U.S. Fish & Wildlife Service

Seasonal distribution and size structure of lake trout in Hidden Lake, Kenai Peninsula, Alaska, 2011

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Kenneth S. Gates

Abstract

Radio and acoustic telemetry is currently being used in Hidden Lake to monitor movements of lake trout *Salvelinus namaycush* and identify spawning areas. Transmitters were deployed in 59 fish over 34 days between February and September 2011. Over half of the acoustic transmitters malfunctioned which reduced the number of transmitters active during the spawning period to seven. Capture methods included angling through lake ice during winter months and trolling from a motorized boat during the remainder of the tagging period. Angling hours and catch totaled 1,298 and 179, respectively. Of the captured fish, 178 were sampled for fork length, weight, girth, and genetics. Sampled fish averaged 1,512 grams in weight, 496 mm in length, and 263 mm in girth. Catch per unit effort varied among tagging periods and is somewhat indicative of fish densities as sampling methods were held constant. However, catch during February was greatly affected by angler experience. Tracking of tagged fish occurred using fixed receiver stations and boat tracking between 31 May and 10 November 2011. Acoustic-tagged fish were detected nearly 100% of the time throughout the tracking period, whereas detection rates for radio-tagged lake trout ranged between 5% and 62%. The distribution of tagged fish in Hidden Lake changed over the season with fish moving to deeper water during summer and moving towards presumed spawning areas in the fall. A second year of tagging and tracking will occur in 2012.

Introduction

Lake trout *Salvelinus namaycush* are important to many recreational fisheries throughout Alaska's lake systems. In southcentral Alaska on the Kenai Peninsula, Hidden Lake is the most popular lake trout sport fishery during most years (Mills 1990-1994; Howe et al. 1995, 1996, 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006 a-b, 2007, 2010 a-b). Hidden Lake is accessible by the Skilak Lake Loop Road and the Sterling Highway and is entirely within the Kenai National Wildlife Refuge (Refuge). Camping and fishing are popular in the area as a campground and boat launch adjacent to Hidden Lake provide easy access. Fishing for lake trout in Hidden Lake occurs primarily during early summer and winter.

Lake trout exhibit intricate life history characteristics and restrictive habitat requirements that make them vulnerable to overharvest which is why many Alaska lake trout fisheries are managed conservatively. They inhabit cold, deep, oligotrophic lakes and are characterized as long-lived and having slow growth rates, low fecundity, and females that exhibit alternate-year spawning regimes (Healy 1978; Martin and Olver 1980; Burr 1987; Szarzi 1993). Age at first maturity varies among lakes of different latitudes, and ranges between five and 10 years for interior Alaska lakes (Burr 1987). Similarly, length at maturity varies among lakes with males maturing at smaller sizes than females (Burr 1987).

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Assessments of lake trout in Hidden Lake have included gill netting efforts designed by the Alaska Department of Fish and Game (Department) to characterize size composition during 1960, 1961, 1965, 1967, 1975, and 1987; harvest creel surveys conducted by the Kenai Fish and Wildlife Field Office (KFWFO) during the winter of 1992, the summer of 1993, and May of 1994; and annual postal Statewide Harvest Surveys (SWHS) conducted by the Department (e.g. Jennings et al. 2007). Annual catch data for lake trout is limited to the SWHS since 1990.

Concerns of over-exploitation have prompted managers to adopt conservative lake trout harvest limits in Hidden Lake. Harvests of lake trout from Hidden Lake averaged 1,353 fish per year during the period 1977-1996 (Appendix 1; Begich and Pawluk 2007). In 1997, the harvest limit was reduced from 12 fish per day (only two of which could be 508 mm (20 inches) or larger) to two fish per day due to concerns of over-harvest. This resulted in a considerable drop in annual harvest. After the 1996 regulation change, harvest of lake trout in Hidden Lake averaged 371 fish per year between 1997 and 2007 (Begich and Pawluk 2007; Jennings et al. 2010a). The harvest limit for lake trout in Hidden Lake was reduced from two fish per day to one fish per day beginning in 2008 (Alaska Board of Fisheries 2008). Harvest has averaged 354 fish since the 2008 regulation change (Jennings et al. 2010b, Jason Pawluk, Alaska Department of Fish and Game, personal communication). Annual estimates of catch are only available since 1990 and have averaged 1,294 from 1990 to 2010 (range 437 to 2,393; Begich and Pawluk 2007, Jennings et al. 2010 a-b, Jason Pawluk, Alaska Department of Fish and Game, personal communication). In general, trends in harvest, catch, and effort have been similar in recent years (Appendix 1). The Department's objectives for this fishery are to provide angling opportunity at a level able to be maintained by the fisheries resource and habitat, and to ensure that the lake trout population does not decline below the level necessary for a sustained harvest (Begich and Pawluk 2007).

This study was designed in two phases with a goal of understanding the current life history and population dynamics of lake trout in Hidden Lake. Phase one will occur during 2011 and 2012 and will use radio and acoustic transmitters to locate spawning areas and to describe the general distribution and movements of tagged lake trout in Hidden Lake. Once spawning areas have been identified, the second phase of the study would determine the feasibility of conducting a mark-recapture abundance estimate of mature fish similar to Szarzi and Bernard (1997). Any future mark-recapture study designed to estimate the spawning population in Hidden Lake would require knowledge of spawning locations and movement of lake trout between these locations during the spawning period. Specific objectives for phase one of the project were to:

1. Identify suspected spawning areas selected by radio/acoustic-tagged lake trout within Hidden Lake;
2. Describe distribution and movements of radio or acoustic-tagged lake trout ≥ 450 mm in Hidden Lake;
3. Collect and describe the general biological characteristics (i.e. length, weight, girth, and genetic samples) of lake trout sampled in Hidden Lake.
4. Estimate the yield potential of lake trout in Hidden Lake.

In addition to the aforementioned objectives, there will be an attempt to validate suspected spawning areas during 2012 using multiple capture techniques, and to compare length, weight, and sex composition of all lake trout collected during 2011 and 2012 to creel survey data collected between 1992 and 1994. Because phase one of the study will continue through the 2012 field season, this report only includes preliminary findings pertaining to the telemetry (i.e.

tag deployment, tracking, and seasonal distributions), analysis of biological information collected to date (i.e. length, weight, and girth), and yield potential for Hidden Lake during 2011. No results are presented for some of the tasks outlined in the methods section (i.e. final fates, study periods, and distance traveled by radio-tagged fish). These findings will be presented in a final report that will be completed after the 2012 field season.

Study Area

Hidden Lake (60°29.08'N, 150°15.83'W; Figure 1) is the third largest lake on the Refuge with a surface area of 683 hectares, a maximum depth of 45.1 m, and a mean depth of 20.2 m (USFWS 1995). Hidden Lake is located in the Kenai River watershed and the outlet stream (Hidden Creek) drains into Skilak Lake. Hidden Lake is primarily fed by groundwater and lake water residence time is approximately 11.7 years (Kyle et al. 1990). In addition to lake trout, Chinook *Oncorhynchus tshawytscha*, coho *O. kisutch*, pink *O. gorbuscha*, and sockeye salmon *O. nerka* utilize Hidden Lake to some extent, although sockeye salmon are responsible for most anadromous fish production (Kyle et al. 1990). Rainbow trout *O. mykiss,* Dolly Varden *S. malma,* threespine stickleback *Gasterosteus aculeatus,* and coastrange *s*culpin *Cottus aleuticus* have also been documented in Hidden Lake (Kyle et al. 1990).

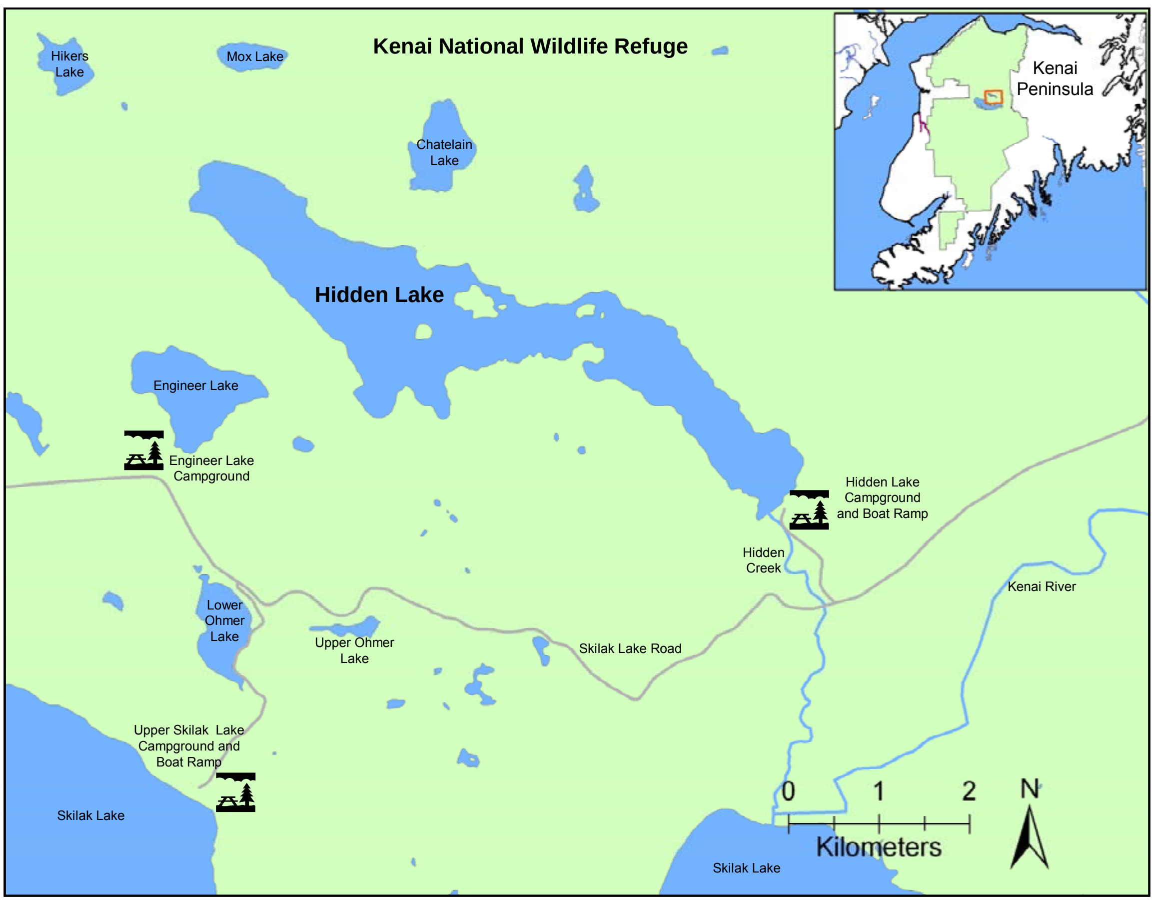

FIGURE 1. — Map of Hidden Lake, located within the boundaries of the Kenai National Wildlife Refuge, Alaska.

Methods

Radio and acoustic transmitters were used to uniquely identify and track movements of suspected male adult lake trout ≥ 450 mm throughout Hidden Lake. A sample size of 60 transmitters was the target goal and was based on available funds and the physical size of Hidden Lake. Deploying large numbers of radio transmitters in a relatively small lake like Hidden Lake would potentially create interference among tagged fish which could have resulted in a loss of information. Movements of tagged fish were documented using a combination of fixed telemetry stations and mobile tracking from boats. The presence of at least two tagged fish in an area during the fall spawning period was used to identify specific lake trout spawning areas. Other than visual observations during night time surveys, no attempt to date was made to capture the putative spawners and verify spawning activity. Twenty of the initial 60 transmitters were low (acoustic) frequency to facilitate tracking fish in water depths greater than 12 m. These transmitters were only active for one spawning season due to the limited battery life. The remaining transmitters operate at higher (radio) frequencies and will be active through two spawning seasons. A combination of acoustic and radio transmitters has facilitated tracking fish at all lake depths during the first year of the study and will provide insight into repeat spawning and spawning site fidelity during the second year. The original deployment scheme and life expectancy for each transmitter type is illustrated in Table 1. In general, this tagging scheme was accomplished and 59 transmitters were deployed by 2 September 2011.

TABLE 1.—Transmitter deployment scheme and expected number of active transmitters during 2011 and 2012.

Tagging Period	Transmitter Type	Estimated Battery Life (d)	Planned Sample Size	Actual Sample Size	Expected to be Active during Fall 2011	Expected to be Active during Fall 2012
Feb/Mar 2011	Radio	609	20	13	13	13
Feb/Mar 2011	Acoustic	371	10	9	9	0
May/Jun 2011	Radio	609	20	26	26	26
May/Jun 2011	Acoustic	371	10	9	9	0
Aug/Sep 2011	Acoustic	371	0	2	2	0
Total transmitters:			60	59	59	39

Fish Capture

Lake trout were captured using hook and line through the lake ice during February and March and by trolling the shoreline from a motorized boat during May, August, and early September. All 178 captured fish were measured for fork lengths and maximum girth to the nearest mm and weighed to the nearest gram. A portion of the pelvic fin ray was collected from 174 individuals and placed in 2 ml sample vials and preserved in 100% ethanol. The fin clip was used to distinguish between a previously captured and sampled fish and new fish. All genetic samples were submitted to the U.S. Fish and Wildlife Service's (Service) Conservation Genetics Laboratory and archived in Anchorage, Alaska.

Radio and Acoustic Telemetry

Radio and Acoustic Tagging.— Male lake trout ≥450 mm were targeted for tagging because they have been documented to spend longer periods of time on the spawning ground, comprise the majority of the spawners, and typically do not skip years between spawning events like females (Martin 1957; Healy 1978; Martin and Olver 1980; Burr 1991; Scanlon 2004). The sex of the sampled fish was difficult to ascertain with absolute certainty because lake trout show little sexual dimorphism especially as immature fish. Therefore, attempts were made to determine the sex of donated sport harvested lake trout by looking into the body cavity through an incision similar in size to incisions used during transmitter implantation. This method of determining sex was abandoned because gonads were not obvious due to low maturation levels and the extreme intrusiveness of this method. If permitted by anglers, we cut open harvested lake trout to determine the sex and simultaneously note external characteristics. After examining several fish, a few subtle external features allowed us to distinguish sex. One characteristic common to all mature females was inflammation or swelling near the anal vent. Male lake trout exhibited very little swelling in this region, if any at all. Male lake trout also appeared to be more slender in their body shape and exhibited a slightly longer nose (snout) than females. In addition, the lower jaw of most male lake trout included a small upward hook which usually extended beyond the upper jaw. A fish received a transmitter if we judged it to be male based on the aforementioned characteristics. Handling effects on all fish were minimized using these external morphological characteristics.

We also targeted fish for tagging that had a fork length ≥450 mm to maximize the probability that fish receiving transmitters were sexually mature and would be tracked to potential spawning areas. Age at maturity reported for male and female lake trout sampled from interior Alaska lakes were used to help determine the 450 mm minimum fork length of a tagged fish. Burr (1987) reported that all sampled male and female lake trout ages six and seven, respectively, were mature during a 1986 study of Paxson Lake. During later studies, Burr (1989 and 1991) found that 99% of the male and female lake trout sampled in Paxson Lake were mature at ages 7 and 8, and that most lake trout were mature after reaching 450 mm (Burr 1988). Knowing this information, the average lengths and associated ranges were calculated for male and female lake trout of ages five to eight sampled in Hidden Lake between 1992 and 1993. Although sample sizes were small for each age class (n<20), the average lengths of lake trout increased with increasing age (Appendix 2). Based on this information, a fork length criterion of 450 mm for tagging minimized the number of immature lake trout receiving a transmitter.

Lake trout selected for tagging were surgically implanted with radio or acoustic transmitters manufactured by Lotek Wireless Incorporated®. Radio transmitters (Model SR-M11-25) measured 11 x 54 mm, weigh 9.7 g in air, were digitally encoded and equipped with a motion sensor, and outfitted with a 609 d battery. Thirty-nine uniquely-coded transmitters were dispersed over four radio frequencies between 162.260 and 162.344 MHz. Acoustic transmitters were also uniquely-coded and allowed us to track fish in deep water throughout Hidden Lake. The acoustic transmitters (Model MA-16-25) broadcast on 76 kHz, measured 16 x 54 mm, weighed 23g in air (13 g in water), and were programmed for a 10-s continuous burst rate resulting in a battery life of 371 days. Regardless of the transmitter type, transmitters did not exceed 2% of the fish's body weight (Winter 1983). All radio or acoustic tagged lake trout received a Floy® T-Bar anchor tag (Model FD-94) as a secondary mark to identify fish to anglers as "Study Fish- do not eat". Radio and acoustic transmitters as well as the T-bar anchor tags were imprinted with KFWFO contact information in case a study fish was harvested. We also posted a large sign at the only access point to the lake explaining the project and providing KFWFO contact information. Outreach efforts to the angling public occurred during all field activities as well as in newspaper articles, campfire talks, and through the local television news media in Anchorage, Alaska.

Surgical procedures were similar to those described by Palmer (1998) and Summerfelt and Smith (1990). Fish receiving a transmitter were anesthetized using a clove oil anesthetic described by Anderson et al. (1997). The stock solution of clove oil was diluted to a preferred concentration of 20 mg/L to initially anesthetize fish. Once the equilibrium of a fish was lost, fork length and girth measurements were taken to the nearest 1 mm prior to being placed ventral side up in a cradle and irrigated with a combination of anesthesia water (10 mg/L solution) and plain lake water throughout the surgical procedure. A 3 to 4 cm incision large enough to accommodate the transmitter was made anterior to the pelvic girdle approximately one centimeter from the midventral axis. The antenna was routed under the pelvic girdle and through the body wall slightly off the midventral axis and anterior to the vent using a 25.4-cm hypodermic needle and grooved director. The incision was closed with three or four individual stitches of absorbable suture material and additionally secured with Vetbond™ tissue adhesive. After surgery, fish were immediately placed in a 113-L plastic container filled with freshwater and allowed to regain their equilibrium prior to being released near the capture site. The aforementioned Floy® T-Bar anchor was applied near the base of the dorsal fin once the fish was placed in the recovery container. Surgical instruments and transmitters were soaked in ChlorhexiDerm™ S disinfectant and rinsed in saline solution before each use.

Radio Tracking.— Telemetry receivers manufactured by Lotek Wireless Incorporated® were used for mobile and fixed station tracking. Fixed receiver stations were used to automatically identify radio-tagged fish traveling near the surface among three similarly sized zones within Hidden Lake (Appendix 3). Each lake zone was determined by natural shoreline features and represents approximately one-third the surface area of Hidden Lake; Zone 1 encompassed the southeastern basin of the lake, Zone 2 represents the middle third of the lake, and Zone 3 represents the northwestern third of the lake. Fixed receiver stations were similar to those used on the Kenai River to monitor rainbow trout movements (Palmer 1998) and on the Kasilof River to monitor coho salmon and steelhead (Palmer et al. 2008; Gates 2009; Gates and Boersma 2010). Data were downloaded approximately every two to three weeks from the fixed receiver stations during mobile tracking events. Mobile tracking was conducted weekly by boat from 31 May to 10 November, 2011, just prior to the lake freezing. The frequency of tracking increased to a maximum of five surveys each week during the suspected spawning period starting in late September. Radio-tagged and acoustic-tagged fish were tracked during most tracking events. In some instances, usually due to time limitations, only one transmitter type was tracked. Tracking by boat for high-frequency radio transmitters included traveling at speeds near 30 km/h, paralleling the lake shore, and transecting the center of the lake in areas greater than 0.54 km wide. To accomplish this, the tracking boat was outfitted with two 4-element Yagi antennas facing forward at a 45 degree angle relative to the centerline. Tracking the low-frequency acoustic transmitters consisted of tracking the center of the lake and maneuvering around structure (i.e. islands, rock piles, etc.) until all acoustic tagged fish were located. This usually occurred independent of the radio tracking due to interference among the several different electrical components necessary for tracking each transmitter type. The acoustic tracking occurred at a much slower speed (< 8 km/h) than the radio tracking and used two hydrophones outfitted with baffles mounted near the bow of the tacking boat approximately 3 m apart. The hydrophones faced forward at a 45 degree angle from the centerline of the boat allowing us to directionally locate fish. A portable global positioning system (GPS) was used during all mobile tracking surveys to accurately identify the latitude and longitude coordinates of each located fish.

Radio tracking during the winter was attempted during March and was determined to be not feasible. The thickness of the lake ice was approximately 0.76 m with approximately 0.3 m of snow on top. This likely limited our detection range of the radio transmitters. Acoustic tracking was not attempted because the sheer volume of holes necessary to operate the hydrophones throughout the lake.

Data Analysis

Fish Capture.— Effort (rod-hour) and catch were recorded during each sampling event to calculate catch per unit effort (CPUE). The number of fish caught per rod–hour defines CPUE and was calculated for all sampling and for each individual sampling period: winter (15-19 February, 7-29 March), spring (10-26 May), and summer (30 August to 2 September, 2011). CPUE is reported to illustrate the level of effort and associated success of using hook and line as a sampling technique for lake trout.

Radio and Acoustic Telmetry.— Radio and acoustic telemetry information collected with various tracking methods was integrated into one database that archives the dates, GPS locations, physical location, and fates of lake trout tagged with a transmitter. GPS locations were recorded as latitude and longitude coordinates using WGS84 datum and summarized on a geographic coverage of Hidden Lake using ArcMap® software. The study period for each tagged lake trout will be defined as the number of days between transmitter implantation and the date of final contact or last observed movement. Distances between consecutive locations and movement between lake regions will be used to describe the movements of each radio- and acoustic-tagged fish. After each tracking event, all lake trout were assigned 1 of 4 possible fates (active, inactive, at-large, and censured; Table 2) and placed into one of three zones of the lake identified in Appendix 3 to further describe their location. Tagged fish detected at the junction of zones were not included in individual zones and are reported separately. Final fates (harvested, suspected spawner, suspected non-spawner, suspected spawning mortality, and mortality; Table 2) will be assigned to all fish after the first (2011) and second (2012) spawning periods. Data from fixed receiver stations will be used to help confirm the locations and movements and fates of radio-tagged fish throughout the study period.

TABLE 2.—Possible fates of tagged lake trout detected within Hidden Lake.

Fate	Description
Active	A fish that has been detected and is emmitting an active radio or acoustic signal.
In-active	A fish that has been detected and is emmitting a mortality signal.
At-large	A fish that has a loss of contact with mobile or fixed receivers.
Censured	A radio/acoustic-tagged fish that has been prematurely been removed from the data set due to tag failure.
Harvested	A fish that is harvested in either subsistence or sport fisheries.
Suspected spawner	A lake trout that was a suspected spawner.
Suspected non-spawner	A lake trout that was a suspected nonspawner.
Suspected spawning mortality	A lake trout that was emitting an active signal prior to the spawning season but switched to an inactive signal during or immediately after the suspected spawning
Mortality	A lake trout that was emitting a mortality signal prior to the suspected spawning season.

Length and Weight Composition.— Basic data summaries, scatter plots, and statistical analyses were used to describe the length and weight composition of lake trout sampled from Hidden Lake. The curvilinear relationship between weight and length is described by Anderson and Neumann (1996) and can be modeled using the following power function

$$W = aL^b, \quad (1)$$

where W = weight,
L = length, and
a and b = parameters.

The curvilinear weight-length relationships were transformed to allow for the estimation of *a* and *b* through linear regression. Transformed data are reported using the following equation

$$\log_{10}(W) = a' + b(\log_{10} L), \quad (2)$$

where W = total weight in grams,
a' = $\log_{10}$a and is the y-axis intercept,
b = slope of the regression line, and
L = fork length in millimeters.

Condition indices in the form of relative weight (W_r) were calculated for individually sampled fish because weight can vary greatly for similar sized fish depending on an individual's body shape. Lake trout with optimal body condition would have a W_r of 100. Relative weight was calculated for each sampled fish using the following equation described by Anderson and Neaumann (1996)

$$W_r = (W/W_s) \times 100 \quad (3)$$

where W = weight, and
W_s = length-specific standard weight predicted by a weight-length regression for lake trout. The following equation describes W_s

$$\log_{10}(W_s) = a' + b(\log_{10} L), \quad (4)$$

where a' = y-axis intercept of the $\log_{10}$(weight) – $\log_{10}$(length) regression equation,
b = slope of the $\log_{10}$(weight) – $\log_{10}$(length) regression equation, and
L = maximum total length.

The standard weight equation (equation 4) has been developed for lake trout by Piccolo and Hubert (1993) using the regression-line-percentile technique developed by Murphy et al. (1990). The y-axis intercept (a') and slope (b) for the $\log_{10}$(weight) – $\log_{10}$(length) regression equation are -5.681 and 3.2462, respectively. The standard weight equation for lake trout is therefore described by

$$\log_{10}(W_s) = -5.681 + 3.2462(\log_{10} L). \quad (5)$$

Because the standard weight equation (equation 5) uses total length of lake trout, fork lengths collected from Hidden Lake were converted to total lengths. Relative weights would be biased high if fork lengths were not converted and fish could appear healthier. Length conversion factors were determined for two lake trout populations by Moshenko and Gillman (1983) from Great Bear (1.117) and Great Slave (1.091) lakes in Canada. Sample sizes from Great Slave Lake were nearly double that for Great Bear Lake, therefore the conversion factor from Great Slave Lake was used to convert fork lengths of lake trout sampled in Hidden Lake to total lengths. The conversion is described by

$$TL = FL(1.091), \quad (6)$$

where TL is the total length in mm and FL is fork length in mm of measured lake trout.

Yield Potential. — The relationship between lake trout productivity and lake size is used to illustrate yield potential (*YP*) in kilograms per year or number of fish per year assuming that habitat increases with lake size. The yield potential of the lake trout fishery in Hidden Lake is calculated using a lake-area model developed by Evans et al. (1991) and is described by

$$\log_{10} YP = 0.60 + 0.721(\log_{10} Area), \qquad (7)$$

where *YP* = yield potential (kg biomass/year), and
Area = Area of lake(s) in ha.

The yield potential is expressed in terms of the number of lake trout (YP_n) and is calculated as

$$YP_n = \frac{YP}{W} \qquad (8)$$

where *W* is the average weight of harvestable lake trout (kg/fish).

Results

Fish Capture

Lake trout were captured between 15 February and 2 September, 2011. A total of 181 lake trout were handled throughout this period of which 179 were caught by Service employees and volunteers and two were donated by anglers from the public. Three of the 181 lake trout were recaptures and were only measured and weighed once. A total of 178 fish were sampled for length, weight, and girth. Sampling was broken into four main events from 15–19 February, 7–29 March, 10–26 May, and 30 August to 2 September, 2011 (Table 3). A total of 1,298 rod-hours (effort) were required to catch 179 lake trout equating to 0.138 fish per rod-hour (CPUE). CPUE was greatest during May (Table 3). No fish were caught during the February sampling period due to the inexperience of the anglers. A total of 59 transmitters were deployed during the entire sample period. Overall, 11 transmitters failed (*N*=3 prior to tagging; *N*=8 after tagging) reducing the total sample size to 49 radio/acoustic tagged fish. All 11 transmitters (*N*=1 radio; *N*=10 acoustic) were replaced by the manufacturer and delivered in two separate batches, one during late August and one in late September. Attempts were made to redeploy the first replacement batch of acoustic transmitters (*N*=5) during the last week of August but unfortunately we were only able to deploy two transmitters by 2 September. We chose not to deploy transmitters after 2 September due to possible tagging effects on fish behavior during the upcoming spawning season.

Radio and Acoustic Telemetry

Transmitters (*N*=59) were deployed into lake trout from Hidden Lake between February and September 2011 (Table 3). The majority (95%) of the transmitters were deployed during March and May. Tagged fish were tracked by boat on 40 different occasions between late May and early November 2011 (Table 4). Tracking fates were assigned to individual fish after each mobile tracking event and summarized monthly during the tracking season (Table 4). The number of radio-tagged lake trout classified as “Active” varied throughout the season as fish moved between different water depths. Acoustic-tagged fish were classified as “Active” most of the season but comprised 100% of the censured transmitters due to transmitter failure. To date, none of the tagged fish have been reported as harvested (Table 4).

TABLE 3.—Effort and catch of lake trout by U.S. Fish and Wildlife Service employees in Hidden Lake during 2011.

Sample period		Number of days sampled	Effort (rod-hours)	Catch	CPUE (catch per rod-hour)	Tagged fish (*N*)
Winter		20	729	62	0.085	22
	[1]Feb	5	140	0	0.000	1
	[1]Mar	15	589	62	0.105	21
Spring						
	May	9	455	107	0.235	35
Summer		3	114	10	0.088	2
	Aug	1	39	4	0.103	1
	Sep	2	75	6	0.080	1
Total		32	1,298	179	0.138	59

[1]Two transmitters were deployed in fish donated by public anglers during February and March (Feb *N*=1, Mar *N*=1). These two fish were not included in the CPUE calculation.

TABLE 4.—In-season tracking fates for radio- and acoustic-tagged lake trout from Hidden Lake, 2011. Tracking fates are reported as an average number of tags for each month that comprises multiple tracking events. Data presented only includes information collected during mobile tracking events.

		Month						
In-season tracking fate		May[a]	Jun	Jul	Aug	Sep	Oct	Nov
Active								
	Radio	17.0	4.0	3.3	0.4	7.4	24.1	13.0
	Acoustic	N/A	9.8	9.3	8.0	9.0	7.5	7.0
	Total	17.0	13.8	12.6	8.4	16.4	31.6	20.0
In-active								
	Radio	1.0	1.0	1.3	0.2	0.8	1.1	1.5
	Acoustic	N/A	0.0	0.0	0.0	0.0	0.0	0.0
	Total	1.0	1.0	1.3	0.2	0.8	1.1	1.5
At-large								
	Radio	21.0	34.0	34.5	38.4	30.9	13.9	24.5
	Acoustic	N/A	2.3	0.0	0.0	0.0	0.1	0.0
	Total	21.0	36.3	34.5	38.4	30.9	13.9	24.5
Censured								
	Radio	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Acoustic	N/A	6.0	8.8	10.2	11.0	12.0	13.0
	Total	0.0	6.0	8.8	10.2	11.0	12.0	13.0
Average number of tagged fish (*N*)		57.0	57.0	57.0	57.2	59.0	59.0	59.0
Number of tracking events		1	5	4	5	8	15	2

[a] Acoustic-tagged fish were not tracked during May (*N*=18)

Average monthly detection rates, reported as a percent, varied within and between transmitter types during mobile tracking events (Figure 2; Table 5). Acoustic-tagged fish were detected nearly 100% of the time throughout the tracking period; whereas, detection rates for radio-tagged lake trout ranged between 5% and 62% (Figure 2; Table 5). The average number of targets (radio- or acoustic-tagged fish) was stable at 39 for radio transmitters; however, the average number of acoustic targets ranged from 7 to 12 throughout the tracking period. Several acoustic-tagged fish were censured early in the tracking period (June *N*=6; Table 4). Two acoustic transmitters were deployed late in the tracking season during late August and early September (Table 3).

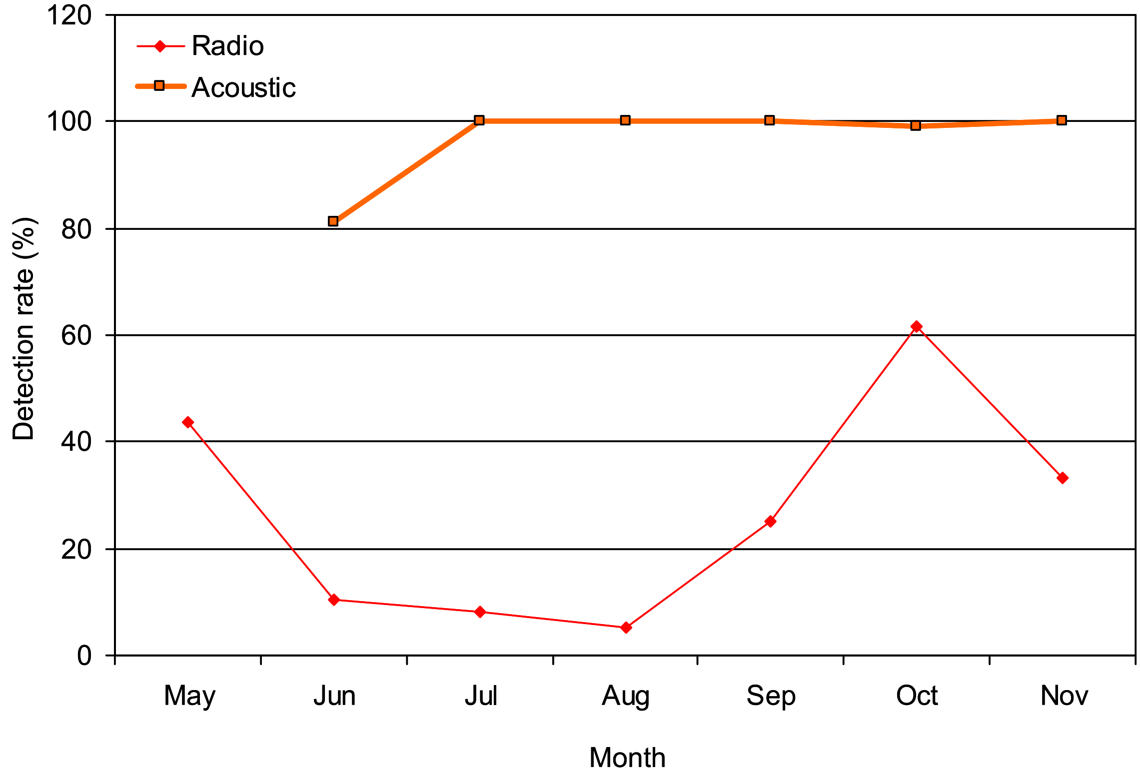

FIGURE 2. —Average monthly detection rates for radio- and acoustic-tagged lake trout in Hidden Lake during 2011. Detection rates were only determined using information collected from mobile tracking events.

TABLE 5.—Summary of mobile tracking events, target totals, detections, and detection rates for tagged lake trout in Hidden Lake between May and November, 2011.

	Month						
Transmitter type	May	Jun	Jul	Aug	Sep	Oct	Nov
Radio							
Tracking events	1	4	4	1	6	15	2
Average number radio targets	39	39	39	39	39	39	39
Average number detections	17	4	3	2	10	24	13
Percent detection	44	10	8	5	25	62	33
Acoustic							
Tracking events	0	4	4	5	8	15	2
Average number acoustic targets	0	12	9	8	9	8	7
Average number detections	0	10	9	8	9	8	7
Percent detection	0	81	100	100	100	99	100

Distributions of tagged lake trout varied throughout Hidden Lake between May and November (Figure 3). The majority of transmitters were detected in Zone 2 during the spring (May=83.3%; Jun=70.7%) and fall (Sep=44.4%; Oct=72.2%; Nov=82.9%) periods. Zone 1, the deepest part of the lake, comprised the majority of detections during July (46.2%) and August (81.4%) (Figure 3; Table 6). Very few detections occurred in Zone 3 (<14%) throughout the tracking period. Several detections occurred on the border of Zones 1 and 2 during July (11.5%), August (9.3%), and September (10.5%).

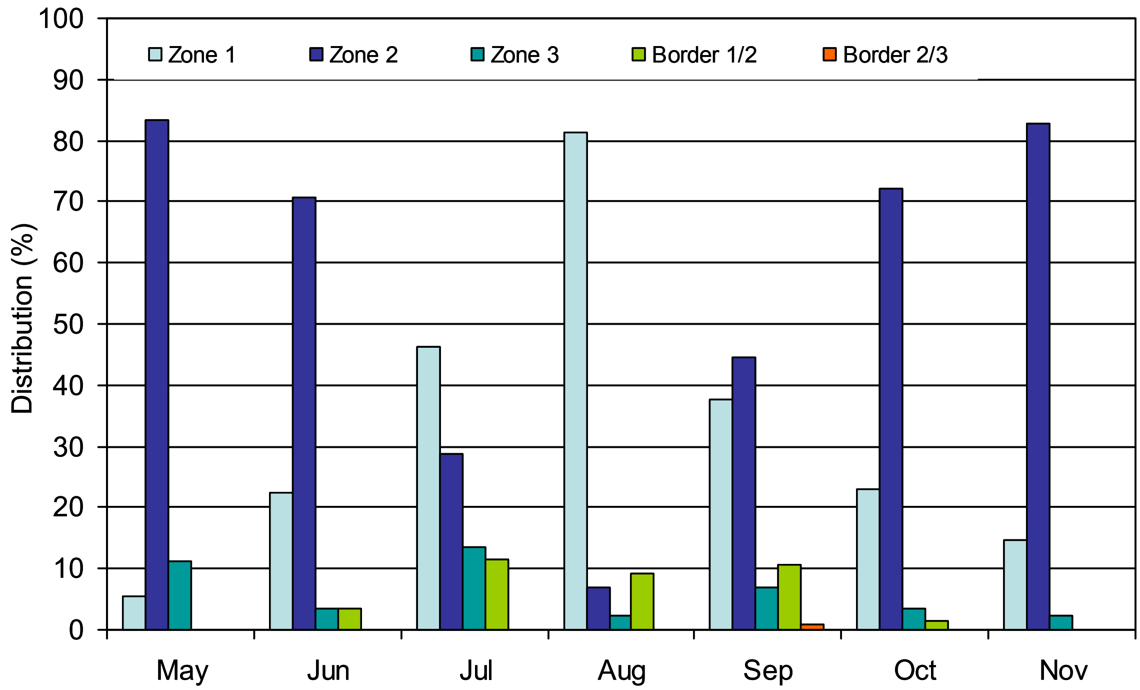

FIGURE 3. —Percent distribution of radio- and acoustic-tagged lake trout in Hidden Lake between May and November 2011.

TABLE 6.—Monthly detections and distributions of radio- and acoustic-tagged lake trout in Hidden Lake during 2011.

	Zone						Zone Border					
	1		2		3		1/2		2/3			
Month	Detections	Percent	Detections	Percent	Detections	Percent	Detections	Percent	Detections	Percent	Total detections	Number of unique fish detected
May	1	5.6	15	83.3	2	11.1	0	0.0	0	0.0	18	18
Jun	13	22.4	41	70.7	2	3.4	2	3.4	0	0.0	58	21
Jul	24	46.2	15	28.8	7	13.5	6	11.5	0	0.0	52	19
Aug	35	81.4	3	7.0	1	2.3	4	9.3	0	0.0	43	11
Sep	50	37.6	59	44.4	9	6.8	14	10.5	1	0.8	133	34
Oct	107	22.9	337	72.2	16	3.4	7	1.5	0	0.0	467	43
Nov	6	14.6	34	82.9	1	2.4	0	0.0	0	0.0	41	23
Total	236	29.1	504	62.1	38	4.7	33	4.1	1	0.1	812	

Length and Weight Composition

Mean fork lengths, weights, and girths were calculated for all sampled lake trout (*N*=178, Feb – Sep) including fish sampled during the winter (*N*=63, Feb and Mar), spring (*N*=106, May), and summer (*N*=9, Aug and Sep) of 2011 (Table 7). Mean fork length, weight, and girth were 496 mm, 1,512 g, and 263 mm for all sampled fish, respectively. Sample sizes were smallest during the summer period (*N*=9) and greatest during the spring (*N*=106). Fork lengths ranged between 375 mm and 632 mm with the majority of the fish ranging between 475 mm and 524 mm (Figure 4).

TABLE 7.—Mean fork lengths, weights, and girths and associated standard errors (SE) and minimum (Min) and maximum (Max) values for lake trout sampled in Hidden Lake during 2011.

Season	Sample size (N)	Fork length (mm)				Weight (g)				Girth (mm)			
		Mean	SE	Min	Max	Mean	SE	Min	Max	Mean	SE	Min	Max
Winter (Feb and Mar)	63	512	6	375	625	1,676	60	620	3,349	267	4	195	360
Spring (May)	106	484	5	385	632	1,407	44	652	3,127	258	3	195	352
Summer (Aug and Sep)	9	515	15	432	565	1,598	134	825	2,249	282	12	225	334
All seasons	178	496	4	375	632	1,512	36	620	3,349	263	2	195	360

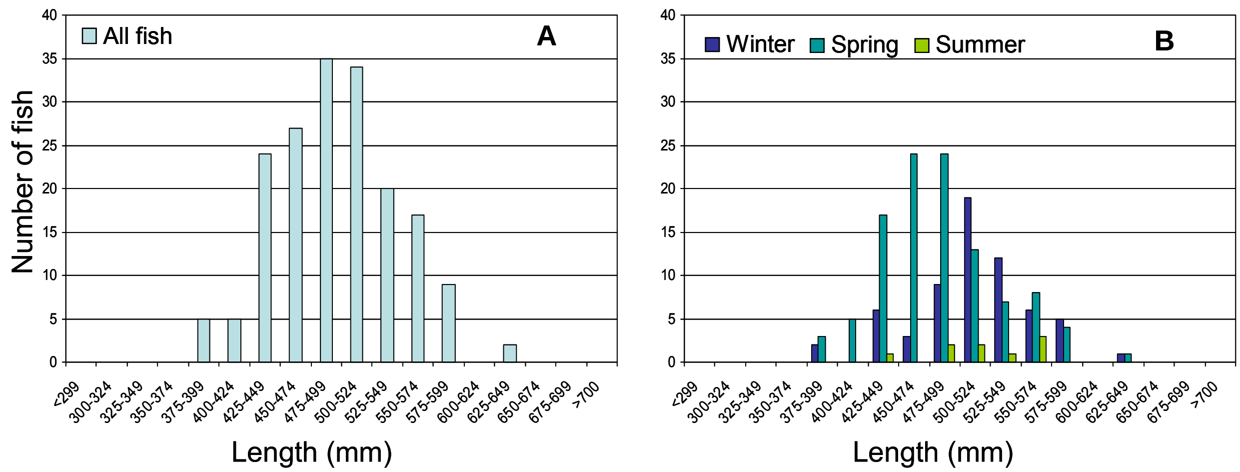

FIGURE 4. —Length frequency histograms for lake trout sampled in Hidden Lake during 2011. (A) all fish; (B) length frequencies of individual sample periods taken from data presented in (A).

Weight and length relationships are curvilinear as weight is a function of length (Figure 5). The average weight-length ratio (g/mm) was 2.99:1 for all sampled lake trout during 2011. The logarithmic relationship between weight and length is linear in shape (Figure 5).

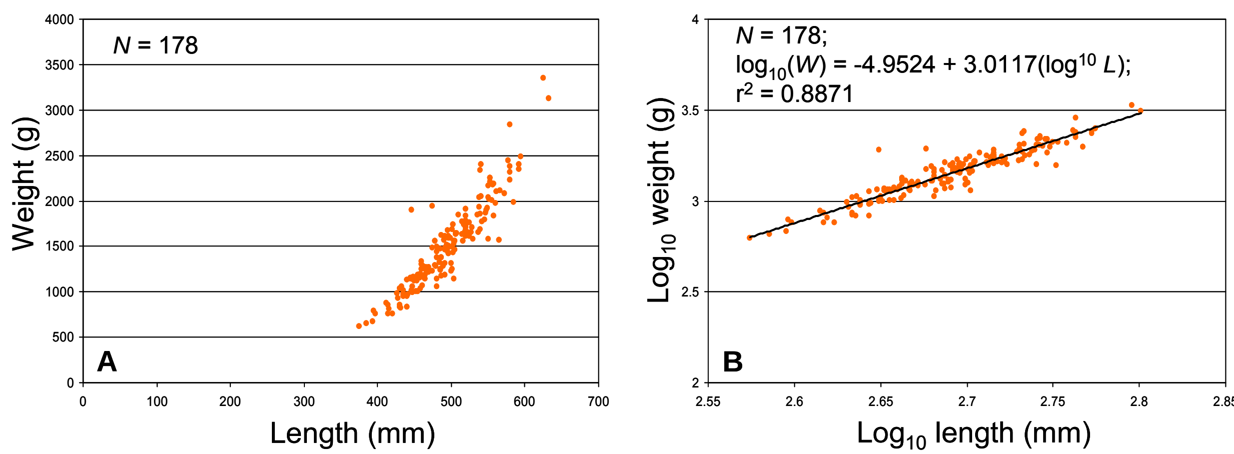

FIGURE 5. —Weight-length relationships of lake trout sampled from Hidden Lake during 2011. (A) The raw data; (B) the logarithmic relationship of data presented in (A).

Relative weights were calculated for 178 sampled lake trout. The majority (75%) of the sampled fish (N=134) fell below the optimal W_r of 100 (Figure 6) and the mean W_r was 95 for all 178 sampled fish. Relative weights appear to be lower for fish with greater lengths than those of smaller lengths (Figure 6; Table 8). Individual W_r's ranged from a low of 66 to a high of 173

(Figure 6; Table 8). Total lengths ranged from 409 mm to 689 mm and averaged 541 mm (Table 8).

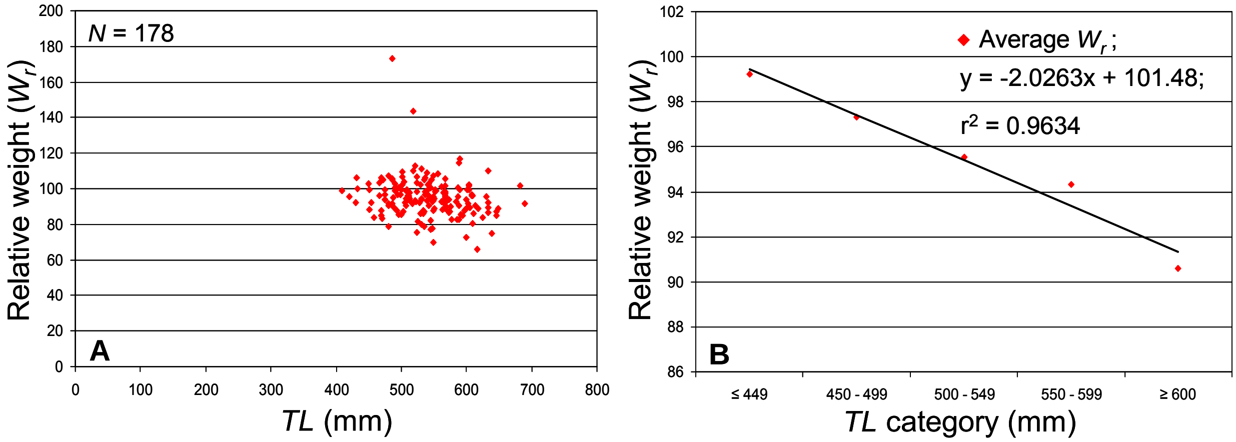

FIGURE 6. —Relative weight (W_r) to total length (*TL*) of lake trout sampled from Hidden Lake during 2011. (A) Individual W_r versus individual *TL*; (B) average W_r for specific 50 mm *TL* categories taken from data presented in (A).

TABLE 8.—Mean relative weights (W_r) and total lengths (*TL*) with associated standard errors (SE) and minimums (Min) and maximums (Max) for lake trout sampled in Hidden Lake during 2011.

		W_r				*TL* (mm)			
Total length category	*N*	Mean	SE	Min	Max	Mean	SE	Min	Max
≤ 449	6	99	2	92	106	429	6	409	449
450 - 499	37	97	2	79	173	480	2	451	499
500 - 549	63	96	1	70	144	528	2	500	549
550 - 599	44	94	1	82	117	573	2	550	598
≥ 600	28	91	2	66	110	623	4	600	689
Total	178	95	1	66	173	541	4	409	689

The yield potential (*YP*) for Hidden Lake is estimated to be 440 kg of lake trout per year based on a lake area of 682.7 ha. The average weight of sampled fish was 1.512 kg during 2011 (Table 2). The resulting yield potential number (YP_n) is 291 lake trout for 2011.

Discussion

Effort to capture lake trout by rod and reel in Hidden Lake was spread over four main sampling events. Fish capture during February proved to be the most difficult and least productive in terms of transmitter deployment. The low productivity was assumed to be primarily a result of angler inexperience rather than a function of fish density. Fish capture rates improved dramatically in March thanks to local anglers who were willing to share their expertise with the tagging crew. Several volunteers assisted during this sampling period yielding 21 tagged lake trout. Sampling during May was the most productive and likely the result of easier fishing mobility compared to the winter sampling, and the distribution of fish in the upper water column during the spring. Sampling during late August and early September was minimal but is thought to be comparable to the March sampling period. Fish were typically much deeper during this period making them harder to target.

A total of 59 transmitters were deployed by early September. Efforts to deploy transmitters initially ended in May with 57 tagged fish. Three of the original 60 transmitters (radio *N*=1; acoustic *N*=2) were censured before deployment because of malfunctions and were never included in the data set. There was no intention to redeploy these three transmitters, if replaced, due to the level of effort required to capture fish. However, by November, a total of 13 additional acoustic transmitters were prematurely censured from the tagged population of fish. Eight of the 13 transmitters were never detected after deployment indicating that transmitter malfunction was a likely cause rather than the tagged fish leaving the study area (Hidden Lake) or dying as all tags were programmed with a mortality signal. After initial tracking events resulted in no detection of these eight transmitters, the original two defective acoustic transmitters were returned to Lotek Wireless Incorporated® for examination. The examination identified a bad switch in the transmitters preventing them from turning on. Although this does not explain why the other tags were never detected, it points to the possibility of a bad batch of transmitters. Ten of the 13 transmitters were replaced by the manufacturer, of which only five were received by the end of August. We were successful at deploying two of the five transmitters during the last week in August at which time we ceased all tagging efforts (2 September) to avoid potential tagging effects on fish behavior during the approaching fall spawning period. The remaining five transmitters were not received until late September which was too late for deployment. All eight remaining acoustic transmitters are scheduled to be deployed during March 2012.

Acoustic transmitters were used in the study in order to locate tagged fish throughout the entire tracking period. Contact with radio-tagged fish was anticipated to be lost once fish migrated to deeper water during the summer months as the lake water warmed. Because Hidden Lake is a relatively shallow lake (about 46 m at the deepest), we expected to relocate all acoustic transmitters during each survey. In general, acoustic-tagged fish were first detected from a distance of 0.5 km to 2.5 km from the fish before their actual location was determined. Once contact was lost with an acoustic transmitter, they were generally never relocated. Detection of radio transmitters during mobile tracking events was minimal from June through early August (≤10%) which is why radio tracking efforts ceased from 4 August to 19 September.

Distribution of fish varied throughout the tracking period. Nearly all of the tagged fish detected during the spring period were located in Zone 2 (May=83%; Jun=71%) which is also where all but two transmitters were deployed. Water depths in Zone 2 are generally <18 m with a small section reaching depths of 30 m adjacent to Zone 1. Zone 1 is almost entirely comprised of water depths between 30 m and 45 m. As summer approached, fewer tagged fish were detected in Zone 2 and increasingly more fish were detected in Zone 1 (Jul=46%; Aug=81%). The majority of the detections during the summer period were from the acoustic-tagged fish but sample size was small for this group of fish (*N*=8-9). However, because the distribution of acoustic-tagged fish was limited to a small area of the lake and was consistent between tracking events, we feel confident that the acoustic-tagged fish represented the distribution of other fish. In addition, as fall approached and the detection rate for radio-tagged fish increased, the distribution of acoustic-tagged fish overlapped with the radio-tagged fish indicating that there were no behavioral differences between the two tagging groups. Few tagged lake trout were detected in Zone 3 throughout the entire tacking period. Explanations for this behavior is limited other than Zone 3 may lack the physical structure and/or food resources that exist in the other two zones. Zone 3 has a fairly uniform depth of approximately 21 m.

Fork lengths and weights were collected from 178 lake trout in Hidden Lake during 2011. The mean fork length of 496 mm and weight of 1.512 kg are greater than all other mean fork lengths and weights reported from Hidden Lake, regardless of capture methods, between 1960 and 1994 (Appendix 4). The mean fork lengths and weights collected during 2011 were not tested for statistical differences among other years with similar data because methods used in previous studies are unclear. Lake trout less than 375 mm are likely present in Hidden lake but were probably not recruited to our sampling gear or distribute themselves differently from larger fish.

Relative weights (W_r) were calculated for each sampled fish to determine the general condition. The overall mean W_r was 95 which could indicate that the condition of the sampled fish is near optimal. A W_r of 100 suggests that an individual or size group of fish is in ecological and physiological optimality (Anderson and Neumann 1996). However, when examining the W_r of different size groups of sampled fish from Hidden Lake, smaller fish appear to be in better condition than larger fish. The reason for lower W_r in larger fish is unclear but it may be a result of the time of sampling, assuming that lake productivity is lower during the winter months and large mature fish with low W_r cannot replenish depleted fat reserves during winter months following the fall spawning period. The other factor that could affect W_r is the total length measurement required in the standard weight (W_s) equation for lake trout. We measured fork lengths of lake trout sampled during 2011 from Hidden Lake and converted them to total lengths using a conversion factor obtained from Great Slave Lake in Canada by Moshenko and Gillman (1983). Changing the conversion factor affects outcome of W_r analyses. Regardless, W_r can be used as a general index of condition to compare to other lake trout populations or among years. Collecting total lengths in addition to fork lengths is a recommendation for future sampling in Hidden Lake. Obtaining a sample size large enough to establish a conversion factor for Hidden Lake would be optimal.

Current management of lake trout in Hidden Lake relies primarily on information (i.e. harvest, catch, and effort) generated from the Department's SWHS. In addition to the SWHS, yield (harvest) generated from the SWHS can be compared to the yield potential computed from a lake-area model developed by Evans et al. (1991) for lake trout. This model assumes the yield of lake trout (productivity) increases or decreases as the available lake area habitat increases or decreases. The yield potential for Hidden Lake is computed at 440 kg of lake trout per year. The average weight of available fish for harvest determines how many fish can be harvested each year. Information collected during this study is the most recent data collected since 1994 and is likely the most applicable to the lake-area model among all sampling years between 1960 and 1994. Sampling methods used during 2011 were identical to methods used by sport anglers and were not biased by selective harvest which could be present in prior creel surveys (1992-1994) or netting bias from previously sampled years. The yield potential in numbers of fish for 2011 (N=291) is the lowest yield potential identified to date (Appendix 5). Harvest information is not yet available for 2011; however, harvest in most prior years has exceeded the estimated yield potential.

Recommendations for 2012

A study of this magnitude in Hidden Lake is unlikely to occur for several years. Therefore, several tasks are recommended for 2012 to maximize the current available data for lake trout in Hidden Lake.

1. Deploy the remaining eight acoustic transmitters from 2011 during March 2012 to supplement the current number of tagged lake trout in Hidden Lake.
2. Deploy an additional 20 acoustic transmitters during May. Each transmitter should be programmed with pressure and temperature sensors to identify depths and temperatures selected by tagged lake trout during the summer season and fall spawning period.
2. Track tagged fish between May and November with similar intensities to 2011 tracking to determine and compare the seasonal distribution and spawning areas among tracking years (i.e. 2011 and 2012). Tracking during May should begin immediately after ice out and tracking during July, August and early September should only focus on acoustic-tagged fish.
3. Maintain day and night time tracking during the spawning period. This will allow a finer scale analysis of movement of tagged fish among spawning locations.
4. Augment the 2011 winter and spring sample (*N*=178) of length (fork and total length), weight, and girth with comparable numbers during 2012. This will achieve a larger total sample size if data are pooled among years assuming no differences in lengths and weight relationships between the two sample years. Pooling data will increase sample sizes for individual length and weight categories.
4. Attempt to sample lake trout near or on spawning areas for length (fork and total length), weight, and girth using most appropriate gear type in order to compare the demographics of the spawning population to available fish for harvest during the winter and spring periods.
5. Develop a fork length to total length conversion factor for lake trout in Hidden Lake. From this, indices of condition could be generated and compared over time and could be a useful management tool.

Acknowledgements

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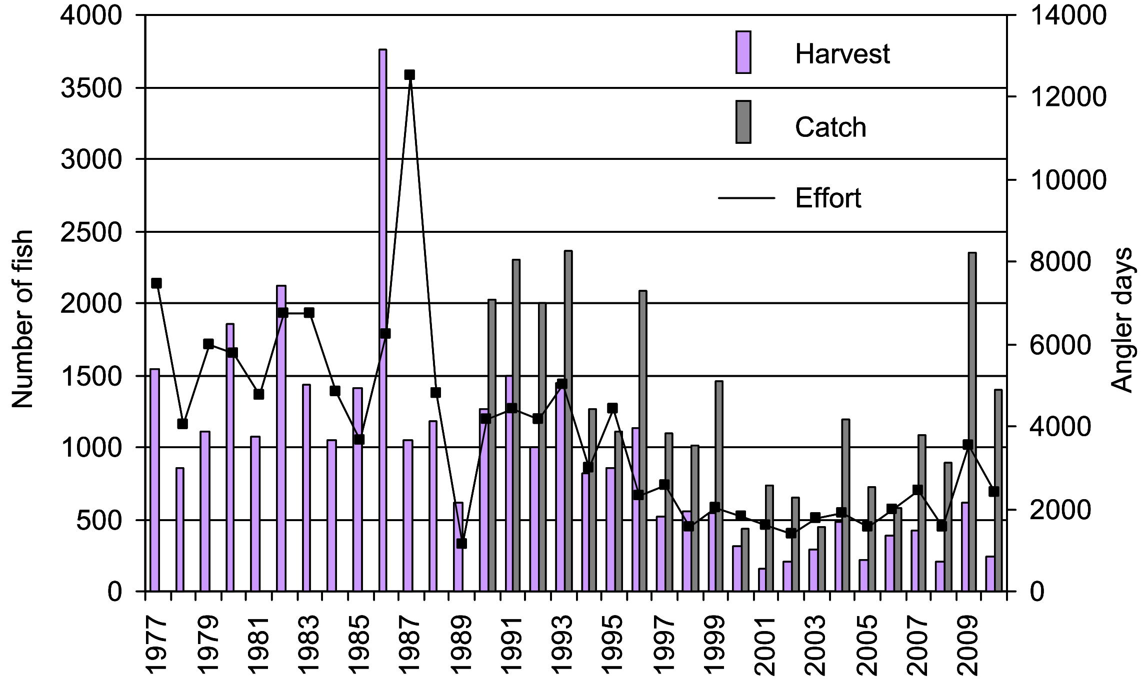
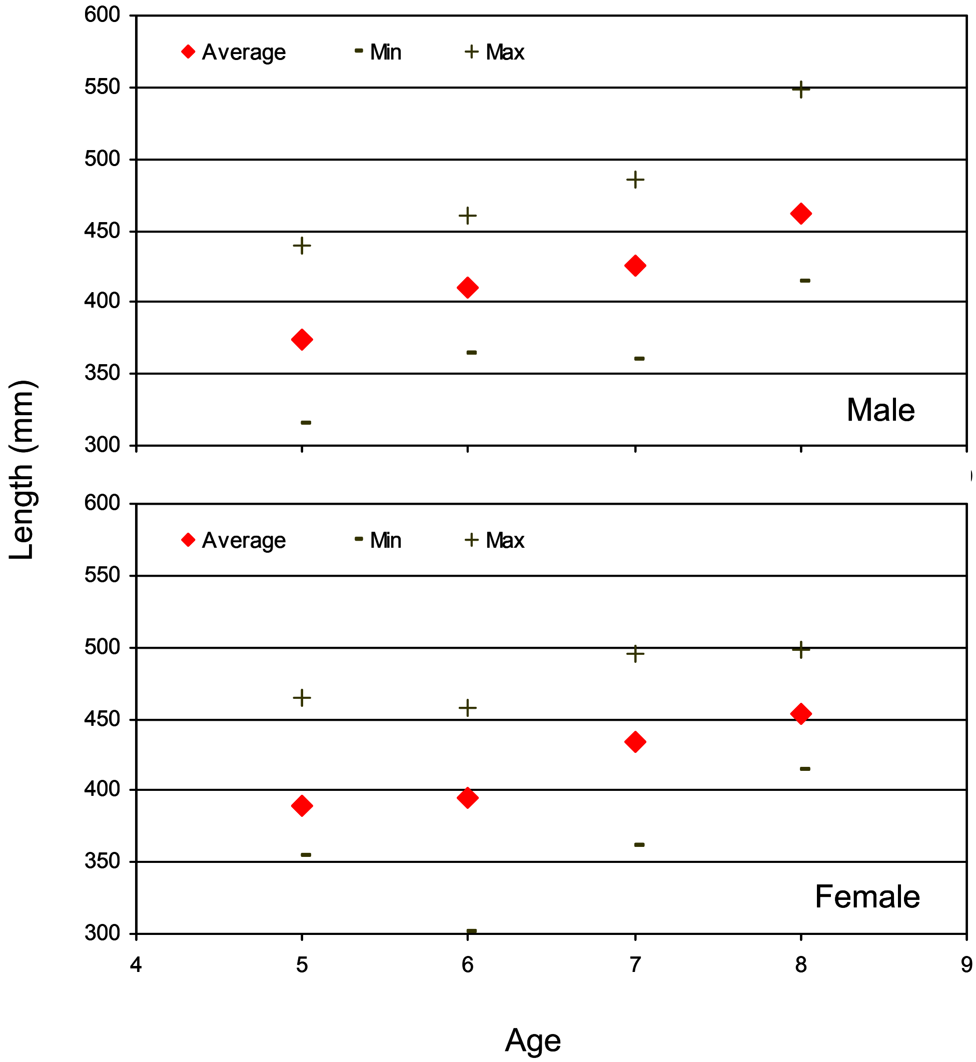
APPENDIX 1. — Harvest, catch, and effort of lake trout in Hidden Lake between 1977 and 2010.

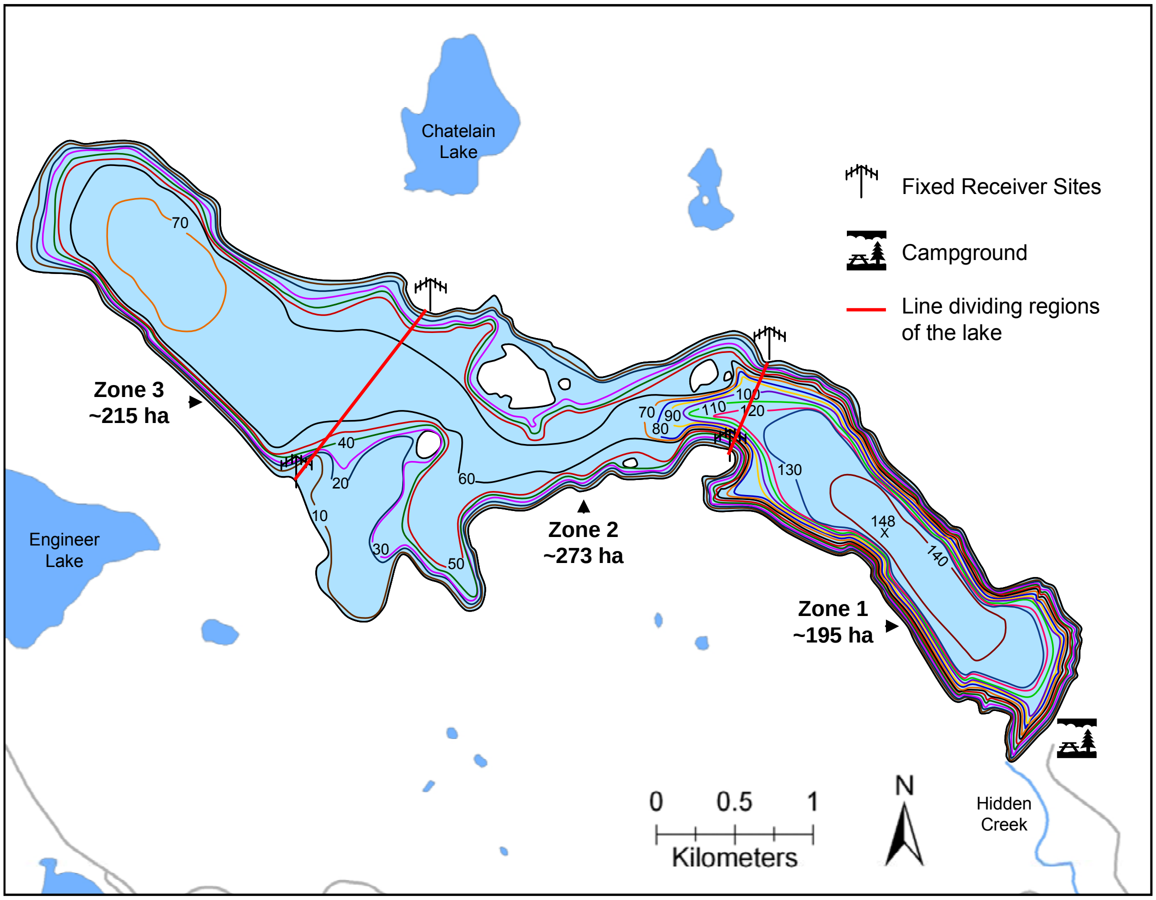


Note: 1977 – 2006 (Begich and Pawluk 2007); 2007 – 2010 (Jason Pawluk, Alaska Department of Fish and Game, personal communication)

APPENDIX 2.— Average, minimum, and maximum fork lengths of aged lake trout sampled during the 1992 and 1993 creel surveys in Hidden Lake, Alaska.



APPENDIX 3. — Bathymetry map of Hidden Lake illustrating fixed telemetry receiver locations and the three regions of the lake that were used to help describe fish movements and locations. Contour lines are reported in feet.



APPENDIX 4. — Mean fork length and weight with associated standard errors (SE) and minimum (Min) and maximum (Max) values of lake trout sampled from Hidden Lake between 1960 and 2011.

		Fork Length (mm)				Weight (kg)			
Year	Sample Size	Mean	SE	Min	Max	Mean	SE	Min	Max
1960[a]	49	393	10	211	534	0.818	0.062	0.07	1.8
1961[a]	3	465	24	424	508	1.284	0.179	1.00	1.6
1965[a]	15	438	10	350	531	1.025	0.078	0.40	1.8
1966[a]	84	445	6	159	532	1.124	0.037	0.04	2.1
1967[a]	15	401	25	181	530	0.921	0.135	0.06	1.8
1975[a]	14	393	18	290	490	0.714	0.102	0.29	1.2
1987[a]	433	404	4	135	585	–	–	–	–
1992[b]	37	396	10	290	520	0.799	0.065	0.22	1.8
1993[b]	84	442	5	280	580	1.158	0.045	0.30	2.3
1994[b]	35	466	6	400	540	1.384	0.058	0.85	2.3
2011	178	496	4	375	632	1.512	0.036	0.62	3.3

[a] Robert Begich, Alaska Department of Fish and Game, personal communication.

[b] U.S. Fish and Wildlife Service, unpublished data.

APPENDIX 5. — Hidden Lake yield potential of lake trout calculated using a lake-area model developed by Evans et al. (1991).