ha and kg/ha exists in the data set (Table 3, Figure 2 a,b) when the estimate from Upper Tangle Lake is removed. The relationship between area and kg/ha ($r^2 = 0.63$; $P < .01$) was not as strong as between area and fish/ha ($r^2 = 0.92$; $P < .01$) in the data set.

Sampling Difficulties and Bias

A number of difficulties have been encountered in attempting to estimate lake trout abundance with mark recapture experiments. Nearly all of the problems encountered in attempting to estimate abundance relate to obtaining sufficient sample sizes with which to calculate meaningful estimates. Because of their low density, lake trout can be difficult to catch. During periods of warm weather, catch rates are very low and lake trout are most often caught in deep water where water temperatures are cooler (Burr 1989). Higher catch rates were noted in Sevenmile Lake (Burr 1988) and Glacier Lake (Burr 1990) in late July and August. This is presumably a result of increased swimming/feeding activity associated with increasing periods of darkness, cooling water temperature, and the approach of the spawning season. Higher catch rates are also reported in spring prior to lake warming in littoral areas (Lester et al. 1991). Where spawning sites have been located (e.g. Paxson Lake), large numbers of lake trout can be sampled with a minimum of fishing effort.

Finding suitable gear for capturing lake trout has also been a problem. In search for a nonlethal fishing method we have compared effectiveness of various fishing gears (Burr 1986). To date, only small mesh gill nets have been found to be effective at catching significant numbers of lake trout in most circumstances. In some lakes (e.g. Twobit Lake), baited hoop nets have been quite effective at catching mid-sized (350 - 500 mm) lake trout. Twobit Lake is unique among the sites studied in that lake trout is the only fish species present other than slimy sculpin. Catch rates in hoop nets at other lakes have been low. The fyke nets have yielded very low catches of lake trout. However, young lake trout (< 200 mm FL) which are not vulnerable to other gear types have been captured in fyke nets, particularly in Sevenmile Lake. Beach seines have been very effective at catching lake trout concentrated on spawning beds. In Paxson Lake for example, more than 1,000

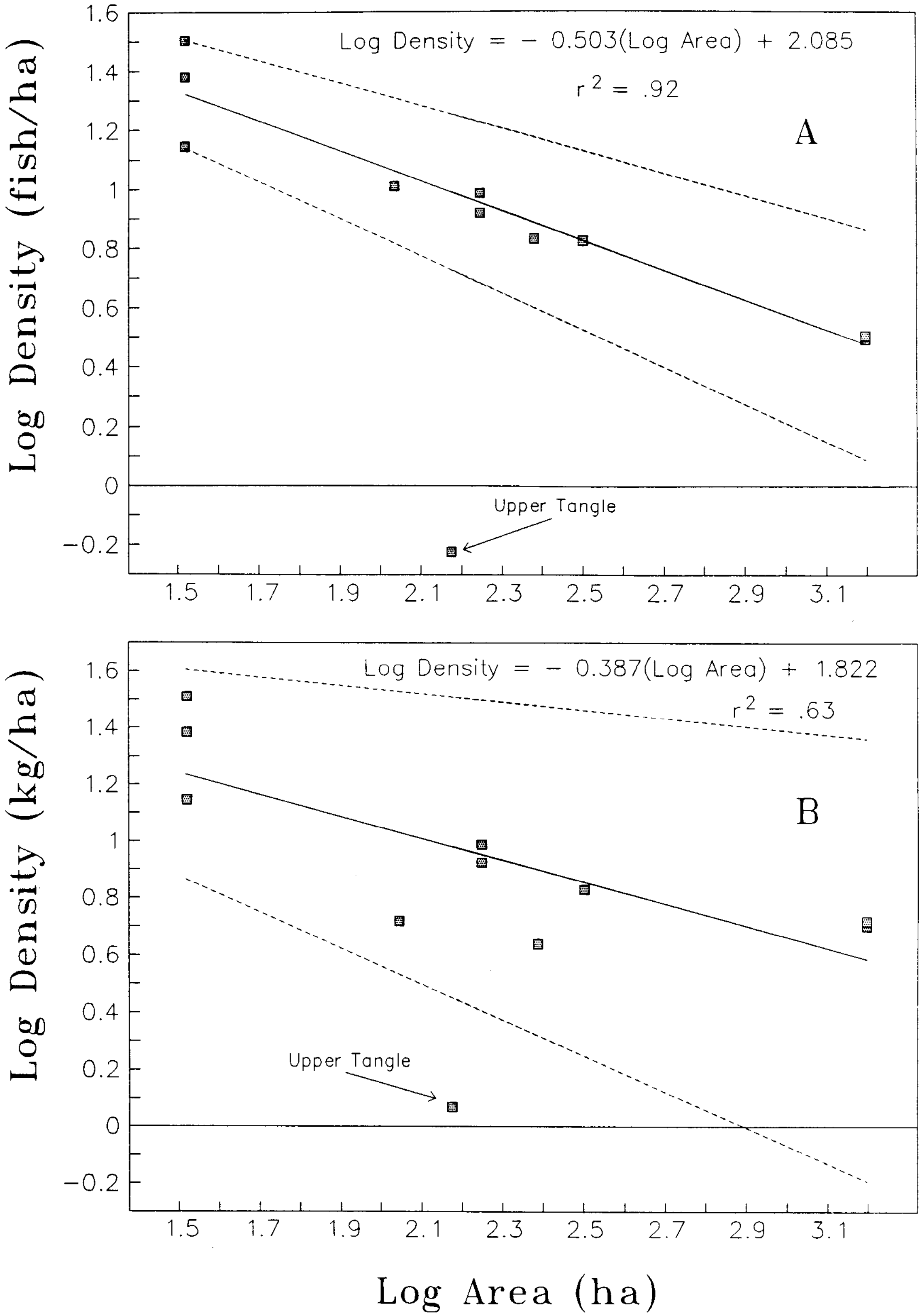

Figure 2. Relationship between lake surface area (ha) and density: panel A - lake trout per ha, panel B - kg per ha. Confidence limits (95%) are shown as broken lines.

lake trout have been caught in a few nights fishing with essentially no incidental mortality.

Fishing mortality associated with gill nets can be substantial. Gill net sampling mortality in excess of 10% is considered unacceptable. In 1986 and 1987, variable mesh (25 mm, 51 mm, 76 mm, 102 mm, 127 mm) monofilament gill nets were used to capture lake trout for mark-recapture experiments. Nets fished in 1986 and early 1987 often exceeded one hour without being attended and fishing mortality exceeded acceptable levels (36% Glacier Lake, 27% Twobit Lake, 28% Landlocked Tangle Lake; Table 4). By reducing fishing time to one half hour or less between checks and by switching to single mesh (51 mm) multifilament nets, fishing mortality was substantially decreased (8% Twobit Lake, 11% Landlocked Tangle Lake). Due to low catch rates in Upper Tangle Lake during 1988, additional gear was fished in an attempt to obtain the needed sample size. With more gear fishing, it became difficult to check the nets within the desired 1/2 hour interval and netting mortalities exceeded acceptable levels. Small lake trout (250 to 350 mm) are particularly vulnerable to the 51 mm mesh as they are easily suffocated when gill flaps are wedged closed. In 1990, both 51 mm and 76 mm mesh gill nets were used in Glacier Lake. The result was higher overall netting mortality. Increased mortality has been repeatedly observed once surface water temperature exceeds 10^{o} C (Burr 1988, 1990). Lake trout are easily stressed in warm water and are apparently unable to withstand netting during these periods. In order to keep mortalities from gill netting within acceptable levels, (10% or less) it appears that netting must be conducted under the following guidelines: (1) net sets of one half hour or less; (2) avoid netting when surface water temperature is greater than 10^{o} C; and, (3) use mesh which is small enough to entangle rather than gill or wedge fish.

In several instances (e.g. Twobit Lake, 1987; Butte Lake, 1988, and Glacier Lake, 1989) single season Petersen mark-recapture experiments were attempted but too few samples were collected to yield meaningful estimates. In these cases, all samples from the first season were pooled and treated as the marking event. Sampling in the following year was conducted to complete the experiment. Because of the year-long hiatus between sampling events, recruitment through growth could not be considered negligible and recruitment was culled. With the small samples which were generally available (200-400 marked fish during each event, and 20-30 recaptures), the technique of Robson and Flick (1965) was often inconclusive and growth of recaptured fish was used in an attempt to remove growth recruitment (Burr 1990, 1991). The effect of unremoved growth recruitment would be to inflate the estimate of abundance. The estimate of abundance from Sevenmile Lake calculated from data collected within a single season in 1987 is significantly less than the estimates for 1988 and 1989. The 1988 and 1989 estimates were calculated from data collected from two seasons. Either abundance increased between 1987 and 1988 or growth recruitment was not completely culled.

In Paxson Lake, only spawning lake trout were sampled. This approach has great appeal because spawning fish are concentrated, are very vulnerable to non-lethal capture methods, and a significant portion of the population of mature fish was sampled. A major drawback to this approach is that no information is obtained on the non-spawning portion of the population. In

Table 4. Mortality rates from gill netting effort in seven lakes in Alaska.

Lake	Year	Gear[a]	Percent Mortality
Sevenmile	1987	GNr	14
Sevenmile	1988	GNt	9
Sevenmile	1989	GNt	6
Sevenmile	1990	GNt	10
Twobit	1987	GNv	27
Twobit	1987	GNt	8
Twobit	1988	GNt	12
Landlock Tangle	1987	GNv	28
Landlock Tangle	1987	GNt	11
Upper Tangle	1988	GNt	23
Glacier	1986	GNv	37
Glacier	1989	GNt	27
Glacier	1990	GNt[b]	28
Butte	1988	GNt	21
Butte	1989	GNt	2
Paxson	1987	GNt, S	7
Paxson	1988	S	<1
Paxson	1989	S	<1

[a] Codes for gear.
[b] 51 mm and 76 mm nets in combination.

Paxson Lake it is likely that a significant portion of the legally retained harvest is from lake trout smaller than those handled in the spawning sample. Stock assessment is confounded as the population from which fish are harvested is different from the population for which abundance is estimated. The current management strategy for lake trout in Paxson Lake and other lakes for which length limits are in effect is to prevent harvest of immature fish (Burr 1987, 1991). However, information regarding the size composition of the harvest is lacking. Without estimates of the size/age composition of the population from which lake trout are caught, and an estimate of the size/age composition of the harvest, the abundance estimate of mature lake trout does not provide a complete picture of the effect of the harvest on the population.

Using spawning fish to estimate the abundance of mature fish in the population assumes that all fish spawn every year once maturity is attained. Results from Paxson Lake indicate that male lake trout probably spawn annually in this population, but females may not (Burr 1991). To correct for this bias, only male lake trout were used to calculate abundance and the estimate was doubled to include females. Current research at Paxson Lake is directed at establishing that the sex ratio is 1:1 as expected from other studies (Martin and Olver 1980). The use of spawning sites to sample the mature population also assumes that spawning fish travel between spawning sites such that all spawners have the same probability of being sampled. Research is in progress to measure the rates of mixing between known sample sites.

In summary, conducting mark-recapture experiments to estimate lake trout abundance can be difficult and frustrating. Sampling must be restricted to periods of cool water temperature to minimize stress to the fish, and to periods when fish are moving or are concentrated. This translates to a brief period following ice out in the spring and a more extended period during late summer and early fall. Lake trout are very vulnerable to handling mortality. Sampling must be conducted carefully to minimize mortality. Low population abundance is characteristic of the species. Hence, a relatively high proportion of these sparse populations must be handled to achieve desired levels of precision and accuracy in estimates of abundance. The estimates of total weight (biomass) of lake trout of mature size were calculated from the estimates of numerical abundance. Hence, these estimates are subject to the same sources of bias discussed above with minor additional variability introduced by the weight-length relationship (Appendix A).

Comparison of Density Estimates of Lake Trout in Alaska with Results from Other Areas

Estimates of density of lake trout of mature size from the seven lakes in Alaska span the range of densities of lake trout reported from other areas (Table 5). In other studies, the density of mature lake trout is generally less than 3 fish per ha (Healey 1978, Table 5). However, the populations studied have generally been piscivorous and/or have come from larger lakes than most of the populations studied in Alaska. Most estimates of Alaskan lake trout densities lie in the mid to upper range of reported densities from outside of Alaska, with the estimates from Sevenmile Lake (14 - 32 fish/ha; 14 - 33 kg/ha) being much higher than most. Where planktivorous/benthivorous populations have been studied, higher densities have been reported. A density

Table 5. Estimates of density of mature lake trout from various water bodies.

Location	Area (ha)	Density		Reference
		Fish/ha	kg/ha	
East Blue Lake Manitoba	97	2.93	2.24	Gibson unpublished in Martin and Olver 1980
Swan Lake Alberta	200	1.13		Paterson 1968
Squeers Lake Ontario	384	18	7.4	Ball 1988
Alexie Lake NWT	547	1.37 1.65		Healy 1978
Goldstream Pond Maine	1,468	1.38 0.87		DeRoche and Bond 1957
Thompson Lake Maine	1,791	10.74[a]		DeRoche unpublished in Martin and Olver 1980
Green Lake Wisconsin	2,964	0.76		Hacker 1958
Opeongo Ontario	5,860	0.41		Martin and Fry 1973

[a] For lake trout 356 mm FL and larger, size at maturity for this population is not documented.

of 12 mature lake trout per ha was reported from Lake Louisa, Ontario (Monroe and Hicks 1984). The highest density of any natural population found in the non-Alaskan literature is 18 mature fish per ha from Sqeers Lake, Ontario - a population of small planktivorous/benthivorous lake trout. The inverse relationship between density and lake area which has been observed in Alaskan lake trout populations is consistent with reports by Carlander (1977), Goddard et al. (1987) and Payne et al.(1990). This implies that smaller lakes produce more fish than larger lakes on a per unit area basis. However, numerical density (fish/ha) does not necessarily correlate well with density in terms of weight. For example, planktivorous/benthivorous populations (e.g. Twobit Lake) and piscivorous populations (e.g. Paxson Lake) of similar biomass per area (5.2 kg/ha vs 5.0 kg/ha, Table 4) may differ widely in numerical density (10.2 vs 3.1) because of the typically small average size of the planktivorous/benthivorous fish. Lake trout size is found to be directly correlated with lake size (Payne et al. 1990). Length compositions of lake trout from the Alaskan study lakes show a slight trend toward larger fish in the larger lakes (Figure 3). However, samples from Paxson Lake include only mature fish while samples from the other lakes include both immature and mature fish. Lake trout from the study lakes, excluding Paxson, averaged less than 420 mm FL. The length at 50% maturity for these lake trout populations are very similar (343 - 402 mm FL, Table 4) and are typically less than what has been reported from other geographical areas (Burr *in press*). Martin and Olver (1980) found that the highest densities of lake trout (4.1 to 9.8 fish per ha) generally occur in those lakes where fish mature at a small size, are planktivorous/benthivorous, and where the average size of fish is between 300-400 mm. Hence, the relatively high densities of lake trout found in these lakes in Alaska is likely due to the small surface area of the lakes studied, the small average size of fish, and the small size at maturity of lake trout in these populations.

TRENDS IN HARVEST AND YIELD

Harvest is defined as the number of fish caught and killed from a waterbody on an annual basis. Yield is the annual harvest of fish expressed in terms of weight per unit area (in this case kg/ha/yr). Lake trout harvest from Alaskan waters is estimated with a statewide mail survey (Mills 1978-1991). Estimates of lake trout harvest are not available for most study lakes. Estimates of harvest are available for Paxson Lake and for the combined Tangle Lakes. In Paxson Lake, estimates of harvest have varied from 707 lake trout in 1978 to 2,139 in 1990. Lake trout harvest from Paxson Lake has averaged 1,615 since adoption of more restrictive regulations in 1987 (Table 6). For the combined Tangle Lakes, estimates of lake trout harvest have ranged between 127 fish and 2,376 fish and averaged 280 fish since 1987.

Data are scanty on the size composition of the lake trout harvest, particularly from the Tangles Lakes. As there is a 18 inch minimum size limit (TL) in place for these populations, it is assumed that all lake trout harvested are 18 inches or larger. To obtain a minimum estimated yield (kg/ha/yr), the predicted weight of 18 inch lake trout was used to calculate the annual harvest in terms of weight. Since this assumes that all lake trout harvested were 18 inches, the calculation provides a minimum estimate of

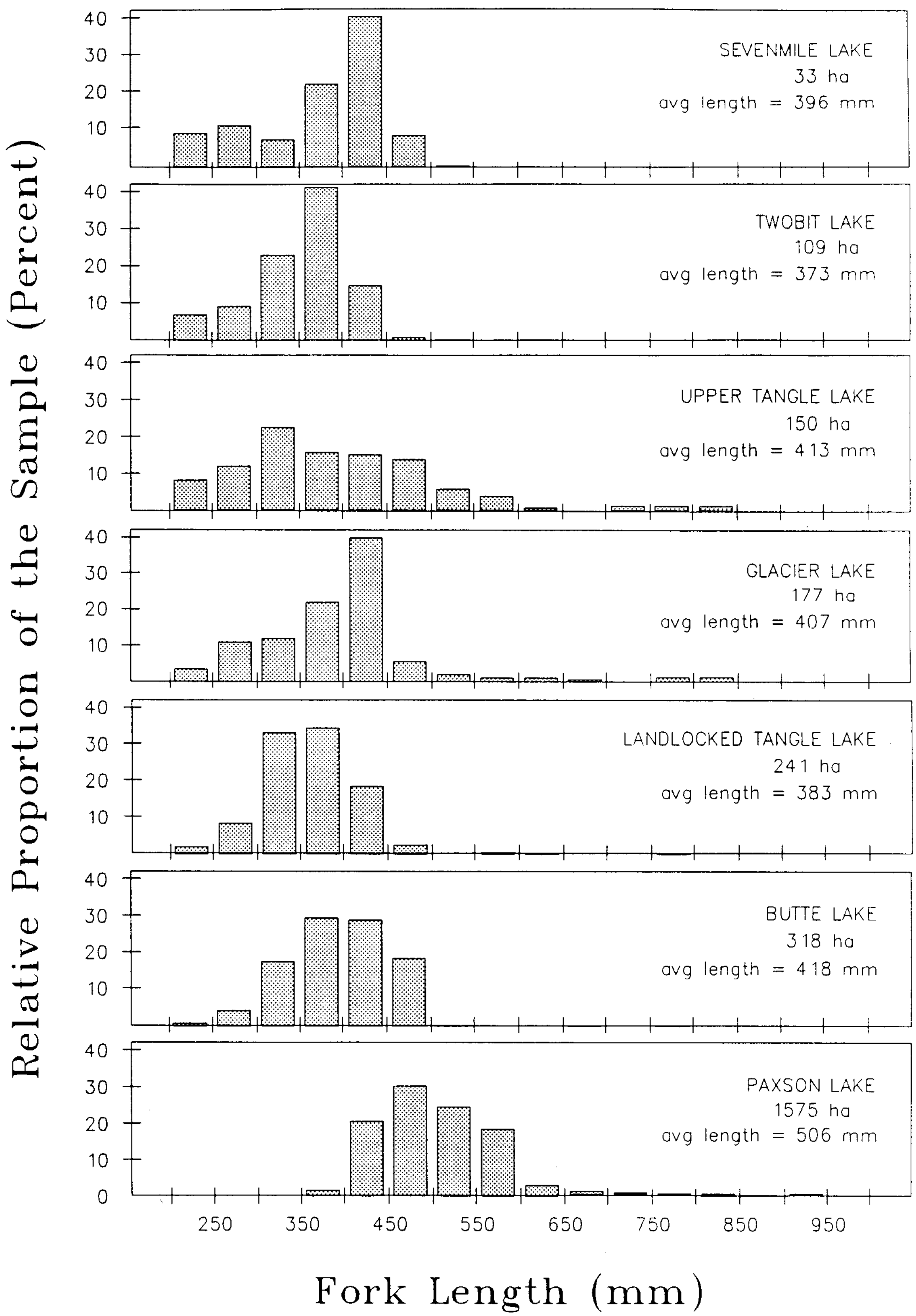

Figure 3. Length distribution of lake trout from seven lakes in Alaska.

Table 6. Harvest and yield of lake trout from Paxson Lake and from the Tangle Lakes, 1977 through 1990.

	Paxson Lake					Tangle Lakes				
		Minimum[b]		Sample[c]			Minimum[b]		Sample[c]	
Year	Harvest[a] (Fish)	Harvest (kg)	Yield (kg/ha)	Harvest (kg)	Yield (kg/ha)	Harvest[a] (Fish)	Harvest (kg)	Yield (kg/ha)	Harvest (kg)	Yield (kg/ha)
1977	925	764	0.49	1,524	0.97					
1978	707	584	0.37	1,165	0.74	416	352	0.44	437	0.55
1979	1,463	1,208	0.77	2,411	1.53	428	362	0.45	450	0.56
1980	1,492	1,232	0.78	2,459	1.56	603	510	0.64	633	0.79
1981	1,295	1,070	0.68	2,134	1.36	864	730	0.91	907	1.13
1982	1,714	1,416	0.90	2,825	1.79	1,079	912	1.14	1,133	1.42
1983	1,710	1,412	0.90	2,818	1.79	2,088	1,764	2.21	2,193	2.74
1984	784	648	0.41	1,292	0.82	636	537	0.67	668	0.84
1985	1,803	1,489	0.95	2,971	1.89	2,376	2,008	2.51	2,496	3.12
1986	944	780	0.50	1,556	0.99	409	346	0.43	430	0.54
1987	1,457	1,203	0.76	2,401	1.52	0	0	0	0	0
1988	1,310	1,082	0.69	2,159	1.37	127	107	0.13	133	0.17
1989	1,557	1,286	0.82	2,566	1.63	478	404	0.50	502	0.63
1990	2,139	1,767	1.12	3,525	2.24	236	199	0.25	248	0.31
PRE 87			0.69		1.38			1.04		1.30
POST 87			0.88		1.75			0.30		0.37

[a] From Mills 1978-1991.
[b] Calculations based on all lake trout harvested at 18" TL.
[c] Calculations based on lake trout harvested at 18" or larger and in proportion to size composition estimated from samples collected for mark-recapture experiments.

annual yield. The minimum estimated yield of lake trout from Paxson Lake has varied from 0.37 to 1.12 since 1977 and averages 0.88 kg/ha/yr since adoption of the more restrictive regulations (Table 6, Figure 4 a,b). During this same period, minimum yield of lake trout from the Tangle Lakes has ranged from 0.13 to 2.51 and has averaged 0.30 kg/ha/yr since 1987 (Table 6, Figure 4 c,d). To obtain a somewhat more realistic view of lake trout yield from these populations, yield was also calculated using the size composition in the samples from the mark-recapture experiments. The estimated yield utilizing this assumption is greater, particularly at Paxson Lake. The average annual yield since 1987 in Paxson Lake is 1.75 kg/ha and in the Tangle Lakes is 0.37 kg/ha.

An increasing level of harvest and yield is evident in the estimates for Paxson Lake (Table 6). More importantly, the restrictive harvest regulations adopted prior to the 1987 fishing season have not reduced harvest. The yield guideline of 0.5 kg/ha/yr has been exceeded each year since 1986. If anglers selectively harvest larger lake trout, yield would be greater than that indicated in Table 6.

Harvest and yield of lake trout from the Tangle Lakes was increasing rapidly until the mid 1980's. With the adoption of the restrictive bag and size limits in 1987, harvest of lake trout in the Tangle Lakes has been maintained at a much reduced level and, in general, within the yield guideline.

The rationale behind the regulatory regime used in Alaska for management of the lake trout sport fishery has been based upon common yield guidelines for all lakes irrespective of lake size. Yield is not independent of lake size. Research is needed to better understand the effect of productivity on lake trout yields especially as related to lake size. Managing all lakes with the same guideline may result in overexploitation of less productive populations and under-utilization of more productive populations of lake trout.

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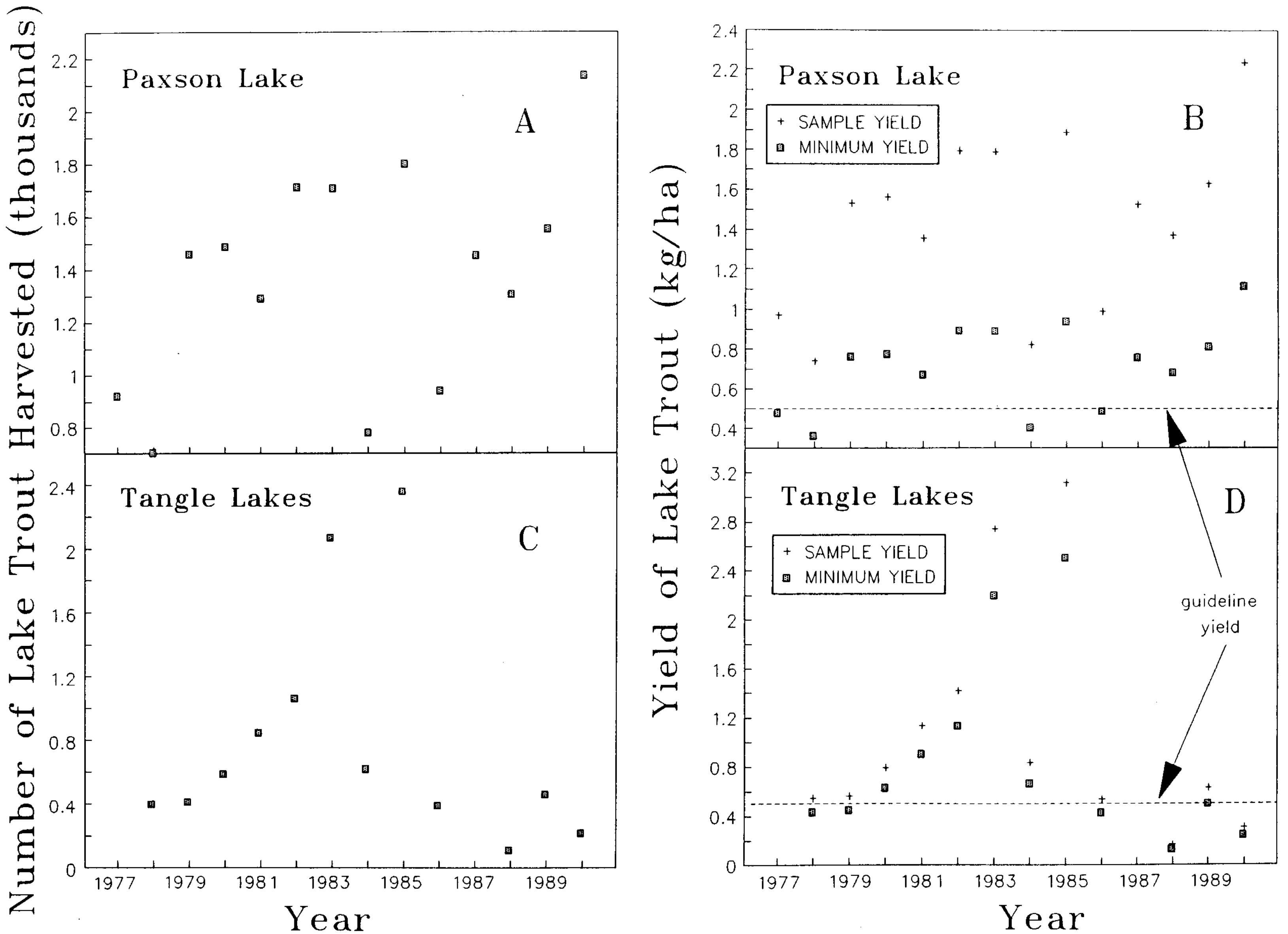

Figure 4. Harvest and yield of lake trout from Paxson Lake and the Tangle Lakes 1977 through 1990. Harvest shown in panels A and C, yield shown in panels B and D.

LITERATURE CITED

Ball, H. E. 1988. The dynamics of a Polyphagous lake trout, *Salvelinus namaycush* (Walbaum), population in a Northwestern Ontario lake. Master's thesis, Department of Biology Lakehead University, Thunder Bay, Ontario. 234 pp.

Burr, J. M. 1987. Stock assessment and biological characteristics of lake trout populations in Interior Alaska, 1986. Alaska Department of Fish and Game, Fishery Data Series No. 35, Juneau. 65 pp.

_____. 1988. Stock assessment and biological characteristics of lake trout populations in Interior Alaska, 1987. Alaska Department of Fish and Game, Fishery Data Series No. 66, Juneau. 53 pp.

_____. 1989. Stock assessment and biological characteristics of lake trout populations in Interior Alaska, 1988. Alaska Department of Fish and Game, Fishery Data Series No. 99, Juneau. 57 pp.

_____. 1990. Stock assessment and biological characteristics of lake trout populations in Interior Alaska, 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-33, Anchorage. 50 pp.

_____. 1991. Lake trout population studies in interior Alaska, 1990, including abundance estimates of lake trout in Glacier, Sevenmile, and Paxson lakes during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 91-7, Anchorage. 50 pp.

_____. *In prep.* Maturity of lake trout from eleven lakes in Alaska. Article, Northwest Science Association, Pullman, Washington.

Carl, L., M.-F. Bernier, W. Christie, L. Deacon, P. Hulsman, D. Loftus, D. Maraldo, T. Marshall, and P. Ryan. 1990. Fish community and environmental effects on lake trout. Lake Trout Synthesis, Ont. Min. Nat. Resour., Toronto. 47 p.

Carlander, K. D. 1977. Biomass, production, and yields of walleye (Stizostedion vitreum) and yellow perch (Perca flavescens) in North American Lakes. Journal of the Fisheries Research Board of Canada. 34:1602-1612.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1, 131-60.

Conover, W. J. 1980. Practical nonparametric statistics. John Wiley and Sons, New York. 493 pp.

Evans, D. O., J. M. Casselman, and C. C. Wilcox. 1991. Effects of exploitation, loss of nursery habitat and stocking on the dynamics and productivity of lake trout populations in Ontario lakes. Lake Trout Synthesis, Ontario Ministry natural Resources. Toronto. 115 pp.

Finney, D. J. 1971. Statistical methods in biological analysis, 2nd ed. Charles Griffin & Company, Ltd. London. 668 pp.

Goddard, C. I., D. H. Loftus, J. A. MacLean, C. H. Olver, and B. J. Shuter. 1987. Evaluation of the effects of fish community structure on observed yields of lake trout (Salvelinus namaycush). Canadian Journal of Fisheries and Aquatic Sciences. 44(Suppl. 2): 239-248.

Healey, M. C. 1978. Dynamics of exploited lake trout populations and implications for management. Journal of Wildlife Management. 42:307-328.

Lester, N. P., M. M. Petzold, W. I. Dunlop, B. P. Monroe, S. D. Orsatti, T. Schaner, and D. R. Wood. 1991. Sampling Ontario lakes: issues and standards. Lake trout Synthesis, Ontario Ministry Natural Resources, Toronto. 117 pp.

Martin, N. V. and C. H. Olver. 1980. The lake charr, Salvelinus namaycush. in E. K. Balon, ed. "Charrs: Salmonid Fishes of the Genus Salvelinus. D. W. Junk, Publishers, The Hague, Netherlands. 925 pp.

Mills, M. J. 1979. Alaska statewide sport fish harvest studies. Alaska Department of Fish and game. Federal Aid in fish Restoration, Annual Performance Report, 1978-1979, project F-9-11, 20 (SW-I-A). 112 pp.

______. 1980. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1979-1980. Project F-9-12, 21 (SW-1): 65 pp.

______. 1981. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1980-1981. Project F-9-13, 22 (SW-1): 78 pp.

______. 1982. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1981-1982. Project F-9-13, 23 (SW-1): 115 pp.

______. 1983. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1982-1983. Project F-9-14, 24 (SW-1): 118 pp.

______. 1984. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1983-1984. Project F-9-16, 25 (SW-1): 122 pp.

______. 1985. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1984-1985. Project F-9-17, 26 (SW-1): 88 pp.

______. 1986. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1985-1986. Project F-9-18, 27 (SW-1): 137 pp.

______. 1987. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1986-1987. Project F-9-19, 28 (SW-1): 91 pp.

______. 1988. Alaska statewide sport fisheries harvest report 1987. Alaska Department of Fish and Game. Fishery Data Series No. 52. 95 pp.

______. 1989. Alaska statewide sport fish harvest report (1988). Alaska Department of Fish and Game, Fishery Data Series No. 122, Juneau. 142 pp.

______ 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game. Fishery Data Series Report No. 90-44, Anchorage. 152 pp.

Monroe, B. P. and F. J. Hicks. 1984. Louisa Lake data summary report. Ontario Ministry of natural Resources Algonquin Fisheries Assessment Unit Ms. Report.

Paterson, R. J. 1968. The lake trout (Salvelinus namaycush) of Swan Lake, Alberta. Alberta Department of Lands Forests. Fish and Wildlife Division of Research Report. 2: 1-149.

Payne, N. R., R. M. Korver, D. S. MacLennan, S. J. Nepskzy, B.J. Shuter, T.J. Stewart, and E. R. Thomas. 1990. The harvest potential and dynamics of lake trout populations in Ontario. Lake Trout Synthesis, Ont. Min. Nat. Resour. Toronto. 72 pp.

Robson, D. S. and W. A. Flick. 1965. A non-parametric statistical method for culling recruits from a mark-recapture experiment. Biometrics 21: 936-947.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd ed. Charles Griffin & Company, Ltd. London. 624 pp.

APPENDIX A

Appendix A1. Weight - Length Relationships For Study Lakes.

Length specific weights were derived for each population from the relationship:

$$W = aL^b \qquad (1)$$

where W = weight in grams, L = fork length in mm, and "a" and "b" are derived parameters

The parameters a and b were estimated for each population by regression of $\log_{10}$ transformed weights and lengths with the function:

$$\log W = \log a + b \log L \qquad (2)$$

When no gear selectivity was detected, the total weight of lake trout of mature size was estimated by:

$$\hat{B}_m = \frac{\hat{N}_m}{n_m} S \hat{W}_m \qquad (3)$$

where $\hat{B}_m$ = total estimated weight of lake trout > LM_{50},
N_m = estimated number of lake trout > LM_{50},
n_m = number of lake trout sampled > LM_{50}, and
W_m = weights (predicted and actual) of lake trout.

When gear selectivity was detected and a stratified estimator was used for population abundance, the total weight of lake trout of mature size was estimated by:

$$\hat{B}_m = S \frac{\hat{N}_i p_{im}}{n_i} S \hat{W}_{im} \qquad (4)$$

where B_m = total estimated weight of lake trout > LM_{50},
N_i = estimated number of lake trout in stratum i,
p_{im} = proportion of lake trout of mature size in stratum i
n_i = number of lake trout sampled in stratum i,
W_{im} = weights (predicted and actual) of lake trout > LM_{50} in stratum i

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Appendix A2. Parameter values "a" and "b" for lake trout weight-length relationship and calculated weight at selected fork lengths for seven lakes in Alaska. Non-observed lengths are not included.

Lake Name	Weight-length relation "a"x 10^{-6}	"b"	r^2	Calculated weight (g) at fork-length (mm) 200	250	300	350	400	500	600
Sevenmile	1.19	3.40	0.92	80	171	317	536	844	1803	
Twobit	160.34	2.55	0.84	116	205	326	483	679	1198	
Upper Tangle	0.79	3.45	0.98	70	152	285	485	770	1664	3123
Glacier	8.55	3.06	0.90	92	182	319	510	767	1518	2650
Landlocked Tangle	0.32	3.59	0.94		131	251	437	706		
Butte	0.51	3.52	0.91	63	139	264	454	726	1592	3023
Paxson	3.43	3.20	0.90				462	707	1443	2583