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ABSTRACT

Information collected during studies of lake trout *Salvelinus namaycush* in Alaska, and studies in the general literature, are examined regarding the effects of various types of length restrictions on fish populations. This review is intended to provide managers with additional information when harvest control measures are considered. Although small lake trout are particularly vulnerable to hooking mortality, the advantages of catch and release fisheries for lake trout are considered to outweigh disadvantages. Selection of length limits should be based on biological characteristics of the stock and the goals of the manager. Minimum length limits are likely to increase yield where recruitment is limited, but will focus harvest on larger fish. Maximum size limits protect brood stock, however elimination of the chance to harvest a trophy would be expected to be resisted by the public. Slot limits are appropriate where recruitment is good, and may improve the quality of the fishery. Potential regulatory actions are recommended.

KEY WORDS: lake trout, *Salvelinus namaycush*, length limits, minimum length limit, maximum length limit, slot limit, management strategy.

INTRODUCTION

Angling effort and exploitation are increasing on stocks of lake trout *Salvelinus namaycush* in some areas of interior Alaska. The sensitivity of lake trout to exploitation is well documented in the literature (e.g. Healey 1978, Martin and Olver 1980, Payne et al. 1990). Quality of angling can deteriorate rapidly with only moderate fishing pressure (Evans et al. 1991). The biological characteristics of the species (slow growth, late maturity, low reproductive potential, slow replacement rate) and the unproductive nature of the environment in which it is adapted (low nutrient, cold temperatures) contribute to the vulnerability of the species to exploitation. Lake trout have narrow environmental tolerance (cold, well oxygenated water). Due to these factors lake trout are found in a small number of lakes where they form sparse populations with low annual sustainable yields (Olver 1988, MacLean et al. 1990). At low to moderate levels of exploitation, lake trout populations have shown the ability to compensate with increased growth, earlier maturity, and possibly increased fecundity (Healey 1978).

The management goal of the Sport Fish Division of the Alaska Department of Fish and Game (ADFG) is to provide the public, on a sustained yield basis, with a variety of angling opportunities while conserving indigenous stocks of fish. This goal is approached through regulations, which attempt to limit harvest to varying degrees. Traditional harvest control measures such as bag limits, length limits and season closures, are effective until their ability to control harvest is undermined by large increases in the demand for recreational fishing (Christie 1978). Angling effort on lake trout stocks in Alaska is not perceived to be so great that the traditional methods of harvest control are ineffective. At the present time, bag and length limits are used as a means of attempting to control the harvest of lake trout in interior Alaska. A bag limit of two lake trout per day, two in possession, is in effect for the Tanana drainage with an 18 inch minimum total length (TL) limit (420 mm fork length) on selected roadside lakes. The Tangle lakes have a more restrictive bag limit of one lake trout per day, one in possession. The 18 inch minimum length limit was established to allow for a few years of spawning prior to harvest. Length limit strategies alternative to the 18 inch minimum restriction now in effect might achieve greater control of the age and size structure of the spawning stock, or be used to tailor fisheries to specific desires (eg. trophy fish).

The purpose of this paper is to review existing data collected during studies of lake trout in Alaska, and studies in the general literature, regarding the effects of various types of length restrictions on fish populations. It is expected that this review of the biological consequences of length limits will provide managers with additional information when considering harvest control measures.

HOOKING MORTALITY

The use of length limits to control harvest of lake trout of a given size or age assumes that most fish which are caught and released within the protected size zone survive. Investigations conducted on lake trout indicate that overall hooking mortality is low. At Great Slave Lake shortly after ice out, hooking mortality for lake trout of all sizes was 7% (Falk et al. 1974). In the upper Great Lakes, overall hooking mortality for lake trout 460 mm - 800 mm FL was 14.9% (Loftus et al. 1988). Hooking mortality for lake trout under a variety conditions in Ontario varied from 4.5% to 27.3% (Hicks and Quinn 1990). Mortality was lowest during spring and fall, and higher during warm water periods. These studies indicate that small lake trout (< 540 mm FL) are particularly vulnerable to hooking mortality. Even in warm water there was little problem with the release of larger lake trout. Mongillo (1984), in a review of hooking mortality in salmonids other than lake trout, noted that fishing with bait caused hooking in critical areas five times more often (50%) than artificial lures (10%). However in Raquette Lake, lake trout which were frequently caught on bait and subjected to rapid increase in temperature and decrease in pressure as they were hauled from deep water, survived the catch and release process frequently enough to produce a net increase in abundance (Barnhart and Engstrom-Heg 1984). Dextrase and Ball (in prep) found overall hooking mortality of lake trout in winter was 10% for fish 240-410 mm FL (average 326 mm). In all cases the advantages of catch and release fishing were considered greater than the negative effects of the relatively low hooking mortality.

MINIMUM LENGTH LIMIT

Minimum size limits (release of all fish under a designated size) have been widely applied to fish populations. The general purpose of minimum length limits for lake trout is to permit fish to mature and spawn at least once before exploitation. In theory, the release of sub-legally sized fish will add to the harvest when they reach legal size or will contribute to future spawning stocks and hence ultimately increase catches. In other words, increasing the size limit should increase the sustainable yield of larger fish by reducing the harvest of younger fish and increasing the recruitment of younger fish into the older age groups. Where exploitation is excessive, the vulnerability of lake trout populations to overharvest could be reduced by using minimum length limits to delay entry of year classes into the fishery (Payne et al. 1990). Size and hence the age of recruitment to the fishery can thus be manipulated. Angling opportunities are maintained with this type of regulation although anglers desiring to keep and eat small pan-sized lake trout will be disenfranchised.

Minimum length limits have often not been effective in regulating lake trout harvest because the length limits imposed were too small to protect immature fish (Olver 1988). Where minimum limits have been sufficiently large, the results have often been positive. For example, after an increase in the length limit from 350 mm FL (15 in TL) to 490 mm FL (21 in TL) in Raquette Lake, New York there was a threefold increase in the spawning stock within two years and harvest rates increased from 0.03 to 0.08 lake trout per hour (lt/hr) (Barnhart and Engstrom-Heg 1984). Smith et al. (1988) recommend that the minimum size limit should be large enough to protect fish through two years of spawning.

Potential negative effects from the use of minimum length limits have been noted. A 305 mm FL (12 in TL) minimum length limit was set for brown trout *Salmo trutta* in the Au Sable River, Michigan with the goal of bringing back large fish to the population (Clark and Alexander 1984). The result was a decline in the number of large fish and a decline in growth rate as brown trout less than the legal size limit became proportionally more abundant ("stockpiling"). Stockpiling of fish has resulted in long term declines in growth and condition due to increased intraspecific competition for populations of wild brown trout (Clark and Alexander 1984) walleye *Stizostedion vitreum* (Serns 1978) and northern pike *Esox lucius* (Kempinger and Carline 1978, Dunning et al. 1982). Total annual mortality has not necessarily decreased with a reduction in fishing mortality (this phenomenon may have been a compensatory response to increased recruitment). In severe cases, stockpiling has resulted in lessened reproductive success in brown trout (Barnhart and Engstrom-Heg 1984) and northern pike (Dunning et al. 1982). For northern pike the yield of older fish actually declined with a minimum size limit due to the increased harvest of older and larger females and a subsequent decrease in egg production. Unlike northern pike, no sexual dimorphism in body size has been shown for lake trout (Martin and Olver 1980) so increased selection for females is not expected.

A problem with minimum size limits is that they focus all of the harvest on large, older fish. Large body size is desirable for females due to the greater reproductive potential. In wild populations, large lake trout represent many year classes. Focusing harvest on large fish, if excessive, has the potential of eliminating the built-in resiliency of the population to environmentally caused failures in recruitment. Giesel (1976) suggests that an extended age distribution represents an evolutionary adaptation by which mortality during early stages is averaged out by repeat spawning over the lifetime of individual fish. If large fish disappear due to angling, any favorable increase in growth or survival of younger age classes would likely be inadequate to offset the loss of old trophy fish. This shift in age structure may also have a negative effect on the quality of reproductive products. In spite of a greater number of young females, the number of young produced may be less than that produced by a smaller number of older females of the same size. Mortality during embryonic, larval, and juvenile stages is higher for progeny from females spawning for the first time than from repeat spawners (Borrisov 1978). Favro et al. (1980) suggested that fishing under a minimum size limit might reduce the genetic growth potential of brown trout by killing most of the larger trout and leaving behind smaller trout to reproduce.

MAXIMUM SIZE LIMIT

Maximum size limits require the release of all fish over a designated size. This type of size limit could protect native brood stock or counter a decline in the age and size of the spawning stock if the limit was sufficiently small. A maximum size limit was successful in rebuilding the age composition for cutthroat trout *Oncorhynchus clarki* in Wyoming (Greswell 1980). The concept is that the fish are susceptible to harvest for a relatively short period of time and harvesting fish prior to maturity "shifts fishing mortality to life stages which may be better able to withstand high levels of exploitation" (Greswell 1980). In general, maximum size limits have not been applied to lake trout populations. The slow growth of lake trout makes them vulnerable for a relatively longer period than faster growing species and the large size potentially attained by lake trout attracts many anglers. Although angling opportunities are maintained, the elimination of the chance to harvest large fish (i.e. no trophies) would be expected to be met with considerable public resistance.

The use of modified maximum size limits where harvest of only one fish over the designated size is allowed, is much more common (Olver 1988). This modification provides some protection for mature brood stock, particularly at times of the year when large fish are most vulnerable (e.g. at ice-out). Angling opportunities are maintained, as well as the opportunity to harvest one large fish. Where this type of regulation has been used it has received public support.

SLOT LIMIT

A protected slot limit is a combination of minimum and maximum size limits. All fish within a protected length range or slot must be released. The objective is to protect the prime spawning aged fish while still allowing anglers to harvest the more numerous smaller fish and the less abundant large (trophy) fish. The concept is that by protecting the vulnerable lake trout in the slot, more adults are available for reproduction which should result in an increase in recruitment. Angling opportunities are maintained for small and very large fish. The retention of small fish is legal so that the ones most vulnerable to hooking mortality can be kept. Often, the daily bag limit is designed as three total, two less than slot, one greater than slot. A strong public information effort is required with the implementation of slot limits. Public reaction will be variable depending in part on the width of the protected slot. Smith et al. (1988) recommend this type of regulation be applied only on an experimental basis where good population dynamic data exist.

Few instances of the use of slot limits for lake trout were found in the literature. An experimental slot limit was applied to the lake trout stock in Smoke Lake, Ontario in 1989 (Hicks and Quinn 1990). The slot limit size was designed to protect lake trout during the period when they were first vulnerable (approximately 275 mm FL) until they were mature. In Smoke Lake, most lake trout are mature at 525 mm FL. The protected slot limit was 360 to 510 mm FL. The use of bait herring was also banned to reduce hooking mortality. Although the study is still in progress, preliminary results show a 78.5% (2,791 to 600 rod hrs) drop in angling effort and a drop in harvest from greater than 100 to 16 lake trout. A drastic reduction in angling effort is not uncommon following the implementation of new regulations (Olver 1988). With time, angler effort is expected to increase illustrating the need for a follow up creel and stock assessment program. It is unknown at this time whether the use of a slot limit will result in increases in the abundance of adult lake trout, mean size, and angler success in Smoke Lake.

To be effective, Hicks and Quinn (1990) recommend that the protected slot size range should be centered on the modal size of the length frequency distribution of the current harvest and be extended in both directions until an appropriate reduction in yield is achieved. The upper limit should not be less than the length of lake trout at age of first spawning. In practice the slot limit that they selected was centered about length of 50% maturity.

Slot limits have also been used in an attempt to recreate multiple age spawning stocks. A combination minimum size (203 mm or 8 in TL) and protected slot (305-406 mm FL or 12-16 in TL) limit was used in an attempt to thin the "overabundant" mid-sized brown trout and to protect the relatively more valuable large brown trout in the Au Sable River, Michigan (Clark and Alexander 1984). They found that the slot limit was not as effective as a 305 mm FL (12 in TL) minimum length limit in producing large fish. The reason was that harvest mortality had a more significant effect in reducing survival of trout to older ages and larger sizes than it had on increasing growth rate to large sizes. Few fish reached the 305-406 mm (12-16 in TL) protected slot because they were harvested at 203-305 mm or 8-12 in TL. Harvest of mid-sized trout had little effect on growth rate of brown trout. Also, a significant decrease in annual recruitment of young fish (age 0) occurred.

In the Yukon Territory, Canada, an area wide slot limit has been applied to lake trout populations in some large lakes which have been designated as "high quality" fisheries. In these "high quality waters", the bag limit is two lake trout. The protected length range is from 600 to 910 mm FL (26 - 39 in TL), only one lake trout over 910 mm FL. These are new regulations and there is presently no assessment of effectiveness. This represents an attempt to manage for trophy fish and has been met with a generally positive public response.

APPLICATION OF VARIOUS LENGTH LIMITS

The impact of size limits will vary depending upon prevailing exploitation rates, growth rates, and the structure of the fish community. The observed size structure is formed through the biological processes of recruitment, survival, and growth. A single length limit is unlikely to produce desirable results over a wide range of lake types and fishing pressures. Even within a relatively small geographic area, large differences between lake trout populations may exist so that a uniform length limit may allow excessive harvest in some lakes and under utilization in others.

Assuming that population parameters do not change appreciably after implementation, various authors (Serns 1978, Schneider 1978, Barnhart and Engstrom-Heg 1984) suggest that a minimum size limit may increase yield under one or more of the following conditions:

(1) limited natural reproduction;
(2) good growth;
(3) low natural mortality; and,
(4) high exploitation.

Table 1. Numbers of sets and dates of sampling events for the stock assessment of burbot populations in Fielding, Round and Upper Tangle lakes in 1993.

Lake	Area (ha)	Sampling Dates	Number of Sets
Fielding	538	6/20-26	240
Round Tangle	155	6/16-19	120
Upper Tangle	142	6/18-21	120
TOTAL			480

As might be expected, the higher the existing fishing mortality, the more noticeable any changes in size limits will be.

Conversely, in a lake where there is high natural production, a slot limit which protects medium sized fish may increase the quality of sport fishing. It allows anglers to keep pan sized fish for consumption thereby thinning out extra large year classes, while protecting medium sized fish which may provide greater numbers of large fish for trophy anglers.

Under conditions with limited fishing mortality and slow growth, length limits are not recommended (Schneider 1978). In dense populations the probability of compensatory declines in growth would appear high if size limits were implemented (Kempinger and Carline 1978). The use of length limits is thus best restricted to larger waters where recruitment is limited but stable.

Where older age classes have been lost, it is necessary to recreate a multiple-age spawning stock. In order to accomplish this, reduction in total mortality is required to ensure accumulation of an adequate number of fish in multiple age classes to meet optimum reproductive needs for self sustaining lake trout populations.

APPLICATION TO ALASKAN LAKES

Six Alaskan Lake Trout Populations

Information on the size composition, maturity schedules, and growth characteristics of six Alaskan lake trout populations in the vicinity of Paxson, Alaska is presented (Figures 1 and 2). Length composition is used herein as an approximation of age structure since ages of lake trout are only available for fish that were killed in the course of sampling. It is likely that Alaskan lake trout stocks exhibit balanced sex ratios as is the case elsewhere (Martin and Olver 1980). There is no evidence of differential natural mortality and since there is little sexual dimorphism, one sex is probably as readily caught by anglers as the other. There is considerable variation in the biological characteristics of these six populations in this small geographic area. These differences will affect the way in which various length limits are likely to affect these populations.

Sevenmile Lake is typical of a fast growing, early maturing planktivoruos/benthivorous population inhabiting a small lake (Figures 1 and 2). Limited resources restrict growth beyond approximately 500 mm FL (Burr 1989, 1990, 1991). A high positive correlation exists between lake area and the maximum size attained (L_{inf}) by lake trout (Payne et al. 1990). Characteristics of this stock are more similar to faster growing species than to the longer lived, slower growing piscivorous stocks of lake trout found in larger lakes. Exploitation at this popular site may be responsible for the absence of older lake trout (> age 15). The fast growth rate and early maturity of this stock may be the result of compensation to continuing angling pressure. Voluntary angler returns of tags indicate that most harvest at Sevenmile, Fielding, and Paxson lakes is of lake trout 400 mm and larger (Figure 3).

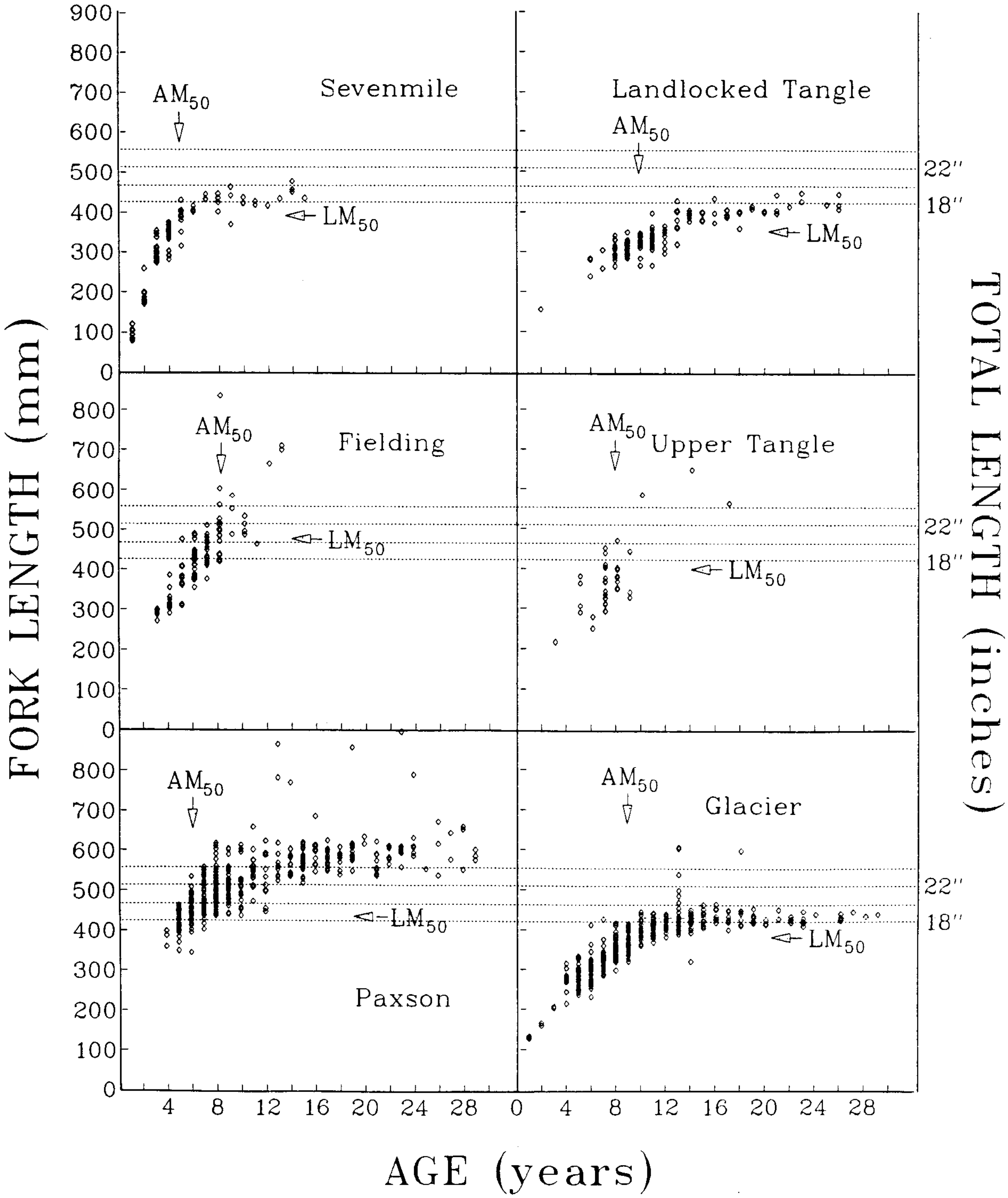

Figure 1. Length and age of lake trout from six populations in Alaska.

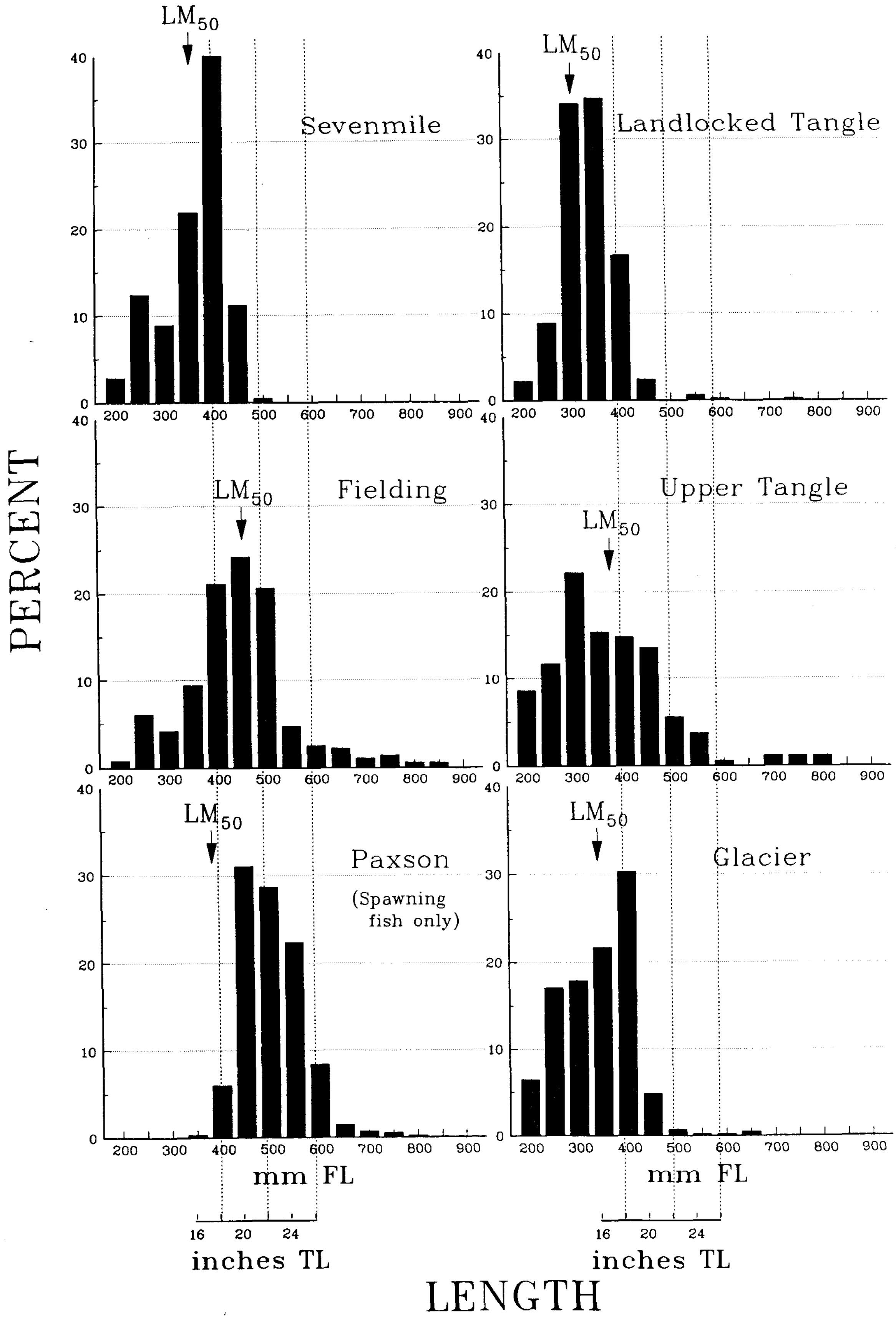

Figure 2. Length distributions of lake trout sampled from six lakes in Alaska (length at 50% maturity is indicated by arrows).

The lake trout population in Landlocked Tangle Lake shows slow growth, and late maturity (the point estimate of AM_{50} for females is age 10)(Burr 1988). Older age classes (> age 15) are well represented in samples (Figure 1). For lake trout, the presence of forage fish is necessary for the attainment of large body size. Round whitefish *Prosopium cylindraceum* are present in Landlocked Tangle Lake and a few large (> 600 mm FL) lake trout are present in the lake. Creel information is very limited but this sparse information indicates that most harvest is of fish 400 to 500 mm FL and harvest of lake trout larger than 600 mm FL is rare.

The lake trout population in Glacier Lake is somewhat similar to the Landlocked Tangle Lake population. Although differences are slight, growth is faster, females mature at an earlier age (the point estimate of AM_{50} is age 9) and lake trout are somewhat larger in Glacier Lake (Burr 1987, 1990, 1991). In addition to round whitefish which are found in Landlocked Tangle Lake, Arctic grayling *Thymallus arcticus* are present. Glacier Lake is connected to the Tangle Lakes system through Rock Creek which passes fish in all but very low water periods. A limited amount of interchange by lake trout between Glacier Lake and the Tangle Lakes system has been reported (Burr 1990). Creel information is limited to casual observations and voluntary angler reports. A few large lake trout have been taken by anglers but most of the catch of lake trout has consisted of fish less than 600 mm FL. Angling effort is considered light to moderate and occurs almost entirely during the open water season.

Growth of lake trout in Upper Tangle Lake is faster and maturity appears to be earlier (the point estimate of AM_{50} is age 8) than other populations which have been studied in the Tangle Lake system (Burr 1989). Population density is very low (Table 1) and, during the open water period, angling effort is high. The low density of adult lake trout combined with the earlier maturity schedule and faster growth indicates a compensatory response to heavy exploitation. However, the substantial proportion of older, larger lake trout (Figure 2) argues against the level of exploitation suggested by the extremely low population density. We have no reports of lake trout larger than 600 mm FL being harvested from this lake.

Lake trout in Paxson Lake demonstrate fast growth, early maturity (the AM_{50} for females is age 6) and substantial numbers of fish in older age classes (> age 15)(Burr 1988 through 1991). Length information included in Figure 2 is for spawning fish only and is therefore not directly comparable with data from the other lakes. An abundant forage base including round whitefish, humpback whitefish *Coregonus pidschian*, Arctic grayling, rainbow trout *Oncorhynchus mykiss* and sockeye salmon *Oncorhynchus nerka* is present. The food supply has increased over the past decade through enhancement of the sockeye salmon stock. This increase in forage base, combined with continuing exploitation, has apparently resulted in a shift downward in the age of maturity (Burr 1990). The characteristics of the lake trout stock in Paxson Lake is representative of a piscivorous stock. Harvest remains high on this very accessible stock and numerous large lake trout are taken annually (Table 1 and Figure 3).

Table 1. Estimated abundance of mature lake trout and harvest from lakes in central Alaska.

Lake (Area)	Estimated Abundance	Estimated Density (fish/ha)	Average Annual Harvest Before[a]	Average Annual Harvest After[a]
Sevenmile (33 ha)	1,055[b] (SE = 138)	31.9 (SE = 4.2)[c]	Unknown	
Fielding (538 ha)	Unknown		265	243
Paxson (1,575 ha)	5,066[b] (SE = 318)	3.2 (SE = 0.2)[c]	1,284	1,441
Landlocked Tangle (241 ha)	1,645[d] (SE = 359)	6.8 (SE = 1.5)	Combined Tangle Lakes 989	Combined Tangle Lakes 303
Upper Tangle (150 ha)	96[e] (SE = 17)	0.6 (SE = 0.1)		
Round Tangle (169 ha)	Unknown			
Shallow Tangle (130 ha)	Unknown			
Lower Tangle (130 ha)	Unknown			
Glacier (177 ha)	1,474[b] (SE = 324)	8.3 (SE = 1.8)[c]	Unknown	

[a] Before and after the imposition of a 18 inch TL (420 mm FL) length limit restriction in 1987 (Mills 1978-1990).
[b] From Burr (1991) for the 1989 period.
[c] SE(Density) = SE(Abundance)/area.
[d] From Burr 1988 for the 1987 period.
[e] From Burr 1989 for the 1988 period.

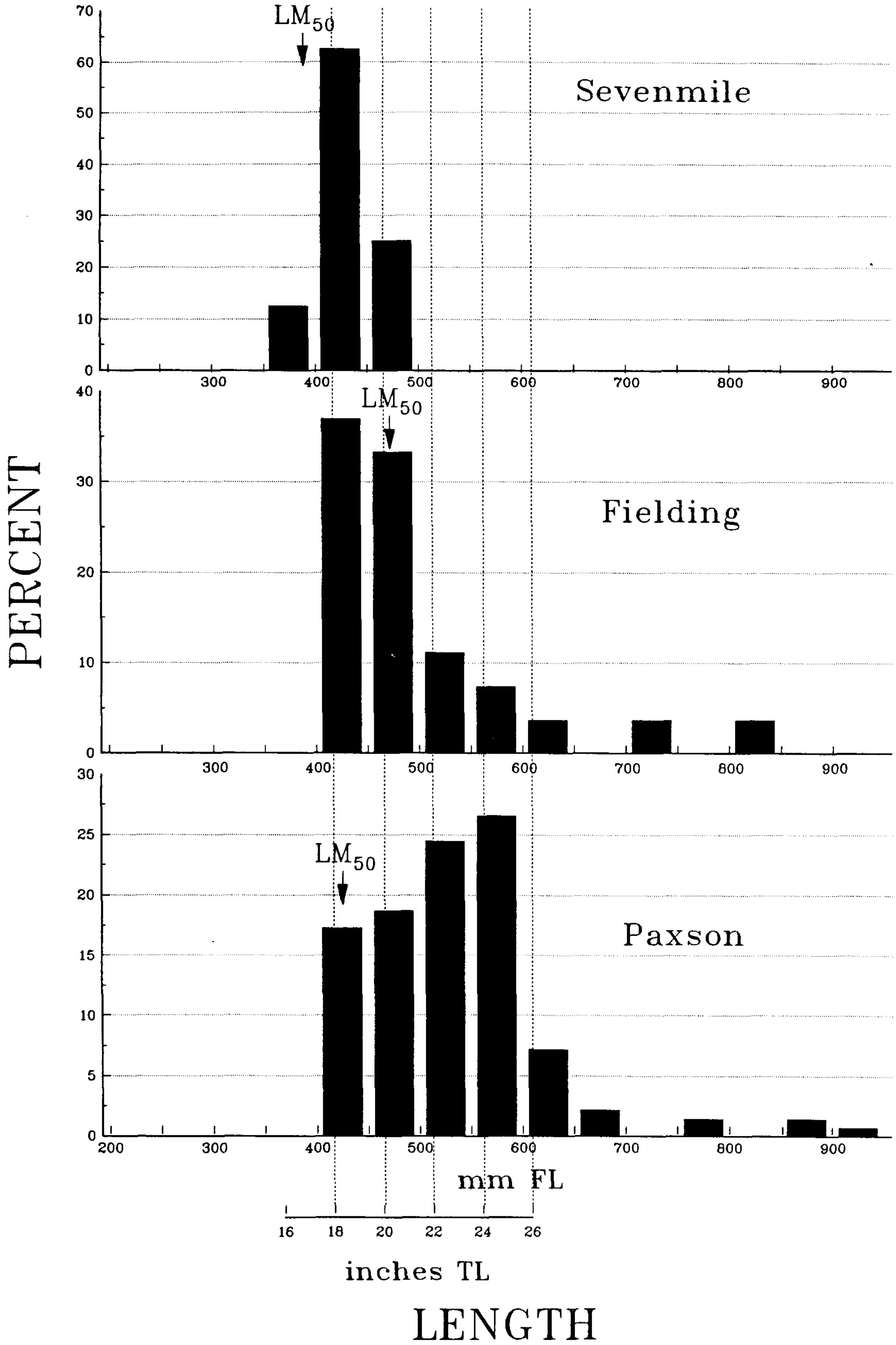

Figure 3. Length distributions of lake trout harvested by anglers at Sevenmile, Fielding and Paxson lakes (length at 50% maturity is indicated by arrows).

Table 2. Maturity schedules for females from selected lake trout populations[a]. Length is given in mm FL and inches TL.

Lake	Maturity[b] 5%	50%	95%
Sevenmile			
Length (mm FL)	363 (15.6")	391 (16.8)	420 (18")
Age (years)	5	5	6
Fielding			
Length (mm FL)	428 (18.4")	481 (20.6")	540 (23.2")
Age (years)	6	8	10
Paxson			
Length (mm FL)	388 (16.6")	426 (18.3")	467 (20")
Age (years)	5	6	8
Lower Tangle			
Length (mm FL)	281 (12")	348 (14.9")	431 (18.5")
Age (years)	7	10	15
Upper Tangle			
Length (mm FL)		400 (17.2")	
Age (years)	5	8	12
Glacier			
Length (mm FL)	328 (14.8")	376 (16.1")	432 (18.5")
Age (years)	7	9	12

[a] From Burr *In prep*; length is given in mm FL and inches TL.
[b] Percent maturity was estimated with probit analysis.

Growth rate and size composition of lake trout in Fielding Lake is similar to Paxson Lake. However, the age of maturity is higher (the AM_{50} of females is age 8) and older age classes appear to be absent (Burr 1990, 1991). Large fish for which age data are available are relatively young. Test netting results indicate that the lake trout population is sparse. Forage fish present are round whitefish and Arctic grayling. Voluntary creel information shows that while most lake trout harvested are less than 500 mm FL, a substantial portion are larger (Figure 3).

Utility of Present Length Limits to Six Alaskan Lake Trout Fisheries

A minimum length limit of 18 inches TL (420 mm FL) has been applied to the Tangle Lakes system, Fielding Lake and Paxson Lake. No length limit has been applied to Sevenmile or Glacier lakes. Since the goal of these minimum length limits is to allow fish to spawn at least once before exploitation, the size limit should be equal to or greater than the length at which 50% of the females in the population spawn (LM_{50}). LM_{50} for females was selected for determining the minimum size limit because females mature at larger size than males (Burr *In prep*, Burr 1988, 1989, 1990) In addition, protection for at least two years of spawning is provided for a portion of these populations except for Paxson Lake. The age classes represented by fish between the length at first maturity and 50% maturity are more than two (Table 2).

Because of the small size of Sevenmile Lake, and the high density and small size of lake trout in the population, the use of a size limit may be counter productive. Nearly all of the lake trout in this population are within the size range which has been found to be most susceptible to hooking mortality. Imposition of a minimum size limit above the LM_{50} would result in a substantial portion of lake trout being unavailable to the angler (Figure 1). A minimum length limit at Sevenmile Lake is most likely to result in further stunting or "stockpiling" with the associated negative effects. A slot limit centered around the LM_{50} (e.g. 15 to 18 in TL; Table 2) would probably be ineffective. As in the example from Michigan with brown trout, the harvest would likely shift to fish below the protected slot. Few fish would be likely to reach the protected range as they would be harvested at less than 15 inches TL (350 mm FL). Due to the lake area effect on L_{inf} (see page 11), a length limit is not likely to result in larger fish. Based on these arguments, I recommend that no length limit be applied to the lake trout population in Sevenmile Lake.

The 18 inch TL minimum size limit applied to Fielding Lake is unlikely to be effective at either protecting the spawning stock or at producing a greater proportion of large fish. The LM_{50} for females is nearly 3 inches larger than the current length limit (Table 2, Figure 2) and provides little protection for juvenile fish which are vulnerable to anglers. A minimum limit of 22 inches TL (511 mm FL) would be more appropriate. This would allow for two or more years of spawning prior to exploitation. No reduction in harvest has been seen under the current regulation (Table 1). A change to 22 inches TL minimum length should result in a marked reduction in harvest although all legal fishing mortality would be on larger fish. To limit the kill of trophy sized fish, a limit of only one fish larger than 700 mm FL (30 in TL) could be considered in combination with the minimum limit. However, since very few anglers catch more than one fish of this size, the effect of the regulation would likely be negligible.

An alternative approach for Fielding Lake would be to use a protected slot limit centered around LM_{50} (eg. 16-24 in TL, 370-560 mm FL). This could be combined with a maximum limit of only one fish above the protected slot. The effect would be to protect most of the spawning stock since this would span the length of first through complete maturity (Table 2). It would allow harvest of pan-sized lake trout which are most vulnerable to hooking mortality and are desired by some anglers (Baker 1988). Anglers desiring to keep a large trophy fish could do so. However since the density of lake trout in Fielding Lake appears to be low and recruitment is unknown, harvest of sub-adult lake trout would not seem prudent.

For stable recruitment, multiple age spawning is needed for lake trout stocks (Martin and Olver 1980). Although large lake trout are present in Fielding Lake, few are older than age 15. With an estimated AM_{50} of 8 years, reproduction is limited to a relatively few age classes which appear to be low in numbers. This population is likely to be very vulnerable to increases in angler effort. With the addition of the new boat launch and better access to the lake, steps should be taken to reduce harvest since effort will likely increase. A change in the minimum length limit from 18 to 22 inches is recommended.

Nearly the same arguments apply to the regulation of harvest of lake trout in Paxson Lake except that the conditions are not as severe. In Paxson Lake the maturity schedule is more knifed edged and the difference between the current minimum length limit and length of 50% maturity is not as great. However the limit is only at best marginally effective. Estimated harvest before and after the imposition of the length limit has not changed (Table 1). Increasing the limit to 20 inches TL (465 mm FL) would effectively protect all of the fish spawning for the first time (Table 2). A 22 inch TL (511 mm FL) limit would be more effective at permitting females to spawn at least twice and would be more likely to reduce harvest (Figure 3). To limit the kill of trophy sized fish, a limit of only one fish larger than 30 in TL (700 mm FL) could be considered. Since more large lake trout are caught in Paxson Lake, the regulation could be effective.

Because of the higher density of lake trout in Paxson Lake, the abundant forage base and probable good natural production, a protected slot limit could be effective at protecting the spawning stock and perhaps increasing the number of large fish. Such a strategy would be most effective if combined with a modified maximum limit of one fish larger than the slot. The slot should be centered around the LM_{50} and extend to cover at least lengths from first to complete maturity (Table 2). My recommendation is to implement a protected slot limit for the lake trout population in Paxson Lake. The suggested regulation is a bag limit of two lake trout with only one larger than a protected slot range from 16 to 24 inches. Angling effort is likely high enough to anticipate a measurable change in the structure of the population.

For the Tangle Lakes the current size limit is well above the LM_{50} for females (Table 2, Figure 1) and should be effective at protecting juveniles and first time spawning fish. In the samples from the Tangle Lakes, older age classes are well represented. The current bag limit of one fish is likely to prevent overharvest of the existing adult population and the length limit should increase the number of juveniles reaching maturity and the abundance of older and hopefully larger trout. The greater number of adults should increase recruitment assuming a stock/recruit relationship exists. Because of their small size and elevation, the Tangle lakes are unlikely to ever produce an abundant population of large fish. Because of the characteristics of these lakes, a protected slot limit would not seem appropriate. The good access and the popularity of this lake and stream system make it unlikely that more a liberal bag limit will ever be consistent with sustained yield management. It will be necessary to continue assessment of these stocks for at least one generation (10 years) to assess the effectiveness of the length limit. Based on these arguments, I recommend a continuation of the current regulation of one lake trout, 18 inches minimum length.

Glacier Lake is connected to the Tangle lakes system and the characteristics of the population are similar to populations in the Tangle Lakes for which we have information. Currently no size limit is in effect for this population. For a lake trout population with slow growth and limited fishing mortality, a length limit would typically not be recommended. However, because this lake is perceived by many anglers to be one of the Tangle Lakes, including it and Landmark Gap Lake in the 18 inch TL minimum length regulation would reduce confusion. At this time angling effort and fishing mortality are not high enough to make the length limit very effective, on the other hand, it is not likely to negatively affect these lake trout populations. Based on these arguments, I recommend that the 18 inch minimum size limit be extended to include Landmark Gap Lake and Glacier Lake. The bag limit of two lake trout per day should be maintained to possibly draw anglers away from the roadside lakes.

Application to Other Alaskan Lake Trout Populations

Population specific data for every lake trout population in Alaska will never be available. Managing lakes on a case by case basis while biologically appealing is not administratively feasible. In addition, a fragmented array of local regulations generated in response to overharvest problems serves only to alienate and confuse the angling public. Given the paucity of population specific information, this section represents an attempt to provide a rational approach to application of length limits to wild lake trout populations in Alaska. I begin with a brief summary of the general characteristics of lake trout populations and the utility of length limits. This is followed by an examination of three approaches for applying length limits.

General characteristics of lake trout populations have been well documented (Martin and Olver 1980, Healey 1978, Payne et al. 1990, Carl et al. 1990 and others). Particularly important to the consideration of length limits is the effect of lake area on lake trout populations. The maximum size attained by lake trout is highly correlated with lake area (Payne et al. 1990). Small lake trout lakes (100 ha and less) tend to be characterized by dense populations of small, planktivorous/benthivorous lake trout, which mature earlier and are recruited to a fishery at a smaller size and younger age than in larger lakes. The age at which these stocks are first vulnerable to fishermen is similar to the age at first maturity. With increasing lake size there is in general an increase in the number of predators and competitors, larger prey size, increasing degree of piscivory, larger maximum size and size at maturity, and lower lake trout biomass. In piscivorous lake trout stocks which are generally found in larger lakes, age of first vulnerability precedes first maturity by some years (Olver et al. 1991).

The use of minimum and protected slot limits which are designed to protect the brood stock makes sense in large piscivorous stocks, in which the age to maturity is considerably greater than the age of vulnerability to a fishery. Piscivorous stocks also tend to be less abundant per-unit-area than planktivorous stocks and a size limit to ensure that lake trout would spawn at least once before exploitation is an appropriate management action. However, there may be little need to impose any type of size limit on planktivorous/benthivorous lake trout stocks, which attain a small maximum size in small lakes, and in which the age of recruitment to a fishery approximates the age of first maturity, thereby allowing substantial spawning escapement. In large lakes where lake trout have considerable growth potential, a modified maximum size limit may be used to manage for a "trophy" fishery.

Change Nothing Approach:

The current approach for lake trout management in most of Alaska uses length limits only in high-use, road-side fisheries. In concert, bag limits are in general more liberal in remote areas (e.g. Brooks Range and western Alaskan lakes) than in more densely populated (by humans) parts of the state. This is an attempt to spread out fishing effort. In the Tanana River area, the daily bag limit is two compared with a daily bag limit of four in northern and western Alaska. The current daily bag limit of 12 lake trout (two, 20 inches or more, 10 less than 20 inches) in effect for the Kenai Peninsula and the Susitna-West Cook Inlet Areas are considered excessive by guidelines for even the most productive of lake trout populations in southern Canada and the lower 48 States (Olver et al. 1991).

There are arguments for and against maintaining status quo. In northern and western Alaska, current fishing effort is relatively low such that present bag limits are likely sufficient. The more liberal regulation in remote areas may attract anglers away from high use road side areas resulting in wider distribution of fishing effort. With no minimum length limit, small lake trout which have been shown to be most susceptible to hooking mortality may be legally retained. In general, the angling public is familiar with present regulations so little educational effort would be required. Arguing against maintaining the current regulatory regime is the probable loss of old large fish. Many of the lake trout lakes in the Alaska and Brooks Mountain Ranges are large in size and contain piscivorous populations which are capable of large maximum size. With increasing effort, current bag limits without length limits will not prevent the continuing loss of large trophy sized lake trout.

Uniform Conservative Approach:

An alternative approach would be to adopt a minimum length limit of 22 inches TL through out a large area such as all of the Arctic Yukon Kuskokwim (AYK) management area. Such an approach is appealing in its ease of administration. The positive results seen in the lake trout population in Raquette Lake might encourage this tact. A minimum of 22 inches TL (512 mm FL) is certain to provide protection to spawning lake trout for most if not all populations. LM_{50} for females estimated for 11 lake trout populations from both small and large lakes in central and northern Alaska ranged from 348 mm FL to 476 mm FL (Burr *In prep.*). However, because of the variability in growth rates and other population characteristics between lakes, size limits should ideally be determined for individual lakes or for sets of similar lakes. Except in high use areas, a minimum length limit is likely to have negligible effects on the populations. Conversely, in high use areas, minimum size limits have the potential to further stunt populations residing in small lakes, thereby actually reducing the potential yield in kilograms of lake trout. This minimum length limit requires the release of lake trout of the size range which is most vulnerable to hooking mortality. We would disenfranchise anglers desiring to keep pan-sized fish from piscivorous populations and would make nearly all planktivorous/benthivorous lake trout residing in small lakes unavailable for harvest. Finally a blanket conservative length limit could result in our loss of credibility to anglers by further restricting harvest without being able to provide a solid rational for doing so.

Experimental Management Approach:

The fact is that we do not know what effect the various length limit and regulatory options will have on the various Alaskan lake trout populations. Further, we do not presently have a program in place which will detect changes in the length composition of the populations for which we have imposed length limits. To acquire new fisheries knowledge, an experimental management approach has been adopted by various resource agencies (Mansell et al. 1978). The concept is to deliberately induce a major change in a fish stock or pattern of use accompanied by vigorous monitoring of the results. To be successful, the experiment must be related to an explicit hypothesis chosen on the basis of management needs. Changes must be major enough to be detected and must be made in carefully controlled conditions and done where we have assessment capability to measure and document the results. Finally, the results or knowledge gained from the experiment must be applicable to other populations with similar characteristics.

To apply the concept of experimental management to the effects of length limits, fishing effort must be sufficiently high so that a significant change in the size/age structure of the stock can be expected. In addition, due to the long generation time that is characteristic of lake trout populations, sufficient time must be allowed to detect changes which occur.

A number of opportunities for the application of the experimental management approach are presently available. In 1987, following a short complete closure of the lake trout fishery in the Tangle lakes, a very restrictive regulation was adopted (one lake trout per day, 18 inch minimum size). A change in the bag limit from 12 lake trout per day to one along with the size restriction is clearly a major change and because effort at the Tangle lakes is high, changes in the size composition should become apparent. In theory, lake trout less than the length limit should become proportionally more abundant and ultimately recruitment should increase as more lake trout are allowed to spawn. It should be possible to test the hypothesis that use of an appropriate minimum size limit will result in increased recruitment and density of lake trout.

A change in the minimum length limit from 18 to 22 inches has been recommended for lake trout in Fielding Lake. Such a change presents an excellent opportunity to measure changes in the size composition of this population. The size of Fielding Lake, the fish species composition and the characteristics of the lake trout population are similar to numerous lake trout lakes in more remote areas of the Alaska and Brooks mountain ranges. The major difference is in the level of fishing effort which is much higher at Fielding Lake. Information gained from this population should be applicable to other lakes containing populations of large piscivorous lake trout.

The adoption of a protected slot limit as recommended for lake trout in Paxson Lake would provide an opportunity to test the effect of this type of length limit. The number of large lake trout is expected to increase under this management regime, and if successful, is likely to be well received by the angling public. Although few lakes in Alaska are likely to have the productive potential of Paxson Lake, numerous lakes in the Upper Copper, Upper Susitna management area which contain lake trout have enhanced populations of sockeye salmon and similar fish species composition. Hence data gathered at Paxson Lake should have broad application. The level of fishing effort at Paxson Lake should be sufficient to expect changes in the lake trout stock. The assessment program in place at Paxson Lake should be capable of detecting changes in the size/age composition of the mature portion of the stock.

I have outlined three examples where the adaptive management approach can be used to assess the effects of various length limit regulations in various types of situations. In each case the size limit suggested is as appropriate for the existing conditions as can be gleaned from the literature. It is important to reemphasize that once the experiment is started, the regulatory regime must be left in place for a sufficient amount of time to permit changes to be detected. Short term fluctuations may well mask long term trends. A long term commitment is required and an agency such as the ADFG is well suited to carry out such long term data collection, analysis, and evaluation.

Recommendations:

1. Continue the use of bag limits without minimum length limits in remote areas to regulate harvest of lake trout. Although outside the topic of this paper, the 12 fish per day bag limit in place in some areas of Alaska is very likely excessive and should be changed to four or less.

2. Institute the use of an area wide modified maximum size limit such that only one lake trout larger than 26 inches (TL) could be legally

retained. This would help to maintain the presence of large trophy sized fish where they exist but would not affect anglers fishing smaller planktivorous/bethivorous lake trout stocks.

3. Utilize the experimental management concept to assess the effects of various length limits in the three lake sets outlined above.

4. Initiate spring index netting on lakes where minimum length limits have been adopted to detect changes in size composition. Spring index netting is the most cost effective method presently known for obtaining the least biased estimate of size composition in lake trout populations (Lester et al. 1990).

SUMMARY/CONCLUSIONS

Selection of a minimum size limit should be based on the biological characteristics of the stock and the goals of the manager. Minimum length limits are likely to increase yield where recruitment is limited but will focus harvest on larger and hence older age classes. Slot limits are appropriate where recruitment is good and may improve the quality of the fishery. The results from the lake trout population at Raquette Lake clearly show that the negative impact of overfishing on spawning stocks and recruitment can be reversed through use of size limits. Where effort is high and/or the catch of large fish is high, a modified maximum limit which permits the harvest of only one large fish may be appropriate. The impact of restrictive regulations on increasing the maximum size (L_{inf}) attained by fish populations has been disappointing. The size of lake trout is largely determined by the amount and quality of the habitat and is positively correlated with lake area (Payne et al. 1990, Evans et al. 1991). In other words where large fish are present they can be maintained through regulations such as length limits but they are unlikely to occur in small, unproductive water-bodies. The approach of experimental fisheries management can and should be applied to assessing the effects of various length limits on Alaskan lake trout populations.

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Table 29. Estimated sport fishery harvests of coho salmon at Birch Lake, 1977-1989.

Part I. Estimated contributions of coho salmon to the annual creels of Birch Lake by stocking cohort.

Total Annual Harvest		Estimated Contribution to Harvest by Stocking Cohort (Year and Size: F = fingerlings & S = subcatchables)					
Year	No. Fish[a]	Age 1 Cohort	No. of Fish	Age 2 Cohort	No. of Fish	Age 3 Cohort	No. of Fish
1977	5,687	1976 F	4,463[b]	1975 F	685[c]	1974 F	133[d]
						1975 S	406[d]
1978	6,354			1976 F	6,126[b]	1975 F	228[d]
1979	132					1976 F	132[e]
1980	0						
1981	2,549	1980 F	2,549[e]				
1982	6,275	1981 F	5,000[b]	1980 F	1,275[c]		
1983	8,686			1981 F	8,261[b]	1980 F	425[c]
1984	6,049					1981 F	6,049[e]
1985	4,672	1984 F	4,672[e]				
1986	4,950	1985 F	2,614[b]	1984 F	2,336[c]		
1987	6,719	1986 F	4,633[b]	1985 F	1,307[c]	1984 F	779[c]
1988	5,548	1987 F	2,796[b]	1986 F	2,316[c]	1985 F	436[c]
1989	4,982	1988 F	2,812[b]	1987 F	1,398[c]	1986 F	772[c]

[a] Data source of annual harvests is Mills 1978-90.

[b] These estimates are the result of the subtraction of the age 2, age 3, or age 2 and 3 combined portion of the annual harvest (obtained as described in footnotes c and d below) from the total harvest that took place in the given year.

[c] These estimates are based upon the assumption that 60% of the harvest from a cohort are harvested at age 1, 30% are harvested at age 2, and 10 % are harvested at age 3.

[d] These estimates are based upon one and/or two assumptions: (a) the ratio of the survival rates of fingerling and subcatchable sized coho salmon to catchable size is similiar to that of rainbow trout in Birch Lake (mean survival of fingerlings = 1.6%, subcatchables = 46 %, and ratio = 30:1); (b) the contribution of age 3 coho salmon to the harvests in 1977 through 1979 are proportional to the number of fingerlings stocked three years earlier.

[e] Only a single age class contributed to the harvest in these years.

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Table 29. (Page 2 of 2).

Part II. Estimated total sport harvests of stocked cohorts of coho salmon from Birch Lake.

Stocking Cohort (Year, Cohort [F=fingerling & S=subcatchable], & No. Stocked)			Year Harvested-Estimated Number of Age 1 Fish	Year Harvested-Estimated Number of Age 2 Fish	Year Harvested-Estimated Number of Age 3 Fish	Total Harvest of Cohort	Percent of Cohort Harvested
1974	F	55,700	1975-unknown	1976-unknown	1977- 133	133+	-
1975	F	95,000	1976-unknown	1977- 685	1978- 228	913+	-
1975	S	5,907	1975-unknown	1976-unknown	1977- 406	406+	-
1976	F	54,900	1977-1,094	1978-5,214	1979- 132	6,440	11.7
1980	F	59,850	1981-2,549	1982-1,275	1983- 425	4,249	7.1
1981	F	30,000	1982-5,000	1983-8,261	1984-6,049	19,310	64.4
1984	F	50,000	1985-4,672	1986-2,336	1987- 779	7,787	15.6
1985	F	55,539	1986-2,614	1987-1,307	1988- 436	4,357	7.8
1986	F	40,000	1987-4,633	1988-2,316	1989- 772	7,721	19.3
1987	F	40,000	1988-2,796	1989-1,398	1990-unknown	4,194[a]	10.5[a]
1988	F	40,000	1989-2,812	1990-unknown	1991-unknown	2,812[b]	-
1989	F	40,000	1990-unknown	1991-unknown	1992-unknown	unknown	-

[a] Minimum estimate because 1 year of harvest statistics is not included in the estimate.

[b] Minimum estimate because 2 years of harvest statistics is not included in the estimate.

Table 30. Estimated sport fishery harvests of stocked fingerling coho salmon at Chena Lake, 1984-89.

Part I. Estimated contributions of coho salmon to the annual creels by stocking cohort.

Total Annual Harvest		Estimated Contribution to Harvest by Stocking Year Cohort					
Year	No. Fish[a]	Age 1 Cohort	No. of Fish	Age 2 Cohort	No. of Fish	Age 3 Cohort	No. of Fish
1984	5,036	1983	0[b]	1982	5,036	1981	0[b]
1985	9,485	1984	7,806[c]	1983	0[b]	1982	1,679[d]
1986	1,778	1985	1,440[d]	1984	338[ce]	1983	0[b]
1987	1,398	1986	678[c]	1985	720[d]	1984	0[e]
1988	2,401	1987	1,441[d]	1986	720[d]	1985	240[d]
1989	2,468	1988	1,508[c]	1987	720[d]	1986	240[d]

[a] Data source of annual harvests is Mills 1985-90.

[b] Coho salmon of this cohort were not stocked.

[c] These estimates are the result of the subtraction of the age 2, the age 3, or the age 2 and 3 combined portion of the annual harvest (obtained as described in footnote d below) from the total harvest that took place in the given year to provide an estimate of the harvest of age 1 fish; or, are the result of the subtraction of the age 1 portion of the annual harvest (obtained as described in footnote d below) from the total harvest that took place in the given year to provide an estimate of the harvest of age 2 fish.

[d] These estimates are based upon the assumption that 60% of the harvest from a cohort are harvested at age 1, 30% are harvested at age 2, and 10 % are harvested at age 3.

[e] The 1984 stocked cohort of coho salmon was heavily exploited as age 1 fish in 1985; it is assumed that few were left to harvest as age two fish in 1986 and that none were left to harvest in 1987 as age three fish.

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Table 30. (Page 2 of 2).

Part II. Estimated total sport harvests of stocked cohorts of coho salmon from Chena Lake.

Year and Number of Fish Stocked in Cohort		Year Harvested-Estimated Number of Age 1 Fish	Year Harvested-Estimated Number of Age 2 Fish	Year Harvested-Estimated Number of Age 3 Fish	Total Harvest of Cohort	Percent of Cohort Harvested
1982	27,607	1983- 0	1984-5,036	1985-1,679	6,715	24.3
1984	30,000	1985-7,806	1986- 338	1987- 0	8,144	27.1
1985	30,000	1986-1,440	1987- 720	1988- 240	2,400	8.0
1986	30,000	1987- 678	1988- 720	1989- 240	1,638	5.5
1987	30,000	1988-1,441	1989- 720	1990-unknown	2,161[a]	7.2[a]
1988	47,885	1989-1,508	1990-unknown	1991-unknown	1,508[b]	-
1989	15,000	1990-unknown	1991-unknown	1992-unknown	unknown	-

[a] Minimum estimate because 1 year of harvest statistics is not included in the estimate.

[b] Minimum estimate because 2 years of harvest statistics is not included in the estimate.

Table 31. Estimated sport fishery harvests of stocked fingerling coho salmon at Quartz Lake, 1977-89.

Part I. Estimated contributions of coho salmon to the annual creels by stocking cohort.

Total Annual Harvest		Estimated Contribution to Harvest by Stocking Year Cohort					
Year	No. Fish[a]	Age 1 Cohort	No. of Fish	Age 2 Cohort	No. of Fish	Age 3 Cohort	No. of Fish
1977	0	1976	0	1975	0	1974	0
1978	14,892	1977	14,892	1976	0	1975	0
1979	34,787	1978	27,341[b]	1977	7,446[c]	1976	0
1980	23,316	1979	7,164[b]	1978	13,670[c]	1977	2,482[c]
1981	50,965	1980	0	1979	46,408[b]	1978	4,557[c]
1982	35,380	1981	19,911[b]	1980	0	1979	15,469[c]
1983	24,042	1982	0	1981	24,042	1980	0
1984	17,069	1983	9,055[b]	1982	0	1981	8,014[c]
1985	26,312	1984	21,784[b]	1983	4,528[c]	1982	0
1986	16,613	1985	4,212[b]	1984	10,892[c]	1983	1,509[c]
1987	15,449	1986	9,712[b]	1985	2,106[c]	1984	3,631[c]
1988	19,009	1987	13,451[b]	1986	4,856[c]	1985	702[c]
1989	9,593	1988	1,249[b]	1987	6,725[c]	1986	1,619[c]

[a] Data source of annual harvests is Mills 1979-90.

[b] These estimates are the result of the subtraction of the age 2, the age 3, or the age 2 and 3 combined portion of the annual harvest (obtained as described in footnote c below) from the total harvest that took place in the given year to provide an estimate of the harvest of age 1 fish; or, are the result of the subtraction of the age 3 portion of the annual harvest (obtained as described in footnote c below) from the total harvest that took place in the given year to provide an estimate of the harvest of age 2 fish.

[c] These estimates are based upon the assumption that 60% of the harvest from a cohort are harvested at age 1, 30% are harvested at age 2, and 10 % are harvested at age 3.

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Table 31. (Page 2 of 2).

Part II. Estimated total sport harvests of stocked cohorts of coho salmon from Quartz Lake.

Year and Number of Fish Stocked in Cohort		Year Harvested-Estimated Number of Age 1 Fish	Year Harvested-Estimated Number of Age 2 Fish	Year Harvested-Estimated Number of Age 3 Fish	Total Harvest of Cohort	Percent of Cohort Harvested
1977	197,400	1978-14,892	1979- 7,446	1980- 2,482	24,820	12.6
1978	55,549	1979-27,341	1980-13,670	1981- 4,557	45,568	82.0
1979	150,095	1980- 7,164	1981-46,408	1982-15,469	69,041	46.0
1981	150,114	1982-19,911	1983-24,042	1984- 8,014	51,967	34.6
1983	46,543	1984- 9,055	1985- 4,528	1986- 1,509	15,092	32.4
1984	155,718	1985-21,784	1986-10,892	1987- 3,631	36,307	23.3
1985	149,976	1986- 4,212	1987- 2,106	1988- 702	7,020	4.7
1986	168,500	1987- 9,712	1988- 4,856	1989- 1,619	16,187	9.6
1987	168,489	1988-13,451	1989- 6,725	1990-unknown	20,176[a]	12.0[a]
1988	150,000	1989- 1,249	1990-unknown	1991-unknown	1,249[b]	-
1989	150,000	1990-unknown	1991-unknown	1992-unknown	unknown	-

[a] Minimum estimate because 1 year of harvest statistics is not included in the estimate.

[b] Minimum estimate because 2 years of harvest statistics is not included in the estimate.

DISCUSSION

Birch, Chena, and Quartz lakes continue to play a major role in providing recreational sport fishing opportunity in the Tanana Valley. In 1989, 26% of all of the angler effort (days fished) and 39% of the sport fish harvest was provided by these three lakes (Mills 1990). Improvements in hatchery methodology and quality of fish should make greater numbers of fish available to anglers in the future.

Birch Lake has received much of the attention in the regional enhancement evaluation program over the past ten years. Swanson strain subcatchable rainbow trout stocked at a mean weight of about 25 g in 1980 and 1981 grew to catchable size by late summer and began entering the sport fishery. Harvest of these cohorts continued at a high rate through the winter and following early summer. The discontinuance of subcatchable rainbow trout stockings and the beginning of an apparently less expensive fingerling rainbow trout stocking program in 1982 resulted in a decline of the rainbow trout sport harvest. Harvest in 1986 was at only about one third the 1981 level. Harvest had rebounded by 1988 after stockings of subcatchable rainbow trout were resumed.

The low survival rates of rainbow trout fingerlings stocked in mid to late summer and of subcatchables stocked under the ice points out the failure of stocking rainbow trout prior to breakup in Birch Lake. During spring in years when heavy snow-pack and/or a late, rapid breakup produced high flows at the outlet of the lake, large numbers of fingerling rainbow trout that had been stocked the previous fall were seen attempting to move down the outlet. Many of them were not strong enough to swim against the current and died when they were forced against the screens of the outlet structure. Nothing was done about this, since the ADFG attempts to maintain high flows at the outlet in order to maintain lake level below the high water mark. Conversely, during the early 1980's when subcatchable rainbow trout were stocked after breakup, the trout that were moving into the outlet in the spring were older fish, strong enough to avoid being pushed onto the screens. Few mortalities were observed and those fish had already contributed to at least one fall and winter sport fishery. The importance of stocking subcatchable rainbow trout after peak spring flows became very apparent in 1989, when the entire complement of subcatchable rainbow trout for the year were stocked under the ice in late winter. In May, 1989, it appeared that a large number of recently stocked subcatchable rainbow trout died in the weir at the outlet, and in the fall the survival rate of that cohort was only 28.3%, far short of the 50% range that was expected based on results of previous studies. It may also help to explain the lower (40%) survival of the subcatchables stocked under the ice in March, 1988, a year of mild spring flows at the outlet. Survival to fall of the subcatchable rainbow trout stocked after breakup in June, 1990, to 52%. The practice of waiting until early summer to stock the fish will likely contribute to a higher survival of stocked fish to catchable size. However, a cost analysis will be needed to determine the stocking practice that will be most effective at maintaining the Birch Lake fishery. Coho salmon compliment rainbow trout and provide about 5,000 fish per year to the sport harvest at Birch Lake. Coho salmon growth rates may decline if the rainbow trout population increases in abundance due to interspecific competition for food.

The increased harvest of rainbow trout in Chena Lake in 1988 and 1989 is most likely the result of the stocking of rainbow trout at or near the requested 100 g size and at the full compliment of 30,000 fish. Observations indicate that the lake is "maturing" and becoming more productive than the sterile gravel pit described by Hallberg (1985). Beavers have colonized portions of the lake, and aquatic vegetation is becoming established. However, it is unlikely that this 105 ha lake could support the high use fishery that it is presently producing (16,180 angler-days and a harvest of 11,968 rainbow trout in 1989) based on stockings of smaller rainbow trout. The reduction of stocking density for coho salmon that was instituted in 1989 may increase the size of the coho salmon available for harvest, making them more desirable to anglers and increasing the harvest rate.

Rainbow trout harvest is increasing in Quartz Lake. The dramatic increase in harvest in 1988 and 1989 is reflected in the total abundance estimates. The fishery is being improved by stocking subcatchable rainbow trout and the continued fingerling stocking program. Subcatchable rainbow trout stocked into Quartz Lake have to date exhibited lower survival to fall than those stocked into Birch Lake. The reason for this is not clear, and there have not been enough cohorts of subcatchable rainbow trout stocked into Quartz Lake in a consistent pattern to determine if this lower survival rate will be a consistent trend. The impact of angler pressure upon a cohort of subcatchable rainbow trout prior to the October survival estimate has not been assessed. Changes in stocking practices may produce differing rainbow trout survival to catchable size rates and subsequent harvest.

Both fingerling and subcatchable rainbow trout are stocked into Quartz Lake annually, and overlapping size ranges of cohorts can make evaluation of individual cohorts difficult. Cohorts of rainbow trout have been marked with adipose fin clips to enable separation and immediate and continuing evaluation, but an overall consistent marking regime has not been established. As part of the continuing evaluation of Quartz Lake rainbow trout stocking practices, a marking regime should be established allowing separation of stocking cohorts having overlapping ages and lengths. Subcatchable rainbow trout to be stocked into Quartz Lake should be given an adipose fin clip. If cohorts of subcatchable rainbow trout are given an adipose fin clip in alternating years, there will be no overlap in size ranges between identifiable cohorts and evaluation of marked cohorts will be possible. This type of marking regime can be started immediately in 1991, since none of the rainbow trout stocked into Quartz Lake in 1990 had adipose clips.

The failure to capture sufficient numbers of coho salmon to conduct mark and recapture experiments is apparently an artifact of coho salmon behavior, since reasonable numbers are harvested annually by anglers (Doxey 1982, 1984; Mills 1985-1988).

The harvest of coho salmon in Quartz Lake was exceeded by the rainbow trout harvest for the first time in 1988. Coho salmon harvests in the late 1980's were at a lower level than during the early 1980's, even though the stocking density has been consistent at between 150,000 and 168,000 fish annually from 1984 through 1989, compared to intermittent and variable stocking levels prior to that time. Lower coho salmon harvests in the late 1980's may be a result of increasing rainbow trout abundance in Quartz Lake over the past decade. A change in coho salmon stocking procedure occurred in 1990.

This report has attempted to summarize available biological and harvest related information pertinent to the continuing rainbow trout and coho salmon stocking of Birch, Chena, and Quartz lakes. As such, this report provides much information related to stocking evaluation. Unfortunately, the success or failure of the stocking program for these three lakes cannot be determined until fishery management criteria and objectives for these three lakes are defined. For example, if the objective of the stocking program for Birch Lake is to provide an annual fishery of 10,000 man-days or more, success has been achieved since 1980. If concurrently, the objective is to produce a harvest rate of two fish per man-day, the program has failed, and if whatever the objective is, the program is to minimize cost, success cannot be judged with information summarized in this report. In conclusion, a full and meaningful evaluation of these stocking programs cannot be conducted until such time that fishery management objectives are defined, and at that time information presented herein will likely be very useful.

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APPENDIX A

Appendix A1. Worksheet for the development of rainbow trout brood tables, Birch Lake.

Year of Harvest	Stocking Cohort Year	Size	Number	Number of Fish Assumed to be Unavailable[a]	Maximum Number of Fish Available[b]	Proportion of Cohort in Population	Number of Cohort in Harvest
1977	1974	Fing.	157		1,084		
	1976	Catch.	766		766		
Total					1,850		
1978	1977	Fing.	9,508		5,126		
1979	1978	Fing.	9,508	(0.33) =	3,138	0.200	829
	1977	Fing.	10,425	-5,126 =	5,299	0.334	1,400
	1979	Sub.	22,492	(0.33) =	7,422	0.468	1,961
Total					15,859		4,190
1980	1978	Fing.	9,508	- 829 =	8,679	0.199	3,741
	1977	Fing.	10,425	-5,126 - 1,400 =	3,899	0.090	1,680
	1980	Sub.	31,337	(0.33) =	10,341	0.238	4,457
	1979	Sub.	22,492	-1,961 =	20,531	0.472	8,849
Total					43,450		18,727
1981	1978	Fing.	9,508	- 829 - 3,741 =	4,938	0.094	2,028
	1981	Sub.	27,708	(0.33) =	9,144	0.174	3,756
	1980	Sub.	31,337	-4,457 =	26,880	0.510	11,040
	1979	Sub.	22,492	-1,961 - 8,849 =	11,682	0.222	4,798
Total					52,644		21,622
1982	1982	Sub.	0				0
	1982	Sub.	27,708	-3,756 =	23,952	0.602	11,067
	1980	Sub.	31,337	-4,457 -11,040 =	15,840	0.398	7,318
Total					39,792		18,385
1983	1982	Fing.	3,582	(0.33) =	1,182	0.026	441
	1983	Sub.	15,586	(0.33) =	5,143	0.113	1,919
	1982	Sub.	26,260	=	26,260	0.578	9,797
	1981	Sub.	27,708	-3,756 -11,067 =	12,885	0.283	4,807
Total					45,470		16,964
1984	1983	Fing.	2,755	(0.33) =	909	0.027	323
	1982	Fing.	3,582	- 441 =	3,141	0.092	1,114
	1983	Sub.	15,586	-1,919 =	13,667	0.400	4,847
	1982	Sub.	26,260	-9,797 =	16,463	0.482	5,839
Total					34,180		12,123
1985	1984	Fing.	3,779	(0.33) =	1,247	0.086	872
	1983	Fing.	2,755	- 323 =	2,432	0.167	1,701
	1982	Fing.	3,582	- 441 - 1,114 =	2,027	0.140	1,418
	1983	Sub.	15,586	-1,919 - 4,847 =	8,820	0.607	6,170
Total					14,526		10,161
1986	1984	Fing.	3,779	- 872 =	2,907	0.131	1,143
	1983	Fing.	2,755	- 323 - 1,701 =	731	0.033	287
	1986	Sub.	56,190	(0.33) =	18,543	0.836	7,293
Total					22,181		8,723

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Year of Harvest	Stocking Cohort Year	Size	Number	Number of Fish Assumed to be Unavailable[a]		Maximum Number of Fish Available[b]	Proportion of Cohort in Population	Number of Cohort In Harvest
1987	1984	Fing.	3,779	- 872 - 1,143	=	1,764	0.031	310
	1987	Sub.	18,585	(0.33)	=	6,133	0.108	1,078
	1986	Sub.	56,190	-7,293	=	48,897	0.861	8,593
Total						56,794		9,981
1988	1988	Sub.	26,869	(0.33)	=	8,867	0.133	2,446
	1987	Sub.	18,585	-1,078	=	17,507	0.263	4,828
	1986	Sub.	56,190	-7,293 - 8,593	=	40,304	0.604	11,116
Total						66,678		18,390
1989	1989	Sub.	14,150	(0.33)	=	4,670	0.107	1,751
	1988	Sub.	26,869	-2,446	=	24,423	0.558	9,157
	1987	Sub.	18,585	-1,078 - 4,828	=	12,679	0.280	4,754
	1989	Catch.	4,045	(0.50)	=	2,023	0.046	758
Total						43,795		16,420

[a] See assumptions for the development of rainbow trout brood tables in Methods.

[b] Natural mortality is not known, and the number of fish estimated to be available is a maximum estimate.

Appendix A2. Worksheet for the development of rainbow trout brood tables, Chena Lake.

Year of Harvest	Stocking Cohort Year	Size	Number	Number of Fish Assumed to be Unavailable[a]		Maximum Number of Fish Available[b]	Proportion of Cohort in Population	Number of Cohort In Harvest
1984	1983	Fing.	614	(0.50)	=	307	0.026	314
	1982	Fing.	408		=	408	0.035	417
	1984	Sub.	9,290	(0.50)	=	4,645	0.394	4,744
	1985	Sub.	6,420		=	6,420	0.545	6,557
Total						11,780		12,032
1985	1984	Fing.	950	(0.33)	=	314		314
	1983	Fing.	614	- 314	=	300		300
	1982	Fing.	408	- 417	=	0		0
	1985	Sub.	14,220	(0.33)	=	4,693		4,830*
	1984	Sub.	9,290	- 4,744	=	4,546		4,546
Total						9,853		9,990
1986	1984	Fing.	950	- 314	=	636	0.034	237
	1983	Fing.	614	- 314 - 300	=	0	0	0
	1986	Sub.	26,192	(0.33)	=	8,722	0.465	3,258
	1985	Sub.	14,220	- 4,830	=	9,390	0.501	3,506
	1984	Sub.	9,290	- 4,744 - 4,546	=	0	0	0
Total						18,748		7,001
1987	1984	Fing.	950	- 314 - 237	=	399	0.012	62
	1986	Sub.	26,192	- 3,258	=	22,934	0.077	3,535
	1985	Sub.	14,220	- 4,830 - 3,506	=	5,884	0.174	907
	1987	Catch.	9,290	(0.50)	=	4,645	0.137	716
Total						33,862		5,220
1988	1986	Sub.	26,192	- 3,258 - 3,535	=	19,399	0.328	3,240
	1988	Catch.	30,091	(0.50)	=	15,046	0.254	2,513
	1987	Catch.	25,406	- 716	=	24,690	0.417	4,124
Total						59,135		9,877
1989	1989	Catch.	30,481	(0.50)	=	15,241	0.240	2,877
	1988	Catch.	30,091	-(2,513)	=	27,578	0.435	5,206
	1987	Catch.	25,406	- 716 - 4,124	=	20,566	0.325	3,883
Total						63,385		11,966

[a] See assumptions for the development of rainbow trout brood tables in Methods.

[b] Natural mortality is not known, and the number of fish estimated to be available is a maximum estimate.

Appendix A3. Worksheet for the development of rainbow trout brood tables, Quartz Lake.

Year of Harvest	Stocking Cohort Year	Size	Number	Number of Fish Assumed to be Unavailable[a]	Maximum Number of Fish Available[b]	Proportion of Cohort in Population	Number of Cohort in Harvest
1977	1976	Fing.	10,871	(0.33)	3,587	0.114	301
	1975	Fing.	14,693		14,693	0.468	1,231
	1975	Fing.	12,957		12,957	0.412	1,086
	1977	Catch.	566	(0.33)	187	0.006	16
Total					31,424		2,634
1978	1977	Fing.	7,735	(0.33)	2,552	0.094	48
	1976	Fing.	10,871	- 301 =	10,570	0.389	199
	1975	Fing.	14,693	-1,231 =	13,462	0.496	254
	1977	Sub.	566	- 16 =	550	0.020	19
Total					27,134		512
1979	1977	Fing.	7,735	- 48 =	7,687	0.413	113
	1976	Fing.	10,871	- 301 - 199 =	10,371	0.558	152
	1977	Sub.	566	- 16 - 11	539	0.029	8
Total					18,597		273
1980	1979	Fing.	2,300	(0.33) =	759	0.091	12
	1977	Fing.	7,735	- 48 - 113 =	7,574	0.909	117
Total					8,333		129
1981	1980	Fing.	6,129	(0.33) =	2,023	0.469	879
	1979	Fing.	2,300	- 12 =	2,288	0.531	992
Total					4,311		1,869
1982	1980	Fing.	6,129	- 877 =	5,252	0.802	4,013
	1979	Fing.	2,300	- 12 - 992 =	1,296	0.197	990
Total					6,548		5,003
1983	1982	Fing.	15,862	(0.33) =	5,234	0.809	1,273
	1980	Fing.	6,129	- 877 - 4,013=	1,239	0.191	301
Total					6,473		1,547
1984	1983	Fing.	16,329	(0.33) =	5,389	0.270	1,481
	1982	Fing.	15,862	-1,273 =	14,589	0.730	4,010
Total					19,978		5,491

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Year of Harvest	Stocking Cohort			Number of Fish Assumed to be Unavailable[a]	Maximum Number of Fish Available[b]	Proportion of Cohort in Population	Number of Cohort in Harvest
	Year	Size	Number				
1985	1984	Fing.	19,150	(0.33) =	6,320	0.199	2,468
	1983	Fing.	16,329	-1,481 =	14,848	0.468	5,799
	1982	Fing.	15,862	-1,273 - 4,010=	10,579	0.333	4,131
Total					31,747		12,398
1986	1985	Fing.	20,116	(0.33) =	6,638	0.205	3,031
	1984	Fing.	19,150	-2,468 =	16,682	0.515	7,616
	1983	Fing.	16,329	-1,481 - 5,799=	9,049	0.279	4,131
Total					32,369		14,778
1987	1986	Fing.	21,131	(0.33) =	6,973	0.208	2,098
	1985	Fing.	20,116	-3,031 =	17,085	0.509	5,140
	1984	Fing.	19,150	-2,468 - 7,616=	9,066	0.270	2,727
	1987	Sub.	1,420	(0.33) =	469	0.014	141
Total					33,593		10,106
1988	1987	Fing.	28,554	(0.33) =	9,423	0.204	5,143
	1987	Fing.	21,131	-2,098 =	19,033	0.413	10,388
	1985	Fing.	20,116	-3,031 - 5,140=	11,945	0.259	6,520
	1988	Sub.	13,466	(0.33) =	4,444	0.096	2,426
	1987	Sub.	1,420	- 141 =	1,279	0.028	698
Total					46,124		25,175
1989	1988	Fing.	10,500	(0.33) =	3,465	0.055	1,510
	1987	Fing.	28,554	-5,143 =	23,411	0.373	10,205
	1986	Fing.	21,131	-2,098 -10,388=	8,645	0.138	3,768
	1989	Sub.	47,323	(0.33) =	15,617	0.249	6,807
	1988	Sub.	13,466	-2,426 =	11,040	0.176	4,812
	1987	Sub.	1,420	- 141 - 698=	581	0.009	254
Total					62,759		27,356

[a] See assumptions for the development of rainbow trout brood tables in Methods.

[b] Natural mortality is not known, and the number of fish estimated to be available is a maximum estimate.