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THE LAKE TROUT OF TWIN LAKES COLORADO

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16. ABSTRACT

Growth, survival, reproduction, recruitment, and food habits of lake trout in Twin Lakes, Colo., were examined during 1974-1975 to document the status of the trout population prior to completion of a 200-megawatt pumped-storage hydroelectric powerplant being constructed on the lake. The powerplant will become operational during 1977, and data collected during this study will be compared to similar data collected during the post-construction period to determine the effect of plant operation on the trout population. Growth of lake trout in Twin Lakes is comparable to that of other lake trout fisheries in the Western United States, such as Lake Tahoe, Nev.-Calif., and Fish Lake, Utah, and is somewhat faster than most lakes located in Canada. Annual mortality was found to be near 50 percent, which compares with other lake trout fisheries of this type. Successful reproduction of lake trout was confirmed by the presence of age classes that had not been stocked. Approximately 90 percent of 4-year-old fish captured during the study were from natural reproduction. Lake trout reaching the legal size limit of 381 mm were usually 4-year-olds, with approximately 20 percent of the population reaching this size each year. Lake trout in Twin Lakes feed primarily on *Mysis relicta*. Chironomid larvae, white suckers, and rainbow trout are also eaten. Possible effects of powerplant operation on the lake trout population are outlined and discussed.

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by

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Colorado Cooperative Fishery Research Unit

Colorado State University, Fort Collins

March 1977

Applied Sciences Branch
Division of General Research
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FOREWORD

This report and the data contained within it are part of an overall research study on the environmental effects of pumped-storage construction and operation being sponsored and coordinated by the Bureau of Reclamation. This particular report presents the results of a study on the ecology of lake trout at Twin Lakes, Colo., which is the site of the Mt. Elbert Pumped-Storage Powerplant. Research at Twin Lakes is being done cooperatively by personnel from the Bureau's Lower Missouri Region and the Division of General Research at the Engineering and Research Center, the Colorado Division of Wildlife, and the Colorado Cooperative Fishery Research Unit. The author was employed by the Colorado Cooperative Fishery Research Unit and completed this study as partial fulfillment of the requirements for a Master of Science degree at Colorado State University.

Data from this study will be used along with those collected from other studies at Twin Lakes to form a pool of information for comparison with data collected following commencement of powerplant operation. In this manner it will be possible to accurately and efficiently document the effects of Mt. Elbert Pumped-Storage Powerplant operation on the ecosystem. In addition, the knowledge presented here will contribute to an understanding of how to better operate this particular powerplant so as to minimize any effects on the fishery. In fact, information on the behavior of Twin Lakes mysid shrimp, an important food source of lake trout, has already been submitted in the consideration of scheduling the pumped-storage operation. Also, as a result of this and other studies at Twin Lakes, a hydraulic study of the tailrace channel design was done by the Bureau's Division of General Research. Results of this study were instrumental in changing the tailrace design to minimize or eliminate disturbance of glacial flour on the bottom of Twin Lakes and the disruption of thermal stratification.

The information gained from the studies at Twin Lakes, along with that from other similar studies in the Western United States, will be used to document the effects of pumped-storage operation. This information will be used to improve the planning process so that the environmental impacts of future pumped-storage facilities can be accurately evaluated and certain environmental features protected or enhanced.

Reviewed by

James F. LaBounty, Research Biologist
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INTRODUCTION

Lake trout, *Salvelinus namaycush* (Walbaum), were introduced to Twin Lakes, Colo., sometime in the late 1800's. No records have been found which document the lake trout's first introduction into these waters. However, Juday [1] [1] examined two lake trout (one was 750 mm long) from Twin Lakes during investigations conducted for the U.S. Bureau of Fisheries in 1902, 1903, and 1904. Investigations into the life history of the Twin Lakes lake trout were conducted from 1958 to 1961 by the Colorado Division of Wildlife in connection with a statewide survey on existing and proposed lake trout waters.

In 1969, due to a growing concern about the effects a planned pumped-storage powerplant might have on the lake trout fishery at Twin Lakes, and since there was a general lack of data on such effects because of the relative newness of this type of facility, the study reported here was initiated. It was necessary to begin the study before construction of the powerplant was completed to provide a set of base data to which post-operative findings could be compared.

The main objectives of this study were: (1) to study the biology of lake trout in Twin Lakes as indicated by age and growth, food habits, reproduction, mortality and survival, and recruitment to 381 mm (15 in), (2) to estimate population size, and (3) to study the degree of utilization of *Mysis relicta* as a food item by the lake trout and the effects of such utilization on lake trout growth.

SUMMARY AND CONCLUSIONS

Twin Lakes lake trout grow at a rapid rate until their fourth year, at which time there is a leveling off until their eighth year, when the growth rate again increases. This change in growth rate is attributed to the lake trout's dependence on *Mysis relicta* until their eighth or ninth year of life. A length-weight relationship of $\ln W = 3.17 \ln L - 12.81$ was determined, and a condition factor (K) of 0.760 was calculated, reflecting the relatively slim shape of these fish. Scales can be used to age lake trout from Twin Lakes with a high degree of confidence up to age 6; however, after age 6 the degree of confidence decreases with age.

Mysis relicta was the most important item in the diet of the lake trout, with larval chironomids also being important. Fish consumed were primarily white suckers, along with some rainbow trout. A larger sample of older fish may show a greater utilization of forage fish species than shown here.

A total annual mortality rate of 0.484 was determined from catch curves. This mortality rate compares favorably with other lake trout populations [2].

Recruitment to 381 mm appears to be around 20 percent of the population each year. Twin Lakes lake trout generally reach the legal size limit (381 mm) during their fourth year of life.

Twin Lakes lake trout spawn in the latter part of October and early November and probably utilize areas along the north and west shore and the north bay of the lower lake for this activity. They also appear to utilize areas along the south and west shores of the upper lake. The duration of spawning varied from 1 to 2 weeks and usually occurred in water depths from 3 to 10 metres. Successful spawning was indicated by the presence of year-classes not stocked.

Operation of the Mt. Elbert Pumped-Storage Powerplant may have an adverse effect on the lake trout. There will likely be increased mortality due to entrainment by the plant, the degree of which cannot be estimated at this time. If plant operations cause a drastic reduction in the population of *Mysis relicta*, a reduction of lake trout growth rate may occur. Increased turbidity caused by a resuspension of glacial flour may have an adverse effect on the lake trout through a reduction in primary productivity and a consequential disruption of the food chain. Degradation of spawning habitat may also occur with increased turbidity and siltation.

APPLICATIONS

The data contained within this report are a significant part of the baseline of information on the aquatic environment of Twin Lakes, Colo., to which findings during the post-operative period will be compared. By such comparison, the impacts of the Mt. Elbert Pumped-Storage Powerplant can be more accurately predicted. The information in this report will be useful to those interested in cold-water fishery management and of particular use to those evaluating the impacts of powerplant operation on fisheries.

DESCRIPTION OF STUDY AREA

Physical

Twin Lakes Reservoir is approximately 24 km (15 mi) south of Leadville, Colo., at an elevation of 2802 m (9193 ft) on the eastern slope of the Sawatch Range, and is accessible by paved highway (Colorado Highway No. 82). The upper lake has a maximum depth of approximately 28 m (92 ft) and a surface area of

[1] Numbers in brackets refer to items in bibliography.

263 ha (650 acres), while the lower lake has a maximum depth of approximately 27 m (89 ft) and a surface area of 736.5 ha (1,820 acres) (fig. 1).

Twin Lakes water and surface elevation is currently controlled by the Twin Lakes Reservoir and Canal Company. The primary water source is Lake Creek, a tributary of the Arkansas River. In 1901, an outlet control structure was constructed to allow storage of irrigation water. Since that time, the dam has been modified and the connecting channel enlarged so that the two lakes now function as a single unit. Additional storage water is supplied via Lake Creek from the Roaring Fork drainage on the western slope through a tunnel under the Continental Divide. Since flows from Twin Lakes became controlled, the maximum fluctuation during the year has been as much as 7.6 m (25 ft) with fluctuations of 6 m (20 ft) not uncommon.

Twin Lakes was originally two natural lakes impounded by terminal glacial moraines. Conifers, grass, and willows are common along parts of the shoreline. Most of the shoreline is sandy due to extreme water level fluctuations, with extensive areas of rock and rubble existing in some areas. The lake bottom is largely composed of varying depths of glacial flour, with some rock and rubble deposits. Most of the rocky areas, however, are along the shorelines and are subjected to exposure during periods of low water. Sand is found throughout the littoral zone. The shoreline and bottom topography are outlined in figure 1.

The growing season for Leadville is approximately 3 months, with an average of 82 frost-free days. Average total precipitation for Leadville (24 km from Twin Lakes) is 469 mm (18.48 in) and average snowfall is 3.17 m (124.7 in). Twin Lakes is usually ice covered from the end of December until the middle of May. Twin Lakes is a dimictic lake with a photic depth generally exceeding 10 m during most of the year.

Chemical

Total dissolved solids in Twin Lakes range from 32 to 88 milligrams per litre (mg/ℓ) and conductivity values are low—52 to 91 x 10^6 μS/cm at 25 °C. The principal anion is bicarbonate, which ranges from 20 to 30.5 mg/ℓ. The principal cation, calcium, ranges from 8.8 to 12 mg/ℓ. Sulfates ranged from 8 to 25 mg/ℓ. Analysis for heavy metal in Twin Lakes gave the following results: copper, 0 to 0.95 mg/ℓ; iron, 0 to 1.5 mg/ℓ; zinc, 1 to 1.7 mg/ℓ; and manganese, 0 to 0.8 mg/ℓ. Dissolved oxygen measurements taken throughout the year ranged from 7.3 to 8.9 mg/ℓ in the upper lake, and from 1.3 to 7.9 mg/ℓ in the bottom zones and 7 to 11 mg/ℓ in the upper zones of the lower lake [3].

Biological

Rooted aquatic vegetation is common in the shallower areas of the lake (3 to 9 m). Nolting [4] reported finding *Chara globularis*, *Potamogeton praelongus*, *Potamogenton amplifolius*, and *Nitella opaca*. Bureau of Reclamation divers reported dense growths of *Potamogeton* sp. at the east end of the lake, as well as stonewarts (to depths of 20 m) [5]. Phytoplankton occurred at all depths, with the greatest concentrations occurring within 4.5 metres of the surface.

Presently, only two species of copepods are found in the lake: *Cyclops* sp., and *Diaptomus* sp. *Mysis relicta* was introduced from Clearwater Lake, Minn., in 1957 [6]. Chironomidae larvae and fingernail clams (*Pisidium* spp.) of the order Pelecypoda, family Sphaeriidae, are found in Twin Lakes [7]. Nolting [4] reported finding *Keratella*, *Filinia*, *Volvox*, *Fragilaria*, *Asplanchana*, *Ceratium*, *Northalea*, *Anabaena*, and *Cladophora* in the lakes.

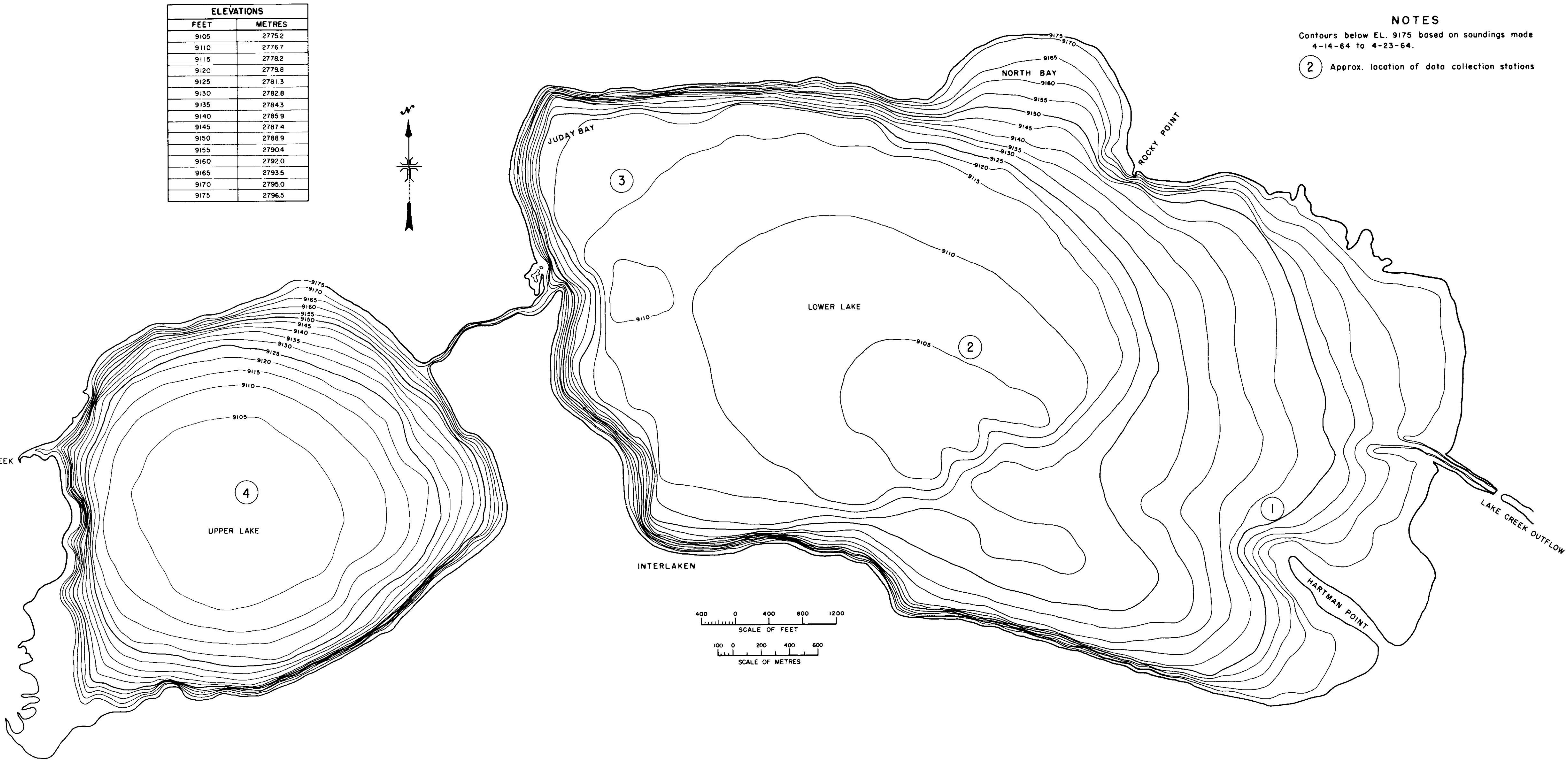
In addition to the lake trout (*Salvelinus namaycush*), brown trout (*Salmo trutta*), rainbow trout (*Salmo gairdneri*), cutthroat trout (*Salmo clarki*), brook trout (*Salvelinus fontinalis*), Kokanee salmon (*Oncorhynchus nerka*), longnose sucker (*Catostomus catostomus*), and white suckers (*Catostomus commersoni*), are found in Twin Lakes. Fathead minnows (*Pimaphales promelas*) and bonneyville cisco (*Prosopium gemmiferum*) have been stocked; however, none have been recovered [8].

As indicated by creel census, Twin Lakes is utilized primarily as a rainbow trout fishery, with extensive stocking of catchable size rainbow trout throughout the summer months. Lake trout and rainbow trout comprise the major portion of the catch at Twin Lakes. Kokanee salmon have also been stocked in the lake; however, they have not contributed significantly to the overall catch. Fishing for lake trout is done by only a small number of fishermen when compared to the total number of fishermen using the lake. Lake trout caught by people fishing for rainbow trout in the summer are caught by accident and do not contribute significantly to the total lake trout catch (table 1). During the winter months the situation is reversed, with the most people fishing for lake trout.

METHODS AND MATERIALS

Fish Collections

The majority of the lake trout collected during this study were caught with experimental nylon gill nets. Data for those fish not caught by gill nets were collected through interviews with fishermen. Angler interviews usually provided weight, sex, total length, and scale samples.



ELEVATIONS	
FEET	METRES
9105	2775.2
9110	2776.7
9115	2778.2
9120	2779.8
9125	2781.3
9130	2782.8
9135	2784.3
9140	2785.9
9145	2787.4
9150	2788.9
9155	2790.4
9160	2792.0
9165	2793.5
9170	2795.0
9175	2796.5

Figure 1.—Bottom topographic map of Twin Lakes, Colo.

Table 1.—*Predicted fishermen use and harvest on Twin Lakes, Colo., May through September 1974, and projected ice fishermen use and harvest from Lower Twin Lake, December 1974 through March 1975. Figures in parentheses are for 1973.*

Time	Location	Average lake trout catch/man-hour		Total lake trout caught		Average rainbow trout catch/man-hour		Average rainbow trout caught	
		Shore	Boat	Shore	Boat	Shore	Boat	Shore	Boat
Summer									
	Upper Twin Lake	*0.004 (.079)	*0.043 (.008)	79 (174)	179 (399)	0.318 (.510)	0.165 (.044)	6147 (11 231)	691 (222)
	Lower Twin Lake	.005 (.005)	.039 (.039)	340 (400)	575 (438)	.264 (.308)	.189 (.291)	17 442 (21 657)	2793 (2837)
Winter									
	Upper Twin Lake**	–	–	–	–	–	–	–	–
	Lower Twin Lake	†0.151		1109		–	–	–	–

* Total shore fishermen = 5830, total hours = 19 320; Total boat fishermen = 1194, total hours = 4199
** No data available for ice fishermen on Upper Twin Lake
† Total ice fishermen = 2210, total hours = 7357

Compiled from tables 2, 3, and 4, Project Report No. 4, Fryingpan-Arkansas Fish Research Investigations, Colorado Division of Wildlife.

Nine experimental nylon gill nets of the common bar mesh sizes from 19.1 to 44.5 mm (3/4 to 1-3/4 in) were used to collect samples. These nets were made up of five sections of nearly equal length. The usual length of a section was 7.62 m (25 ft), but not all nets measured a full 38.1 m (125 ft) long because of wear and tear occurring during the study. All nets were 1.8 m (6 ft) deep. Several 38.1-m (125-ft) long, 19.1-mm (3/4-in) bar-mesh-size nylon gill nets were used in a number of attempts to conduct a mark and recapture study, and also to capture mature spawning fish for fecundity studies. Scale samples from fish caught by these nets were included in the age and growth studies, as normal sampling did not provide adequate representation of larger fish.

Extensive fish collections were not made due to the limitations of equipment and in an effort to minimize mortality of large, trophy lake trout.

Samples were collected during May, August, and November, with 17 gill net sets during each sampling period. Nets were set along a transect line extending across the lakes (fig. 2). In addition, three nets were set at a depth of less than 15 m and three at a depth greater than 15 m in the lower lake. In the upper lake, only one net was set at a depth of less than 15 m. Those sets not on the transect line were set at random. Because only nine nets were used, sampling usually took place on 2 or 3 consecutive days. All nets were set on the bottom.

Gill Net Selectivity

There is no doubt that there is some bias involved in the use of any gill net for population studies [9], but the use of experimental nets of more than one mesh size does give a more representative sample. The older fish captured during this study are probably under-represented because of the use of small mesh gill nets. It is believed that this bias is offset somewhat by the tendency of these fish to be captured by entanglement. The Colorado Division of Wildlife has for several years used 19.1-mm (3/4-in) mesh gill nets in capturing spawning lake trout with an apparent very low level of mortality.[2]

A 30.5- by 1.2-m (100- by 4-ft) by 12.7-mm (1/2-in) mesh nylon net was used to capture young-of-the-year. A vertical gill net of the same mesh size was also used in an attempt to capture young-of-the-year, but was not successful.

Initially, nets were pulled and reset every 3 hours. It was found that the majority of fish were caught in the early morning hours so, thereafter, all sets were made in the evening and pulled in the morning. Average time of each set was 12 hours.

Collecting and Analyzing Data

Within 30 minutes to 1 hour after capture, all fish were measured to the nearest millimetre and weighed to the nearest gram. All other pertinent data concerning date, depth of capture, and location of net were recorded at time of capture.

Scales were removed from approximately 600 fish for age and growth studies. Fish scales from years prior to 1974 were collected by the Colorado Division of Wildlife. Scales were removed from the right side of the fish, immediately above the lateral line and below the posterior end of the dorsal fin. In those cases where it was observed that this area had been damaged by the gill netting operations, the scales were removed from the same location on the left side.

An average of six scales from each fish were mounted on a plastic slide. Impressions were then made by placing slides in a Carver Laboratory Press, at a temperature of 65.5 °C (150 °F), under a pressure of 6 metric tons, for 30 seconds. The slides were then observed using a Bioscope, Model 60-A, to a magnification of 50X.

Ages were determined by counting annuli identified by the criteria described by Everhart, Eipper, and Young [10]. No central check as described by Van Oosten and Eschmeyer [11] was found. A strip of paper was placed along the medial anterior radius from the focus to the edge of the scale, and the locations of annuli were marked on this paper. The sample number and the year of capture were recorded on these strips. Distances to the annuli and the scale radius were then measured to the nearest millimetre and the data recorded. A computer program was used to fit the body length and scale radius to a third degree polynomial of the form:

$$TL = b_0 + b_1 S + b_2 S^2 + b_3 S^3$$

where:

TL = total length, and
S = scale or annuli radius.

After determining the relationship between the body length and scale radius, the program back-calculated the body length for each annulus, computed a grand average of all back-calculated lengths at each annulus, and performed a "student" T-test for Lee's phenomenon for all ages of fish.

[2] Larry M. Finnell, Colorado Division of Wildlife, personal communication.

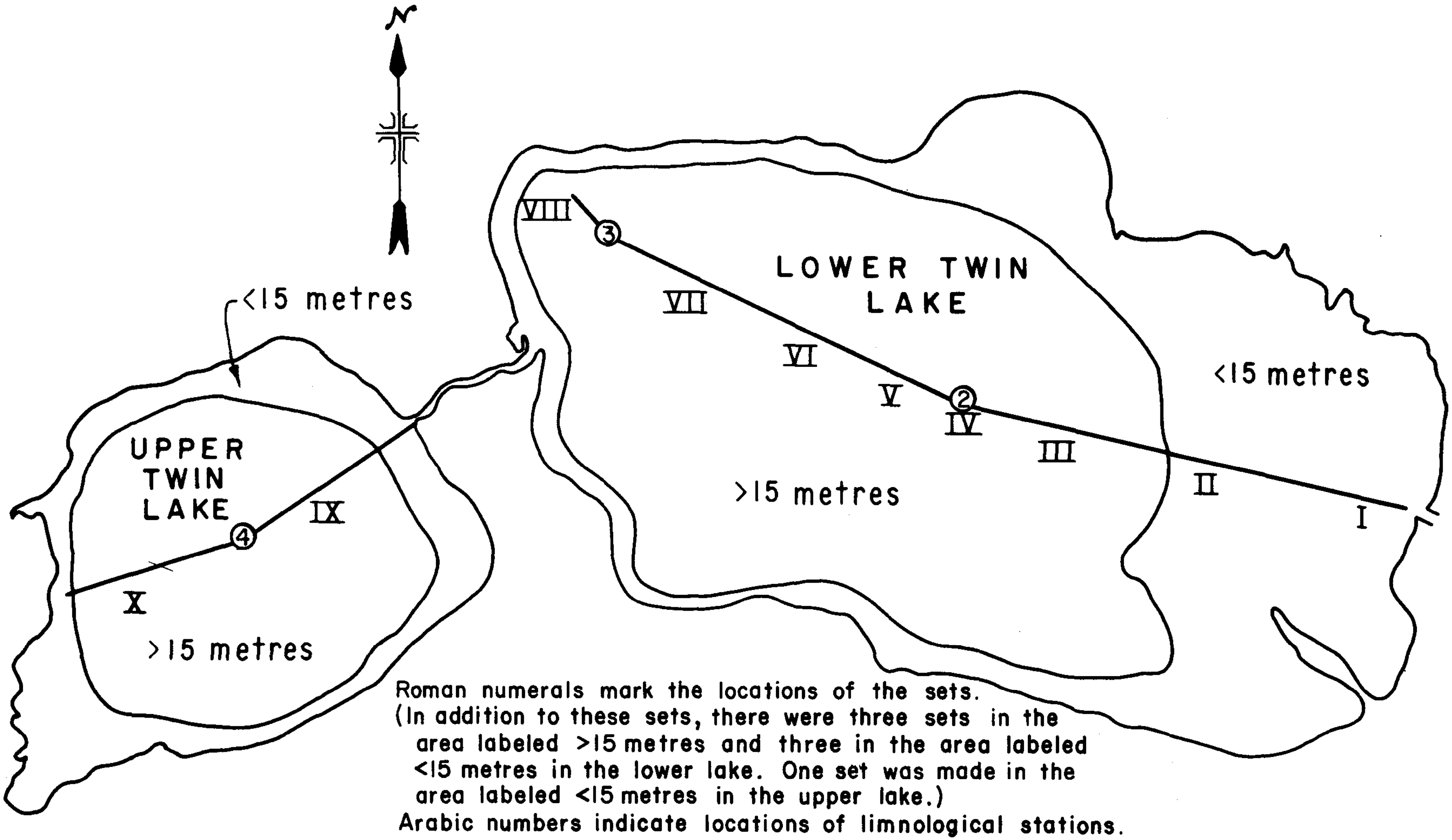


Figure 2.—Location of quarterly gill net sets in Twin Lakes, Colo.

Otoliths and brachiostegal rays were collected from 28 fish in an attempt to corroborate age determination from scale readings. These structures were difficult to read with confidence because annuli were bunched together and obscure. Thin sectioning of both otoliths and branchiostegal rays did not improve their readability.

All of the scales collected in 1970 through 1973 were read twice. The first reading was done prior to the beginning of this study by Larry M. Finnell, Wildlife Researcher, Colorado Division of Wildlife. The scales were then read a second time by the author, with agreement occurring in 285 out of 313 cases (91 percent) in the number of annuli and disagreement in approximately 30 percent of the cases on the location of annuli. These disagreements most often occurred in reading the scales of older fish (older than 6 years) and were due mainly to the tendency of annuli being bunched near the edge of the scale.

Length-weight relationships were based on the formula:

$$\ln W = \ln c + n \ln L$$

where:

- ln = natural logarithm
- W = weight in grams,
- L = total length in millimetres, and
- c, n = constants.

Data were arranged in 10-mm categories and were combined without regard to sex, state of maturity, method of collection, or the time of collection.

Condition factor K was calculated from the formula:

$$K = \frac{(W)\,(10^5)}{L^3}$$

where:

- W = weight in grams,
- L = total length in millimetres, and
- 10^5 is a factor to bring the value of K near unity [2].

In computing the condition factor, no attempt was made to differentiate between sexes or take into account the time of capture. An average of the condition factors computed for each 10-mm category was calculated and a grand average was calculated which included all size categories.

Stomachs were removed from a sample of fish collected at the same time that total length, weight, sex, and scale samples were taken. Stomach contents were preserved in a 10-percent formalin solution. The stomach was considered to be that portion of the gut from the esophagus to the pyloric valve. The majority of stomach samples were collected during the 1974 quarterly gill net sampling periods of May, August, and November. The remaining stomachs were collected between these sampling periods and during the period of ice cover. Stomachs of 216 fish were examined using a dissecting microscope to identify the contents. Insects were identified to order and, in come cases, to family. Identification of fish remains was relatively easy due to the limited number of species present in Twin Lakes. These identifications were made on the basis of scales and bony parts (those remains that could not be identified were classified as unknown).

Stomach contents data are presented in three ways: (1) the percentage of stomachs in which each food item occurred, (2) the ratio of the number of food items of each type to the total number of food items present in all stomachs, and (3) the percent volume of the total for each food item.

Volumes are reconstructed. Volumes of food other than fish that exceeded 0.1 percent of the total volume in stomachs were measured by water displacement. Fish residues were reconstructed to preingested volume using the relationship of the combined length of the last five vertebrae to the volume of whole fish captured for that purpose (fig. 3) [12]. All fish remains that were identifiable contained the necessary vertebrae to use this relationship. To determine the relationship of volume to the length of the five terminal vertebrae, 29 white suckers and 22 rainbow trout were used.[3] The only other fish species found in the stomach samples was one small lake trout. This fish had not been digested, making a determination of its preingestion volume relatively easy by the water displacement method.

Mortality was calculated using the method of catch curves, described by Ricker [9] and also by the method described by Ssentongo and Larkin [13].

RESULTS AND DISCUSSION

Age and Growth

Body-scale relationship.—A growth curve representing the body-scale relationship was plotted from empirical data (fig. 4). While several investigators have used a straight-line relationship [14, 15], it was felt that a curvilinear plot best described the relationship.

[3] Condor, J., unpublished report, 1975.

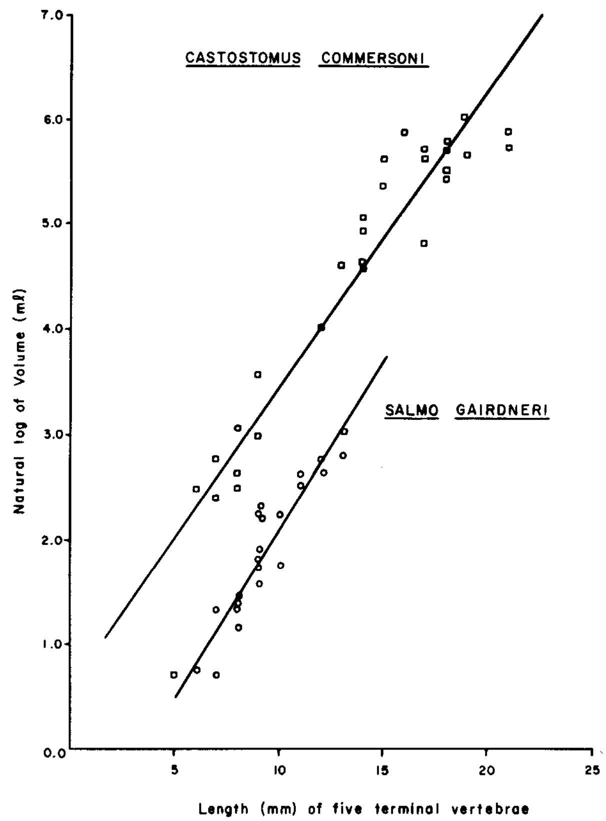


Figure 3.—Relationship of volume to the length of the five terminal vertebrae of 29 white suckers and 22 rainbow trout.

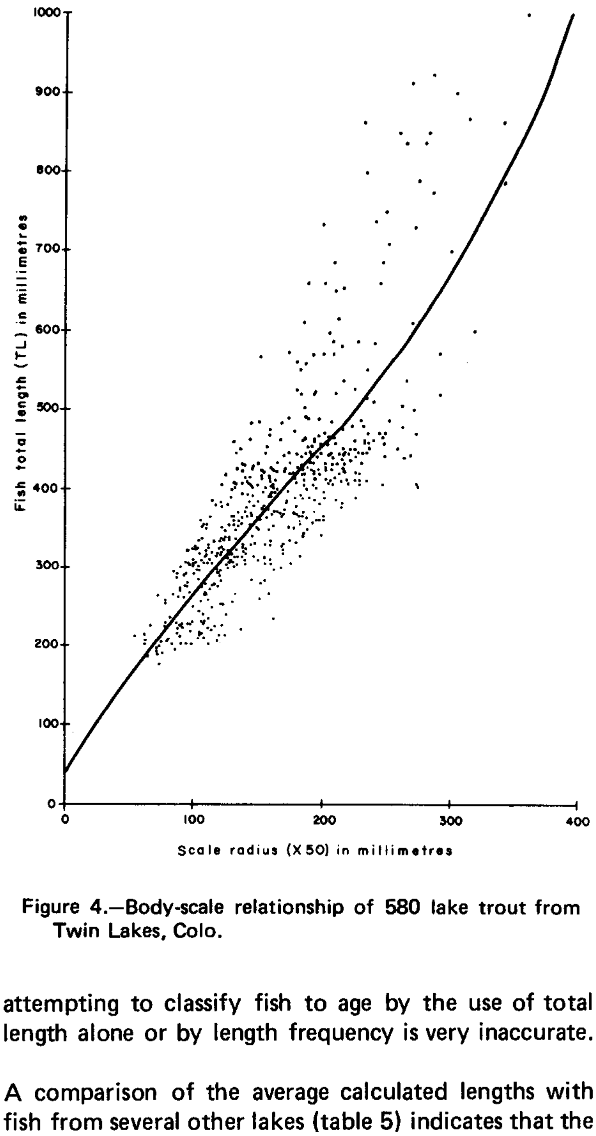


Figure 4.—Body-scale relationship of 580 lake trout from Twin Lakes, Colo.

Carlander [2] has shown that the applicability of a third-degree polynomial and computer technology makes the fitting of this curve to the data easier than by doing it manually. The body length (total length)-scale radius relationship computed for this set of data was:

$$TL = 38.1 + 2.944S - 0.00734S^2 + 0.0000151S^3$$

where:

TL = total length in millimetres, and
S = scale radius in millimetres x 50.

The correlation coefficient equaled 0.816.

This formula was then used to back-calculate the lengths of each fish at all annuli. The results (tables 2 and 3) indicate some evidence of Lee's phenomena, although there is no definite trend with this occurring in a number of age classes. The probable cause of the occurrence of Lee's phenomena is the small sample size in the older group. As can be seen from table 4, attempting to classify fish to age by the use of total length alone or by length frequency is very inaccurate.

A comparison of the average calculated lengths with fish from several other lakes (table 5) indicates that the lake trout of Twin Lakes may grow at a faster rate during the first 5 years of life, and then at a slower rate for the remaining years calculated. This slower rate of growth is most likely related to the diet of these fish and will be discussed under food habits.

Growth increments for the past 10 years were calculated by the method used by Hile [16]. These data were analyzed as growth in the first year of life versus growth in the second and later years of life (fig. 5). In examining the plot of these growth increments for the first year of life, it can be seen that there is a general trend upward from 1964 to 1968, with a gradual decline until 1973, where there is an increase to 1974. For the 10-year period, the growth increment showed a maximum difference of around 30 percent, with the majority of differences within 12

Table 2.—*Average length at capture and average calculated length at end of each year of life for each age group of lake trout, arranged by year class and year of capture. General growth data based on all age groups from Twin Lakes, Colo.*

Year class	Year of capture	Age group	No. fish	TL at capture (mm)	Calculated length at end of year of life (mm) 1	2	3	4	5	6	7	8	9	10	11	12
1960	1971	XI	2	826	140	206	270	326	382	436	479	549	610	661	711	–
1961	1971	X	2	858	141	216	275	323	369	415	481	568	640	727	–	–
1962	1970	VII	1	610	123	188	282	335	423	458	502	–	–	–	–	–
	1971	IX	2	908	130	207	264	325	363	421	480	535	588	–	–	–
	1974	XII	1	840	130	199	236	282	333	377	409	443	485	526	556	591
1963	1970	VIII	1	709	128	170	212	256	331	418	469	528	–	–	–	–
	1975	XII	1	1000	159	252	303	368	441	504	551	601	662	720	762	811
1964	1970	VI	1	462	147	208	278	320	361	411	–	–	–	–	–	–
	1971	VII	2	708	151	218	269	316	367	430	499	–	–	–	–	–
	1974	X	3	813	113	161	217	270	304	343	384	431	479	521	–	–
	1975	XI	1	869	118	159	218	262	311	352	398	447	517	562	623	–
1965	1970	V	4	432	106	175	229	292	345	–	–	–	–	–	–	–
	1971	VI	6	564	142	204	264	336	395	443	–	–	–	–	–	–
	1973	VIII	1	638	131	241	300	369	426	490	533	572	–	–	–	–
	1974	IX	3	713	125	186	242	286	340	396	458	506	569	–	–	–
	1975	X	2	888	128	179	241	292	334	382	432	469	510	556	–	–
1966	1970	IV	10	358	133	211	279	333	–	–	–	–	–	–	–	–
	1971	V	14	445	130	200	264	328	385	–	–	–	–	–	–	–
	1972	VI	5	483	151	253	334	411	485	530	–	–	–	–	–	–
	1973	VII	3	622	147	224	315	388	442	511	554	–	–	–	–	–
	1974	VIII	2	677	125	174	229	276	337	391	478	530	–	–	–	–
	1975	IX	2	786	132	195	244	296	350	382	422	452	485	–	–	–
1967	1970	III	4	311	145	232	293	–	–	–	–	–	–	–	–	–
	1971	IV	19	381	138	206	268	335	–	–	–	–	–	–	–	–
	1972	V	26	427	157	230	292	361	439	–	–	–	–	–	–	–
	1973	VI	10	469	157	236	311	373	425	477	–	–	–	–	–	–
	1974	VII	11	579	126	180	232	281	332	374	422	–	–	–	–	–
	1975	VIII	2	655	128	185	227	279	321	358	392	426	–	–	–	–

Table 2.—*Average length at capture and average calculated length at end of each year of life for each age group of lake trout, arranged by year class and year of capture. General growth data based on all age groups from Twin Lakes, Colo.*—Continued

Year class	Year of capture	Age group	No. fish	TL at capture (mm)	Calculated length of end of year of life (mm)											
					1	2	3	4	5	6	7	8	9	10	11	12
1968	1971	III	15	326	145	223	297	–	–	–	–	–	–	–	–	–
	1972	IV	8	374	159	245	317	384	–	–	–	–	–	–	–	–
	1973	V	53	443	151	235	314	383	442	–	–	–	–	–	–	–
	1974	VI	16	499	133	188	240	292	345	398	–	–	–	–	–	–
	1975	VII	3	587	134	176	246	291	326	364	413	–	–	–	–	–
1969	1971	II	1	249	132	213	–	–	–	–	–	–	–	–	–	–
	1972	III	1	310	140	229	272	–	–	–	–	–	–	–	–	–
	1973	IV	47	390	148	231	313	386	–	–	–	–	–	–	–	–
	1974	V	14	432	163	214	276	325	379	–	–	–	–	–	–	–
1970	1973	III	39	312	147	240	330	–	–	–	–	–	–	–	–	–
	1974	IV	58	398	132	201	263	327	–	–	–	–	–	–	–	–
1971	1972	I	2	173	182	–	–	–	–	–	–	–	–	–	–	–
	1973	II	34	230	147	235	–	–	–	–	–	–	–	–	–	–
	1974	III	95	321	130	199	257	–	–	–	–	–	–	–	–	–
1972	1974	II	47	258	132	206	–	–	–	–	–	–	–	–	–	–
1973	1974	I	6	209	156	–	–	–	–	–	–	–	–	–	–	–
Average calculated length					140	214	281	345	400	420	450	498	551	605	689	701
Average growth increment					140	74.5	67.5	63.7	58.3	49.3	50.3	49.8	53.9	54.3	58.6	61.5
Number of fish reaching age					580	572	490	336	194	83	45	25	19	12	5	2

Table 3.—*Calculated total length at the end of year of life of each* year-class *of lake trout from Twin Lakes, Colo.*

Year class	Number of fish	Calculated length at end of year of life (mm)											
		1	2	3	4	5	6	7	8	9	10	11	12
1960	2	*140	*206	*270	*326	*382	*436	*479	*549	*610	*661	*711	–
1961	2	*141	*216	*274	*323	*369	*415	*481	*568	*640	*727	–	–
1962	4	128	200	262	318	371	419	468	504	554	*526	*556	*591
1963	2	*144	*211	*258	*312	*386	*461	*510	*565	*661	*720	*762	*811
1964	7	129	184	241	289	331	379	425	435	489	531	*623	–
1965	16	127	193	251	312	367	425	462	505	545	*556	–	–
1966	36	135	211	279	341	404	477	495	*491	*485	–	–	–
1967	72	146	216	275	332	407	417	417	*426	–	–	–	–
1968	95	147	224	294	358	411	*373	*413	–	–	–	–	–
1969	63	151	227	304	372	379	–	–	–	–	–	–	–
1970	97	138	217	290	327	–	–	–	–	–	–	–	–
1971	131	135	208	257	–	–	–	–	–	–	–	–	–
1972	47	132	206	–	–	–	–	–	–	–	–	–	–
1973	6	156	–	–	–	–	–	–	–	–	–	–	–
Maximum difference		29	43	63	83	80	98	78	70	65	*	*	*
Maximum difference as a % of lowest calculated length		22.8	23.4	26.1	28.7	24.2	25.8	18.3	16.1	13.3	*	*	*

*Calculated length excluded from calculations of the maximum difference because of inadequate representation.

Table 4.—*Length frequency distribution of age groups of lake trout (by all sampling methods) from Twin Lakes, Colo.*

Interval (mm)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
140-159	1	–	–	–	–	–	–	–	–	–	–	–	1
160-179	1	–	–	–	–	–	–	–	–	–	–	–	1
180-199	2	5	–	–	–	–	–	–	–	–	–	–	7
200-219	2	19	1	–	–	–	–	–	–	–	–	–	22
220-239	1	21	2	–	–	–	–	–	–	–	–	–	24
240-259	–	10	3	–	–	–	–	–	–	–	–	–	13
260-279	1	7	13	1	–	–	–	–	–	–	–	–	22
280-299	–	8	20	1	–	–	–	–	–	–	–	–	29
300-319	–	7	47	2	–	–	–	–	–	–	–	–	56
320-339	–	2	34	10	–	–	–	–	–	–	–	–	46
340-359	–	2	14	15	–	–	–	–	–	–	–	–	31
360-379	–	1	12	27	2	–	–	–	–	–	–	–	42
380-399	–	–	5	25	6	–	–	–	–	–	–	–	36
400-419	–	–	3	31	24	–	–	–	–	–	–	–	58
420-439	–	–	–	20	22	2	–	–	–	–	–	–	44
440-459	–	–	–	5	32	9	–	–	–	–	–	–	46
460-479	–	–	–	3	14	7	–	–	–	–	–	–	24
480-499	–	–	–	1	6	5	–	–	–	–	–	–	12
500-519	–	–	–	1	2	4	–	–	–	–	–	–	7
520-539	–	–	–	–	1	3	5	–	–	–	–	–	9
540-559	–	–	–	–	–	2	1	–	–	–	–	–	3
560-579	–	–	–	–	1	3	2	1	–	–	–	–	7
580-599	–	–	–	–	–	2	3	–	–	–	–	–	5
600-619	–	–	–	–	–	–	3	–	1	–	–	–	4
620-639	–	–	–	–	–	–	–	–	–	–	–	–	0
640-659	–	–	–	–	–	–	–	2	–	–	–	–	2
660-679	–	–	–	–	–	–	2	1	–	–	–	–	3
680-699	–	–	–	–	–	–	3	–	–	–	–	–	3
700-719	–	–	–	–	–	–	–	2	–	–	–	–	2

Table 4.—*Length frequency distribution of age groups of lake trout (by all sampling methods) from Twin Lakes, Colo.—Continued*

Interval (mm)	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
720-739	–	–	–	–	–	1	–	1	1	–	–	–	3
740-759	–	–	–	–	–	–	–	–	1	–	–	–	1
760-779	–	–	–	–	–	–	–	–	–	1	–	–	1
780-799	–	–	–	–	–	–	–	–	1	–	1	–	2
800-819	–	–	–	–	–	–	–	–	–	1	–	–	1
820-839	–	–	–	–	–	–	–	–	1	–	–	–	1
840-859	–	–	–	–	–	–	–	–	–	2	–	1	3
860-879	–	–	–	–	–	–	–	–	–	2	2	–	4
880-899	–	–	–	–	–	–	–	–	–	–	–	–	0
900-919	–	–	–	–	–	–	–	–	2	–	–	–	2
920-939	–	–	–	–	–	–	–	–	–	1	–	–	1
940-959	–	–	–	–	–	–	–	–	–	–	–	–	0
960-979	–	–	–	–	–	–	–	–	–	–	–	–	0
980-999	–	–	–	–	–	–	–	–	–	–	–	–	0
1000-1019	–	–	–	–	–	–	–	–	–	–	–	–	1
Average TL	200	246	318	389	438	498	595	669	790	847	840	920	–
No. of fish	8	82	154	142	111	38	19	7	7	7	3	2	580

Table 5.—*Average calculated total length at each annulus for lake trout of various lakes [2] and Twin Lakes, Colo.*

Lake	No. of fish	Calculated length at end of year of life (mm)											
		1	2	3	4	5	6	7	8	9	10	11	12
L. Michigan	1 319	150	221	284	345	394	386	—	—	—	—	—	—
Bear L., Utah	44	221	343	434	500	554	592	630	673	693	726	747	765
Fish L., Utah	295	137	213	295	376	445	508	587	691	770	823	813	838
Cayuga L., N.Y.	238	122	193	282	386	478	554	610	650	—	—	—	—
Granby L., Colo.	—	99	170	236	282	—	—	—	—	—	—	—	—
L. Tahoe, Calif.	—	130	201	272	348	414	465	514	574	630	683	929	770
29 lakes, Canada	12 239	102	173	236	269	335	386	424	467	513	561	610	700
Twin Lakes, Colo.	580	140	214	281	345	400	420	450	498	551	605	689	701

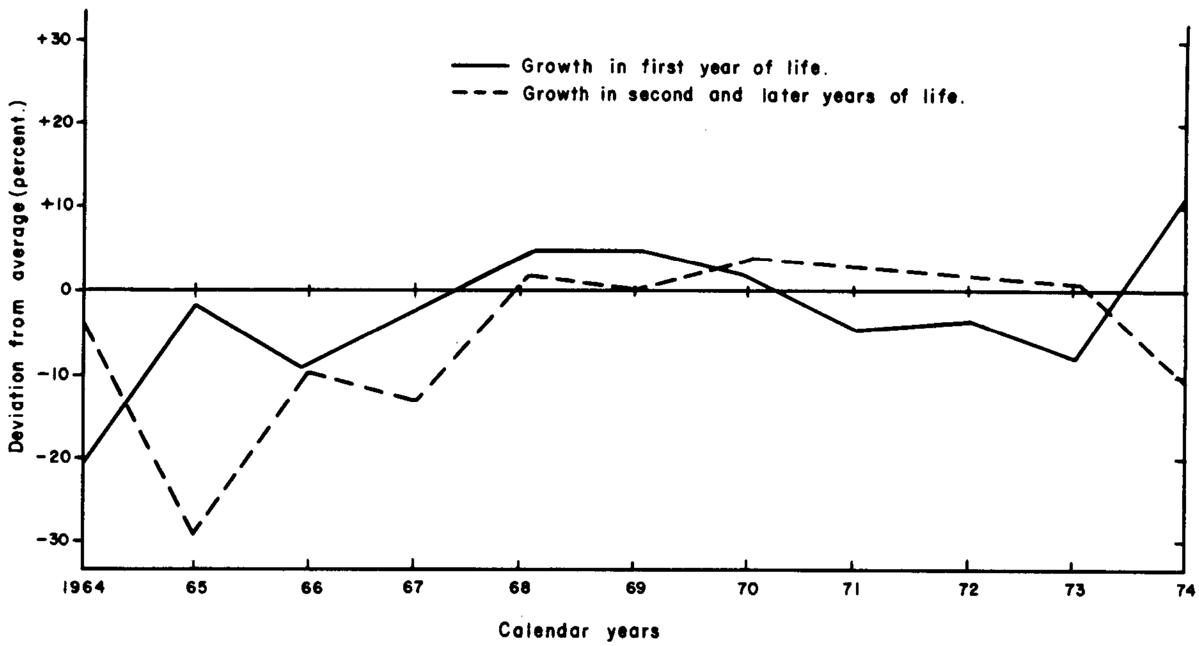


Figure 5.—Annual deviation from average of the growth of lake trout from Twin Lakes, Colo. (1964 to 1974).

percent of the average. This is a small difference, and growth rates during the first year of life for these lake trout are fairly constant, with an overall trend that is increasing. Following the first year, the growth increment has fluctuated around the mean a maximum of 30 percent, with the majority of differences within 12 percent. Except for the period 1964 to 1968, the growth increment per year has been relatively constant. Overall, there has been a general trend upward in the yearly growth increment over the past 10 years. The large differences during the period from 1964 to 1968 for both the first year of growth and the second and later years of growth are probably the result of small sample size for these years. The general upward trend in the annual growth increment over the entire period may be due to the establishment of *Mysis relicta* in the lakes during 1957. By 1964 these food items may have already been contributing significantly to the diet of the lake trout.

A comparison of average TL (total length) of each age class of the lake trout captured during this study (table 1) with data collected by Nolting [4] indicates that growth for fish 1 to 5 years old was faster in Twin Lakes. The availability of a new food source, *Mysis relicta*, is the most obvious reason for this increased growth. Fish 6 years and older showed about the same growth rate during both studies.

Validity of aging by scales.—Aging lake trout by detecting annulus formation on scales is a well-established procedure [2, 17]. Determining ages by this method was fairly easy for those fish 1 to 6 years old. However, scales from older fish were quite difficult to read as crowding of annuli near the edge of the scale was fairly common, especially in fish 8 years or older. For this reason the scales of older fish were read very carefully at least three times each to assure accuracy. Attempts to check scale readings with ages of known-age fish were not successful, since no older known-age fish were captured. In those cases where the ages of the captured fish were known, ages determined by scale reading always agreed. These known-age fish were from the 1971 plant and could be identified by an adipose-fin clip.

Age composition and year-class strength.—The dominant class in the 1974 collection was the 1971-year-class which made up 41.59 percent of the lake trout sampled. Of this class, 52 percent were males and 48 percent were females. In order of abundance, based on gill net catches for 1974, the 1971-year-class ranked first (41.59 percent); then 1970 (23.9 percent); 1972 (18.6 percent); 1969 (6.6 percent); 1968 (4.0 percent); 1973 (2.7 percent); and other (2.6 percent).

Age composition of the samples in 1974 and other years is illustrated in table 6. Even though fish captured by all means are listed in table 6, the numbers also reflect the relative abundance of each age group in the gill net samples. Because few large fish were caught during the netting operations, it was

Table 6.—*Average total length of lake trout from Twin Lakes in different years of capture and for all years combined*

Age group	Item	Year of capture 1970	1971	1972	1973	1974	1975	Average length	No. in age group
I	TL (mm)	–	–	173	–	209	–	200	
	No.	–	–	2	–	6	–		8
II	TL (mm)	–	249	–	230	258	–	246	
	No.	–	1	–	34	47	–		82
III	TL (mm)	306	322	310	314	319	–	318	
	No.	4	15	1	39	95	–		154
IV	TL (mm)	358	381	376	391	398	–	389	
	No.	10	19	8	47	58	–		142
V	TL (mm)	432	445	427	443	431	–	438	
	No.	4	14	26	53	14	–		111
VI	TL (mm)	462	564	483	468	499	–	498	
	No.	1	6	5	10	16	–		38
VII	TL (mm)	610	686	–	622	580	587	595	
	No.	1	1	–	3	11	3		19
VIII	TL (mm)	709	737	–	572	677	655	669	
	No.	1	1	–	1	2	2		7
IX	TL (mm)	–	908	–	–	713	786	790	
	No.	–	2	–	–	3	2		7
X	TL (mm)	–	858	–	–	813	888	847	
	No.	–	2	–	–	3	2		7
XI	TL (mm)	–	826	–	–	–	869	840	
	No.	–	2	–	–	–	1		3
XII	TL (mm)	–	–	–	–	840	1000	920	
	No.	–	–	–	–	1	1		2

necessary to acquire additional scale samples from fish of this size from fishermen catches and nets set especially to capture larger fish.

Age at maturity.—Records of the sex of fish collected prior to 1973 are sketchy and incomplete. Data that included the sex of the fish captured during that time were combined with the data collected during 1974 and 1975. The youngest mature male captured was 4 years old. Of all 4-year-old males captured, 20.9 percent were mature, 57.9 percent of the 5-year class were mature, 71.4 percent of 6-year-olds were mature, and all males older than 6 years of age were mature. The youngest mature female examined was also 4 years old, with 8.1 percent of all 4-year-old female fish being mature. Fifty percent of the 5-year-old female fish were mature, and 66.7 percent of the 6-year-old females were mature. No samples of 8-year-old female fish were collected, but those of 9 years and older were all found to be mature fish.

Lake trout in Twin Lakes mature early when compared to trout from other fisheries, where some lake trout do not mature until their 13th to 17th year [2]. Early maturing lake trout have been reported by others. Martin [18] found that slower growing lake trout (which fed primarily on plankton) matured at a younger age and smaller size than fish whose diet consisted primarily of fish. Twin Lakes lake trout are not primarily plankton feeders; however, much of their diet is not fish.

Length-weight relationship.—No difference was found between male and female lake trout of all ages; consequently, the data were combined and divided according to size classes (table 7) to make the data more manageable. A least-squares-regression (fig. 6) yielded the formula:

$$\ln W = 3.17 \ln L - 12.81$$

where

W = weight in grams, and
L = total length in millimetres.

The correlation coefficient was 0.99. In comparison with lake trout of other lakes as reported by

Table 7.—*Length classes, mean total length of class, mean weight of class, ln (natural log) of mean length and weight, and condition factor (K) of lake trout from Twin Lakes, Colo.*

Length class (mm)	No. of fish in class	Mean TL (mm)	Mean Wt (g)	ln of $\overline{TL}$	ln of $\overline{Wt}$	K
170-179	1	177.0	37.0	5.18	3.61	0.667
180-189	–	–	–	–	–	–
190-199	3	193.0	63.7	5.26	4.15	0.886
200-209	4	206.5	69.5	5.33	4.24	0.789
210-219	4	215.0	67.7	5.37	4.22	0.681
220-229	3	227.0	82.0	5.42	4.41	0.701
230-239	3	232.3	94.3	5.45	4.55	0.752
240-249	–	–	–	–	–	–
250-259	4	256.3	135.8	5.55	4.91	0.807
260-269	7	264.7	147.0	5.58	4.99	0.793
270-279	12	274.8	159.1	5.62	5.07	0.767
280-289	9	282.6	168.8	5.64	5.13	0.748
290-299	15	294.2	191.8	5.68	5.26	0.753
300-309	15	304.7	215.7	5.72	5.37	0.762
310-319	14	314.2	235.7	5.75	5.46	0.760
320-329	18	324.4	258.0	5.78	5.55	0.756
330-339	14	334.5	271.8	5.81	5.61	0.724
340-349	6	344.8	317.8	5.84	5.76	0.775
350-359	8	354.0	341.0	5.87	5.83	0.769
360-369	6	362.8	379.5	5.89	5.94	0.795
370-379	9	372.1	376.1	5.92	5.93	0.730
380-389	6	382.0	435.2	5.94	6.08	0.781
390-399	6	394.2	451.2	5.98	6.11	0.737
400-409	14	404.6	487.1	6.00	6.19	0.735
410-419	10	414.8	534.9	6.03	6.28	0.749
420-429	12	424.7	565.6	6.05	6.34	0.738
430-439	5	434.8	614.6	6.07	6.42	0.748
440-449	3	442.7	648.0	6.09	6.47	0.747
450-459	8	454.5	668.4	6.12	6.50	0.712
460-469	3	464.7	781.7	6.14	6.66	0.779
470-479	3	471.3	805.0	6.16	6.69	0.769
480-489	2	485.0	857.0	6.18	6.75	0.751
490-499	1	498.0	998.0	6.21	6.91	0.808
500-509	3	501.3	1069.5	6.22	6.97	0.848
510-519	1	510.0	863.0	6.23	6.76	0.651
520-529	1	527.0	1087.0	6.27	6.99	0.743
530-539	1	537.0	1308.0	6.29	7.18	0.845
560-569	3	566.7	1520.0	6.34	7.33	0.835
600-610	1	604.0	1940.0	6.40	7.57	0.880
610-619	1	614.0	2050.0	6.42	7.63	0.886
620-629	1	624.0	2180.0	6.44	7.69	0.897
690-699	1	693.0	3370.0	6.54	8.12	1.013
710-719	1	719.0	3300.0	6.58	8.10	0.888
750-759	2	752.0	3875.0	6.62	8.26	0.911
770-779	1	775.0	4380.0	6.65	8.38	0.941
790-799	1	790.0	4300.0	6.67	8.37	0.872
800-810	1	800.0	5902.0	6.68	8.68	1.153
840-849	1	840.0	6123.0	6.73	8.72	1.033

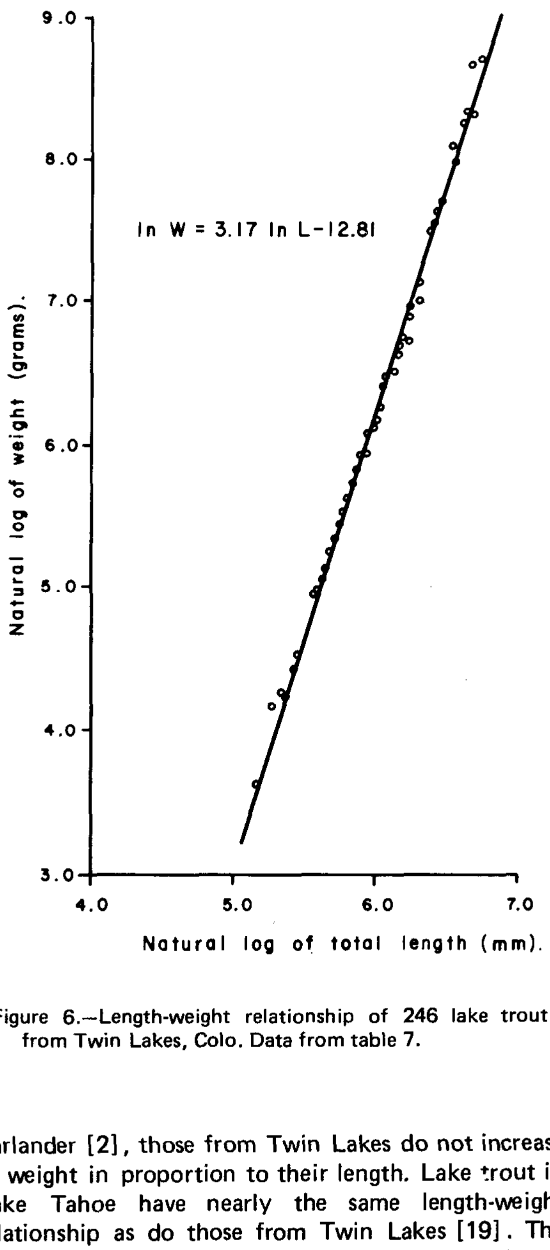


Figure 6.—Length-weight relationship of 246 lake trout from Twin Lakes, Colo. Data from table 7.

Carlander [2], those from Twin Lakes do not increase in weight in proportion to their length. Lake trout in Lake Tahoe have nearly the same length-weight relationship as do those from Twin Lakes [19]. The lake trout of Lake Tahoe are considered to be slower growing than other lake trout and it was felt that inadequate transitional food was the cause of the slower growth. Lake trout in Twin Lakes show the same growth pattern but not to the same extent. Lake trout in Twin Lakes feed heavily on *Mysis relicta* and do not make the transition to eating fish until much later than most other populations of lake trout.

Condition factor.—The condition factor for each size class (table 7) shows a gradual increase in plumpness as the fish become longer. A difference was found between the average condition factor for those fish under 413 mm and those over 413 mm total length. This total length approximates the minimum size of lake trout that were thought to be mature. The difference in condition factor between these size classes reflects the plumper shape of mature fish, which have greater development of gonadal tissue. This difference in K may also reflect the greater utilization of fish in the diet of older fish. A grand average condition factor of 0.760 with a 95-percent confidence interval of 0.756 to 0.764 reflects a slower weight gain in relationship to total length of Twin Lakes lake trout and also reflects the slimmer shape of these fish. The condition factor for immature fish remains fairly constant throughout the year, while the condition factor for mature fish drops somewhat after the spawning period, reflecting the loss of weight due to reduction of gonadal tissues.

Food Habits

The food habits of lake trout in Twin Lakes have been investigated several times. In 1907, Juday [1] examined the stomachs of several lake trout, finding a trout (species unknown) in one stomach and nothing in the others. From 1958 to 1959, Nolting [4] conducted a food habits study, finding that lake trout up to 381 mm (15 in) fed primarily on insects (Diptera) and fish. This analysis was based on size classes rather than ages, although a comparison may be made if the first class of 127 to 378 mm is considered the 1- to 4-year-old size range, 381 to 632 mm the 5- to 10-year-old size class, and 635 to 965 mm the 11-year-old and older size class. Of these, 7.6 percent in the first class, 36.3 percent in the second, and 61.0 percent in the third class had fish remains in their stomachs. The next major food item found were Diptera larvae, which occurred in at least 40 percent of the stomachs in each class. In comparing these data with those of tables 8 and 9, there is a marked reduction of the percentage occurrence of both these food items in the stomach samples collected during 1974. Examining the percent of the total volume of each food item indicates that fish provided the majority of the volume, even though occurring infrequently.

Mysis was introduced into Twin Lakes during 1957, but probably did not contribute significantly to the food of the lake trout until several years later [20]. In stomach samples from fish collected in 1974, *Mysis* was found in fishes of all ages, the frequency of occurrence decreasing as the age of the fish increased (fig. 7). Along with this decrease, there appears to be a corresponding increase in the frequency of occurrence of fish in the stomach samples (fig. 7).

Table 8.—*Food of lake trout from Twin Lakes, Colo., from May 1974 to May 1975*[1] *(based on percent of occurrence, number, and volume)*

Category	Occurrence	Number	Volume
Insecta			
Terrestrial			
Vespidae	0.5	*	*
Chalcidae	0.5	*	*
Muscidae	0.1	*	*
Formicidae	2.4	*	*
Lyaaeidae	0.1	*	*
Aquatic			
Chironomidae			
larva	26.3	3.2	0.3
pupae	22.5	33.4	5.8
adult	*	*	*
Hymenoptera	0.1	*	*
Elimidae	0.5	*	*
Trombidiformes	0.5	*	*
Chrysomelidae	*	*	*
Lepidoptera	0.5	*	*
Syrphidae	0.5	*	*
Tricoptera	0.5	*	*
Mollusca			
Gastropoda	10.5	0.4	*
Arthropoda			
Mysis relicta	87.6	62.2	22.7
Gammarus sp.	0.1	*	*
Pices			
Unknown	2.9	*	*
Salmo gairdneri	1.4	*	20.2
Catostomus commersoni	6.2	0.2	49.6
Salvelinus namaycush	0.5	*	0.9
Other			
Vegetation	6.7	0.2	0.5
Bait, fish eggs, corn, and fish	2.4	*	0.4

[1] Of the 216 stomachs examined, 209 contained food.
* Less than 0.1 percent.

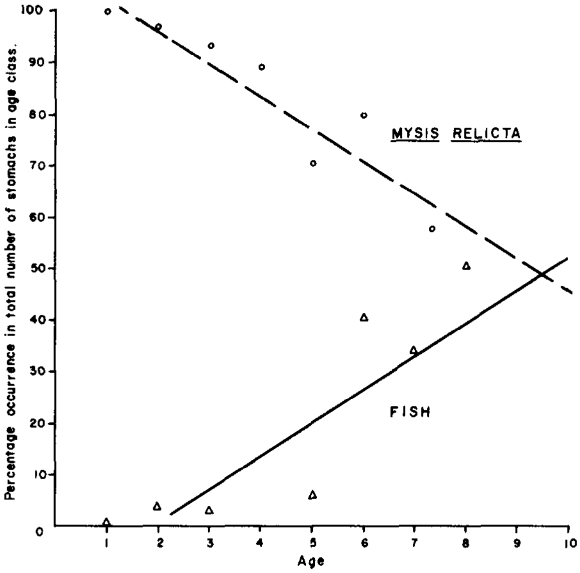


Figure 7.—Comparison of the frequency of occurrence of fish and *Mysis relicta* in the stomach samples of 209 lake trout from Twin Lakes, Colo.

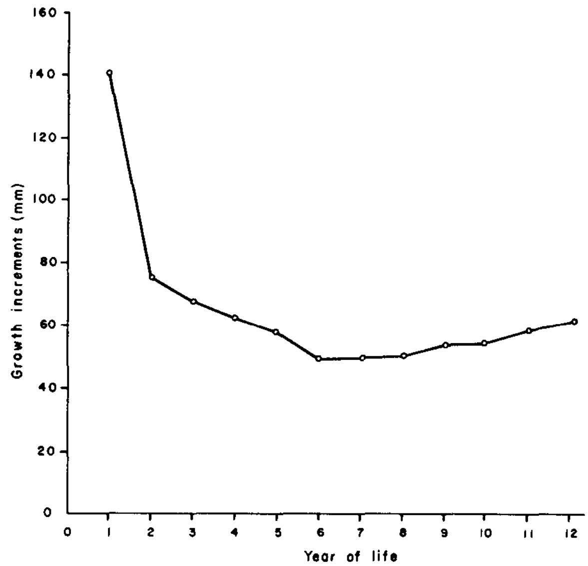


Figure 8.—Calculated increments of growth, in length, for each year of life for 580 lake trout from Twin Lakes, Colo.

Daly [21] found lake trout collected from Lake Superior as long as 330 mm still feeding on *Mysis*. Royce [22] found lake trout feeding on *Mysis* until they attained a length of about 254 mm, and then switching to a primarily fish diet. Twin Lakes lake trout rely on *Mysis relicta* as a source of food at all lengths.

Chironomid larvae and pupae were found in large numbers in the stomach samples (tables 8 and 9). It should be noted, however, that the incidence of chironomid pupae was greatest during mid-June, coinciding with their emergence period. Terrestrial insects do not appear to contribute significantly to the diet of these lake trout. The presence of small freshwater clams and chironomid larvae indicates that the lake trout often feed near the bottom.

The most frequently eaten fish was the white sucker, with rainbow trout also being consumed. The Colorado Division of Wildlife supplements the rainbow trout population by frequent stocking during the summer months. Local fishermen report that the lake trout feed heavily on stocked rainbow trout; however, this study does not confirm that belief. It is possible that a larger sample size of older, larger fish might indicate a greater utilization of these rainbow trout.

Twin Lakes lake trout between 5 and 8 years old appear to have a period when their growth rate is slower than that for 0 to 5 and 8 to 12 years old (fig. 8). This leveling off of the growth rate may be due to the continued reliance on *Mysis* as a major food item to the exclusion of fish. This reliance appears to continue until around the ninth year of life as indicated by the percent occurrence and percent total numbers of *Mysis* in the stomach samples. After the ninth year of life, the percentage occurrence of fish in the samples is much greater than that of *Mysis relicta*, reflecting a greater utilization of fish as a food source at this time.

Mortality and Survival

The instantaneous mortality rate was calculated for each of the sampling periods and for all samples combined, using the total hours and number of nets as one effort (table 10). This method involves computing the linear regression of age (X) against numbers caught (Y).

Ninety-five percent confidence limits for instantaneous mortality rates for the time periods examined were: May—0.540 to 0.846; August—0.0 to 2.944; November—0.175 to 1.984; and for the total—0.357 to 1.279.

Ssentongo and Larkin [13] used the relationship between the average age of the catch and the age at first capture to estimate mortality (i). Presumably, the closer these variables are, the higher the mortality. The formula used is:

$$i = \frac{1}{\bar{t} - t_c} \; \frac{n}{n+1}$$

Table 9.—*Summary of stomach contents of lake trout sampled from Twin Lakes, Colo., from May 1974 to May 1975*

Number of stomachs examined	4		31		73		53		17		15		12		2		1		1	
Size classes of fish	I		II		III		IV		V		VI		VII		VIII		IX		X	
	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O	%A	%O
Terrestrial insects	–	–	*	3.2	4.5	3.9	5.7	*	–	–	–	–	–	–	–	–	–	–	–	–
Aquatic insects																				
Chironomidae																				
larvae	–	–	3.3	48.4	7.4	41.1	3.5	13.2	–	–	*	20.0	–	–	–	–	–	–	–	–
pupae	18.2	75.0	5.2	19.4	8.1	26.0	41.6	15.1	64.5	17.6	71.5	33.3	78.8	25.0	–	–	–	–	–	–
adult	–	–	–	–	*	4.1	*	3.7	–	–	–	–	–	–	–	–	–	–	–	–
Hymenoptera	–	–	–	–	*	2.7	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Elimidae	–	–	–	–	*	1.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Trombidiformes	–	–	–	–	*	1.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Chrysomelidae	–	–	–	–	*	4.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lepidoptera	–	–	–	–	*	1.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Syrphidae	–	–	–	–	*	1.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tricoptera	–	–	–	–	*	1.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Mollusca																				
Gastropoda	–	–	1.1	12.9	1.1	17.8	*	9.4	–	–	–	–	–	–	–	–	–	–	–	–
Arthropoda																				
Mysis relicta	81.8	100.0	90.3	96.8	82.1	93.2	52.3	88.7	34.1	70.6	27.7	80.0	20.9	58.3	99.5	100.0	–	–	100.0	100.0
Gammarus sp.	–	–	*	3.2	–	–	–	–	*	5.9	–	–	–	–	–	–	–	–	–	–
Pices																				
Unknown	–	–	–	–	*	1.4	*	1.9	–	–	*	13.3	*	16.7	–	–	–	–	–	–
Salmo gairdneri	–	–	–	–	–	–	*	1.9	–	–	*	6.7	–	–	–	–	100.0	100.0	–	–
Catostomus commersoni	–	–	–	–	–	–	*	9.4	*	5.9	*	20.0	*	16.7	*	50.0	–	–	–	–
Salvelinus namaycush	–	–	*	3.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Vegetation	–	–	–	–	–	–	*	3.7	*	5.9	*	13.3	–	–	–	–	–	–	–	–
Bait	–	–	–	–	–	–	*	5.7	–	–	–	–	–	–	–	–	–	–	–	–

* Less than 0.1 percent

%A = the percent of total number of food items present in all stomachs

%O = the percent of stomachs in which a food item occurred

Table 10.—*Lake trout gill net collection at Twin Lakes, Colo., 1974, arranged by date of capture and age at capture*

Date	Age										Total	No. of marked fish*
	1	2	3	4	5	6	7	8	9	10		
May	–	6	12	16	7	4	**–	–	2	1	48	1
August	4	8	30	12	2	4	**1	–	–	–	62	2
November	2	30	52	25	6	**1	1	–	–	–	117	3
Total	6	44	94	53	17	9	2	–	3	1	227	6

* Adipose-fin-clipped fish from the 1971 plant.
** Brackets denote that portion of the data used to compute the instantaneous mortality rate (i) by the method of Ricker [23].

where

$\bar{t}$ = the average age of the catch,
t_c = age of first capture, and
n = number of fish caught.

For this study, t_c was set equal to two (table 10), $\bar{t}$ was equal to 3.90 in May, 3.68 in August, 3.26 in November, and 3.51 for the total. These values were computed from the data in table 10. Ninety-five percent confidence limits for the instantaneous mortality rates for the sample periods and the total were: May–0.506 to 0.527; August–0.568 to 0.606; November–0.779 to 0.800 and the total–0.655 to 0.667. These rates all overlap with the confidence limits set for those rates computed using the catch curves. Because the use of the total catch in the second method allows the use of 226 degrees of freedom, which facilitates the narrowing of the confidence limits, this estimate of the instantaneous mortality rate was used. This estimate of mortality (i) is 0.661, which has a corresponding annual mortality rate (a) of 0.484. These estimates are based on the combined rates of both natural and fishing mortality, and may be somewhat high for those fish under the legal size limit of 381 mm (15 in). Hooking mortality of fish under the legal size limit may be a contributing factor here, but no data are available to evaluate what portion of the mortality rate is due to this factor.

Population Estimate

Several attempts were made to estimate the lake trout population size in Twin Lakes using mark and recapture methods. In the population estimate efforts, an attempt was made to mark as many fish as possible. This proved to be very difficult since capture by gill nets resulted in high mortalities (25 to 30 percent) and capture by hook and line was slow and resulted in an excessively large number of small fish being caught. Using both methods, approximately 250 fish were marked and returned to the lake.

During the recapture period, no marked fish were caught. This can be attributed to several factors. If the fish learned to avoid the nets after being caught once, a much lower rate of return would result; however this did not appear to be the case in this instance, as fish that had been marked in earlier studies were recaptured. A second possibility is that there is an increased mortality of fish that have been handled and tagged. A third factor is that the numbers of fish marked and returned to the lake are such a small percentage of the total population that any returns would be the exception rather than expected. This last element is believed to be the primary cause of the lack of returns.

If a constant mortality rate is assumed for all ages of fish and for preceding years, there is a way that a marked population of fish already in the lake can be used to represent the marked population for a mark and recapture study. In 1971, 15 480 4- to 6-inch fish were stocked in Twin Lakes. If 10 percent of this number is subtracted for handling mortality, and the instantaneous mortality rate of 0.661 is applied to the remaining number of fish using the formula

$$N_t = N_o e^{-it} \quad [9]$$

it is possible to estimate the number of these fish remaining in the lake at the time the 1974 samples were collected. Remembering that these stocked fish were all adipose-fin clipped, the number caught in the nets bearing this mark becomes the recaptures, while the number calculated by using the instantaneous mortality rate becomes the population of the marked fish at large. Because of the small number of recaptures, a Schnabel-type estimate was used to fully utilize the number of recaptures obtained. The data in table 10 were used to determine total catch (C_t). Population levels of the marked fish were calculated to be 2390 in May 1974; 2026 in August 1974; and 1718 in November 1974. Using the formula given in Ricker [9] for a Schnabel estimate, a population estimate of 73 556 was calculated. Treating the recaptures as a Poisson variable, the 95-percent confidence limits were constructed to be 33 690 to 200 608. These confidence limits are wide as a result of having only six recaptures.

This population estimate is of limited value because of such wide confidence limits placed on it; however, it is the best estimate at the present time. Any variation in the mortality rate, hence the population estimate, of the adipose-fin-clipped fish would have an effect on the size estimate of the overall population. The basic assumption is that the fin-clipped fish suffer the same mortality rate as the rest of the population. This is not entirely true since the fin-clipped fish have not yet reached the legal size limit and, therefore, do not suffer any fishing mortality aside from accidental hooking. The estimate of the number of marked fish at large is probably too low, thus making the overall estimate too low. If there is differential mortality between the fin-clipped and unclipped fish, this could cause an overestimation of the population due to there being fewer marked fish present than calculated. For the above reasons, little confidence is placed on the population estimate in the lake.

Recruitment

Recruitment is defined as those fish entering the catchable population. The legal size limit for lake trout in Twin Lakes is 381 mm (15 in), with no weight restrictions. From the back-calculations in table 2, it can be seen that fish whose length is 381 mm are nearly 4 years old. The length of fish when captured also indicates that fish of 381-mm length are between their fourth and fifth years of life. The length frequency distribution (table 4) shows a considerable overlap between ages 3, 4, and 5. The conclusion from this is that, on the average, it takes 4 years for a fish to reach the legal size limit. If the mortality rate is applied to an initial number of fish over a period of 4 years, using the formula $N_t = N_o e^{-it}$, the number reaching catchable size (those remaining after 4 years) are about 7 percent of the initial-year-class size.

The quantity of fish entering the catchable population each year may be estimated by using the same logic and calculations as that for the population estimate. By using the number of 3-year-olds in the catch as the catch, and comparing the number of adipose-fin-clipped fish with these (in a Schnabel estimate), an estimate of the number of 3-year-old fish can be made. Then by applying the annual mortality rate, an estimate of the number of 4-year-olds can be made. Based on factors previously discussed, this estimate was determined to be 15 550 four-year-olds, or about 20 percent of the population. This agrees fairly well with the relative abundance of 4-year-olds, which made up 23.3 percent of the total catch (table 10). Again, it should be noted that a low degree of confidence is placed on the actual figures of recruits entering the population each year, but that the percentage of the population reaching legal size is felt to be reasonably accurate.

Reproduction

Loftus [24] and others have reported lake trout spawning in streams, although the majority of observations of this act have been in lakes and reservoirs. Eschmeyer [25], Martin [18], DeRoche [34], and Royce [22] have reported that spawning in lakes most often occurs over large boulders and/or rubble bottoms. These locations are primarily determined by currents and wind action which keep them clear of sand and mud [35].

Spawning of lake trout in Twin Lakes has been observed near shore in 3 to 10 metres of water [4]. There is considerable boulder and rubble bottom along the north shore and along the west shore of the south bay in the lower lake. Nolting observed lake trout spawning in the two bays of the lower lake, capturing 42 spawners in November (7 to 9 and 11 to 14) 1958, and 37 spawners from October 26 to November 1, 1959. Ninety-four spawners were captured in 1960; 40 in the lower lake and 54 in the upper lake. Temperatures during these periods ranged from 6.1 to 7.8 °C.

During the last week of October 1974, 3/4-inch-bar-measure gill nets were set in the areas mentioned above. The nets were placed in varying depths of water in an area known to have been used in the past by the lake trout to spawn. Water temperature during this period ranged from 9 to 14.2 °C, depending on the depth at which the nets were set. Very few mature fish were captured during several days of netting, and those that were had already spawned. After several more days of netting, no ripe fish were caught and it was concluded that spawning had already taken place.

In 1975, beginning in the early part of October, nets were set once a week in known spawning areas in an

Table 11.—*Stocking records for Twin Lakes, Colo., from 1953 to 1974. (Compiled from Colorado Division of Wildlife records, Denver, Colo.) (1 inch = 25.4 mm)*

Year	Size (inches)	Species			Remarks
		Kokanee	Rainbow	Lake trout	
1953	0-2		26 810		
	6+			71 780	
1954	0-2	100 400			
	6+		63 100		
1955	0-2	706 112			
	6+		40 050		
1956	0-2	199 680			
	6+		50 757		
1957	0-2	201 824			
	6+		68 145		
1958	0-2	200 000			
	6+		53 395		
1962	0-2	157 050			
	4-6			11 480	29 380 Kamloops (6+) stocked in May
	6+		91 700	6000	
1963	0-2	44 000			
	2-4		178 000		
	6+		60 800		
1964	0-2				13 380 Natives (cutthroat)
	6+		72 765		
1965	0-2		203 825		
	6+		67 800		
1966	0-2				25 000 Cutthroat
	4-6			6800	
	6+		129 600		
1967	0-2			50 000	110 700 Fathead Minnows
	6+		106 550		
1968	0-2			12 250	
	6+		95 100		
1969	0-2	212 000			
	6+		205 850		
1970	0-2	135 000	203 900	3294	
	6+		168 240		
1971	4-6			*15 480	2500 Bonneyville Cisco
	6+		230 250		
1972	4-6		102 100		
	6+		215 000		
1973	0-2	252 000			
	3-6			35 100	
	6+		208 360		3400 Bonneyville Cisco
1974	0-2	353 400			
	6+		89 840		

* Marked w/adipose-fin clip

attempt to determine the onset of spawning. No mature fish were captured at this time, indicating that either the lake trout had not moved into the area to spawn or that they were using areas not sampled with the nets. Spawning must have occurred between the third week and the end of October (approximately 9 days), since only spent fish were captured during the first week of November. The shortness of the spawning period and the rapid onset of spawning activity is believed to have been caused by a drop in temperature due to a storm moving into the area during this period. Royce [19] reported that spawning of lake trout has been advanced by lower temperatures and cloudy days. Different races of lake trout apparently spawn at different temperatures and also at different depths. These races of trout also show differences in the durations of their spawning periods [2]. Twin Lakes has been stocked with lake trout from various locations and there is high probability that several races exist in the lake.

Because so few fish were captured during the spawning periods of 1974 and 1975, estimates of fecundity and sex ratios were not possible. Nolting [4] was able to capture a number of spawners in 1958 and 1960. Their average total length in 1958 was 749 mm (29.5 in) and average weight was 5.2 kg (11.4 lb). Average number of eggs per kilogram of body weight was 781.8. In 1960, average body weight was 5.2 kg (11.4 lb) and the average total length was 785 mm (30.9 in). Average number of eggs per kilogram of body weight was 1284.6. These averages were calculated from 10 fish in 1958 and 14 fish in 1960. The sex ratios were three males to one female in 1958 and two males to one female in 1960.

Spawning success was difficult to measure since no samples of young-of-the-year were taken. This was attributed in part to the methods employed in trying to capture these fish. Sampling of deposited eggs was also difficult because of the areas and bottom type used. The success of spawning of Twin Lakes lake trout can be inferred by comparing the composition of the catch (tables 6 and 10) with the stocking records (table 11). In 1969, there were no lake trout stocked, but, from 1972 to 1974, fish of this year-class were caught in gill nets. In 1973, this year-class was approximately 25 percent of the catch. In 1972, there were no lake trout stocked, but in 1974 approximately 20 percent of the catch were fish of this year-class. Another indication of the spawning success is found by comparing the number of fish of the 1971-year-class with fish of the same year-class that were stocked and had their adipose fin clipped. Of all the samples taken during 1974, only 6 out of 94 fish had been adipose-fin-clipped. The remaining 88 represent those fish resulting from natural reproduction.

Impact of Mt. Elbert Pumped-Storage Powerplant on the Lake Trout Population

Operation of the plant.—The pumped-storage powerplant being built at Twin Lakes, like all such plants, has two cycles of operation. During periods of low power demand, water will be pumped uphill from Twin Lakes into a forebay above the plant. Then, during periods of high power demand, the water will be allowed to flow back downhill from the forebay through the powerplant into the lake, generating electricity as it passes through the plant's turbines.

The forebay is located on a ridge approximately 150 m above the Mt. Elbert Powerplant. Fluctuations in water levels for the forebay will be near 4.5 m maximum, with a maximum fluctuation of 0.67 m for lower Twin Lake. Historically, since placement of the controlled outlet structure, Twin Lakes has had a yearly fluctuation of around 5.5 m, with maximum levels usually occurring in the late spring and minimum levels during late summer.

To determine the effect that the tailrace channel design would have on the flow patterns of the water as it leaves and enters Twin Lakes, the Bureau of Reclamation's Engineering and Research Center conducted extensive tests of different types of channels, using models that could be monitored for changes in temperature and water velocities [26].

By the use of these models, a tailrace channel was designed that angles 27° south of the centerline of the plant and has a bottom width of 18 m and a side slope of 3 to 1. Where the channel enters the lake, a berm 1.5 m high and 3.0 m wide will be constructed across the channel. This berm will serve to deflect the water flowing into the lake away from the bottom sediments. Model tests indicate that there will be no appreciable change in the thermal stratification of the lakes, except in the local area of the tailrace channel [26].

The effects on the glacial flour deposits of the water entering Twin Lakes during the generating cycle were tested by the use of the models and dye tracers. Results of these tests are inconclusive. The possibility does exist that water from the forebay, if much colder than the lake waters, could dive to the bottom and disturb the glacial flour. Once these deposits are resuspended it would be very difficult to get them to settle out while continuing the daily pumping and generating cycles. The berm at the end of the tailrace channel should reduce the likelihood of this happening.

Effects of powerplant operations on lake trout.—Factors affecting the growth, survival, and reproduction of the lake trout that could be influenced by the operation of the Mt. Elbert Powerplant include: (1) food habits of the lake trout, (2) thermal stratification of the lakes, (3) turbidity caused by resuspension of bottom sediments, and (4) entrainment of fish and fish products by the plant.

Gregg [20] indicated that substantial numbers of *Mysis* may be entrained by the Mt. Elbert Powerplant and that they would suffer a high degree of mortality. Whether or not the numbers of *Mysis* entrained will be large enough to reduce their population in the lake to the point that they no longer can be utilized as a major food source by lake trout is not known. At the present time, *Mysis* contribute significantly to the diet of the lake trout, especially during the winter months. The disappearance of these organisms would definitely have a negative affect on the growth rate of these fish. However, there is also the possibility that reduced availability of *Mysis* would force the remaining lake trout to better utilize the forage fish present to a greater extent, possibly shortening or eliminating the "transitional period" noted by reduced growth between their fifth and ninth years.

Disruption of the thermal stratification is not foreseen as a problem except in the immediate vicinity of the plant.

If resuspension of glacial flour deposits occurs, it would have an adverse effect on the lake trout growth and reproduction. Lake trout are primarily sight feeders [27], and an increase in turbidity would affect their efficiency in foraging for food, resulting in a slower rate of growth.

Lake trout spawn on clean rock rubble or gravel [22] which allow the eggs to roll into crevices for protection. Lake trout are not capable of cleaning sediments from these crevices and a resuspension of the glacial flour with a later settling out would make present spawning areas unattractive for spawning. If this causes lake trout to spawn in unsuitable areas, egg survival would be decreased.

The relationship between primary productivity and fish production is well documented [28]. Increased turbidity may cause a reduction of primary production because of reduced light penetration. Effects on the lake trout would be difficult to assess and the turbidity would necessarily have to be of long duration. Another possible danger of the resuspension of these sediments would be the release of nutrients stored in them into the lake. This could cause an increase in biological oxygen demand, thus lowering the oxygen concentration in the lake. The degree to which the oxygen concentration would be lowered cannot be estimated, but it is conceivable that it could be low enough to have an adverse effect on the fish and their eggs. An increase in the turbidity could also increase the concentrations of heavy metals which have been found in the bottom sediments [29, 30]. The resuspension of these metals could have an adverse effect on fish mortality and the survival of their eggs.

Entrainment of fish and fish eggs is a definite possibility. Marcy [31], Liston [32], and McNatt [33] have found entrainment of fish and fish products by pumped-storage powerplants. Liston observed a 55- to 65-percent mortality of fish passing through a powerplant during the pumping cycle and a 40-percent mortality during the generating cycle. The combined mortality rate for fish passing through the powerplant during both cycles was 74 percent. At the present time, the installation of protective devices to reduce entrainment of fish and fish products at the Mt. Elbert Powerplant is not contemplated because the problems of installation and maintenance of such devices make them impractical.

During the past few years, downstream losses of lake trout from Twin Lakes have been observed [8]. These losses have occurred during periods of high outflow. It is possible that these lake trout were attracted to the outflow by the current caused by release of this water. If this is the case, lake trout may be attracted to the plant during the pumping cycle and subsequently entrained.

Gregg [20], in his studies of the effect of turbulence on *Mysis*, reported that these organisms have a negative reaction to turbulence, and will try to avoid it if possible. This may have a beneficial effect on the lake trout. If the *Mysis* move away from the tailrace channel and the area of the powerplant, lake trout may not frequent the area in search of food, thus reducing the likelihood of their entrainment.

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ABSTRACT

Growth, survival, reproduction, recruitment, and food habits of lake trout in Twin Lakes, Colo., were examined during 1974-1975 to document the status of the trout population prior to completion of a 200-megawatt pumped-storage hydroelectric powerplant being constructed on the lake. The powerplant will become operational during 1977, and data collected during this study will be compared to similar data collected during the post-construction period to determine the effect of plant operation on the trout population. Growth of lake trout in Twin Lakes is comparable to that of other lake trout fisheries in the Western United States, such as Lake Tahoe, Nev.-Calif., and Fish Lake, Utah, and is somewhat faster than most lakes located in Canada. Annual mortality was found to be near 50 percent, which compares with other lake trout fisheries of this type. Successful reproduction of lake trout was confirmed by the presence of age classes that had not been stocked. Approximately 90 percent of 4-year-old fish captured during the study were from natural reproduction. Lake trout reaching the legal size limit of 381 mm were usually 4-year-olds, with approximately 20 percent of the population reaching this size each year. Lake trout in Twin Lakes feed primarily on *Mysis relicta*. Chironomid larvae, white suckers, and rainbow trout are also eaten. Possible effects of powerplant operation on the lake trout population are outlined and discussed.

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