Fishery Data Series No. 96-40

Evaluation of a Thermal Habitat Volume Model for Estimation of Sustained Yield for Lake Trout in Selected Lakes of Southwest Alaska, 1994-95

by

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November 1996

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd
Spell out acre and ton.	

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s
Spell out year, month, and week.	

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$log_{2,}$ etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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EVALUATION OF A THERMAL HABITAT VOLUME MODEL FOR ESTIMATION OF THE SUSTAINED YIELD FOR LAKE TROUT IN SELECTED LAKES OF SOUTHWEST ALASKA, 1994-95

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ABSTRACT

This was a 2-year study to evaluate the thermal habitat volume (THV) model for estimating sustained yield for lake trout *Salvelinus namaycush* in 15 lakes in Southwest Alaska. During 1994 bathymetric profiles were taken at three study lakes where no bathymetric maps existed. Temperature profiles were collected from 14 study lakes in 1994 and 10 study lakes in 1995. Bathymetric maps of the 15 study lakes were digitized into electronic files, and provided a useful method for estimating THV based upon the temperature data. The THV for lake trout is defined as the volume of water found between 12°C and 8°C. In previous studies a strong relationship has been found between the July THV and the sustained yield of lake trout in Ontario, Canada and Southcentral Alaska. THVs in this study resulted in estimates of sustained yield of lake trout ranging from 0.6 kg/ha/yr in lower Ugashik Lake to 6.4 kg/ha/yr in Lower Twin Lake. On average, the THVs from Southwest Alaska lakes are higher than the THVs found for similar sized lakes in Ontario, Canada, and Southcentral Alaska, and are most likely the result of lack of lake stratification in the Southwest Alaska lakes while the Ontario and Southcentral lakes do stratify during the summer months. The Southwest Alaska lakes currently receive little or no fishing pressure, so the accuracy of the sustained yield estimates could not be substantiated through historic harvest records. Recommendations were made to reduce the study to only those lakes with reliable harvest information based on the Statewide Harvest Survey and where temperature data can be collected in a cost efficient manner.

Key words: Lake trout, *Salvelinus namaycush*, thermal habitat volume, Southwest Alaska, sustained yield.

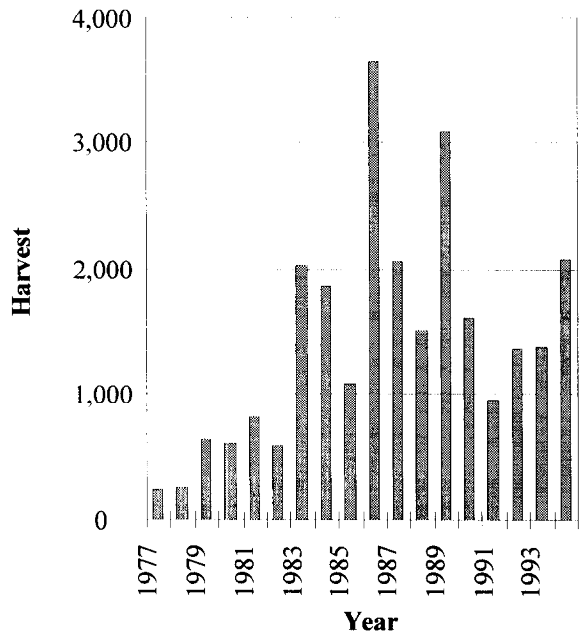
INTRODUCTION

Harvests of lake trout *Salvelinus namaycush* by recreational fisheries in the Southwestern Alaska Sport Fish Management Area (Figure 1) remained below 1,000 fish annually from 1977 to 1982 (Mills 1979-1983). Since 1983, the harvest of lake trout has ranged from 1,000 to 3,600 fish annually (Mills 1984-1994). Current harvests are not considered excessive; however, growing interest in the recreational fisheries of Southwest Alaska has prompted resource managers to consider the effects of increased sport harvests. Presently, sport bag limits for lake trout are considered liberal: four per day and in possession with no size limit (ADF&G 1994). Little biological information concerning the harvest is available.

Lake trout is a slow growing, late maturing, long-lived species that is easily over-harvested (Burr 1987, Szarzi 1993). The growth of lake trout is generally slow and not clearly related to latitude (Scott and Crossman 1973). In Alaska, age at complete maturity ranges from 7 to 20 years and is related to latitude; fish mature later in life the farther north they reside (Burr 1987). Lake trout in Alaska can reach more than 50 years of age (Burr 1987). In Southcentral Alaska, Szarzi (1993) found female lake trout did not generally spawn every year, while male lake trout generally do. Fecundity of lake trout is size related, and ranges from 400 to 1,200 eggs per 453 kilograms weight of the female (Scott and Crossman 1973). A broad range of age classes and good recruitment into the population are needed to prevent over-exploitation or to help populations rebound from overexploitation (Szarzi 1993).

Payne et al. (1990) developed a model relating thermal habitat volume (THV: defined for lake trout as the volume of water between 8°C and 12°C) measured in July and the harvest of lake trout. The lakes in the Payne et al. (1990) study all had years of harvest data (determined to be sustainable), were >100 ha, had fairly stable temperature regimes, and moderate to high fishing pressure. The model of Payne et al. (1990) estimates a maximum sustainable yield (MSY) of lake trout from a study lake with the above characteristics. Payne et al. (1990)

considered this estimate to be the *potential* MSY for each study lake.



From: Minard and Dunaway 1995

Figure 1.-Historical harvest of lake trout from the Southwestern Alaska Sport Fish Management Area.

Lake trout habitat in the lakes of Southwestern Alaska may be similar to that studied in Canada. Szarzi (1993) found that for Paxson Lake in the Copper River drainage, and Lake Louise and Susitna Lake in the Susitna River drainage of Southcentral Alaska, the THV model provided estimates of MSY for lake trout similar to other models. Application of the THV model to lakes in Southwest Alaska may allow estimation of MSY for selected lakes known to hold lake trout. Although the Division of Sport Fish does not emphasize management for maximum sustained yield of resident species, comparison of MSY estimates with current levels of yield allows managers to evaluate the current levels of harvest.

The specific objectives in 1994 and 1995 were:

1. Measure the thermal habitat volume, used to estimate the maximum sustainable yield, for lake trout in selected lakes in Southwest Alaska.
2. Estimate the mean weight of the sport harvest of lake trout from lakes measured for THV.
3. Evaluate the THV model by estimating MSY for lake trout and comparing those yield estimates to statewide harvest survey information.

METHODS

SITE DESCRIPTIONS

All lakes in this study are in a National Park, National Wildlife Refuge, or State Park (Figure 2). Naknek and Brooks lakes are located within Katmai National Park and Preserve. Lower Ugashik Lake is in the Alaska Peninsula National Wildlife Refuge. Lake Clark National Park and Preserve contains Lake Clark, Kontrashibuna, Lower Twin, Upper Twin, Turquoise, and Telaquana lakes. Goodnews, Kanuktik, Kagati, Heart, and Arolik lakes are all in the Togiak National Wildlife Refuge. Finally, Tikchik Lake is within the Wood-Tikchik State Park. These lakes are remote and primarily accessible by airplane only (Table 1), with the exception of Naknek Lake being accessible also by road and boat, and Lower Ugashik Lake and Lake Clark being accessible also by boat. Selection of lakes to be sampled was completed considering the sport harvest of lake trout and geographic distribution of representative lakes throughout the area.

ESTIMATION OF THERMAL HABITAT VOLUME

The thermal habitat volume (THV) for lake trout is defined as the volume of lake water within the temperature range 8°-12°C during the period of maximum thermal stability which generally occurs in July or August (Payne et al. 1990). To estimate THV, both the depth and temperature profiles of the lake must be measured. Of the 15 Southwestern Alaska lakes for which THV was estimated during either 1994 and/or 1995, bathymetric charts developed previously by the National Park Service, U.S. Fish and Wildlife Service (USF&WS), U.S. Geological Survey, National Marine Fisheries Service, or University of Washington-Fisheries Research Institute, were available for 12 of the lakes. The remaining three (Lower Ugashik, Turquoise, and Telaquana lakes) were sampled for bathymetric data in 1994 (Table 2). Temperature profiles were established from two or more sampling trips to each of the 15 lakes (Tables 2 and 3).

Bathymetric Data Collection

A three-step process was used in 1994 to gather and summarize bathymetric data for Lower Ugashik, Turquoise, and Telaquana lakes: (1) identify transects on a high quality map of the lake, (2) measure depths along those transects, and (3) transcribe the depth profile of each transect onto the map of the lake. As guidelines for selecting transect locations, the major axis (i.e., length; the longest straight line distance from one shore to the opposite shore) and the minor axis (i.e., width; the longest straight line to opposite shores that is perpendicular to the major axis) were identified and drawn on each map. At

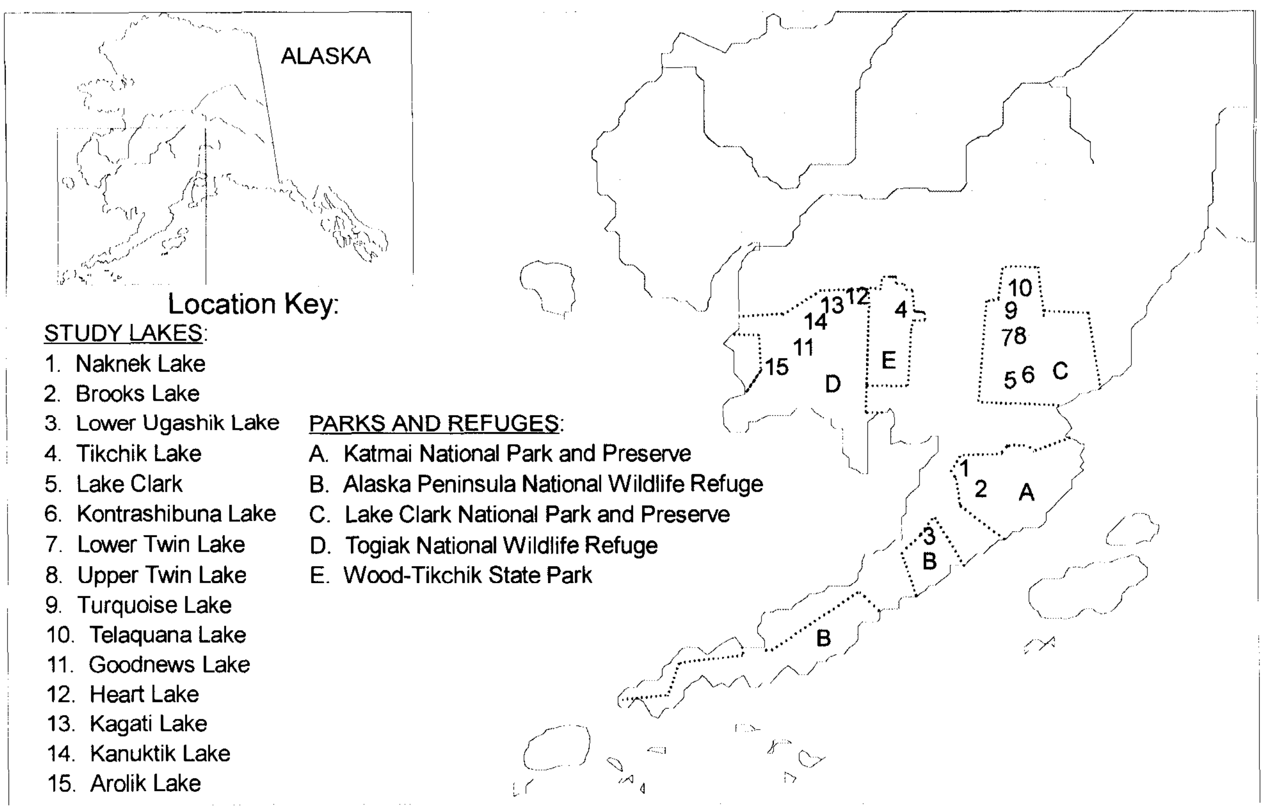


Figure 2.-Locations of study lakes, and boundaries of parks and refuges containing study lakes.

Table 1.-Study lakes, USGS quadrangles where they are located, and sampling year(s) for temperature data.

Site	Latitude	Longitude	USGS Quadrangle	Sampling Year(s) for Temperature Data	
Naknek Lake	58° 39' N	155° 52' W	Mt. Katmai	1994	1995
Brooks Lake	58° 30' N	155° 44' W	Mt. Katmai	1994	1995
Lower Ugashik Lake	57° 41' N	156° 39' W	Ugashik	1994	1995
Tikchik Lake	59° 59' N	158° 30' W	Dillingham	1994	1995
Lake Clark	60° 15' N	154° 00' W	Lake Clark	1994	1995
Kontrashibuna Lake	60° 12' N	154° 00' W	Lake Clark	1994	
Lower Twin Lake	60° 38' N	153° 35' W	Lake Clark	1994	
Upper Twin Lake	60° 38' N	153° 35' W	Lake Clark	1994	
Turquoise Lake	60° 47' N	152° 57' W	Lake Clark	1994	
Telaquana Lake	60° 57' N	152° 52' W	Lake Clark	1994	
Goodnews Lake	59° 28' N	160° 31' W	Goodnews Bay	1994	1995
Heart Lake	60° 07' N	159° 38' W	Bethel	1994	1995
Kagati Lake	59° 52' N	160° 05' W	Goodnews Bay	1994	1995
Kanuktik Lake	59° 44' N	160° 19' W	Goodnews Bay	1994	1995
Arolik Lake	59° 27' N	161° 06' W	Goodnews Bay		1995

Table 2.-Dates of temperature and bathymetric sampling of the 14 study lakes in 1994.

Site	Temperature Sampling Event 1	Temperature Sampling Event 2	Bathymetric Sampling
Brooks Lake	23 July	24 August	
Naknek Lake	30-31 July	24 August	
Lower Ugashik Lake	11 August	29 August	9-13 July 1994
Tikchik Lake	6 August	20 August	
Lake Clark	5 August	17 August	
Kontrashibuna Lake	5 August	18 August	
Lower Twin Lake	4 August	16 August	
Upper Twin Lake	4 August	16 August	
Turquoise Lake	5 August	17 August	2 July 1994
Telaquana Lake	5 August	16 August	29 June-1 July 1994
Goodnews Lake	18 July	16 August	1986
Heart Lake	18 July	16 August	1987
Kagati Lake	18 July	23 August	1986
Kanuktik Lake	18 July	8 September	1988

Table 3.-Dates of temperature sampling of the 10 study lakes in 1995.

Site	Event 1	Event 2	Event 3	Event 4
Brooks Lake	July 3	July 14	August 8	
Lower Ugashik Lake	July 10	August 15		
Tikchik Lake	July 11	July 27	August 15	
Lake Clark	July 6	July 26	August 10	
Naknek Lake (Bay of Islands Arm)	July 3	July 14	August 15	
Naknek Lake (Iliuk Arm)	July 3	July 20	August 13	
Goodnews Lake	July 18	July 30	August 10	August 21
Heart Lake	July 18	July 30	August 10	
Kagati Lake	July 18	July 30	August 10	August 21
Kanuktik Lake	July 18	July 30	August 10	August 21
Arolik Lake	July 20	July 30	August 10	August 21

least three transects parallel to the length of the lake were drawn: the major axis and one transect on each side of the major axis, parallel to the major axis, and intersecting the minor axis half the distance between the shore and the point where the major and minor axes intersected. Likewise, at least three transects were drawn parallel to the width of the lake: the minor axis and one transect on either side of the minor axis, parallel to the minor axis, and intersecting the major axis half the distance between the shore and the point where the major and minor axes intersected. Also, at least three transects were drawn from islands to recognizable landmarks on shore. The depth along each transect was measured by skiff with a Lowrance model Eagle Mach I chart recording fathometer[1]. A Trimble model Scout global positioning system (GPS) unit[1] was used to identify the transect end points and to navigate along the transects. The speed of the skiff was held constant to ensure that the length of the fathometer trace was proportional to the distance that the skiff traveled along the transect. Fathometer traces were inspected and the distance to each 2.5-meter change in depth recorded on these printouts. The ratio between the map transect lengths and the fathometer trace lengths were calculated and used to transcribe lake depth in 2.5-meter intervals on the map transects.

The depth profile of each lake was converted to a set of three-dimensional points describing the lake bottom using a Summasketch III Professional digitizing tablet and program Digitize by Rockware Inc.[1] A reference point was identified on each map as the origin of an X-Y coordinate system. The X and Y dimensions were calculated from a set of reference points supplied to the program and scaled in meters. The Z dimension was entered for each X-Y pair and scaled in negative meters from the lake surface. For Lower Ugashik, Turquoise, and Telaquana lakes, this was accomplished by digitizing the depths along the transects and the lake boundaries. For the remaining 12 lakes, the contour lines and lake boundaries were digitized from existing maps. The data points were then supplied to program Surfer by Golden Software Inc.[1] to extrapolate a surface that defined the lake bottom. Surfer was then used to conduct volume and area calculations as well as to draw bathymetric maps of the

[1] Use of brand names does not constitute endorsement.

lakes. Bathymetric maps of each study lake are found in Appendix A.

Temperature Data Collection

Two approaches were taken to collect water temperature data in the study lakes: in 1994 multiple sites were sampled once in July or early August and again in August, while in 1995 a single site was sampled twice in July and twice in August.

Measurements of water temperature in 1994 at three locations on each lake (Appendix B1) were taken by field crews from the Alaska Department of Fish and Game (ADF&G), National Park Service, and U. S. Fish and Wildlife Service. One sample of temperature was taken in July or early August and the second sample in August (Table 2). The same three locations, defined by GPS coordinates, were used for both sampling excursions. These locations were in the deepest parts of the lake and were separated by at least 1 kilometer.

Measurements of water temperature in 1995 were recorded at one location on each lake during July and August (Appendix B2). One sample of temperature was taken in early to mid-July, the second sample in late July, the third sample in mid-August, and the fourth sample in late August (Table 3). The same location, defined by GPS coordinates, was used for all sampling excursions. These sampling locations were in the deepest part of the lake.

Measurements in both years were made at 2.5-meter intervals using a Grant/YSI model 3800[1] or a Hydrolab 4041[1] from the surface to a depth of at least 50 meters or until the lake bottom was encountered. The mean temperature and its coefficient of variation at each 2.5-meter depth were estimated for each sampling event.

Thermal Habitat Volume

Two methods were used to determine the thermal habitat volume; i.e., the volume of water within the temperature range 8°-12°C, in the study lakes in 1994.

The first approach was (Payne et al. 1990):

$$THV = \frac{(D_2 - D_1)\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)}{300} \quad (1)$$

where:

D_2 = deepest depth that the average temperature is 8°C,

D_1 = shallowest depth that the average temperature is 12°C,

A_2 = cross-sectional area of the lake at D_2, and

A_1 = cross-sectional area of the lake at D_1.

The second approach was to use Surfer, a computer program which utilizes the depth contour data from the bathymetric maps to estimate the volume calculations. Based upon the results of the two methods in 1994, it was decided to calculate the THV in 1995 only using the Surfer program.

The data from the month with the least variable mean temperature over all depths was used to calculate THV (Szarzi 1993). The average temperature at each depth in a month, $\bar{t}_d$, is:

$$\bar{t}_d = \frac{\sum_{i=1}^{p} t_i}{p}, \quad (2)$$

and its variance:

$$var[\bar{t}_d] = \sum_{i=1}^{p} \frac{(t_i - \bar{t}_d)^2}{p-1} (2a,2b), \quad (3)$$

where p is the number of temperature profiles collected in a particular month. The variability among temperature profiles during a particular month s_M^2 is calculated by summing the variance of temperature measurements at depth, over all depths:

$$s_M^2 = \sum_{j=1}^{d} \text{var}[\bar{t}_d](3) . \tag{4}$$

The month with the smallest value of s_M^2, the average depths at which the temperatures are 12°C and 8°C, is used to estimate THV.

BIOLOGICAL INFORMATION

The weight of at least 28 sport harvested lake trout from each lake needed to be taken to the nearest 10 grams to meet objective 2 (Cochran 1977). This information was the most challenging to gather because sport fishing effort for lake trout is so diffuse in Southwest Alaska. We attempted to obtain weight information from three sources. First, commercial sport fishing guides were solicited to help. Interested guides were given equipment, training, and materials needed to collect weight and length data. This was planned to provide samples from a wide geographic area. Second, field crews from the Alaska Department of Fish and Game, National Park Service, and U. S. Fish and Wildlife Service collected weight data from anglers on an opportunistic basis. Third, a historical lake trout database was examined for hook-and-line caught lake trout that had been weighed from the target lakes.

POTENTIAL HARVEST AND SUSTAINED YIELD

Thermal habitat volume was used as a predictor variable to estimate potential harvest of each lake according to (Payne et al. 1990):

$$\log_{10}(\text{MSY}) = 2.15 + 0.714 \log_{10}(\text{THV}) , \tag{5}$$

where:

MSY = potential harvest (kg yr^{-1}), and

THV = thermal habitat volume in cubic hectometers (hm^3).

Potential sustained yield (SY; kg ha^{-1} yr^{-1}) was then calculated as:

$$\text{SY} = \frac{\text{MSY}}{\text{A}} , \tag{6}$$

where:

SY = potential sustained yield (kg ha^{-1} yr^{-1}),

MSY = potential harvest (kg yr^{-1}), and

A = surface area of the lake (ha).

The sustained yield can be converted to numbers of lake trout per year by dividing MSY by the mean weight of lake trout sampled at the lake.

ACTUAL HARVEST WEIGHT

The actual harvest of lake trout from each lake in kg/yr was estimated by:

$$\hat{Y} = \hat{H}\bar{w} , \tag{7}$$

and its variance by (Goodman 1960):

$$\hat{\text{Var}}(\hat{Y}) = \left[\hat{H}^2 \hat{\text{Var}}(\bar{w})\right] + \left[\bar{w}^2 \hat{\text{Var}}(\hat{H})\right] - \left[\hat{\text{Var}}(\bar{w}_t)\hat{\text{Var}}(\hat{H})\right] , \tag{8}$$

where:

$\hat{H}$ = sport harvest of lake trout from the lake estimated by the Statewide Harvest Survey, and

$\bar{w}$ = mean weight of lake trout sampled at the lake.

RESULTS

WEIGHT AND LENGTH INFORMATION

Sample size requirements (n ≥28) for lake trout were met at six study sites: Kontrashibuna Lake, Lake Clark, Tikchik Lake, Naknek Lake, Brooks Lake, and Kagati Lake (Table 4). Nineteen harvested lake trout were weighed at Lower Twin Lake, and 20 lake trout were sampled at Heart Lake. The above samples were collected by either fishing guides, National Park Service, USF&WS, or ADF&G personnel. Because sample size requirements were not met at the other study lakes, the average weight of lake trout from Naknek Lake was substituted to estimate yield of these lakes. Lake trout from Naknek Lake were the largest fish of any of the study sites. This would provide conservative estimates of yield for these other sites.

The historic sampling and harvest information for lake trout that was available provided no usable weight information. A great majority of the data in the archives was from lake trout captured using gillnets. Weight information from lakes with small sample sizes (Telaquana, Turquoise, and Lower Ugashik lakes) or old data (Goodnews Lake and Goodnews River) can be found in Appendix C.

Sampling dates for each lake were the following:

Table 4.-Biological information used from lakes where adequate sample sizes were collected.

	Lower Twin Lake	Kontrashibuna Lake	Lake Clark	Tikchik Lake	Naknek Lake	Brooks Lake	Kagati Lake[a]	Heart Lake[a]
Sampling Year(s)	1994	1994	1994	1994	1994	1995	1988-90	1987
Length (mm)								
Sample Size	19	58	45	53	34	30	743	20
Mean	401	441	533	536	556	544	487	457
Mode	410	508	610	470	570	570	480	431
Standard Deviation	25	74	117	50	41	31	31	64
95% Upper Confidence Interval	413	460	568	550	570	556	490	487
95% Lower Confidence Interval	389	421	498	522	542	532	485	427
Maximum	440	610	820	648	650	600	671	709
Minimum	352	279	360	440	485	490	380	398
Weight (g)								
Sample Size	19	58	45	53	34	30	726	20
Mean	788	867	1,909	1,763	2,051	1,618	1,478	1,195
Mode	700	455	800	1,800	2,000	1,814	1,500	900
Standard Deviation	164	374	1,063	465	490	229	329	740
95% Upper Confidence Interval	867	965	2,229	1,890	2,223	2,295	1,502	1,540
95% Lower Confidence Interval	709	769	1,589	1,635	1,880	940	1,454	849
Maximum	1,200	2,270	5,200	2,900	3,200	1,950	3,850	4,150
Minimum	550	340	700	1,100	1,250	1,043	700	700

[a] From Lisac and MacDonald *In prep.*

Lower Twin Lake	28 June 1994
	4 August 1994
	30 August 1994
Kontrashibuna Lake	6 July 1994
	8 August 1994
	30 August 1994
Lake Clark	3 June 1994
	8 June 1994
	12 June 1994
	15 June 1994
	9 July 1994
Tikchik Lake	24 July-15 August 1994
Naknek Lake	17 June 1994
	30 June 1994
	1 July 1994
	15 July 1994
Brooks Lake	1995
Kagati Lake	1988-1990
Heart Lake	1987

The mean length and weight for lake trout (Table 4) ranged from 401 mm and 788 g at Lower Twin Lake (n=19) to 556 mm and 2,051 g at Naknek Lake (n=34).

Thermal Habitat Volume (THV) and Yield Estimates

Thermal habitat volume for lake trout was estimated for 14 study lakes in 1994 and 10 study lakes in 1995 for both early and late temperature profiles (Table 2, Table 3, and Appendix D). Naknek Lake, by far the largest lake in this study at 56.321 ha, was given special consideration for estimating the THV. Water temperature measurements were taken in the two deep sections of the lake located on the eastern half of the lake: North Arm and Iliuk Arm (Appendix A8 and A9). The North Arm data were considered representative of all of Naknek Lake except Iliuk Arm, and the Iliuk Arm data were used only for the Iliuk Arm area. The THV values calculated from the two sections were then combined to provide an estimate of THV for the entire Naknek Lake.

The criteria for selecting the THV value to represent each study lake each year was based upon which month or time period had the least mean temperature variation. In 1995, only four of the ten study lakes were sampled twice in both July and August as scheduled (Table 5). The July sum of mean temperature variances was lower than August for all four lakes.

Table 5.-Sums of mean temperature variances at 2.5-meter intervals for sites where two sampling events occurred in both July and August, 1995.

Site	July	August
Goodnews Lake	8.01	9.29
Kagati Lake	1.71	7.80
Kanuktik Lake	5.26	6.41
Arolik Lake	1.30	19.62

The July THV values in 1995 were then used to estimate potential harvest (kg/yr) and potential sustained yield (in both kg/ha/year and in number of fish/yr: Table 6). Based upon the assumption that July temperature data were also least variable in 1994, THV estimates in 1994 from July (or closest sampling event to July) temperature data were used to calculate potential harvest and sustained yield in 1994 (Table 6).

The minimum and maximum estimates of THV (12 hm^3 to 5,852 hm^3), MSY (817 kg/yr to 69,161 kg/yr), and SY (398 fish/yr to 33,721 fish/yr) corresponded to the smallest and largest lakes in 1995, Arolik Lake (surface area 224 ha) and Naknek Lake (surface area 56,321 ha), respectively. The potential sustained yield ranged from

Table 6.-Thermal habitat volumes (THV) and potential harvest and sustained yield for lake trout from Southwest Alaska study lakes, 1994 and 1995.

Site	Year	Surface Area (ha)	THV[a] (hm^3)[b]	Potential Harvest (kg/yr)	Potential Sustained Yield (kg/ha/yr)	Mean Weight (kg)	Potential Sustained Yield (fish/yr)
Brooks Lake	1994	5,480	1,040	20,148	3.7	1.618	12,452
	1995	5,480	945	18,814	3.4	1.618	11,628
Naknek Lake	1994	56,321	5,688	67,768	1.2	2.051	33,041
	1995	56,321	5,852	69,161	1.2	2.051	33,721
Lower Ugashik Lake[c]	1994	17,693	4,763	59,705	3.4	2.051[c]	29,110[c]
	1995	17,693	436	10,835	0.6	2.051[c]	5,283[c]
Tikchik Lake	1994	5,892	345	9,159	1.6	1.763	5,195
	1995	5,892	298	8,249	1.4	1.763	4,679
Lake Clark	1994	30,659	3,163	44,569	1.5	1.909	23,347
	1995	30,659	3,853	51,316	1.7	1.909	26,881
Kontrashibuna Lake	1994	2,345	487	11,715	5.0	0.867	13,512
Lower Twin Lake	1994	831	162	5,336	6.4	0.789	6,763
Upper Twin Lake[c]	1994	1,503	178	5,717	3.8	2.051[c]	2,785[c]
Turquoise Lake[c]	1994	1,300	75	3,086	2.4	2.051[c]	1,505[c]
Telaquana Lake[c]	1994	4,632	646	14,332	3.1	2.051[c]	6,988[c]
Goodnews Lake[c]	1994	382	48	2,227	5.8	2.051[c]	1,086[c]
	1995	382	13	871	2.3	2.051[c]	425[c]
Heart Lake	1994	565	86	3,400	6.0	1.195	2,845
	1995	565	75	3,078	5.4	1.195	2,576
Kagati Lake	1994	1,057	152	5,102	4.8	1.478	3,452
	1995	1,057	69	2,917	2.8	1.478	1,974
Kanuktik Lake[c]	1994	807	122	4,363	5.4	2.051[c]	2,127[c]
	1995	807	66	2,801	3.5	2.051[c]	1,366[c]
Arolik Lake[c]	1995	224	12	817	3.6	2.051[c]	398[c]

[a] THVs were estimated from temperature data collected in July (or closest sampling event to July).

[b] hm^3 = cubic hectometers.

[c] Too few weight samples were obtained from this lake to estimate mean weight. The mean weight of lake trout from Naknek Lake (the largest mean weight available) was used to estimate sustained yield (fish/yr) for this lake. This probably results in a conservative estimate of sustained yield.

0.6 kg/ha/yr in 1995 at Lower Ugashik Lake to 6.4 kg/ha/yr in 1994 at Lower Twin Lake.

Nine lakes had estimates of THV and SY for 1994 and 1995: Brooks, Naknek, Lower Ugashik, Tikchik, Goodnews, Heart, Kagati, and Kanuktik lakes, and Lake Clark (Table 7). The most dramatic change in estimates between years occurred at lower Ugashik Lake: the THV was 4,763 hm^3 in 1994 versus 436 hm^3 in 1995; the MSY was 59,705 kg/yr in 1994 versus 10,835 kg/yr in 1995; and the SY was 29,110 fish/yr and 3.4 kg/ha/yr in 1994 versus 5,283 fish/yr and 0.6 kg/ha/yr in 1995.

CURRENT HARVEST

Average annual harvest of lake trout from each study lake during the past 5 years and the past 10 years varied from less than 1 to approximately 300 (Table 8). Lakes with a low 5-year or 10-year average harvest also have few respondents to the Statewide Harvest Survey (less than five a year most likely) and these may *not* have accurate estimates of lake trout harvest. Table 8 shows the average number of respondents for each of the study lakes.

The harvest of lake trout from lakes with fewer than 12 respondents is not considered reliable (Mills and Howe 1992). The estimated harvest of lake trout in three lakes (Table 8) included harvest from nearby rivers: Naknek Lake included Naknek Lake, Bay of Islands, Iliuk Arm, Brooks River, and Naknek River; Goodnews Lake included Goodnews Lake and Goodnews River; and Kagati Lake included Kagati Lake and Kanektok River. The harvest of lake trout in these three lakes and adjoining rivers is considered part of the local lake trout stock.

Table 7.-Comparison of THV and potential sustained yield (fish) with their respective dates of sampling.

Site	1994 Sampling Date	1995 Sampling Date	1994 THV (hm^3)[a]	1995 THV (hm^3)[a]	1994 Potential Sustained Yield (fish/yr)	1995 Potential Sustained Yield (fish/yr)
Brooks Lake	23-July	July Mean	1,040	945	12,452	11,628
Naknek Lake	31-July	July Mean	4,840	5,852	29,443	33,721
Lower Ugashik Lake	11-Aug	10-July	4,763	436	29,330	5,283
Tikchik Lake	6-Aug	July Mean	345	298	5,195	4,679
Lake Clark	5-Aug	July Mean	3,163	3,853	24,090	26,881
Goodnews Lake	18-July	July Mean	48	13	1,086	425
Heart Lake	18-July	July Mean	86	75	2,845	2,576
Kagati Lake	18-July	July Mean	152	69	3,452	1,974
Kanuktik	18-July	July Mean	122	66	2,127	1,366

[a] hm^3 = cubic hectometers.

Table 8.-Average number of respondents (households) to the Statewide Harvest Survey who reported fishing at the study lakes during 1985-1994, and average estimated harvest of lake trout from the Statewide Harvest Survey during that period.

	10-Year Average (1985-1994)		5-year Average (1990-1994)	
Site	Respondents[a]	Harvest	Respondents[a]	Harvest
Brooks Lake	13	76	19	84
Naknek Lake[b]	221	170	297	93
Lower Ugashik Lake	15	46	18	44
Tikchik Lake	25	162	37	104
Lake Clark	30	283	45	284
Kontrashibuna Lake	<1	2	1	4
Twin Lake (both Upper and Lower)	3	45	3	16
Turquoise Lake	<1	5	<1	0
Telaquana Lake	1	20	2	40
Goodnews Lake[c]	121	12	15	10
Heart Lake	<1	4	<1	8
Kagati Lake[d]	44	67	48	4
Kanuktik Lake	<1	2	<1	3
Arolik Lake	<1	2	<1	4

[a] <1 indicates at least some response (although the average is less than 1).

[b] Naknek Lake includes Naknek Lake, Bay of Islands, Iliuk Arm, Brooks River, and Naknek River harvest data.

[c] Goodnews Lake includes Goodnews Lake and Goodnews River harvest data.

[d] Kagati Lake includes Kagati Lake and Kanektok River harvest data.

DISCUSSION

Current recreational harvest levels appear fairly minimal and should not affect the lake trout abundance or production at any of the study lakes. The current daily bag limit of four lake trout also does not appear excessive. However, due to the remote nature of these lakes and the infrequent reports of harvest for some of these lakes, the estimates of lake trout harvest from the Statewide Harvest Survey may be biased.

The THV model developed by Payne et al. (1990) for estimating the sustained yield of lake trout relies upon the accuracy of the THV estimate. The estimation of THV for each lake is based upon two parameters: the bathymetric and temperature profile data. The temperature profile data will vary both on a temporal and spatial scale. Determining what constitutes the "best" temperature data, be it an average of several measurements at several locations or a single measurement at one location, thus becomes critical. Payne et al. (1990) determined that temperature profile data collected during July from Ontario lakes contained the least variation. Szarzi (1993) found that July temperature data at Paxson Lake in 1991-1992 and at Lake Louise in

1991 were less variable than August temperature data, while at Lake Louise in 1992 the temperature data were equally variable between July and August.

The sampling methods in this study for collecting temperature data in 1995 were different than those in 1994. In 1994 each lake was sampled once in July and once in August at three locations, while in 1995 each lake was scheduled to be sampled twice in July and twice in August at one location. Variation in temperature data occurred both on a temporal and spatial scale within each lake. The THV estimates presented in Table 6 were estimated from temperature data collected in July, or data collected in early August if the July sampling trip did not occur (Table 7).

Estimates of THV at lakes can vary significantly from year to year. The THV estimate for the Southcentral Alaska lake, Lake Louise, varied from 52.6 hm^3 in 1991 to 291.3 hm^3 in 1992 (Szarzi 1993). For Lower Ugashik Lake in Southwest Alaska, the THV estimate was 4,763 hm^3 in 1994 and only 436 hm^3 in 1995 (Table 7).

The majority of the estimates of yield (and THV) from Southcentral Alaska lakes (Szarzi 1993) are below yield estimates from Southwest Alaska lakes. At Paxson Lake estimates of yield from 1991 and 1992 were very similar (0.99 kg/ha and 1.03 kg/ha, respectively). At Lake Louise, however, yield estimates were 0.37 kg/ha/yr in 1991 and 1.21 kg/ha/yr in 1992. The yield estimate for Lake Susitna is 0.52 kg/ha/yr. These estimates of yield are generally below the yield estimates for lakes in this study (Table 6). Lower Ugashik Lake had the smallest estimates of yield from Southwest Alaska study lakes at 0.6 kg/ha/yr in 1995. Yield estimates for Southwest Alaska lakes range from this low, to a high of 6.4 kg/ha/yr for Lower Twin Lake in 1994.

The estimates of yield (and THV) from Ontario lakes can also be compared to lakes in Southwest Alaska. Payne et al. (1990) estimated the yield of 20 lakes in Ontario, Canada. Most of these lakes were significantly larger than the lakes included in this study: 14 out of the 20 Ontario lakes ranged in size from 115,200 to 8,241,400 ha; while the 15 Southwest Alaska lakes ranged in size from 224 to 56,321 ha. Payne et al. (1990) found that the estimated yield in the Ontario lakes ranged from 0.02 kg/ha/yr to 3.0 kg/ha/yr. A trend also appeared in that larger lakes had smaller estimates of yield and smaller lakes had greater estimates of yield (kg/ha/yr). Seventeen of 20 lakes in the Ontario study had an estimated yield of between 0.02 to 0.87 kg/ha/yr; considerably smaller than the lakes in Southwest Alaska. Comparison of lakes of the same relative size (surface area) shows Naknek Lake (56,321 ha) had an estimated yield of 1.2 kg/ha/yr while Amisk Lake (32,100 ha) in Ontario had an estimated yield of less than half that at 0.42 kg/ha/yr. The yield estimate of 2.9 kg/ha/yr at Telaquana Lake (4,632 ha) in Southwestern Alaska was nearly four times that of Lake Opeongo (5,894 ha; 0.68 kg/ha/yr) in Ontario. In only one case did similar sized lakes in Canada and Southwest Alaska have similar estimated yields: Bone Lake (121 ha) had an estimated yield of 2.12 kg/ha/yr while Goodnews Lake (382 ha) had an estimate of 3.4 kg/ha/yr.

The estimated THV for lakes in Southwest Alaska are on average considerably higher than those from Southcentral Alaska and Ontario. This is likely due to lack of stratification of the water column. The study lakes in Southwest Alaska during the summer of 1994 and 1995 did not appear to stratify like Ontario or Southcentral Alaska study lakes. A temperature profile from 8°-12°C could be found, but at times 12°C started at the lake surface. The lack of stratification in the study lakes is due to the frequent storms passing over the Alaska Peninsula which result in strong winds that cause a lake's water column to mix (LaPerriere 1996). The estimated yields for Southwest Alaska study lakes were generally larger than Ontario and Southcentral Alaska lakes because of the large THV to surface area ratio for Southwest Alaska lakes. While an 8°-12°C temperature profile is present in the study lakes it is unclear if a relation exists between lake trout production in the lakes of Southwest Alaska and THV.

Population estimates developed from lake trout tagging projects were available for comparison with estimated sustained yields derived from the THV model for Paxson Lake in Southcentral Alaska and Kagati Lake in Southwest Alaska. Szarzi (1993) estimated a mature lake trout population of 9,124 fish (SE=1,707) for Paxson Lake in 1991, while the estimated sustained yield based on the THV model was 866 fish/yr in 1991 and 1,014 fish/yr in 1992. Mark-recapture data from a tagging study conducted by the U.S. Fish and Wildlife Service at Kagati Lake (Lisac and MacDonald *In prep*) provided a population estimate based on the Jolly-Seber model (Seber 1982) of 2,119 fish in 1989 (95% confidence interval of 0 to 5,803) and 2,329 fish in 1990 (95% confidence interval of 0 to 6,973). The potential sustained yield estimated by the THV model for Kagati Lake of 3,542 fish/yr in 1994 and 1,974 fish/yr in 1995, provides indications that either the THV model may be severely overestimating the potential sustained yield of Kagati Lake, or that the true population size in Kagati Lake may be closer to the upper limits of the 95% confidence limits than the Jolly-Seber population point estimates for 1989 and 1990.

The estimates of THV, MSY, and SY developed from this initial project for lakes in Southwest Alaska should be considered preliminary. It is clear from Szarzi's report (1993) and the results of this study in Southwest Alaska that a much longer series of data needs to be collected and examined to make a more reliable analysis of THV and lake trout production in Southwest Alaska lakes.

CONCLUSIONS

Based on the work from 1994-1995, it is difficult to determine the feasibility of using the THV model for estimating maximum sustained yield for lake trout in southwest Alaska. Temperature profile information collected from the study lakes showed a distinct lack of stratification which may compromise the utility of the THV model. In lakes where the THV models have been successfully used, lake stratification is common to all. If lakes do not distinctly stratify, as it appears that they may not in southwest Alaska, then the volume of water of a desirable or limiting temperature may not be a limiting factor.

The THV model produced a potential sustained yield (fish/yr) nearly equal to the estimated population size for Kagati Lake, the only study lake in Southwest Alaska where both estimates were available for this study. At this time we are unable to determine if such apparent overestimation of sustained yield values derived from the THV model is occurring with the other study lakes in Southwest Alaska.

Assuming the THV model is applicable, then the estimates of sustained yield are far greater than harvest estimates presently reported in the Statewide Harvest Survey. Estimates of sustained yield contained in this report are highly preliminary and often based on incomplete sampling information. Improvements in the quality, and the utility of the estimates of sustained yield are contingent upon determining the applicability of the THV model to lakes in Southwest Alaska and increasing the sample sizes of sport harvested lake trout.

RECOMMENDATIONS

We recommend that the number of study lakes be reduced to a few lakes which have both adequate sample sizes of biological data from lake trout and where temperature data can be obtained in a cost efficient manner by NPS, USF&WS, or ADF&G personnel. Results from a thorough study on a few lakes will then provide baseline information on how to proceed with estimating sustained yield of lake trout from Southwest Alaska lakes. It may be that another variable, such as surface area of the lake, will ultimately prove more appropriate than THV for modeling lake trout populations in Southwest Alaska lakes.

The population dynamics of lake trout in Southwest Alaska lakes need to be more thoroughly documented. In addition to estimating mean weight from a minimum of 28 lake trout weights, length, sex, and age data need to be collected. Development of a database of abundance estimates, mortality, and carrying capacity is necessary for evaluating sustained yield models based on abiotic characteristics of the lake.

It is appropriate to continue evaluating the THV of Southwest Alaska lakes by collecting temperature data during July and August in the deepest area of the lake. The ideal sampling method would be to establish a monitoring station which continuously records the temperature at various depths, by attaching temperature data loggers at various locations on an anchored/buoyed line. The more cost effective approach would be to continue to take two temperature profiles at least 10 days apart during both July and August. Once the temperature data are obtained, THV could be estimated using the Surfer program.

ACKNOWLEDGMENTS

This project was a cooperative effort between the Alaska Department of Fish and Game (ADF&G), National Park Service (NPS), and the United States Fish and Wildlife Service (USF&WS). Many fishery professionals dedicated their time and expertise to provide the data contained in this report. In alphabetical order they are: Alan Bennett (NPS), Dan Dunaway (ADF&G), Buddy Goatcher (NPS), Ron Hood (USF&WS), Dan Hourihan (DNR), Ross Kavanagh (NPS), Jim Larson (USF&WS), Mark Lisac (USF&WS), Rob MacDonald (USF&WS), John Moran (USF&WS), and Rick Potts (NPS).

Field data used to create the bathymetric maps were collected over the years by numerous agencies and research groups, including NPS, USF&WS, U.S. Geological Survey, National Marine Fisheries Service, the University of Washington-Fisheries Research Institute, and ADF&G. The bathymetric maps were digitized into electronic files by ADF&G personnel.

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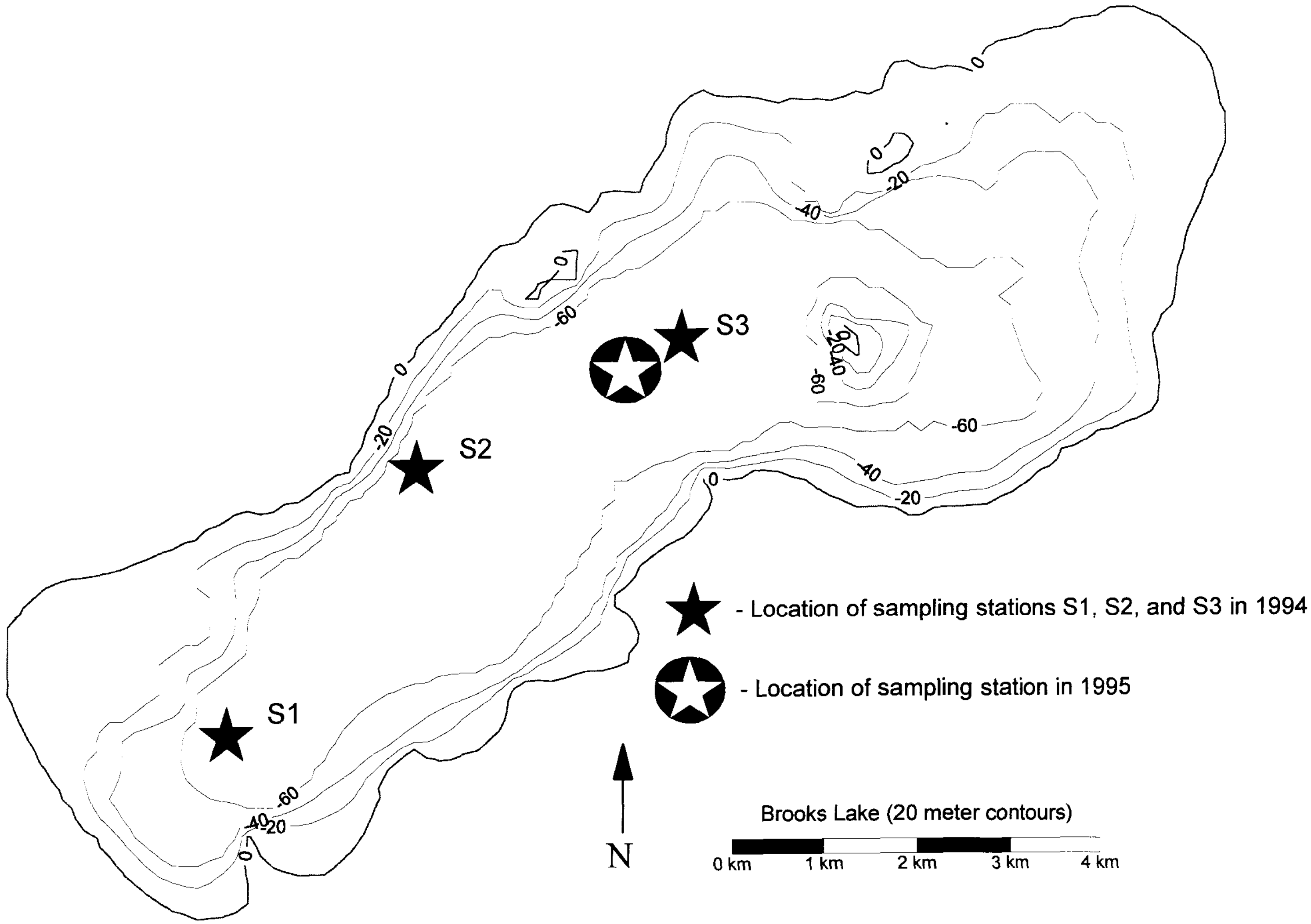
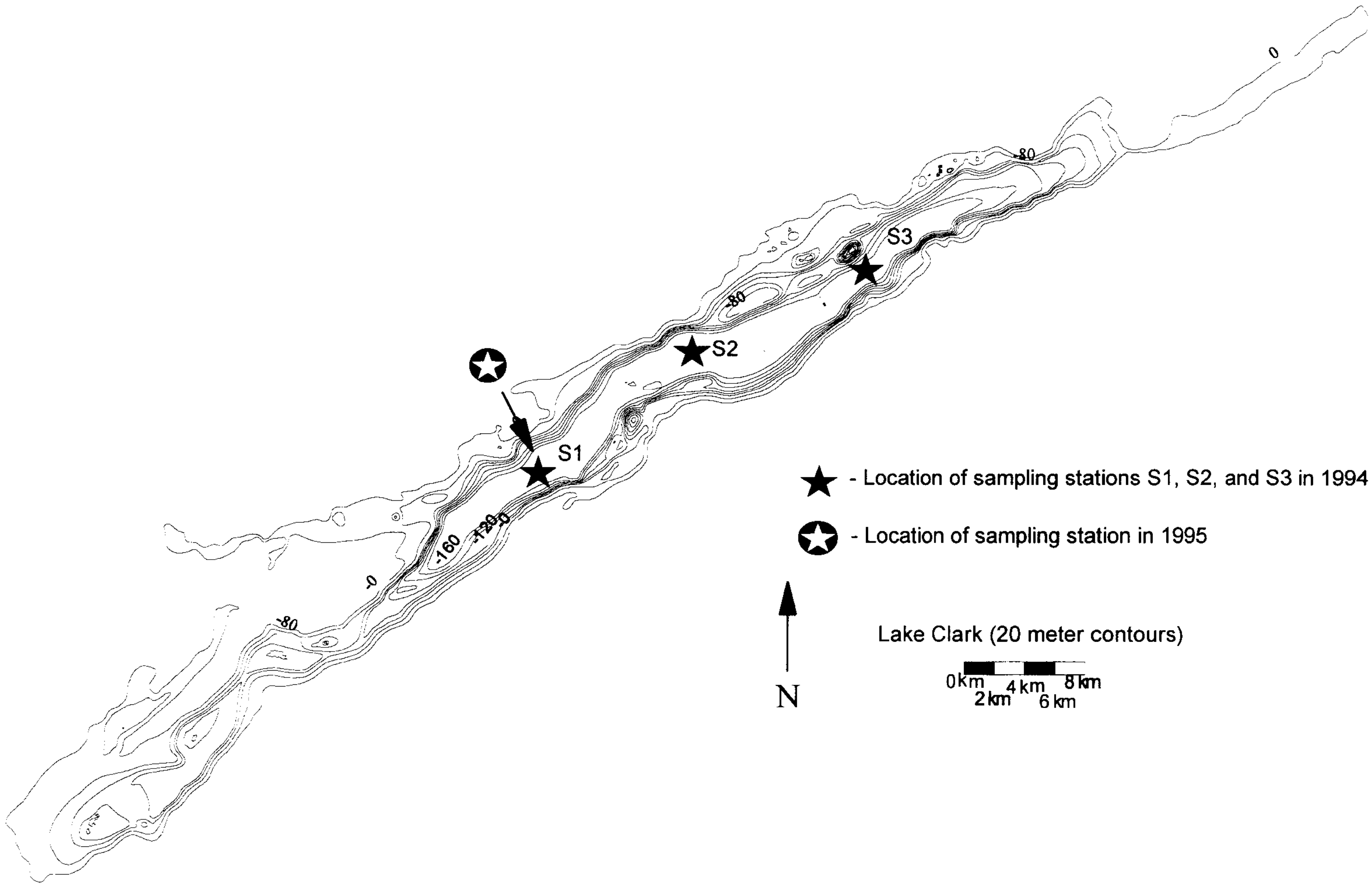
APPENDIX A. BATHYMETRIC MAPS OF STUDY LAKES



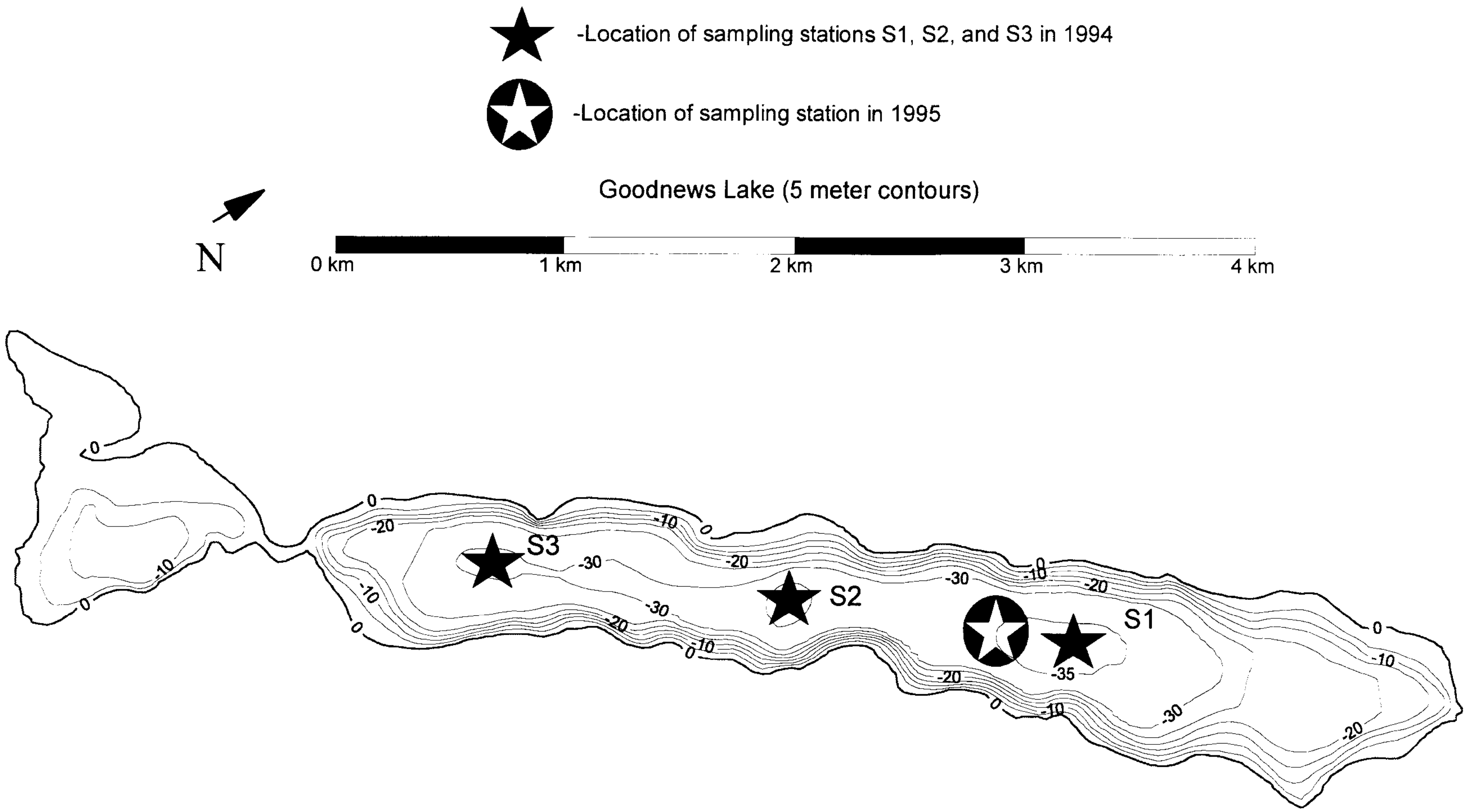
Source: National Marine Fisheries Service (formerly known as Bureau of Commercial Fisheries) map, 1963.

Appendix A1.-Bathymetric map of Brooks Lake.



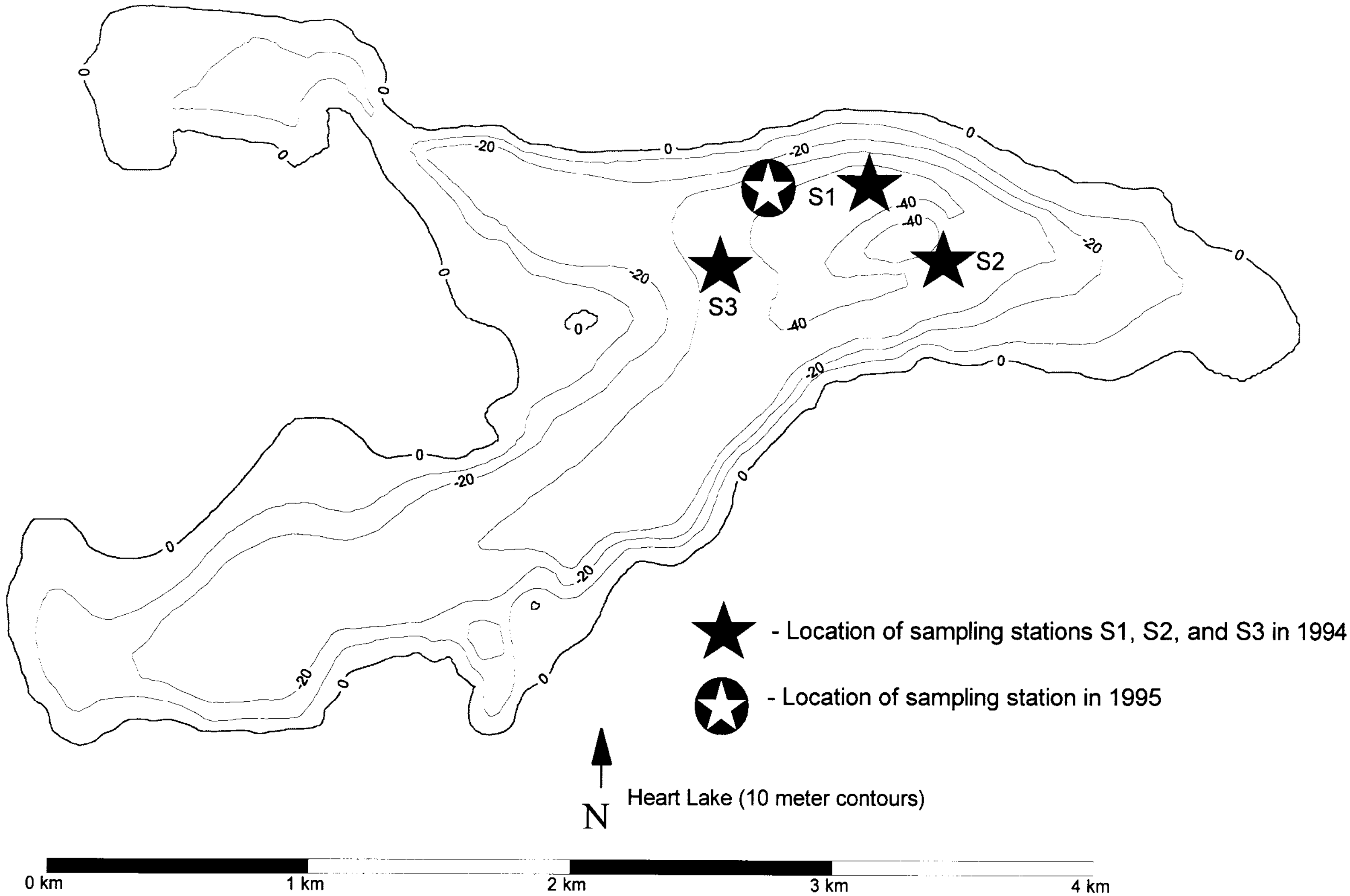
Source: University of Washington-Fisheries Research Institute map, 1969.

Appendix A2.-Bathymetric map of Lake Clark.



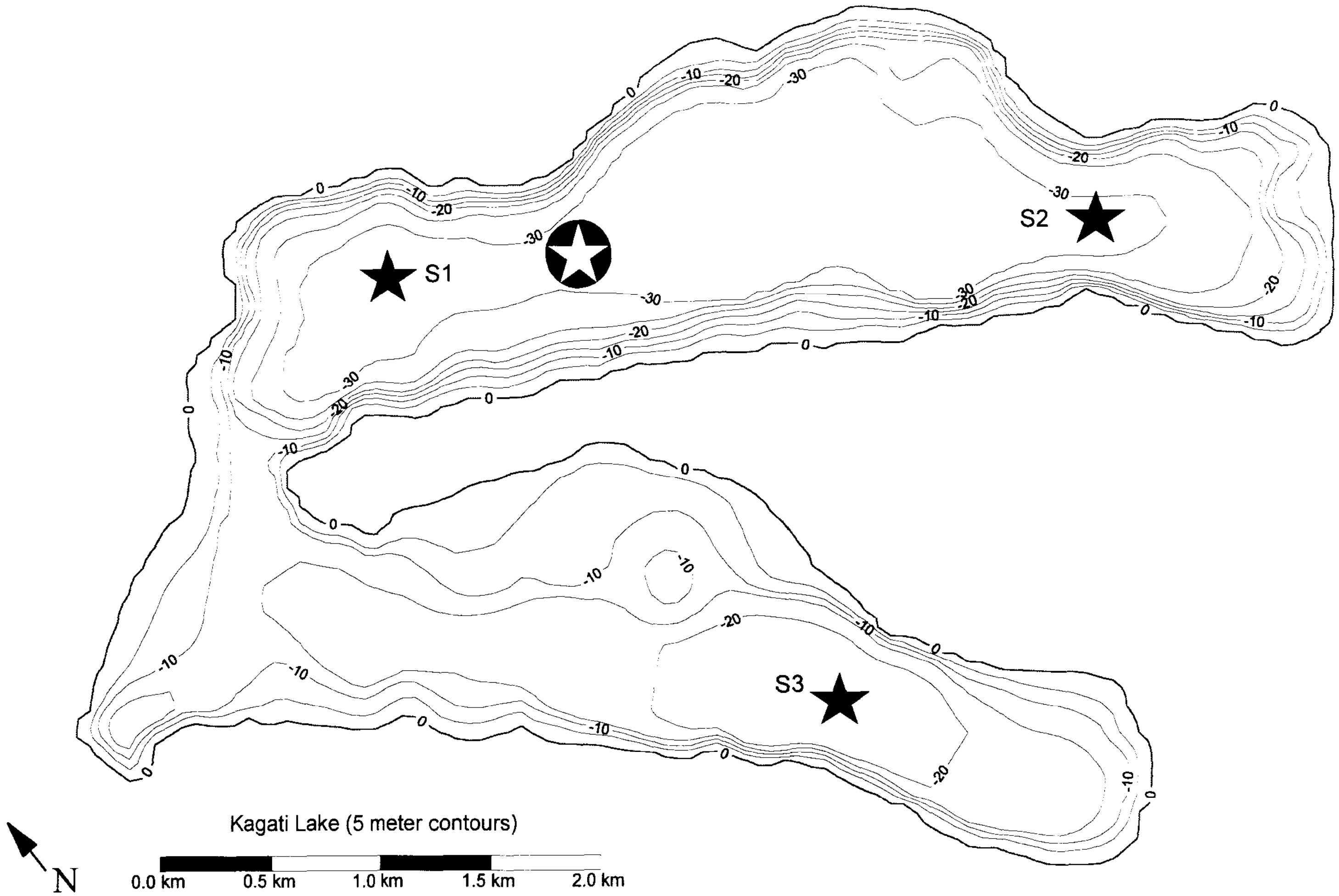
Source: MacDonald 1996.

Appendix A3.-Bathymetric map of Goodnews Lake.



Source: MacDonald 1996.

Appendix A4.-Bathymetric map of Heart Lake.

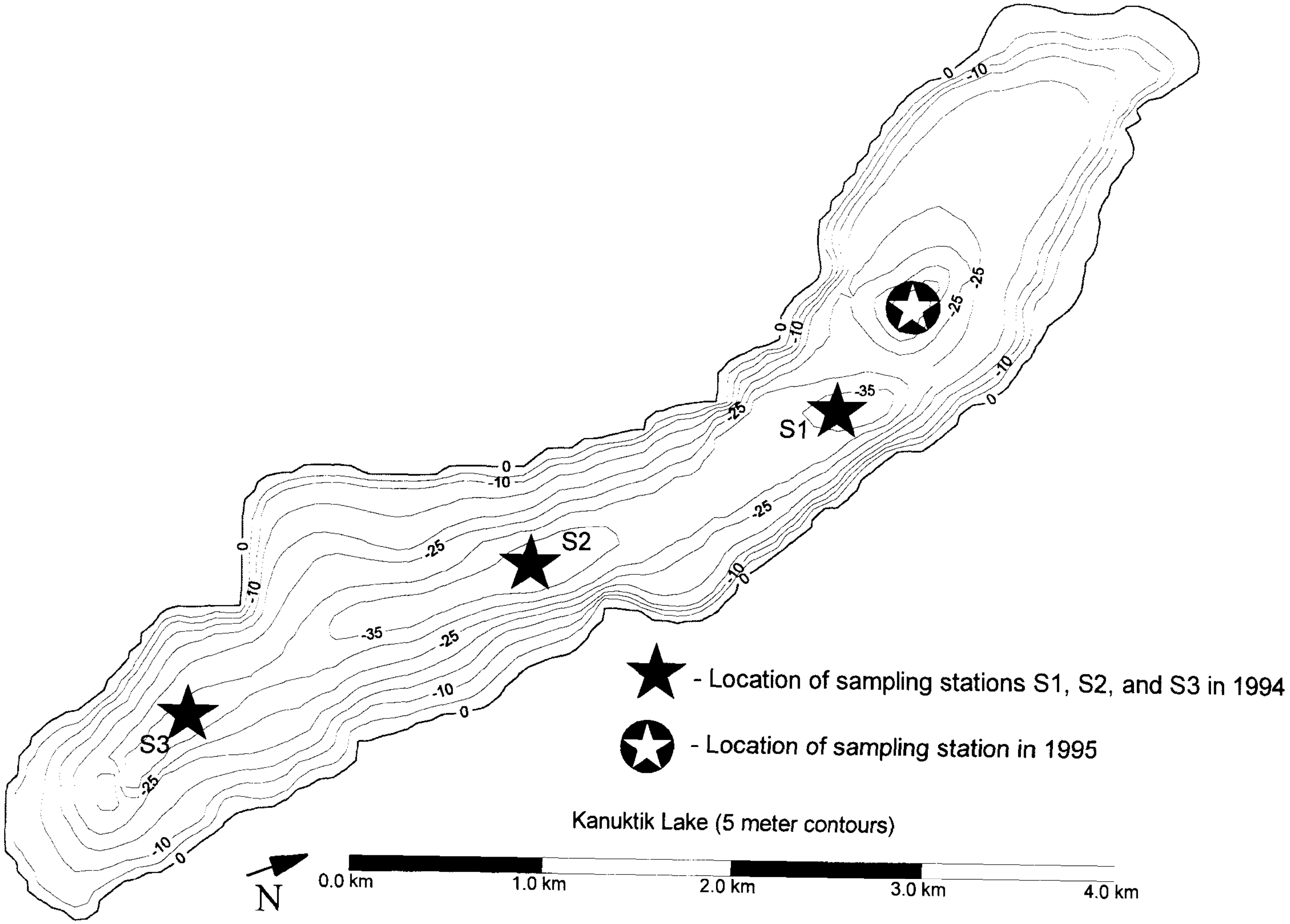


★ - Location of sampling stations S1, S2, and S3 in 1994

✪ - Location of sampling station in 1995

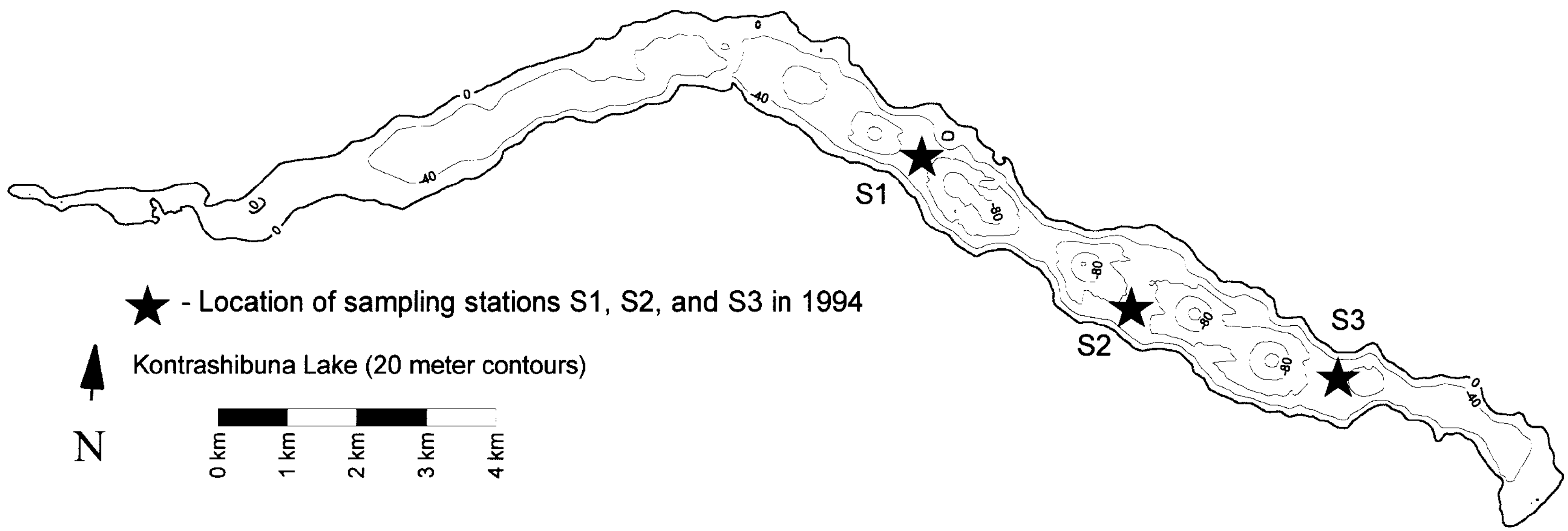
Source: MacDonald 1996.

Appendix A5.-Bathymetric map of Kagati Lake.



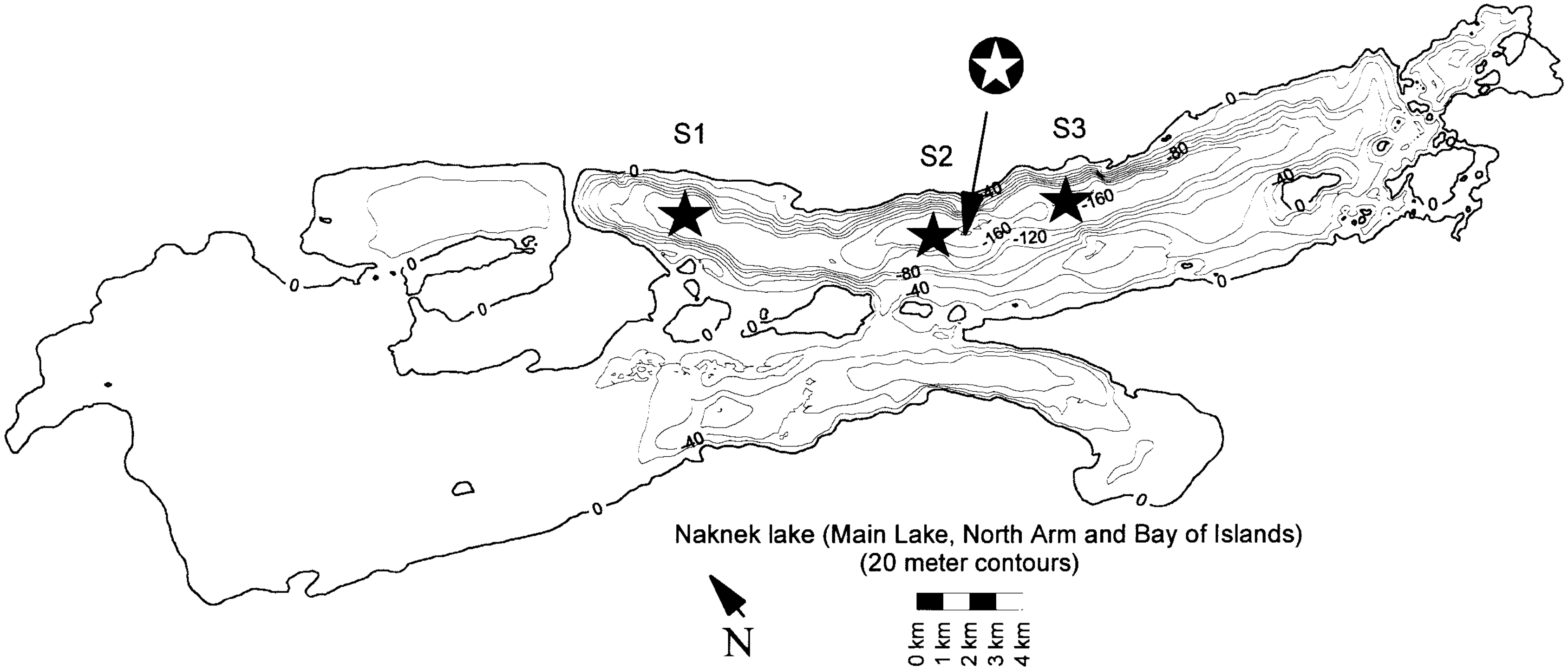
Source: MacDonald 1996.

Appendix A6.-Bathymetric map of Kanuktik Lake.



Source: U.S. Geological Survey map, 1966.

Appendix A7.-Bathymetric map of Kontrashibuna Lake.

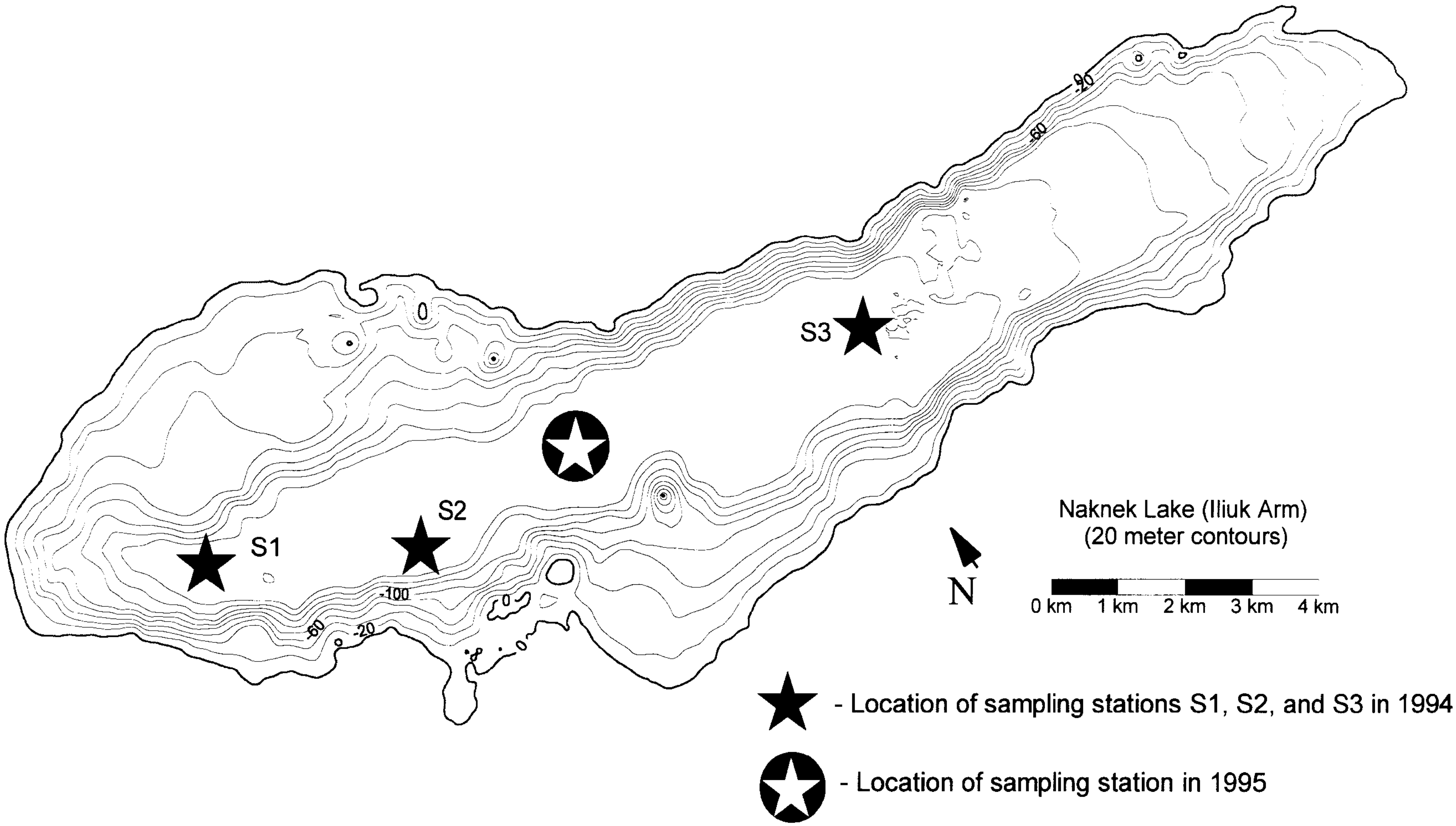


★ - Location of sampling stations S1, S2, and S3 in 1994

✪ - Location of sampling station in 1995

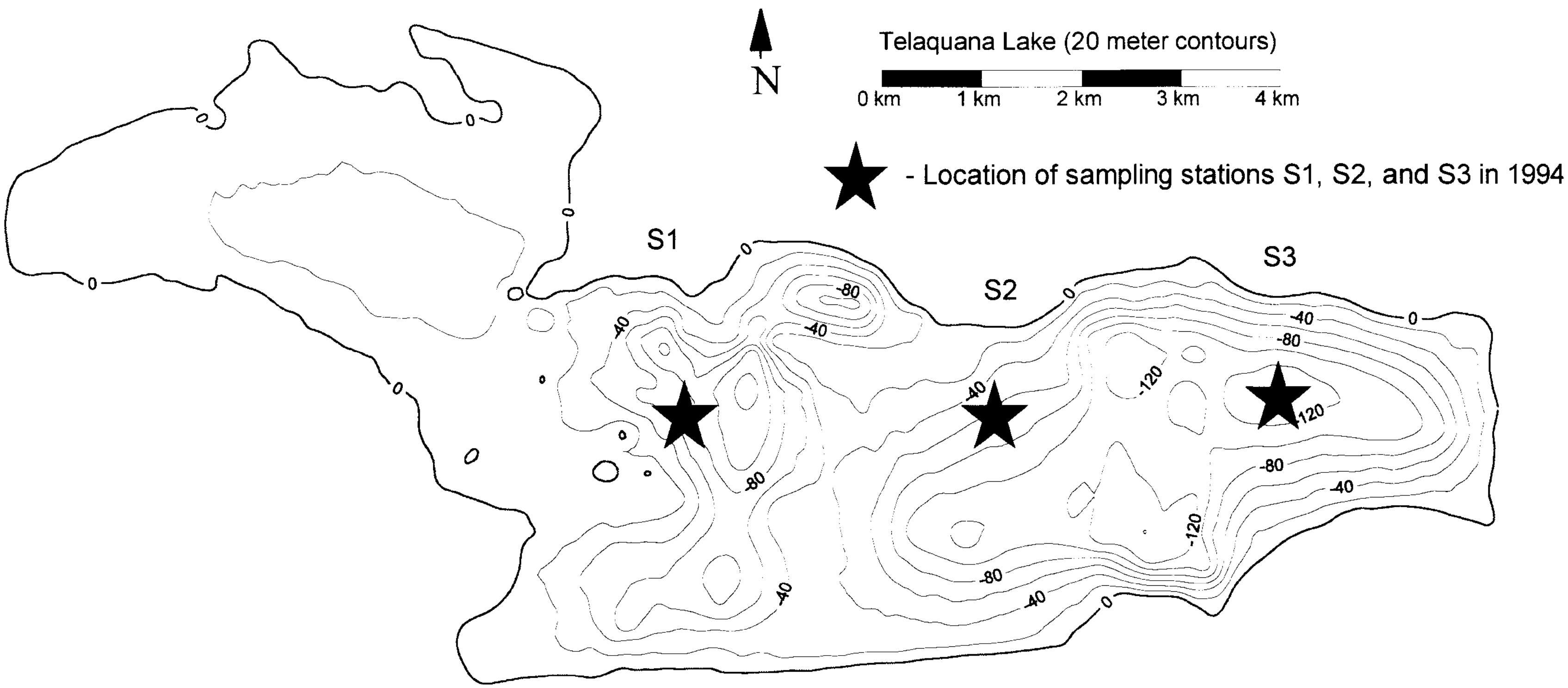
Source: National Marine Fisheries Service (formerly known as Bureau of Commercial Fisheries) map, 1963.

Appendix A8.-Bathymetric map of Naknek Lake, excluding Iliuk Arm.



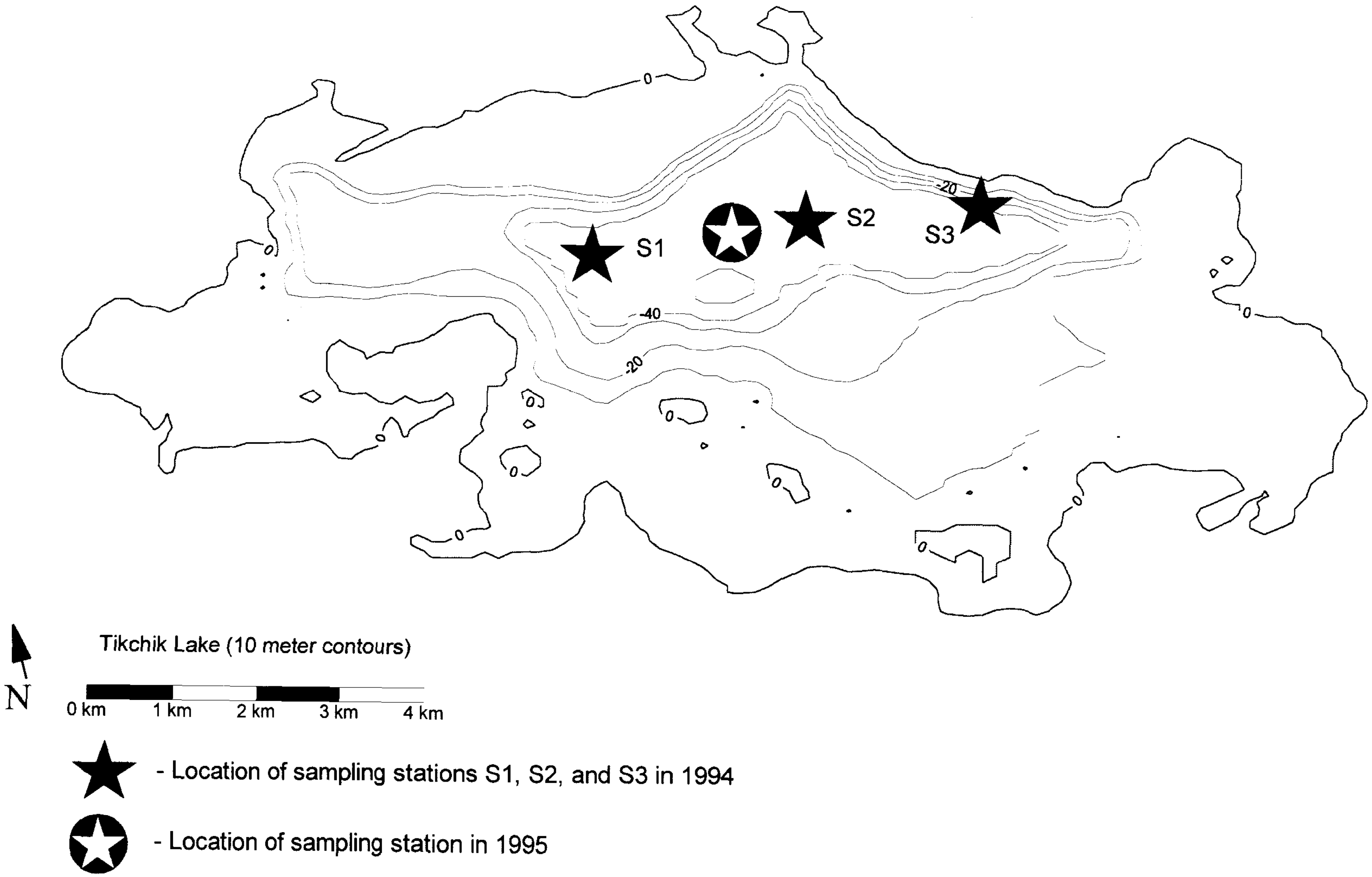
Source: National Marine Fisheries Service (formerly known as Bureau of Commercial Fisheries) map, 1963.

Appendix A9.-Bathymetric map of the Iliuk Arm of Naknek Lake.



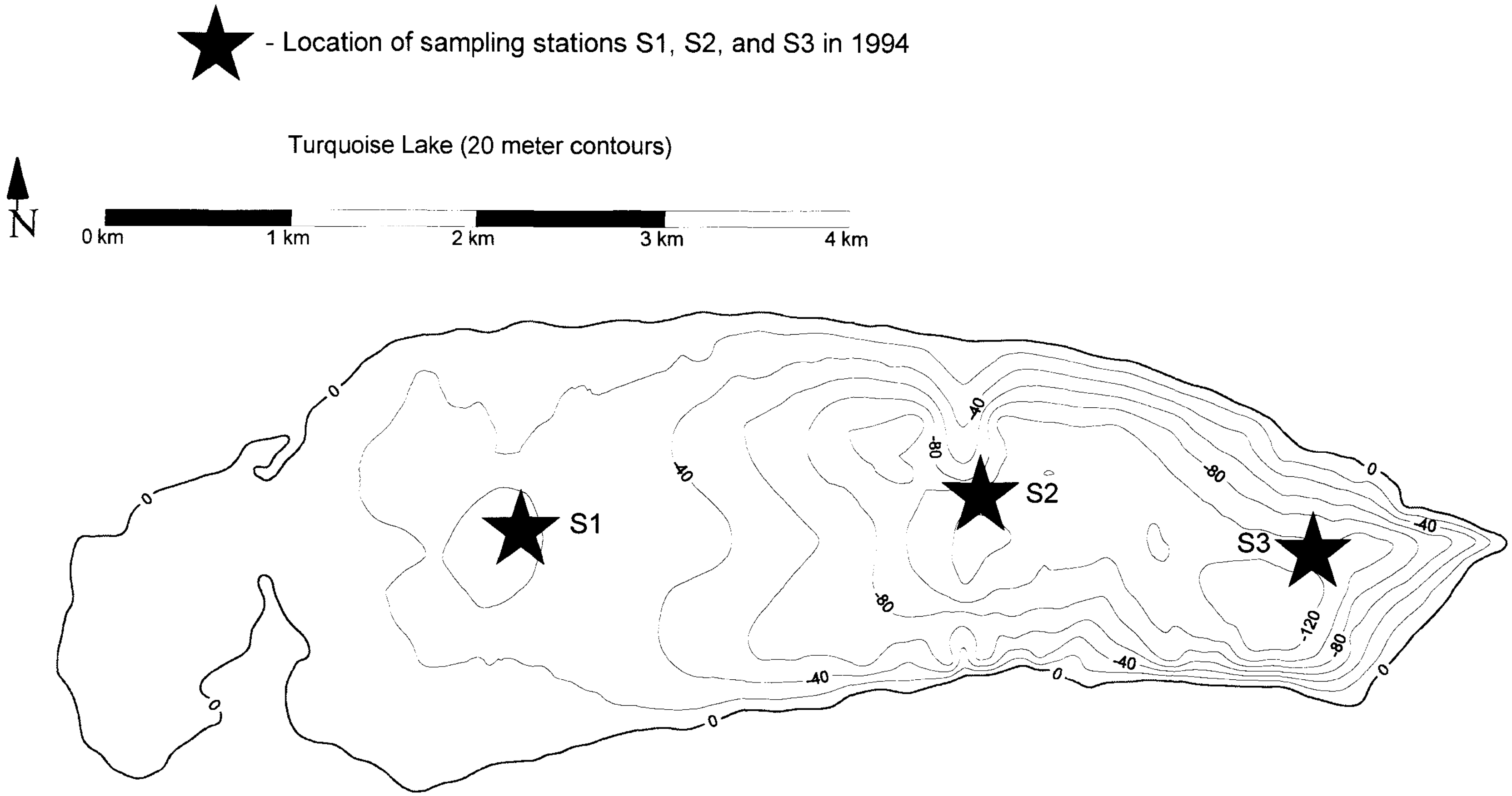
Source: Alaska Department of Fish and Game map, 1994.

Appendix A10.-Bathymetric map of Telaquana Lake.



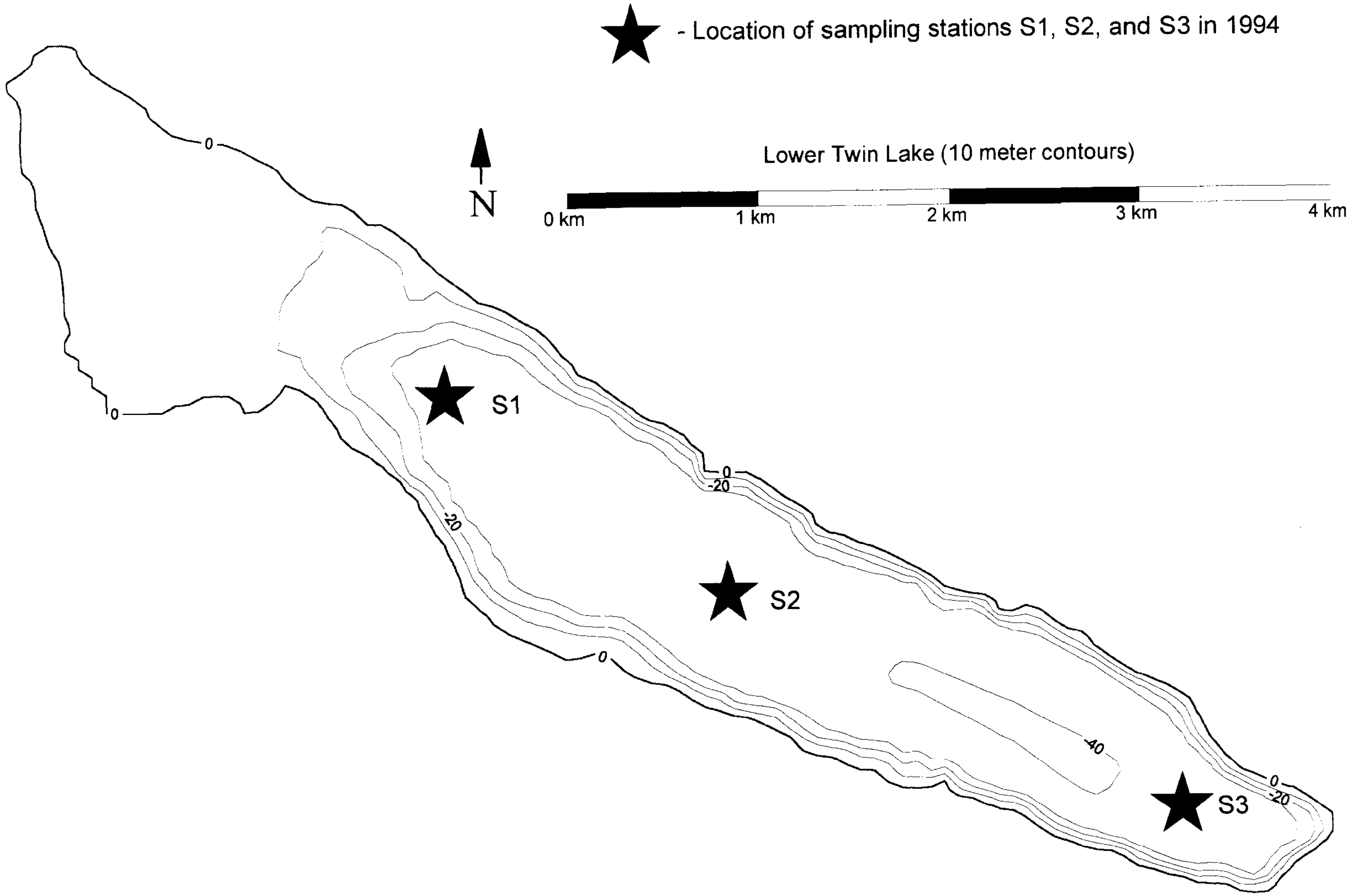
Source: University of Washington-Fisheries Research Institute map, 1964.

Appendix A11.-Bathymetric map of Tikchik Lake.



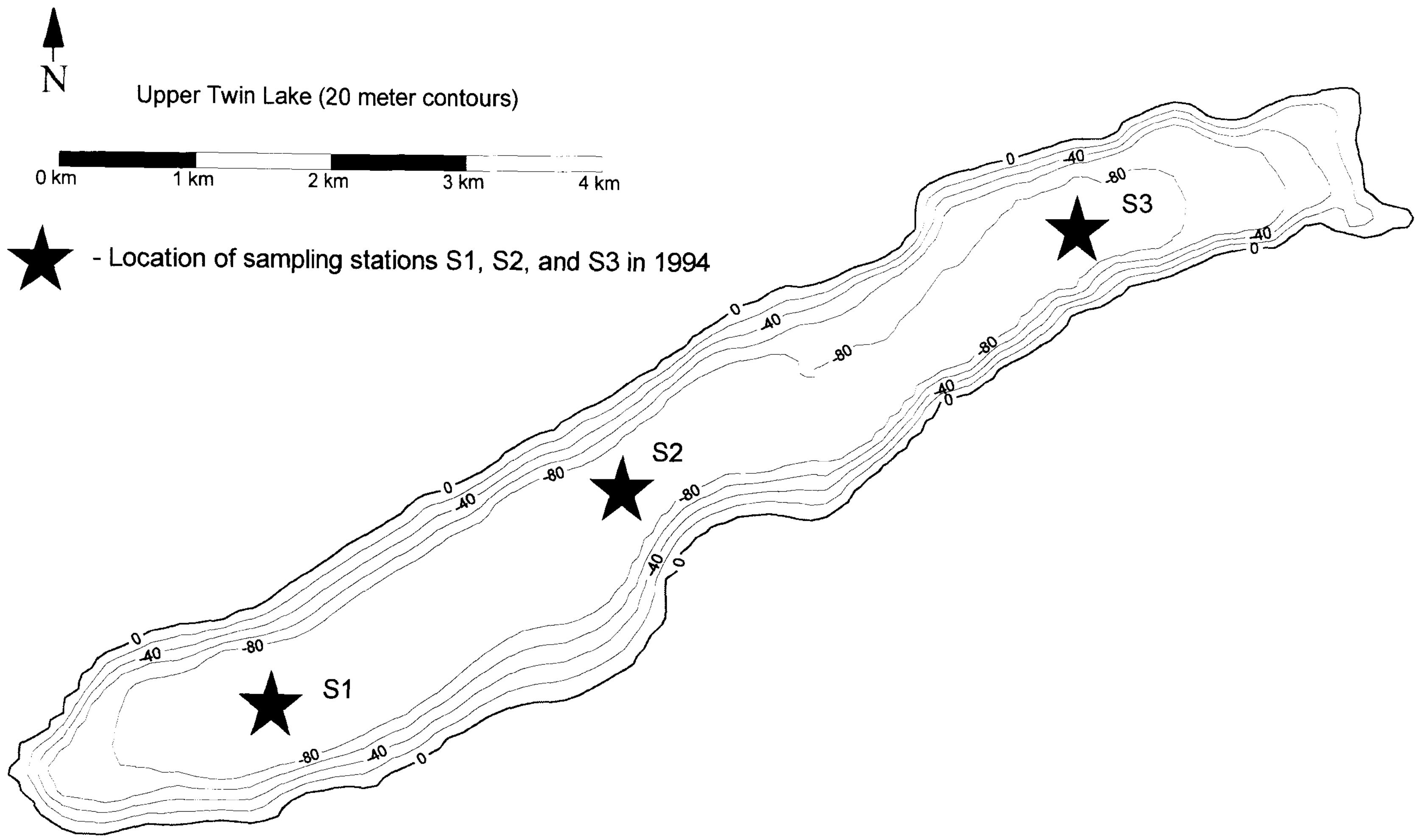
Source: Alaska Department of Fish and Game map, 1994.

Appendix A12.-Bathymetric map of Turquoise Lake.



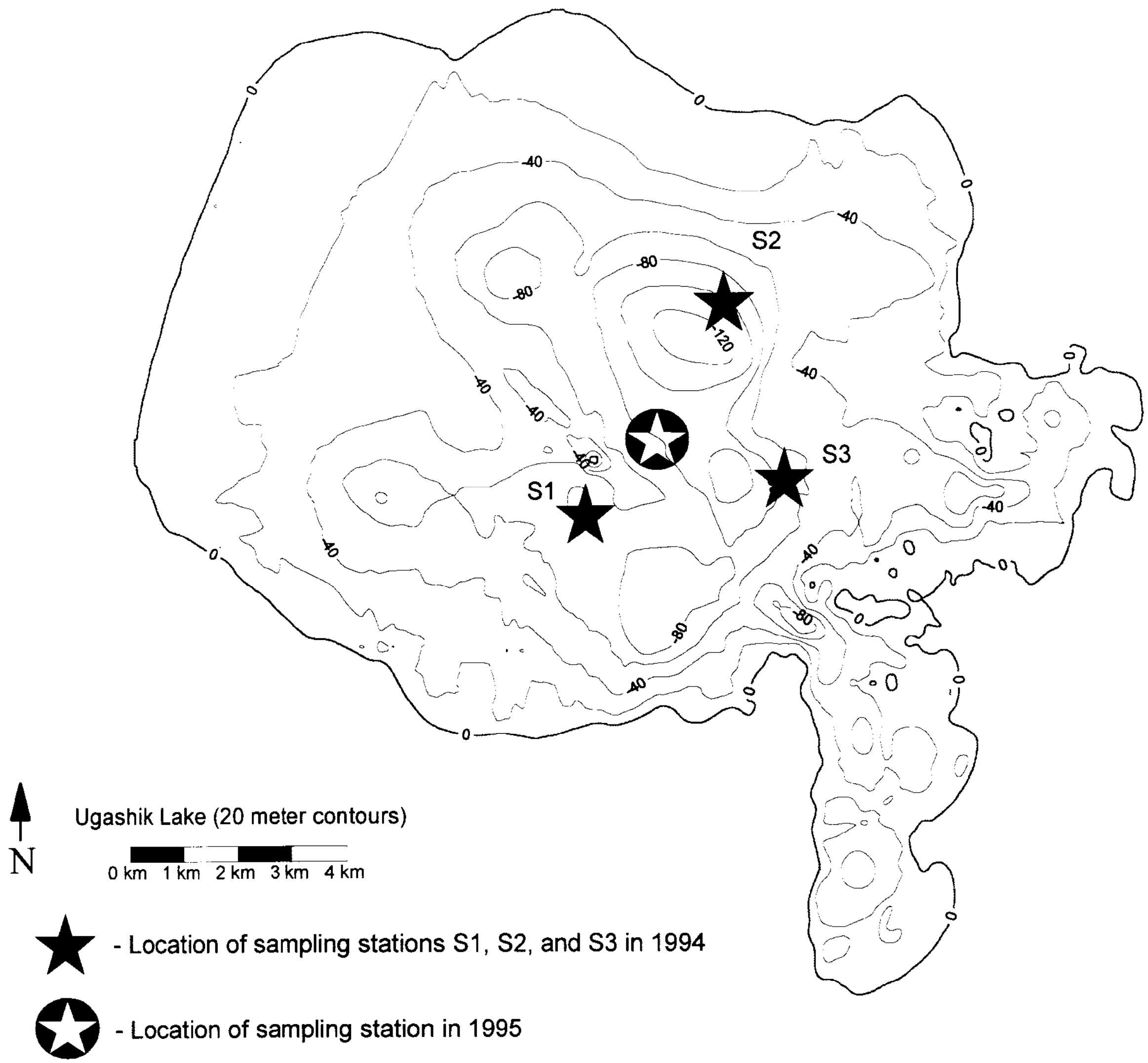
Source: U.S. Geological Survey map, 1968.

Appendix A13.-Bathymetric map of Lower Twin Lake.



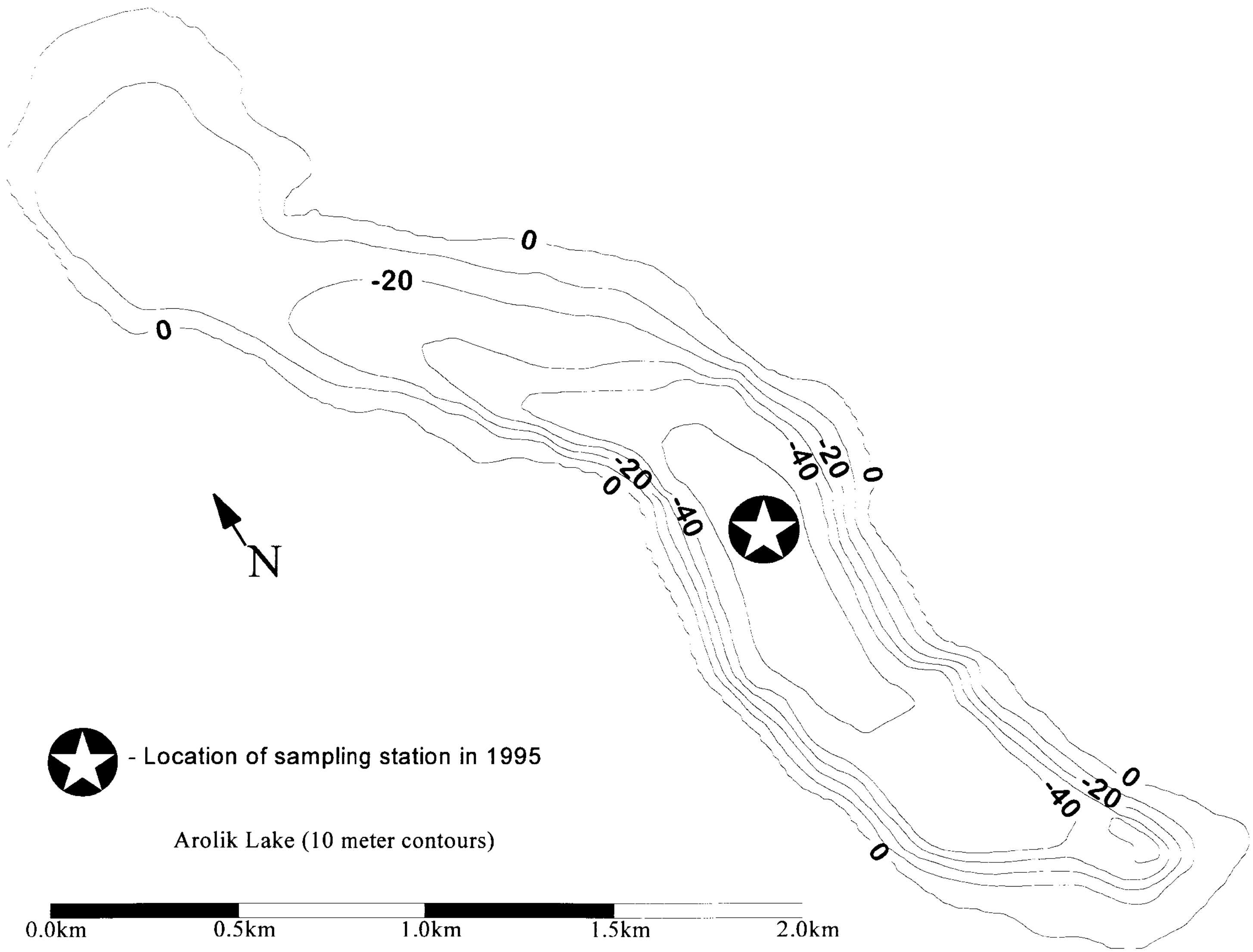
Source: U.S. Geological Survey map, 1968.

Appendix A14.-Bathymetric map of Upper Twin Lake.



Source: Alaska Department of Fish and Game map, 1994.

Appendix A15.-Bathymetric map of Lower Ugashik Lake.



Source: MacDonald 1996.

Appendix A16.-Bathymetric map of Arolik Lake.

APPENDIX B. LOCATIONS OF SAMPLING STATIONS FOR WATER TEMPERATURE MEASUREMENTS

Appendix B1.-Locations of sampling stations for water temperature measurements at the study lakes in 1994.

	Station 1 (S1)		Station 2 (S2)		Station 3 (S3)	
Study Lake	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Naknek Lake (excluding Iliuk Arm)	58° 41.541' N	155° 57.180' W	58° 39.418' N	155° 47.539' W	58° 39.181' N	155° 40.907' W
Iliuk Arm of Naknek Lake	58° 32.208' N	155° 41.003' W	58° 31.580' N	155° 37.019' W	58° 31.286' N	155° 31.983' W
Brooks Lake	58° 28.933' N	156° 00.983' W	58° 30.300' N	155° 57.600' W	58° 30.990' N	155° 54.630' W
Lower Ugashik Lake	57° 28.836' N	156° 52.717' W	57° 29.547' N	156° 49.407' W	57° 30.969' N	156° 52.140' W
Tikchik Lake	59° 58.084' N	158° 21.522' W	59° 57.749' N	158° 17.311' W	59° 57.814' N	158° 16.269' W
Lake Clark	60° 13.411' N	154° 19.180' W	60° 16.395' N	154° 12.255' W	60° 18.856' N	154° 02.863' W
Kontrashibuna Lake	60° 11.027' N	154° 01.606' W	60° 10.034' N	153° 58.882' W	60° 09.356' N	153° 55.430' W
Lower Twin Lake	60° 39.097' N	154° 00.160' W	60° 38.530' N	153° 58.499' W	60° 37.845' N	153° 55.615' W
Upper Twin Lake	60° 38.246' N	153° 51.822' W	60° 39.215' N	153° 49.058' W	60° 40.292' N	153° 45.925' W
Turquoise Lake	60° 47.559' N	153° 57.305' W	60° 47.427' N	153° 54.331' W	60° 47.371' N	153° 52.884' W
Telaquana Lake	60° 57.255' N	153° 53.121' W	60° 56.909' N	153° 50.512' W	60° 57.005' N	153° 45.664' W
Goodnews Lake	59° 29.970' N	160° 31.810' W	59° 29.030' N	160° 33.790' W	59° 28.830' N	160° 34.710' W
Heart Lake	60° 06.400' N	159° 38.590' W	60° 06.360' N	159° 38.230' W	60° 06.220' N	159° 38.870' W
Kagati Lake	59° 53.050' N	160° 05.210' W	59° 51.850' N	160° 02.760' W	59° 51.510' N	160° 05.120' W
Kanuktik Lake	59° 43.060' N	160° 18.490' W	59° 42.100' N	160° 18.400' W	59° 41.450' N	160° 18.350' W

Appendix B2.-Locations of sampling stations for water temperature measurements at the study lakes in 1995.

	Station 1 (S1)	
Study Lake	Latitude	Longitude
Naknek Lake (excluding Iliuk Arm)	58^{o} 39.393' N	155^{o} 47.058' W
Iliuk Arm of Naknek Lake	58^{o} 31.497' N	155^{o} 36.832' W
Brooks Lake	58^{o} 30.764' N	155^{o} 54.732' W
Lower Ugashik Lake	57^{o} 30.914' N	156^{o} 52.400' W
Tikchik Lake	59^{o} 57.720' N	158^{o} 17.630' W
Lake Clark	60^{o} 13.424' N	154^{o} 19.134' W
Goodnews Lake	59^{o} 29.860' N	160^{o} 32.070' W
Heart Lake	60^{o} 06.500' N	159^{o} 38.740' W
Kagati Lake	59^{o} 52.870' N	160^{o} 05.000' W
Kanuktik Lake	59^{o} 43.290' N	160^{o} 18.490' W
Arolik Lake	59^{o} 27.400' N	161^{o} 06.500' W

APPENDIX C. BIOLOGICAL DATA FROM LAKES WHERE SAMPLE SIZE GOALS WERE NOT MET

Appendix C1.-Mean lengths and weights of lake trout collected using hook and line methods during 1994 from lakes where sample size goals were not met.

	Telaquana Lake	Turquoise Lake	Lower Ugashik Lake
Length (mm)			
Sample Size	4	5	1
Mean	409	399	440
Standard Error	29.28	16.25	
Weight (g)			
Sample Size	5	5	1
Mean	2,282	630	1,150
Standard Error	1,434.72	40.62	

Appendix C2.-Historical biological information from the sport harvest at Goodnews Lake and Goodnews River, collected during 1975.

	Weight (g)	Fork Length (mm)
Sample Size	16	17
Mean	1,463	502
Mode	1,600	504
Standard Deviation	461	58
95% Upper Confidence Interval	1,707	532
95% Lower Confidence Interval	1,218	473
Maximum	2,350	632
Minimum	500	400

APPENDIX D. THERMAL HABITAT VOLUME AND YIELD ESTIMATES

Appendix D1.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles collected during the first temperature sampling event in 1994.

	Depth (m)		Volume (hm^3)[a]		Area (ha)			THV (hm^3)[a]		Potential Harvest (kg/yr)		Potential Sustained Yield (kg/ha/yr)	
Lake	at 12°C	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Payne	Surfer	Payne	Surfer	Payne
Brooks	0.0	22.5	2,284	1,244	5,480	5,480	3,751	1,040	1,032	20,148	20,039	3.7	3.7
Naknek	5.0	25.0	12,956	8,116	47,350	39,957	16,451	4,840	5,470	60,388	65,904	1.3	1.4
Iliuk Arm	2.5	12.5	8,466	7,618	8,972	8,769	8,240	848	850	17,415	17,447	1.9	1.9
Total Naknek			21,421	15,734	56,321	48,726	24,691	5,688	6,320	67,768	73,066	1.2	1.3
Tikchik	10.0	32.5	430	85	5,892	2,455	841	345	355	9,159	9,351	1.6	1.6
Lake Clark	5.0	17.5	24,931	21,769	30,659	27,001	23,792	3,163	3,172	44,569	44,668	1.5	1.5
Kontrashibuna	2.5	27.5	912	425	2,345	2,246	1,673	487	488	11,715	11,739	5.0	5.0
Lower Twin	0.0	30.0	186	25	831	831	394	162	180	5,336	5,754	6.4	6.9
Upper Twin	0.0	12.5	938	760	1,503	1,503	1,360	178	179	5,717	5,732	3.8	3.8
Turquoise	0.0	6.0	578	502	1,300	1,300	1,180	75	74	3,086	3,063	2.4	2.4
Telaquana	2.5	20.0	1,912	1,267	4,632	4,558	2,889	646	646	14,332	14,340	3.1	3.1
Goodnews	0.0	17.5	69	21	382	382	207	48	51	2,227	2,333	5.8	6.1
Heart	0.0	25.0	100	14	565	565	157	86	85	3,400	3,371	6.0	6.0
Kagati	0.0	20.0	188	36	1,057	1,057	462	152	148	5,102	5,004	4.8	4.7
Kanuktik	0.0	20.0	151	29	807	807	410	122	119	4,363	4,296	5.4	5.3
Lower Ugashik	2.5	45.0	6,105	1,342	17,693	17,553	5,864	4,763	4,755	59,705	59,630	3.4	3.4

[a] hm3 = cubic hectometers.

Appendix D2.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles collected during the second sampling event in 1994.

	Depth(m)		Volume (hm³) [a]		Area (ha)			THV (hm³) [a]		Potential Harvest (kg/yr)		Potential Sustained Yield (kg/ha/yr)	
Lake	at 12°C	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Payne	Surfer	Payne	Surfer	Payne
Brooks	12.5	27.5	1,662	1,061	5,480	4,546	3,568	601	607	13,624	13,716	2.5	2.5
Naknek	17.5	35.0	9,493	6,643	47,350	20,559	13,453	2,850	2,954	41,377	42,451	0.9	0.9
Iliuk Arm	0.0	25.0	8,687	6,621	8,972	8,972	7,698	2,067	2,082	32,892	33,064	3.7	3.7
Total Naknek			18,181	13,264	56,321	29,530	21,151	4,917	5,036	61,072	62,127	1.1	1.1
Tikchik	15.0	30.0	324	107	5,892	1,925	988	217	215	6,575	6,527	1.1	1.1
Lake Clark	10.0	25.0	23,617	20,043	30,659	25,576	22,270	3,573	3,586	48,628	48,748	1.6	1.6
Kontrashibuna	12.5	32.5	701	344	2,345	1,999	1,565	357	356	9,392	9,362	4.0	4.0
Lower Twin	10.0	30.0	118	25	831	554	393	93	94	3,603	3,628	4.3	4.4
Upper Twin	0.0	15.0	938	726	1,503	1,503	1,337	212	213	6,470	6,490	4.3	4.3
Turquoise	1.0	10.0	565	458	1,300	1,293	1,073	107	106	3,975	3,954	3.1	3.0
Telaquana	5.0	22.5	1,800	1,196	4,632	4,378	2,722	604	616	13,661	13,853	2.9	3.0
Goodnews	10.0	20.0	39	16	382	256	191	22	22	1,291	1,296	3.4	3.4
Heart	17.5	30.0	31	7	565	272	120	25	24	1,391	1,360	2.5	2.4
Kagati	0.0	25.0	188	16	1,057	1,057	341	173	166	5,589	5,445	5.3	5.2
Kanuktik	0.0	37.5	151	0	807	807	0	151	103	5,083	3,873	6.3	4.8
Lower Ugashik	0.0	57.5	6,546	756	17,693	17,693	3,699	5,790	5,651	68,634	67,452	3.9	3.8

[a] hm^3 = cubic hectometers.

Appendix D3.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles collected during July 1995.

	Depth(m)		Volume (hm^3) [a]		Area (ha)			THV (hm^3)[a]	Potential Harvest (kg/yr)	Potential Sustained Yield (kg/ha/yr)
Lake	at 12°C	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Surfer	Surfer
Brooks	0	20	2,284	1,339	5,480	5,480	4,045	945	18,814	3.4
Naknek	0	17.5	15,124	9,493	47,350	47,350	20,559	5,630	67,280	1.4
Iliuk Arm	0	2.5	8,687	8,466	8,972	8,972	8,769	222	6,682	0.7
Total Naknek			23,811	17,959	56,321	56,321	29,328	5,852	69,161	1.2
Tikchik	7.5	22.5	497	199	5,892	2,870	1,434	298	8,249	1.4
Lake Clark	2.5	17.5	25,622	21,769	30,659	28,594	23,792	3,853	51,316	1.7
Goodnews	7.5	12.5	45	32	382	272	233	13	871	2.3
Heart	0	20	100	25	565	565	250	75	3,078	5.4
Kagati	7.5	17.5	118	49	1,057	824	570	69	2,917	2.8
Kanuktik	2.5	12.5	132	66	807	742	573	66	2,801	3.5
Lower Ugashik	2.5	5	6,105	5,669	17,693	17,553	17,301	436	10,835	0.6
Arolik	7.5	15	38	26	224	172	134	12	817	3.6

[a] hm^3 = cubic hectometers.

Appendix D4.-Thermal habitat volume (THV) and sustained yield estimates using temperature profiles collected during August 1995.

	Depth(m)		Volume (hm^3) [a]		Area (ha)			THV (hm^3)[a]	Potential Harvest (kg/yr)	Potential Sustained Yield (kg/ha/yr)
Lake	at 12°C	at 8°C	below 12°C	below 8°C	surface	at 12°C	at 8°C	Surfer	Surfer	Surfer
Brooks	17.5	35	1,443	803	5,480	4,235	3,315	640	14,241	2.6
Naknek	0	37.5	15,124	6,314	47,350	47,350	12,874	8,809	92,617	2.0
Iliuk Arm	0	35	8,687	5,877	8,972	8,972	7,180	2,810	40,964	4.6
Total Naknek			23,811	12,192	56,321	56,321	20,055	11,620	112,862	2.0
Tikchik	5	30	575	107	5,892	3,516	988	468	11,393	1.9
Lake Clark	5	32.5	24,931	18,413	30,659	27,001	21,246	6,519	74,697	2.4
Goodnews	0	17.5	69	21	382	382	207	48	2,227	5.8
Heart	0	22.5	100	19	565	565	231	81	3,253	5.8
Kagati	0	25	188	16	1,057	1,057	341	173	5,589	5.3
Kanuktik	0	27.5	151	7	807	807	174	144	4,906	6.1
Lower Ugashik	5	40	5,669	1,661	17,693	17,301	6,901	4,008	52,780	3.0
Arolik	0	20	52	20	224	224	106	32	1,682	7.5

[a] hm^3 = cubic hectometers.