Special Publication No. 17-17

Stormy Lake Northern Pike Distribution and Movement Study to Inform Future Eradication Efforts

by

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Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

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

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
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
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
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	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
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.
minute (angular)	'
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
variance	
population	Var
sample	var

SPECIAL PUBLICATION NO. 17-17

STORMY LAKE NORTHERN PIKE DISTRIBUTION AND MOVEMENT STUDY TO INFORM FUTURE ERADICATION EFFORTS

by
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ABSTRACT

Thirty invasive northern pike (*Esox lucius*) with a fork length greater than 400 mm were implanted with radio transmitters to identify congregation sites, including potential spawning areas, in Stormy Lake (Nikiski, Alaska), an anadromous waterbody. Some radio transmitters were recovered from dead study fish and most were redeployed in new study fish resulting in an overall study population of 45 individual northern pike. Study fish were located during periodic tracking surveys over a 20-month period. Habitat parameters (water temperature, depth, distance from shore, and presence of vegetation) were recorded when possible at study-fish locations. Most study-fish congregations were found in close association with dense aquatic macrophytes in shallow water (<3 m). Congregation sites were typically clustered within large emergent vegetation beds that were utilized year-round. During the spawning season, many northern pike were detected near the lake outlet, raising concern that northern pike eggs or larvae could drift and pass through a mesh fish barrier near the outlet and invade the remainder of the Swanson River drainage where they are currently not found. Most northern pike dissected in this study were sexually mature at 400 mm FL but some males matured at smaller sizes; annual spawning is most likely for sexually mature fish. Of 12 study fish that were located during both the 2010 and 2011 spawning seasons, most repeated site occupancy at 1 or more areas across years, suggesting spawning site fidelity may occur in this population.

Key words: northern pike, *Esox lucius*, radio transmitters, Stormy Lake, Kenai Peninsula

INTRODUCTION

Northern pike (*Esox lucius*) do not naturally occur in Southcentral Alaska. Their presence on the Kenai Peninsula is the result of illegal introductions first documented in the 1970s (anonymous report[1]). When introduced to waters outside their native range, northern pike can harm native fish populations (Rutz 1996). In Southcentral Alaska, northern pike are known to prey heavily on rearing salmonids Rutz (1996, 1999) and in some cases, they have been implicated in the decline of local salmon populations and other native fish species (McKinley 2013; Sepulveda et al. 2013, 2015). Because of the negative ecological and economic impacts associated with their introductions, northern pike are considered an invasive species in Southcentral Alaska.

In 2000, an illegally introduced northern pike population was confirmed by the Alaska Department of Fish and Game (ADF&G) to exist in Stormy Lake (Begich and McKinley 2005), but the population had probably been present in earlier years. Stormy Lake is located on the Kenai Peninsula about 8.5 miles northeast of the community of Nikiski (Figures 1 and 2). In 2012, invasive northern pike were removed from Stormy Lake by means of a piscicide. This study was designed to track the movements and locate congregation sites of radiotagged northern pike to help inform future northern pike eradication strategies.

Northern pike in Stormy Lake appear to have reduced populations of some native fish species inhabiting the lake. Anecdotal angler reports describe Stormy Lake as a well-known producer of large rainbow trout (*Oncorhynchus mykiss*) and Arctic char (*Salvelinus alpines*) prior to the northern pike introduction. ADF&G netting surveys in 2009 and 2010 captured relatively few native fish species in Stormy Lake (Appendix A1) and the ADF&G Statewide Harvest Survey estimated no Arctic char or rainbow trout were caught by sport anglers in 2009 (Jennings et al. 2011). In comparison, in the decade prior to northern pike introduction (1990–1999), the estimated average native sport fish catch from Stormy Lake was 374 rainbow trout and 340 arctic char (Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish [cited March 2018]. Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/).

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1 Report titled *Northern Pike (Esox Lucius) in the Soldotna Creek System*, author is anonymous, available at the Soldotna ADFG office.

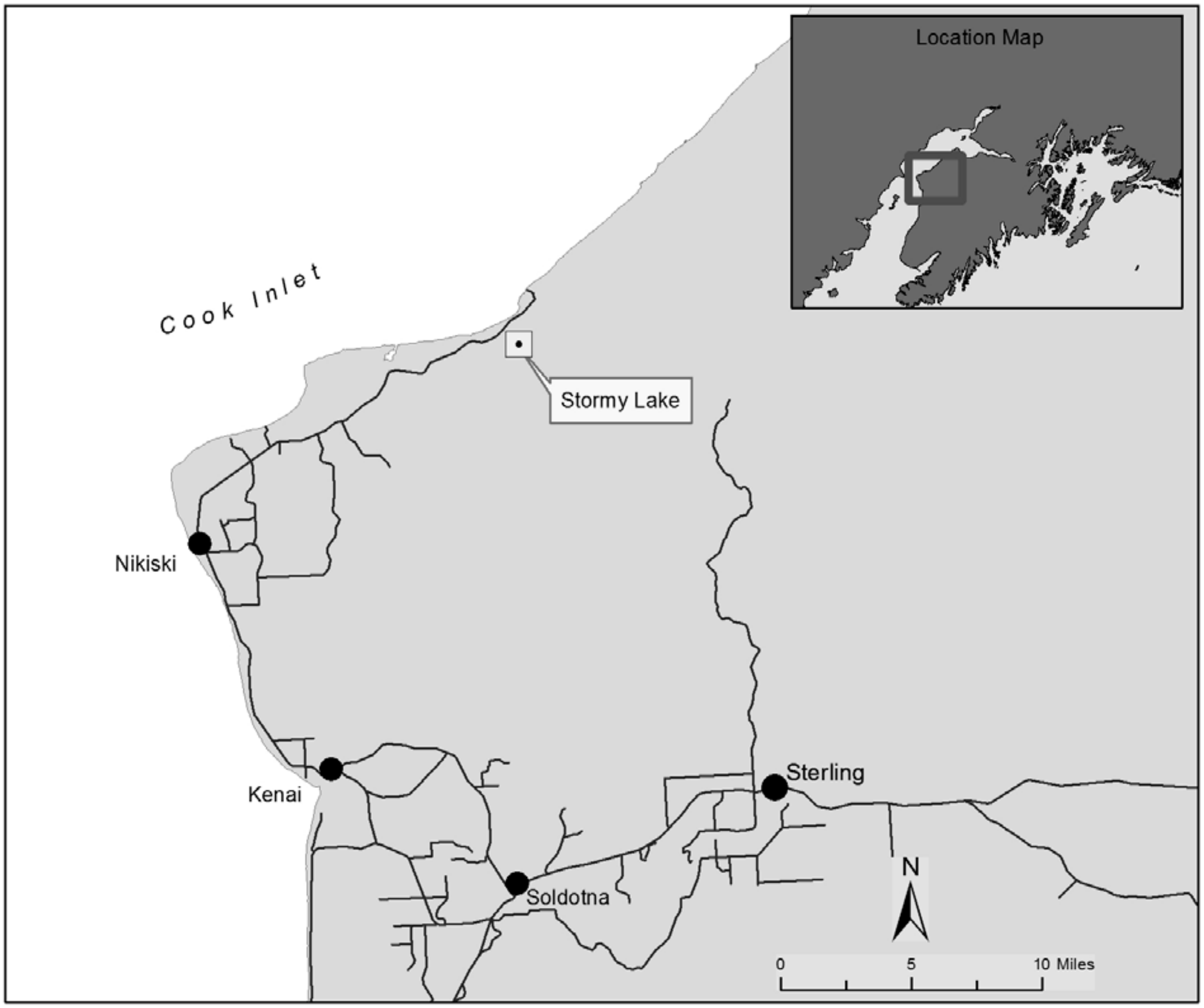

Figure 1.–Location of Stormy Lake on the Kenai Peninsula.

The native fish assemblage of Stormy Lake includes threespine stickleback (*Gasterousteus aculeatus*), lamprey (*Lampetra* spp.), sculpin (*Cottus* spp.), rainbow trout, Arctic char, longnose sucker (*Catostomus catostomus*), and coho salmon (*Oncorhynchus kisutch*). (Begich and McKinley 2005). These same species apparently also utilize the Stormy Lake outlet creek. Additional native fish species found elsewhere in the Swanson River drainage include sockeye salmon (*O. nerka*), Chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), eulachon (*Thaleichthys pacificus*), and Dolly Varden (*Salvelinus malmo*) (Jones et al. 1993). Stormy Lake covers about 400 surface acres and has a volume of nearly 7,000 acre-feet and a maximum depth of about 50 feet, so some (deep water) refugia may exist for native species to avoid the habitat preferred by northern pike (vegetated, relatively shallow water) (Inskip 1982).

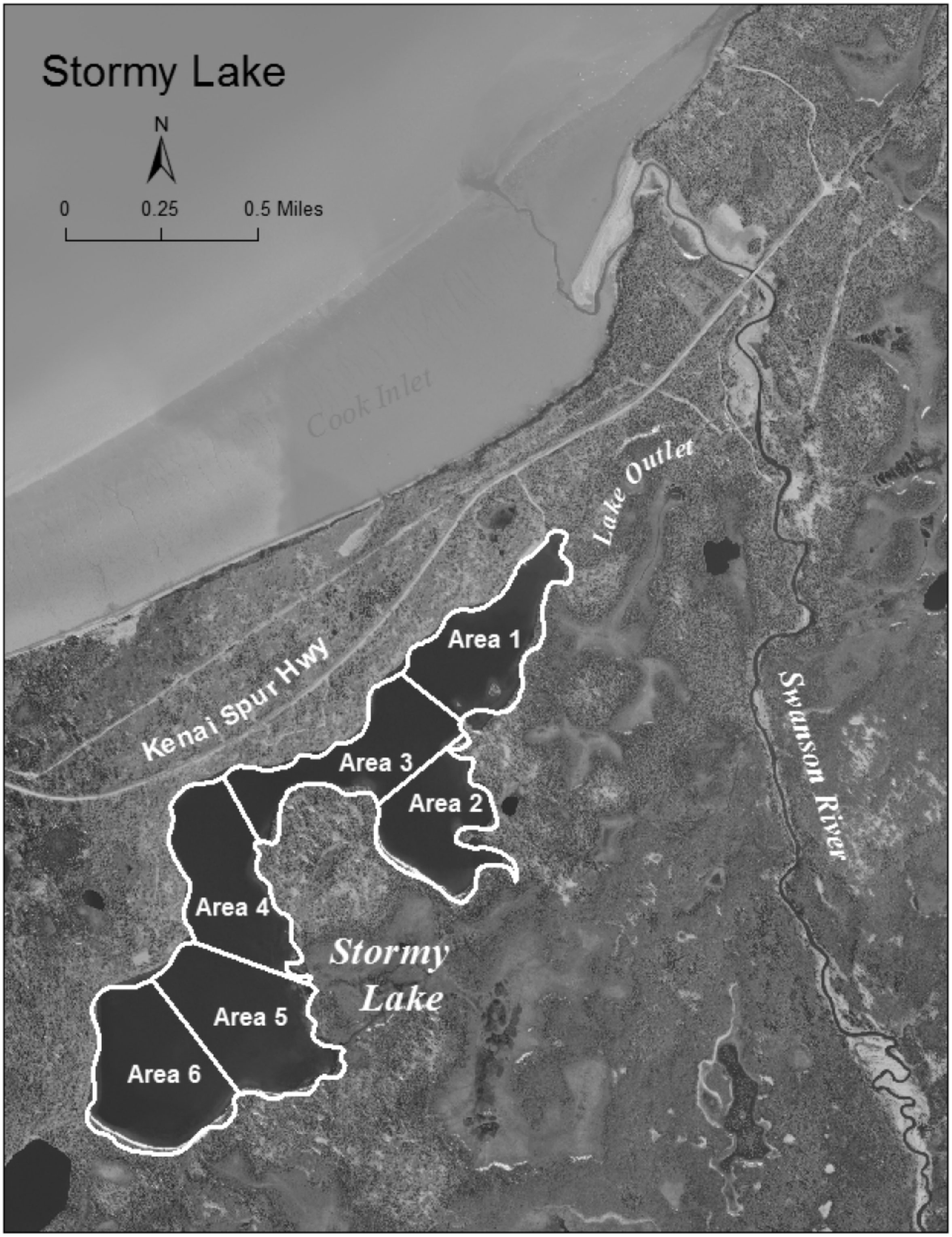

Figure 2.–Aerial image of Stormy Lake modified to show the 6 study areas.

Source: Aerial image from Alaska Geospatial Council.

Objectives and Tasks

The primary goal of this study was to identify locations in Stormy Lake where northern pike congregate. Radiotelemetry methods were used to determine the locations of study fish during the period of September 2009 through May 2011.

Objective

1) Identify up to 4 radiotagged northern pike congregations within Stormy Lake with 95% confidence that all 4 have been located.

Tasks

1) Document the location of radiotagged northern pike during 3 temporal periods: 1) June–October (open water season), 2) November–March (ice cover), and 3) April–May (spawning period) during 2010 and 2011.
2) Record habitat parameters at the locations of radiotagged northern pike that include the following: surface water temperature, water depth, estimated distance from shore, and presence of visible aquatic vegetation.
3) Record fork length (FL; tip of nose to fork of tail) and sex of radiotagged northern pike.

METHODS

Sample Size

A sample size of 30 radiotagged northern pike was needed to identify up to 4 congregation sites (i.e., spawning areas). For this study, a congregation site was defined as 2 or more radiotagged fish within a perimeter area no greater than 0.42 hectares. This area has a practical application for northern pike removal because it is equal to the potential capture area of a 120-foot long (36.6 m) gillnet tethered at one end with a free end that can swing 360 degrees. At the time of this study, it was unknown if netting or chemical treatment would be used for future northern pike removal.

We assumed most mature northern pike in Stormy Lake spawned annually. This assumption is supported by field observations that most northern pike (>350 mm) captured by ADF&G in early May in other Kenai Peninsula lakes during 2006–2008 were observed with milt, ovarian fluid, eggs, or a flaccid abdomen. A study in Minto Flats, Alaska also supports this assumption because 68–79% of radiotagged fish were identified as participating in spawning during consecutive years (Roach 1998c).

To determine the sample size, we calculated the probability that if 4 distinct congregation sites existed in Stormy Lake, each site would be occupied by at least 1 radiotagged fish with 95% confidence that all 4 sites were located. This was achieved by first assuming a multinomial probability model parameterized by the number of radio transmitters along with 4 congregation site probabilities that were all equal to 0.25. The probabilities were rendered by summing over the entire multinomial sample space minus the partitions that contained a zero.

This sample size calculation assumed 27% mortality within the first year of the study. The mortality rate was based on the average mortality rate occurring in 3 interior Alaska northern pike studies (19%, 25%, and 35%) (Joy and Burr 2004; Roach 1998a; Taube and Lubinski 1996). Failure or expulsion of a radio transmitter is a rare event (<1%) (Advanced Telemetry Systems, personal communication) and was not accounted for. The number and locations of primary spawning sites in Stormy Lake were obviously unknown but potential sites were identified from field observations and aerial photos of inundated vegetation beds that appeared suitable for spawning as defined by Inskip (1982).

STUDY-FISH COLLECTION

The guideline minimum body length for selecting study fish was 450 mm FL, although smaller fish could be selected if not enough fish were available at or above 450 mm FL. A 450 mm FL northern pike is estimated to weigh about 608 g (http://en.wikipedia.org/wiki/Northern_pike, accessed April 2016). Our radio transmitters weighed 24 g, and therefore a conservative transmitter to bodyweight ratio of about 3.9% was anticipated for fish of 450mm FL. Similar northern pike length and transmitter weight criteria were used successfully in a northern pike study in Minto Flats, Alaska (Roach 1998a).

Northern pike were captured using variable mesh gillnets paneled with six 20-foot sections of three-quarter in, 1 in, 1¼ in, 1½ in, 1¾ in, and 2 in stretch monofilament mesh. Each net was 120 feet in length and 6 feet in depth with a braided polypropylene floating line and sinking lead line. It was planned that set gillnets would be tended every 20 minutes and fished only during the daytime to reduce trauma to captured fish. Other capture gear was not considered due to the low capture efficiency experienced when using hoop traps in previous studies (Begich and McKinley 2005) and poor angler success (Jennings et al. 2010).

To ensure that northern pike selected for this study reasonably represented individuals from all areas of the lake, we divided the lake into 6 study areas of similar surface area (Figure 2). Each study area was netted with similar effort during the initial capture period of September 9 through October 2, 2009.

We utilized a radio transmitter deployment strategy that limited the number of northern pike that could be captured from a single study area, radiotagged, and released during a single collection cycle. This number equaled the number of radio transmitters available for release at the start of the cycle divided by the number of study areas (6). For example, a maximum of 5 radio transmitters (30 radio tags/6 areas = 5 radio tags per area) could be released in a single area during the first sampling cycle. Following cycles would repeat this release strategy until all radio transmitters were deployed. Later on in the study, northern pike were collected opportunistically from any lake area to replace study fish that died.

Although we attempted to reduce capture-related stress by not exceeding 20 minutes between net checks, extremely low catch rates prompted us to fish gillnets unattended overnight to meet our collection needs. All northern pike captured alive were removed from gillnets and transferred to a 4 ft × 4 ft × 6 ft net pen for recovery holding and to assess their suitability as study fish.

SURGERY

Northern pike selected as study fish were anesthetized with food grade clove oil following the solution and dosage guidelines recommended by Peake (1998). While anesthetized, each study fish was measured for FL and a uniquely numbered Floy FD-68[2] internal anchor tag (or similar tag) was attached below and posterior to the dorsal fin.

[2] Product names used in this publication are included for completeness but do not constitute product endorsement.

The Model 1845 radio transmitters were made by Advanced Telemetry Systems (ATS) with 10 transmitters assigned to each of 3 frequencies: 152.043, 152.073, and 152.133 MHz. The transmitters in each frequency were given unique pulse codes to differentiate them. The estimated battery life of the radio transmitters was extended to 871 days by programming the transmitter's signal to remain silent for 7 periods (5–9 seconds) and to transmit for 5 periods.

A custom-made fish cradle was used to hold the fish horizontally for surgery with their ventral side facing up. While in the cradle, the fish was positioned so the head extended beyond the cradle. A turkey baster was used by a surgery assistant to continuously aerate the fish by using it to transfer lake water from a 5-gallon bucket to the fish's gill filaments. Gill filaments were exposed by the assistant gently lifting the operculum.

A 2–3 cm long incision was made along the *linea alba*, anterior to the pelvic girdle (Hart and Summerfelt 1975). The transmitter antenna was inserted into an open end of a hollow five-sixty-fourths-inch diameter stainless steel rod. The other end of the rod was solid and rounded with the last half inch bent at a 50 degree angle. After the initial incision was made, the solid end of the rod was inserted into the incision and gently pushed posteriorly. Light pressure was maintained on the rod in such a way that the angled rod tip created a slight outward bulge on the exterior of the fish's abdomen. Once the rod tip was moved past the pelvic girdle, a scalpel was used to make a tiny incision (4–5 mm) directly above the rod tip. This exposed the rod tip which was then pierced completely through the small incision leaving the antenna trailing outside the fish. The radio transmitter was then pushed fully into the abdominal cavity through the initial larger incision while simultaneously pulling on the exposed antenna cable. Three to 5 sutures (3-0, FS-I) and Vetbond or similar surgical glue was used to close the large incision but the small antenna incision was not closed. No antibiotics were used. All radiotagged fish were placed in a net pen until they recovered (i.e., swimming ability was restored), and then released immediately back into the lake.

Surgery-related data were recorded, including duration of anesthesia induction and influence, duration of the surgery, radio transmitter frequency and pulse code, Floy tag assignment, and biological data (Appendix B1). Fork length (FL) was measured to the nearest millimeter. Identification of sex, maturity, and spawning ripeness of study fish was attempted via examination of the gonads through the surgical incision but discontinued after it was deemed too stressful to the fish.

DATA COLLECTION

Tracking of study fish was done by boat, snowmachine, and foot surveys. Tracking was conducted approximately twice each month except during mid-April through mid-May when tracking frequency increased to at least twice per week when spawning activity appeared greatest (Table 1). Tracking continued for the duration of the study (September 2009–May 2011).

A stationary radio receiver (ATS model 4000 receiver linked to an ATS model 5041B Data Collection Computer [DCC] with an antenna tower) was established at the lake outlet in early September 2009 and was operated until May 10, 2010. The station was powered with a 12-volt battery that was replaced every 2 weeks. The battery also received supplemental recharging from a single solar panel.

Table 1.–Radiotracking survey schedule.

Year	Date	Daytime survey	Nighttime survey
2009	16 Sep	X	
2009	01 Oct	X	
2009	16 Oct	X	
2009	30 Oct	X	
2009	17 Nov	X	
2009	04 Dec	X	
2009	18 Dec	X	
2010	05 Jan	X	
2010	26 Jan	X	
2010	04 Feb	X	
2010	11 Feb	X	
2010	26 Feb	X	
2010	19 Mar	X	
2010	02 Apr	X	
2010	15 Apr	X	
2010	16 Apr	X	
2010	19 Apr	X	
2010	20 Apr	X	X
2010	21 Apr	X	X
2010	22 Apr	X	
2010	23 Apr	X	X
2010	26 Apr	X	
2010	27 Apr	X	X
2010	28 Apr	X	
2010	30 Apr	X	
2010	03 May	X	
2010	04 May	X	
2010	06 May	X	X
2010	07 May	X	
2010	11 May		X
2010	13 May		X
Number of surveys		29	7

Year	Date	Daytime survey	Nighttime survey
2010	18 May	X	
2010	20 May	X	
2010	27 May	X	
2010	11 Jun	X	
2010	28 Jun	X	
2010	13 Jul	X	
2010	27 Jul	X	
2010	13 Aug	X	
2010	27 Aug	X	
2010	8 Sep	X	
2010	23 Sep	X	
2010	13 Oct	X	
2010	27 Oct	X	
2010	26 Nov	X	
2010	17 Dec	X	
2011	13 Jan	X	
2011	18 Feb	X	
2011	18 Mar	X	
2011	13 Apr	X	
2011	20 Apr	X	
2011	25 Apr	X	
2011	26 Apr	X	
2011	28 Apr	X	X
2011	2 May	X	
2011	3 May	X	
2011	5 May	X	
2011	9 May	X	
2011	11 May	X	
2011	13 May	X	
2011	23 Jun	X	
Number of surveys		30	1

The sensitivity (gain) of the stationary site's receiver was intentionally reduced so that study fish could only be detected if they entered the lake outlet. The detection range of the receiver was tested periodically by placing a radio transmitter in the water at varying distances from the stationary site and making adjustments to the receiver's sensitivity if needed.

During mobile tracking surveys, study fish were located as precisely as conditions allowed using directional homing with a 4-element handheld H antenna (Telonics model RA-23) connected to an ATS 4500C receiver. Throughout the study, the receiver's gain control was standardized to "level 7." The standardized setting typically allowed for initial detection distances of greater than 200 meters and allowed us to estimate distance from individual study fish based on maximum signal strength. To estimate distance we conducted a field trial to assess signal strength at known distances using a transmitter submerged in shallow water (<2 m).

Trackers recorded study-fish locations (latitude and longitude) using the receiver's internal GPS when peak signal strength was observed. Typically, multiple records were collected for each fish during a single survey. The record (including waypoint data) associated with the highest signal strength was used to select the most precise location for each study fish detected.

When feasible, the lake study area where study fish were located was manually recorded during tracking surveys using visual landmarks and a lake map. This was helpful to readily discern significant fish movement or to aid in finding a hard-to-locate study fish between tracking events. The lake study area assignments were also used as an aid in assessing general fish movement during the data analysis.

When practical, select habitat parameters were manually recorded where study-fish signal strength was greatest. Recorded habitat parameters included surface water temperature, water depth, estimated distance from shore, and presence of aquatic vegetation. Water depth was estimated during tracking surveys using an electronic fathometer or by referencing a bathymetric map. Distance from shore was estimated using a Leica 1200 rangefinder. The presence or absence of aquatic vegetation was visually observed. During open water tracking surveys, surface water temperature was taken once at a single location and was not collected during periods of ice cover.

We recovered radio transmitters from dead study fish when feasible. Recovered transmitters were typically redeployed in "new" northern pike on an opportunistic basis. All radio transmitters had return information printed on them to encourage anglers harvesting study fish to return them to ADF&G. Signage at the Stormy Lake boat launch also provided radio transmitter recovery information to anglers.

Northern pike spawning status was assessed opportunistically for both study fish and non-study fish. Eleven study fish as well as 37 non-study northern pike were sacrificed and spawning status successfully assessed. This was done most intensely at the conclusion of this study when an effort was made to collect and remove study fish using gillnets. Study fish recaptured but released alive during earlier phases of the study were also assessed for spawning status by examination of physical external characteristics when captured during the spring spawning period. Physical traits indicative of recent spawning activity or readiness included at least one of the following: flaccid abdomen, dripping eggs or ovarian fluid, dripping milt, or a swollen ovipositor.

CONGREGATION SITE IDENTIFICATION

A study fish congregation was defined as 2 or more radiotagged fish occurring within 120 feet of each other during the same temporal period. A prerequisite for the selection of study-fish tracking records used for identifying congregation sites required that only tracking records associated with receiver signal strengths of ≥135 units be used. Field trials using a tethered radio transmitter submerged in calm shallow water (<4 feet), and visual observations of study fish during tracking surveys indicated that signal strengths of ≥135 reflected a fish location that was <120 feet from the tracking receiver.

DATA ANALYSIS

Electronic tracking data were downloaded from an ATS R4500C tracking receiver after each tracking survey and manually filtered to select only those records representing the strongest signal strength for each study fish located during a survey. Habitat parameters at study-fish locations were recorded manually on field forms during the survey then manually transcribed to an electronic tracking database. These edited data were compiled into a single Excel workbook and imported into an ArcGIS geodatabase. This allowed us to graphically represent fish locations on a map of Stormy Lake while selecting for variables such sex of fish, time period, and proximity to other study fish.

At the completion of the study, all study fish were assigned a fate that described their individual outcome. A list of the assigned fate codes and their definitions are listed below:

1) Gillnet mortality (GM): a study fish that died as a result of accidental gillnet capture (gillnets were used to capture study fish and to collect fish for assessing spawning condition).
2) Entanglement net mortality (EM): a study fish that died in an entanglement net used for capturing Arctic char for another project.
3) Angler harvest (AH): a study fish that was harvested by a sport angler and reported to ADF&G.
4) Unknown mortality (UM): a study fish that died after 60 or more days postsurgery from unknown causes likely unrelated to short-term handling stress.
5) Censored (C): a study fish that was never located after its release.
6) Handling mortality (HM): a study fish that died less than 60 days postsurgery and not associated with angler harvest or net recapture.
7) Intentional recapture (IR): a study fish that was intentionally captured and sacrificed. This was primarily done to recover radio transmitters and to identify sex and spawning condition.
8) Remained alive (RA): a study fish that remained alive and unrecovered at the end of the study.
9) Shed radio transmitter (SR): a live study fish confirmed to have expelled its radio transmitter during the study.

Although not listed as a specific objective or task, we opportunistically examined study fish for evidence of spawning and whether their movement behavior displayed potential fidelity to spawning sites across years because there is a scarcity of this information for Kenai Peninsula invasive northern pike populations.

RESULTS

STUDY-FISH COLLECTION

The initial release of study fish began on September 9, 2009, and concluded September 29, 2009. The gillnetting effort was distributed relatively equally between all 6 lake study areas (Table 2). Within the first 2 days of gillnetting, it was apparent that our capture rate was far below expectations; therefore, we increased our netting effort by fishing gillnets overnight and unattended.

We expended 1,523 hours of netting effort to collect fish during September 2009. An additional 77 hours of netting effort was expended during October 2009 so that a radio transmitter recovered from a dead study fish could be redeployed in a "new" fish. The September catch included 88 northern pike, 141 longnose suckers, and 2 Arctic char (Table 2). More unrecorded collection effort (gillnetting and hook-and-line) was expended opportunistically beyond October 2009 to replace study fish that died. Including the fish used to replace original study fish that died, a total of 45 northern pike were surgically implanted with a radio transmitter and released.

Table 2.–Gillnetting effort, catch, and number of study fish by lake study area during September 8–29, 2009.

		Catch				
Lake study area	Gillnet hours fished [a]	Northern pike captured	Northern pike released as study fish	Ratio of study fish released to number captured	Long-nose sucker captured	Arctic char captured
1	253.5	24	6	0.25	24	
2	246.9	13	2	0.15	33	
3	243.9	20	4	0.20	10	
4	247.1	13	8	0.62	20	
5	267.1	11	8	0.73	38	2
6	264.8	7	2	0.29	16	
Total	1,523.4	88	30		141	2
Average	253.9	14.7	5.0	0.37	23.5	2.0

[a] In October of 2009, additional netting effort (about 77 hours) was expended, mostly in Area 4, and a radio transmitter recovered from a study fish that had died was redeployed in a newly caught northern pike.

The majority of northern pike caught by gillnets were deemed unsuitable as study fish because they were either dead, seriously injured, or undersized (FL < 450 mm). Common capture-related injuries that eliminated fish from consideration as study fish included major scale loss, bleeding from the gills or mouth, glazed (opaque) or bulged eyes, slowed respiration, distorted body shape, and loss of equilibrium.

Because it was difficult to identify the sex of northern pike using external traits during nonspawning periods, we planned to identify the sex of all study fish by examining their gonads through the surgical incision used to implant the radio transmitter. However, it was difficult to use this method without causing additional stress to the fish, so this practice was discontinued.

We did not know if the length frequencies of our study fish were representative of the entire northern pike population capable of being recruited to our gillnets. We graphically compared the length range frequencies of study fish captured during 2009–2011 to northern pike collected from Stormy Lake for other purposes unrelated to this study during 2003, and 2009–2011 (Figure 3). We used a Kolmogorov–Smirnov (K-S) test (Conover 1980) to compare lengths of the study fish to non-study fish which yielded a P-value of 0.199 and a D test statistic value of 0.199, suggesting that the length frequency of study fish did not differ significantly from the collected non-study fish.

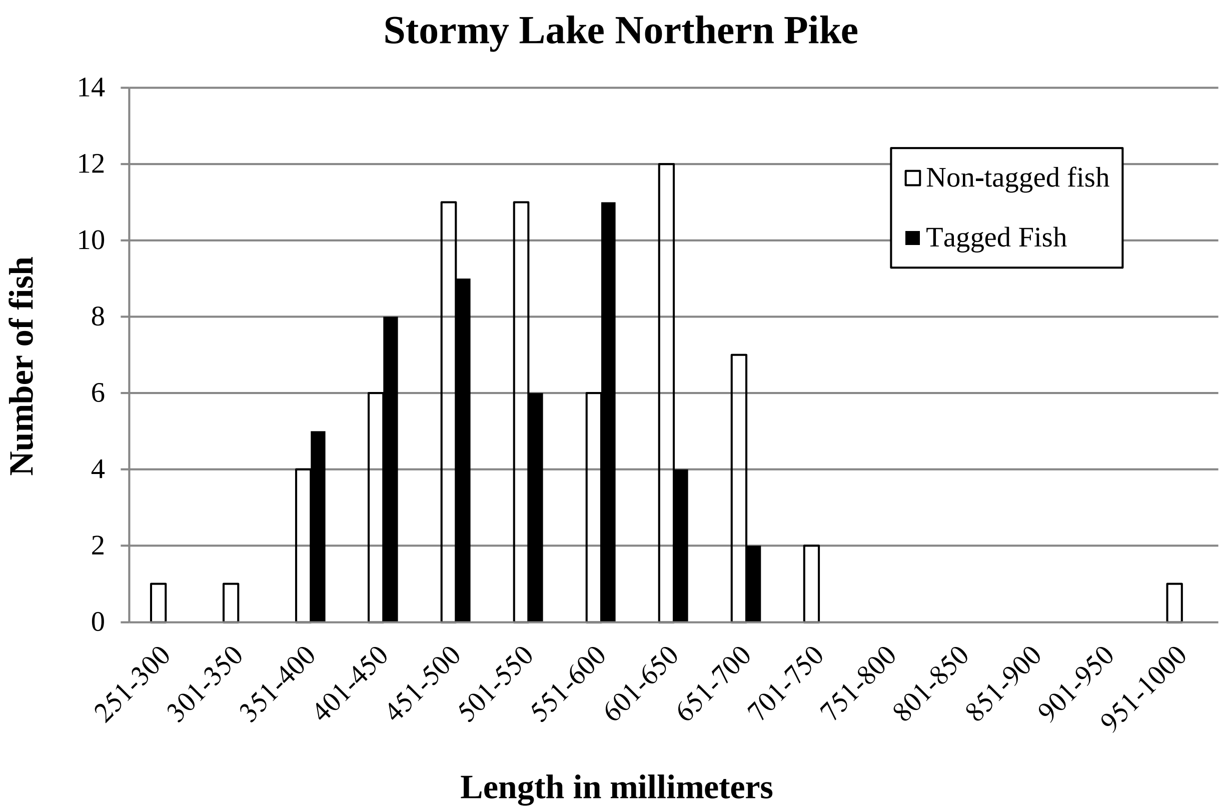

Figure 3.–Length range frequencies of Stormy Lake study fish (2009–2011) and non-study northern pike (2003, 2009–2011).

CONGREGATION SITES

Northern pike located within 120 ft of another northern pike during open water, ice cover, and spawning periods are shown in Figures 4, 5, and 6 respectively[3]. Most study fish were located year-round in water less than 3 meters deep with an average depth of about 1 meter (Figures 4–6 vs. Figure 7). Study-fish were usually surrounded by or in close proximity to visible aquatic macrophytes or submerged shoreline vegetation. During all periods, the largest concentrations of study fish were consistently located in the large bulrush bed (about 15 surface acres) in the nearshore regions of Areas 4 and 5. Emergent vegetation in Areas 1, 2, and 3 were utilized most frequently during the winter ice cover and spring spawning periods.

[3] In Figure 4, identification of congregation sites was limited by plant growth preventing nearshore radiotracking by boat in the eastern portions of Areas Four and Five; some undetected congregation sites probably existed further east in these areas.

Figure 4.–Study-fish congregations (each dot represents 2 or more fish within 120 ft proximity) during Period 1 (open water, June through October), September–October 2009 and June–October 2010.

Figure 5.–Study-fish congregations (each dot represents 2 or more fish within 120 ft proximity) during Period 2 (ice cover, November through March), November–March 2009–2010 and 2010–2011.

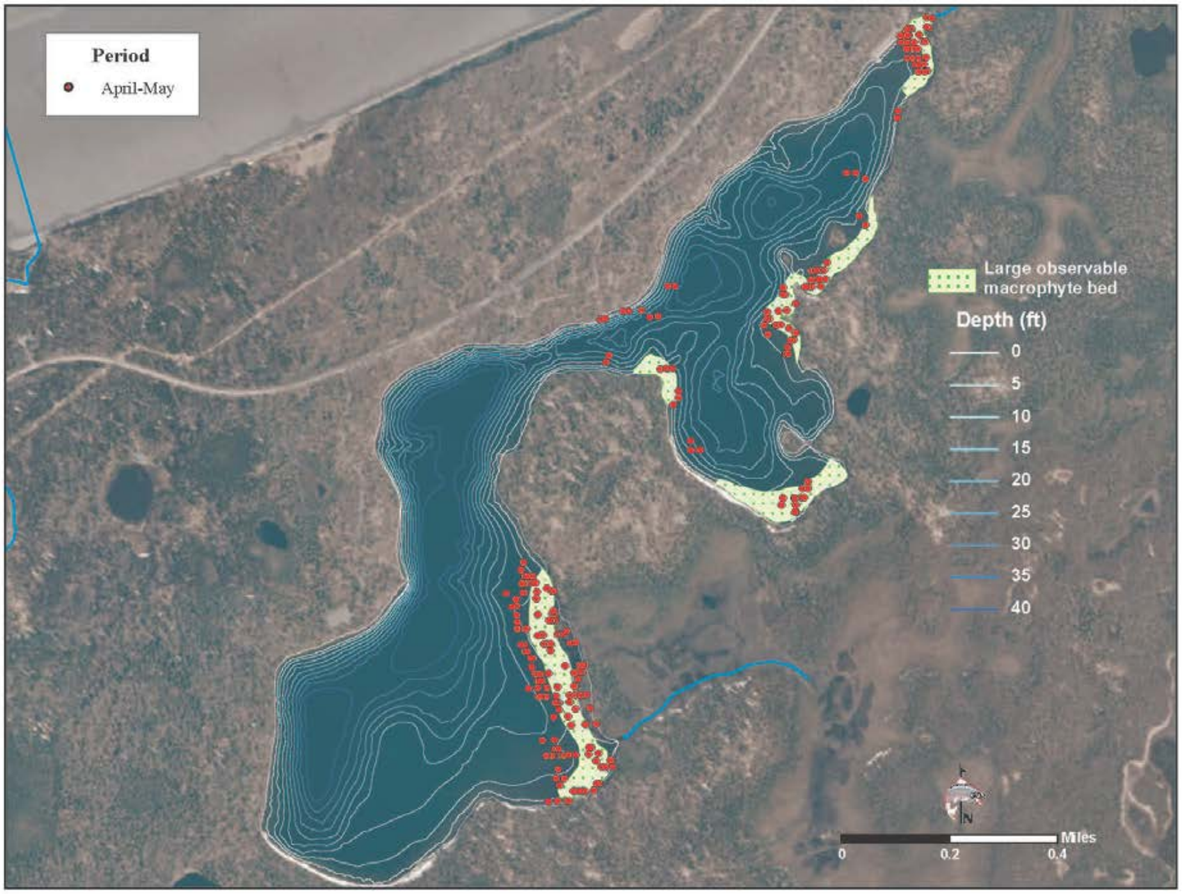

Figure 6.–Study fish congregations (each dot represents 2 or more fish within 120 ft proximity) during Period 3 (spawning, April through May), April–May 2010 and 2011.

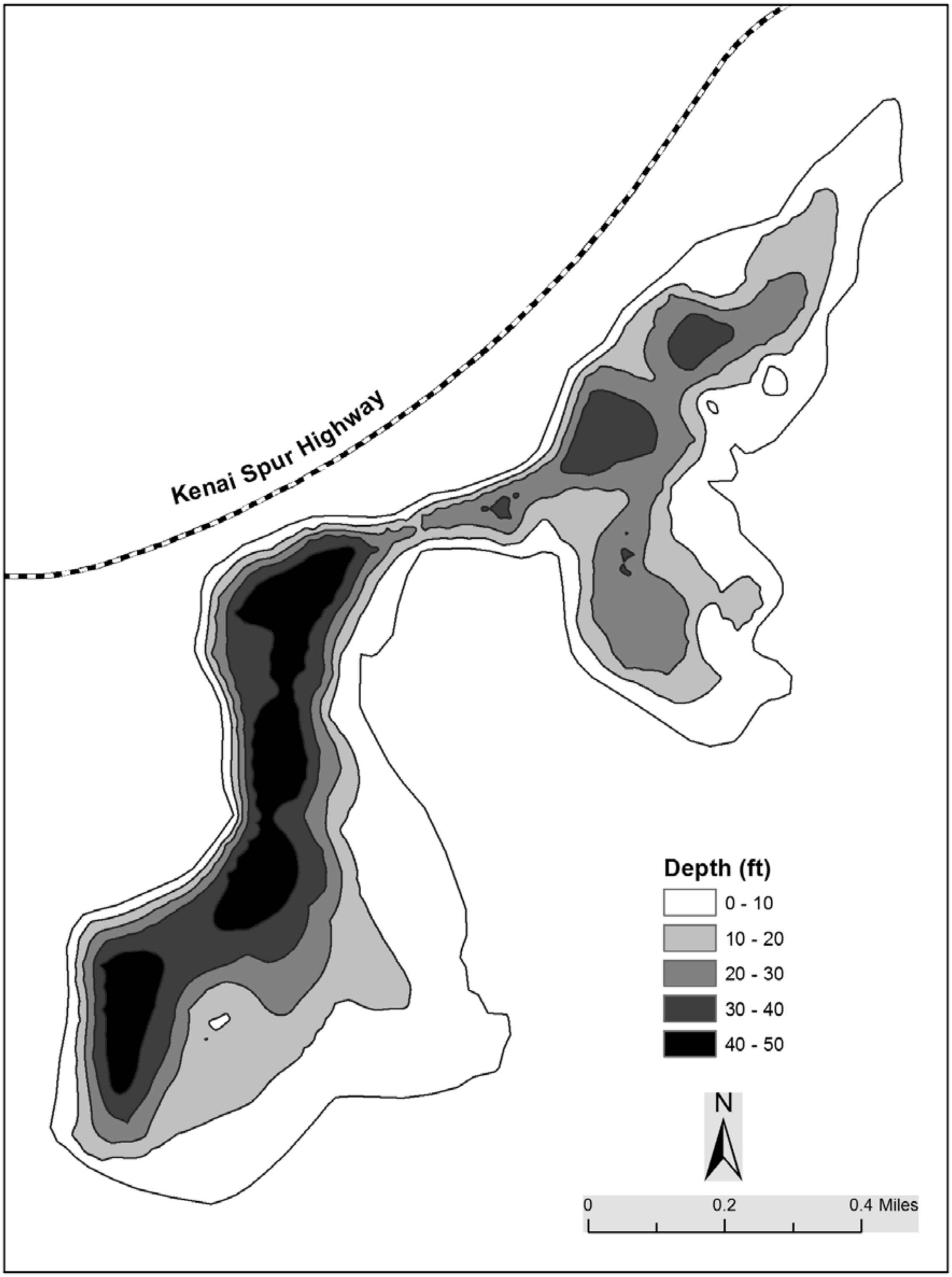

Figure 7.–Bathymetric map of Stormy Lake

Source: Massengill (*In prep*).

MOVEMENT AND HABITAT UTILIZATION

Individual study fish displayed a wide range of movement behavior. Comparing just the study fish that survived greater than 60 days postrelease (*N* = 29 out of 45), 4 were detected occupying just 1 study area and only 1 was detected occupying all 6 study areas; the average occupation was 3.3 study areas (Table 3). Eleven of the 29 fish were detected in 4 of the lake study areas.

Table 3.–Count of how many times a study fish surviving more than 60 days postrelease was detected in each lake area and count of unique areas each fish utilized.

Floy tag number	Lake study area 1	2	3	4	5	6	Total detections	Number of study areas utilized by each study fish
1	14	15	5	1	1		36	5
2	31						31	1
3	1	35	2		2		40	4
4	6						6	1
4.1	13		1		11	1	26	4
6	2	32					34	2
8	44	2	2	1	9		58	5
10	1		1	4	32	1	39	5
14	3	3	1	4	49		60	5
17				14	35		49	2
18				4	5		9	2
19	19	3	1	3	29	1	56	6
23				1	7		8	2
24	18				11	1	30	3
26	28		1	4	8		41	4
30	19				13	1	33	3
31		17	14	4	23		58	4
32		12	6	1	25		44	4
33	21			2	30	2	55	4
34		1		1	58	1	61	4
35	2		1	13	27		43	4
39		1	2	4	44		51	4
1078	37	1	5		10		53	4
1079	25	11			6		42	3
1081		13	1		5		19	3
1082			3	5	7	1	16	4
4792	16						16	1
4793					16		16	1
4794	4		1		12		17	3
Grand total	316	156	54	69	490	10		
Average								3.3

Note: Some study fish immediately died after release or were never located after release, and these fish were excluded from this table.

To compare movement between the study areas and occupancy trends over time, we graphically compared the number of study fish that were detected in each study area at least one time, including the associated percentage of all fish detections this represented, during all 3 time periods (Figures 9–11). Using this approach, it appeared that movement of study fish between study areas was remarkably consistent across periods[4]. The change in the total number of study-fish utilizing Areas 1, 3, and 6 varied by 2 or less fish between periods.

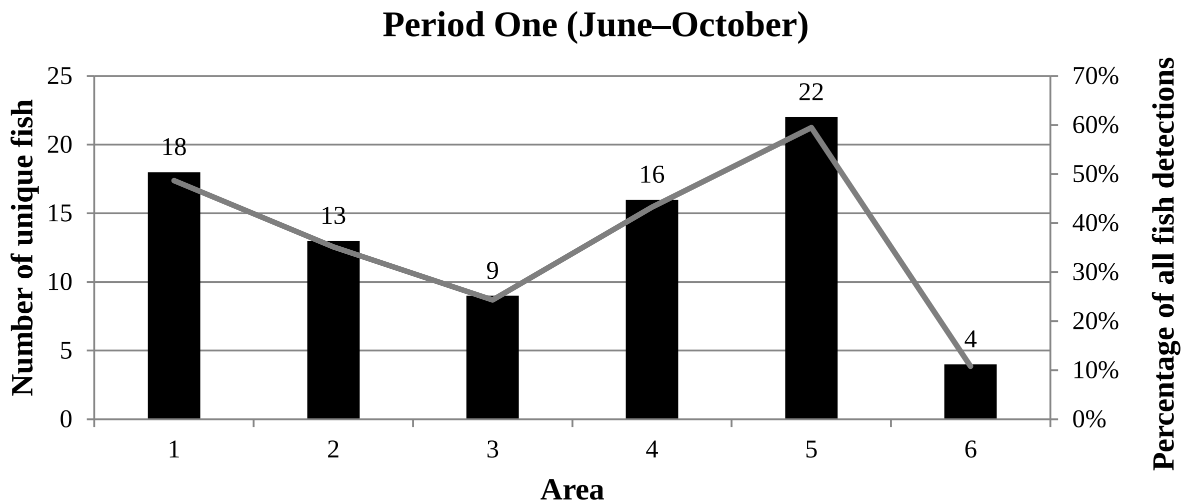

Figure 8.–Number of unique study fish detected (bars) and associated percent of study fish available (line) detected during Period 1 (June–October) in each study area (live signals only; *N = 37*).

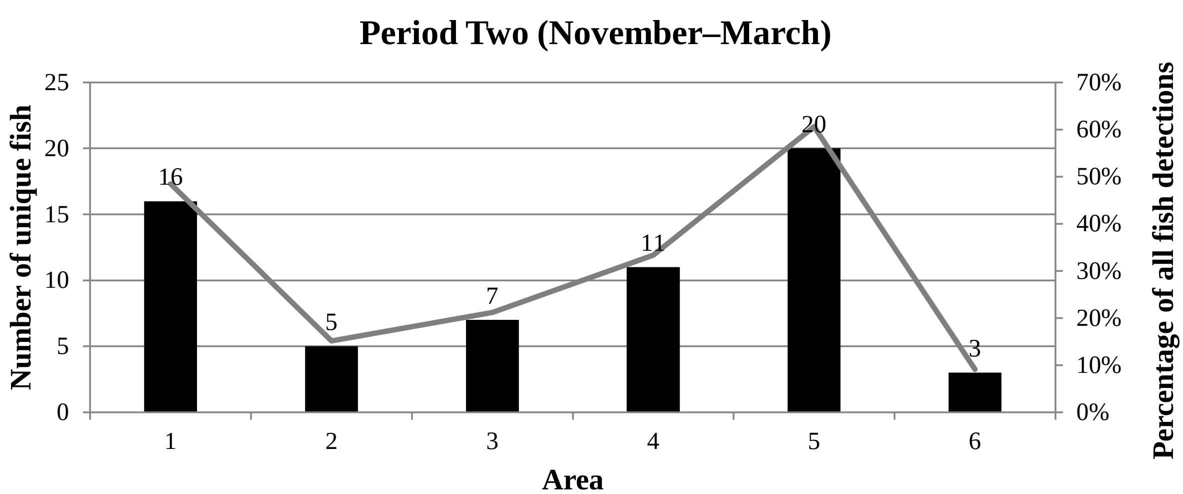

Figure 9.–Number of unique study fish detected (bars) and associated percent of study fish available (line) detected during Period 2 (November–March) in each study area (live signals only; *N* = 33).

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4 In reference to Figures 9–11, each detection refers to an individual study fish detected once during a single tracking survey. A single study fish could contribute multiple detections to the figure only if the detections occurred during different tracking surveys.

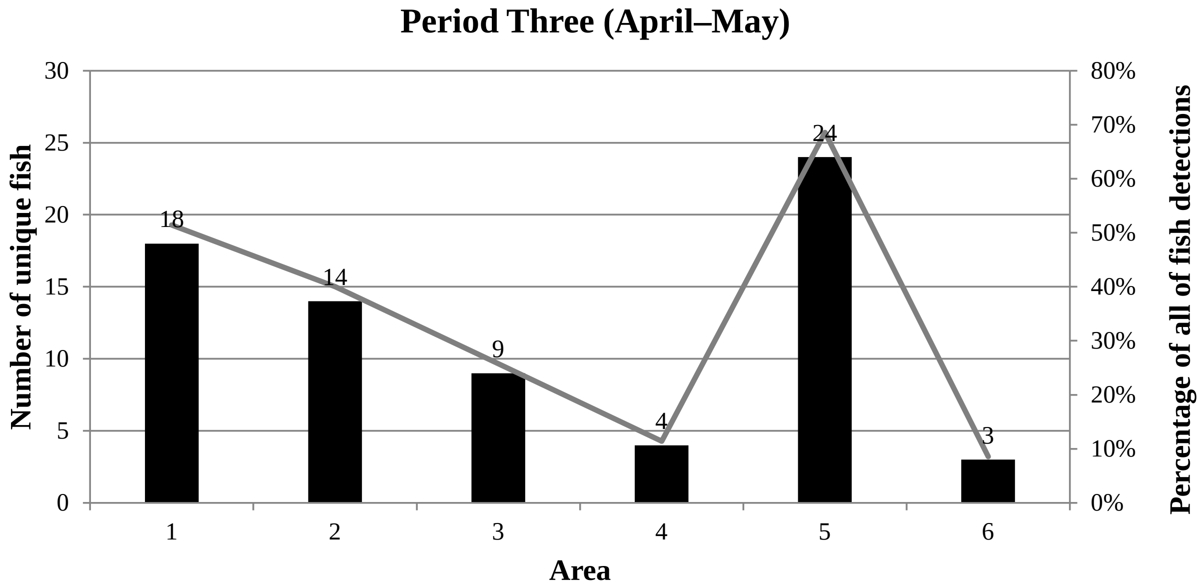

Figure 10.–Number of unique study fish detected (bars) and associated percent of study fish available (line) detected during Period 3 (April–May) in each study area (live signals only; *N* = 35).

During the April–May spawning periods of 2010 and 2011, the majority of study fish were detected at least once in the bulrush bed found in Areas 4 and 5 (Table 4). This bulrush bed appeared to contain the greatest amount of suitable cover and spawning habitat in the lake, followed by a bulrush bed in Area 1. Area 1 encompasses the lake outlet where ADF&G maintains a net barrier designed to prevent northern pike from leaving the lake and invading the Swanson River. Nearly half (46%) of all available study fish were detected in Area 1 during the spawning periods of 2010 and 2011 (Table 4). Foot tracking surveys during the spawning periods indicated that many study fish were located very close to the shoreline, particularly during low light periods, as evidenced by frequent nearshore visual sightings.

Table 4.–Number and percentage of live study fish detected in the bulrush bed of Areas 4 and 5 and those detected in the bulrush bed near the lake outlet (Area 1) during the spawning seasons of 2010 and 2011.

Year	Live study fish present in lake	Number of study fish detected in bulrush bed of Areas 4 and 5	Percent of study fish detected in bulrush bed of Areas 4 and 5	Number of study fish detected in bulrush bed of Area 1	Percent of study fish detected in bulrush bed of Area 1
2010	31	20	65%	15	48%
2011	18	14	78%	8	44%

Study fish were rarely located along the western shoreline of Stormy Lake or in Area 6 (southernmost portion of the lake) regardless of period and despite the initial capture of some study fish at these locations. One notable exception was the lake outlet (northern part of Area 1) where study fish were naturally restricted by narrowing of the lake, and therefore exact bank preference was difficult to ascertain.

The eastern shoreline of Stormy Lake clearly supports more visible aquatic vegetation and is generally shallower nearshore than the western half as indicated by bathymetry mapping (Figure 7). We observed that the eastern shoreline also experiences earlier nearshore ice loss than the western shoreline, presumably from increased sun exposure and surface water inputs.

BIOLOGICAL OBSERVATIONS

Twelve recaptured study fish were examined for gonadal development. Of these, 11 were examined postmortem of which 1 had been examined alive 5 months earlier. A single fish was only examined while alive (using external characteristics) prior to release (Table 5). Most of the examinations occurred near the end of our study when we intentionally recaptured and sacrificed 9 study fish during the 2011 spring spawning season and all appeared ready to spawn or had just spawned. Two study fish that were examined postmortem in the fall of 2010 had gonadal development consistent with spawn readiness for the upcoming spawning season; one of these fish had been examined (alive using external characteristics) 5 months prior. Another study fish captured and released in the spring of 2010 had external signs of spawn readiness (soft extended belly). With the dead study fish, we were generally able to confirm sex, length change, and spawning status (Appendix C1).

In addition, 37 nonstudy northern pike collected in the spring of 2010 and 2011 were assessed postmortem for spawning status, of which 33 were in confirmed spawning (or postspawning) condition (89%; Table 5). Twenty of these were also measured for FL and all but 2 spawners were ≥400 mm FL; 17 were in spawning or postspawning condition (85%).

Of the study and nonstudy fish examined, 10 females were measured for FL and assessed for spawning status. The largest (N = 7; ≥503 mm FL) were in spawning or postspawning condition whereas the smallest (N = 3; <383 mm FL) were immature. No females were examined for spawning status with FL between 502 mm and 383 mm. Males appeared capable of spawning at a smaller size than females. Of the 22 males (both study and nonstudy fish) assessed for spawning status and measured for length (length range: 390–748 mm), all were either actively milting or in postspawning condition. Some nonspawning fish less than 400 mm FL were not identified for sex.

We monitored the surface water temperature of Stormy Lake regularly during this study (Table 6). Prior to this study, monthly water temperature data were collected for a full calendar throughout the water column in 1-meter increments in Area 1. Surface and mean water column temperatures during September 2007 through September 2008 are shown in Figure 12. We noted that the nearshore water temperatures along the large bulrush bed in Areas 4 and 5 were seasonally influenced by warmer surface water runoff from an adjacent wetland and averaged slightly higher than the lake outlet. These warmer water inputs appeared to attract spawning northern pike as evidenced by multiple observations of milling northern pike during April and May.

Table 5.–Summary of spawning assessment for both study fish and nonstudy fish available at Stormy Lake, 2009–2011.

Fish status	Year	Recovery date	Season	Floy tag no.	Length [a]	Sex [b]	Spawning condition	Capture area
Study [c]								
	2010	27 Apr	Spring	1079	678	F	Soft full belly (ripening to spawn)	1
	2010	30 Apr	Spring	1078	505	M	Milting	1
	2011	16 May	Spring	4792	407	M	Postspawning	1
	2011	17 May	Spring	19	661	F	Postspawning	5
	2011	17 May	Spring	32	570	F	Postspawning	5
	2011	17 May	Spring	4794	480	M	Postspawning	5
	2011	17 May	Spring	14	560	M	Postspawning	5
	2011	18 May	Spring	33	683	F	Postspawning	5
	2011	18 May	Spring	4.1	515	M	Postspawning	5
	2011	18 May	Spring	1079	711	F	Post spawning	5
	2011	18 May	Spring	4793	492	M	Post spawning	5
	2011	4 Oct	Fall	1078	572	M	Gonad development consistent with spawning in upcoming spring	4
	2011	12 Oct	Fall	8	748	M	Gonad development consistent with spawning in upcoming spring	4
Nonstudy [d]								
	2010	6 May	Spring		NA	F	Mature eggs	2
	2010	18 May	Spring		NA	F	Postspawning	1
	2010	18 May	Spring		NA	M	Post spawning	1
	2010	18 May	Spring		NA	M	Post spawning	1
	2010	18 May	Spring		NA	M	Post spawning	1
	2010	18 May	Spring		NA	U	Not known	1
	2010	18 May	Spring		NA	U	Not known	1
	2010	19 May	Spring		NA	M	Milting	1
	2010	19 May	Spring		NA	M	Milting	1
	2010	19 May	Spring		NA	M	Milting	1
	2010	19 May	Spring		NA	M	Milting	1
	2010	19 May	Spring		NA	U	Not known	1
	2011	12 May	Spring		NA	F	Undeveloped eggs	1
	2011	12 May	Spring		NA	M	Milting	1
	2011	12 May	Spring		NA	M	Milting	1
	2011	12 May	Spring		NA	U	Not known	1

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Table 5.–Page 2 of 2.

Fish status	Year	Recovery date	Season	Floy tag no.	Length [a]	Sex [b]	Spawning condition	Capture area
Nonstudy [d]								
	2011	12 May	Spring		NA	U	Not known	1
	2011	13 May	Spring		NA	M	Milting	1
	2011	13 May	Spring		NA	M	Milting	1
	2011	13 May	Spring		NA	M	Milting	1
	2011	13 May	Spring		NA	M	Milting	1
	2011	13 May	Spring		NA	M	Milting	1
	2011	16 May	Spring		480	F	Not known	5
	2011	16 May	Spring		503	M	Postspawning	5
	2011	16 May	Spring		509	M	Postspawning	5
	2011	16 May	Spring		515	M	Postspawning	5
	2011	16 May	Spring		470	M	Postspawning	5
	2011	16 May	Spring		503	F	Postspawning	5
	2011	16 May	Spring		630	M	Postspawning	5
	2011	16 May	Spring		390	M	Postspawning	5
	2011	16 May	Spring		425	M	Postspawning	5
	2011	16 May	Spring		605	F	Postspawning	5
	2011	16 May	Spring		452	M	Postspawning	5
	2011	16 May	Spring		457	M	Postspawning	5
	2011	16 May	Spring		472	M	Postspawning	5
	2011	17 May	Spring		382	F	Undeveloped eggs	5
	2011	17 May	Spring		362	F	Undeveloped eggs	5
	2011	17 May	Spring		406	M	Postspawning	5
	2011	17 May	Spring		430	M	Postspawning	5
	2011	17 May	Spring		395	M	Postspawning	5
	2011	17 May	Spring		471	M	Postspawning	5
	2011	17 May	Spring		340	F	Undeveloped eggs	5
	2011	17 May	Spring		403	M	Postspawning	5

[a] Fish with Floy tag numbers 1079 and 1078 were released at recapture without measuring length; given length is the initial capture measurement.

[b] "U" means sex is unknown; typically these fish were small (FL < 300 mm), although most were not measured.

[c] All study fish were greater than 400 mm and were spawners.

[d] The spawner to nonspawner ratio for nonstudy fish with spawning status determined and FL greater than 400 mm (disregarding 1 fish over 400 mm with an undetermined spawning status) was 15 to 0. The spawner to nonspawner ratio for those with FL less than or equal to 400 mm was 2 to 3.

Table 6.–Surface water temperature data collected from Stormy Lake during 2009–2011.

Year	Date	Time period	Lake study area	Water temperature °C
2009	8 Sep	1	3	12
2009	10 Sep	1	3	10
2009	11 Sep	1	3	11
2009	24 Sep	1	3	7
2009	25 Sep	1	3	7
2009	28 Sep	1	3	6
2009	29 Sep	1	3	6
2009	17 Nov	2	3	1
2010	16 Apr	3	5	3
2010	6 May	3	1	6
2010	6 May	3	5	6.5
2010	7 May	3	1	6
2010	7 May	3	5	5.5
2010	10 May	3	5	6.5
2010	11 May	3	1	6.5
2010	11 May	3	5	8
2010	13 May	3	1	8
2010	14 May	3	1	3.5
2010	19 May	3	1	11.5
2010	19 May	3	3	9.5
2010	20 May	3	3	9.5
2010	11 Jun	1	1	15
2010	13 Jul	1	1	16
2010	27 Jul	1	1	17
2010	27 Aug	1	1	17
2010	27 Oct	1	1	5
2010	28 Oct	1	1	5
2010	26 Nov	2	1	1
2011	28 Feb	3	5	1
2011	26 Apr	3	1	5
2011	26 Apr	3	5	5
2011	28 Apr	3	1	3
2011	28 Apr	3	3	1.5
2011	2 May	3	1	2
2011	2 May	3	5	4
2011	3 May	3	1	4
2011	3 May	3	5	4
2011	5 May	3	1	3.5
2011	5 May	3	5	3
2011	9 May	3	1	5
2011	9 May	3	5	6
2011	11 May	3	1	6
2011	11 May	3	5	5
2011	13 May	3	1	6
2011	20 May	3	1	11.5
2011	20 May	3	3	9.5
2011	28 Jun	1	1	16
2013	9 Sep	1	3	13

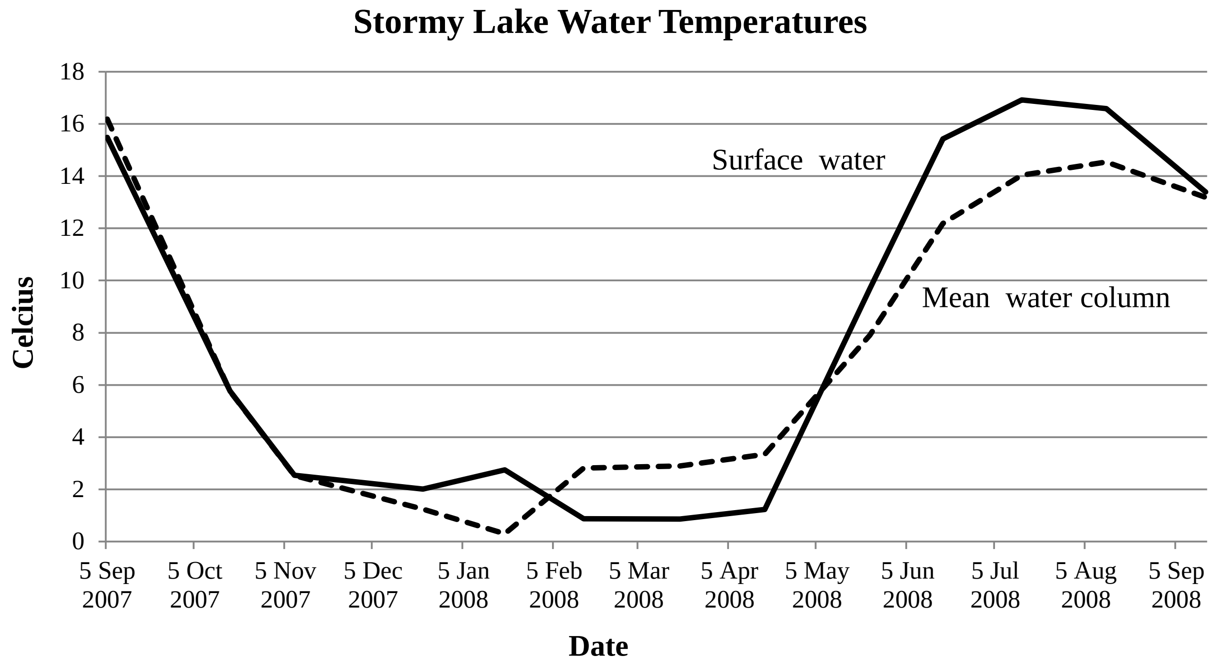

Figure 11.–Stormy Lake surface and mean water column temperatures, September 2007–September 2008.

Our observations indicate Stormy Lake northern pike initiate spawning while the lake is still mostly ice covered in late April and by mid-May, spawning activity is generally completed as evidenced by the postspawning condition of both males and females captured just after ice-out. All spawning female northern pike were in postspawning condition by May 15th (Table 5), and 1 female captured on April 27th, 2010, had a full soft belly and appeared ripe for spawning. During the peak of spawning (early May), surface water temperatures in Areas 1 and 5 ranged from 1°C to 11°C (depending on location, weather conditions, and time of day). Trackers observed a notable increase in visible northern pike spawning activity when water temperatures approached 6.5°C along nearshore areas. Inskip (1982) reports that female northern pike typically have completed spawning when water temperatures exceed 13°C.

To investigate whether spawning site fidelity may exist for study fish, we mapped the locations for the unique study fish that were present for 2 spawning seasons (2010 and 2011) (Figures 13–24). For almost all available fish (for exception see Figure 17), each individual was detected at least once in 2011 at essentially the same location where it was detected in 2010 during Period 3.

We examined growth rates of study fish by examining length data (Appendix C1) from just the study fish recaptured after 60 or more days postrelease. Thirteen study fish were used to analyze growth rates, which averaged 408 days between measuring events and averaged a 27-mm length increase. Stress from capture and implantation of an internal radio transmitter may have resulted in slower than normal growth of the study fish. However, similar annual growth rates were observed for northern pike in Bristol Bay, Alaska (Chihuly 1979).

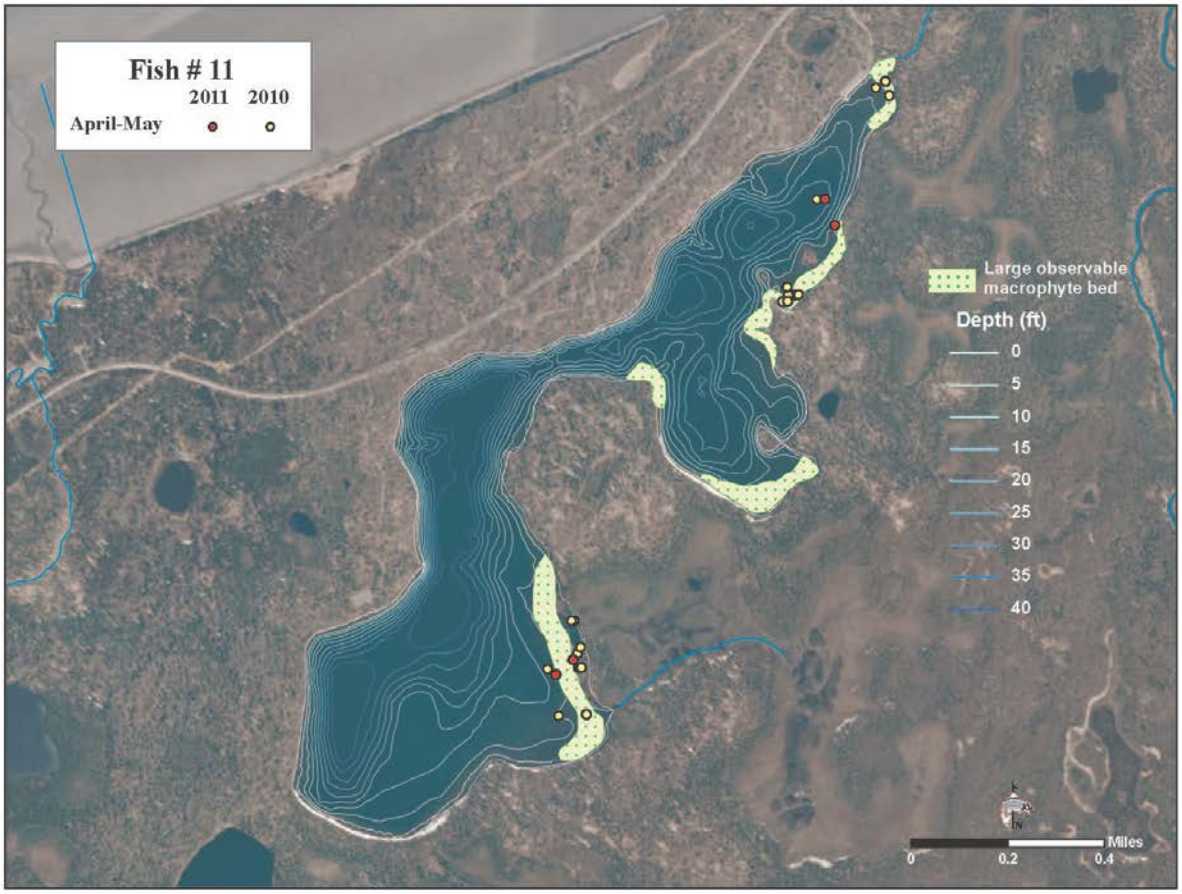

Figure 12.–Single locations of study fish #11 during each tracking run during Period 3 in 2010 and 2011.

Figure 13.–Single locations of study fish #12 during each tracking run during Period 3 in 2010 and 2011.

Figure 14.–Single locations of study fish #15 during each tracking run during Period 3 in 2010 and 2011.

Figure 15.–Single locations of study fish #16 during each tracking run during Period 3 in 2010 and 2011.

Figure 16.–Single locations of study fish #17 during each tracking run during Period 3 in 2010 and 2011.

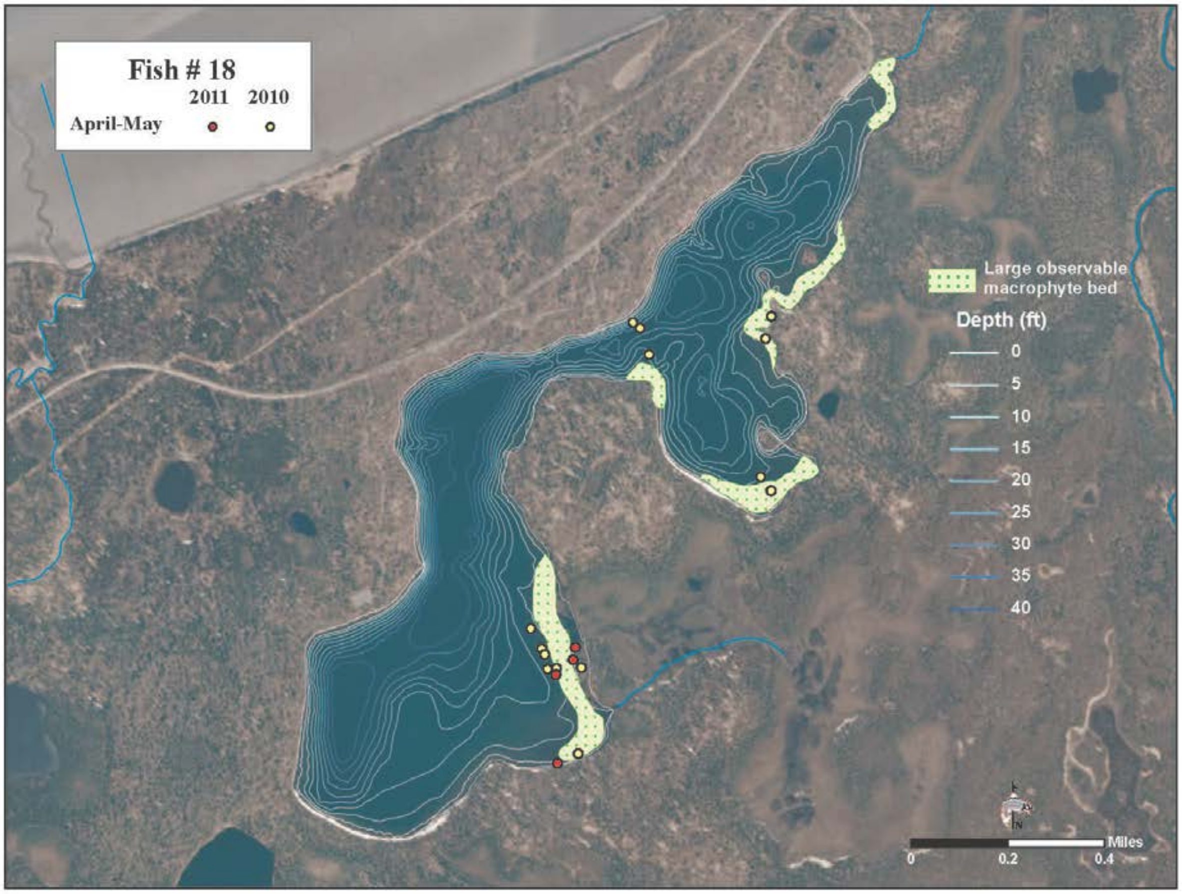

Figure 17.–Single locations of study fish #18 during each tracking run during Period 3 in 2010 and 2011.

Figure 18.–Single locations of study fish #20 during each tracking run during Period 3 in 2010 and 2011.

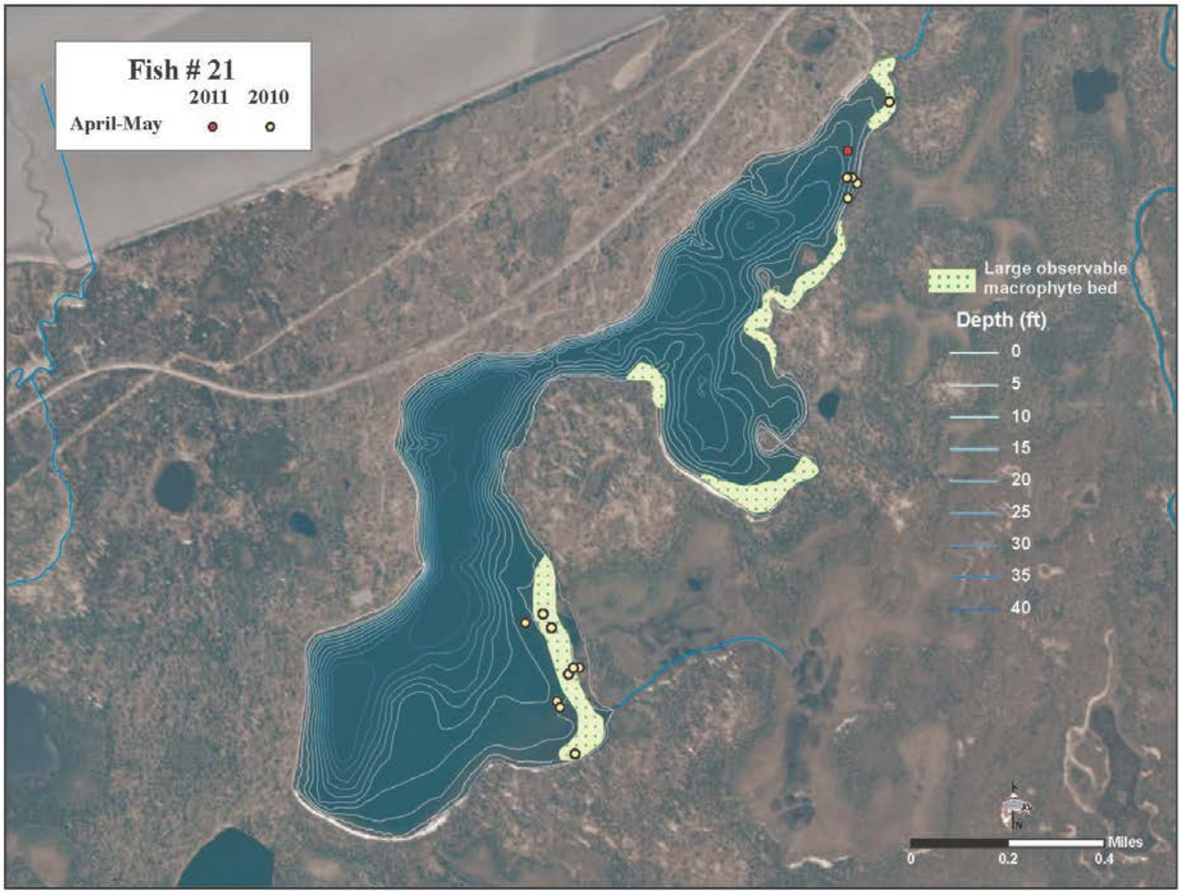

Figure 19.–Single locations of study fish #21 during each tracking run during Period 3 in 2010 and 2011.

Figure 20.–Single locations of study fish #22 during each tracking run during Period 3 in 2010 and 2011.

Figure 21.–Single locations of study fish #27 during each tracking run during Period 3 in 2010 and 2011.

Figure 22.–Single locations of study fish #29 during each tracking run during Period 3 in 2010 and 2011.

Figure 23.–Single locations of study fish #30 during each tracking run during Period 3 in 2010 and 2011.

STUDY FISH MORTALITY

Sixteen of 45 study fish (36%) died within the first 60 days of release (Table 7). After discounting 4 of these study fish killed by accidental net recapture or angler harvest, 12 (27%) died of suspected capture- or surgery-related stress (Tables 7 and 8). Overall, 31 of the radiotagged study fish (69%) died before the study ended.

Table 7.–Floy tag number, date of radio transmitter implant, sex, minimum days postsurgery survival, and general fate for Stormy Lake northern pike study fish.

Floy tag number	Year of transmitter implant	Date of transmitter implant	Sex [a]	Days of postimplant survival	Fate code [b]
1	2009	8 Sep	U	465	UM
2	2009	8 Sep	U	245	UM
3	2009	8 Sep	U	414	UM
4	2009	9 Sep	M	215	SR
4.1[c]	2010	20 May	M	363	IR
5	2009	9 Sep	U	22	HM
6	2009	9 Sep	U	260	UM
7	2009	9 Sep	U	0	GM
8	2009	10 Sep	M	762	IR
9	2009	10 Sep	U	6	HM
10	2009	10 Sep	U	351	UM
11	2009	10 Sep	U	6	HM
12	2009	10 Sep	U	19	GM
14	2009	10 Sep	M	614	IR
16	2009	11 Sep	U	35	HM
17	2009	11 Sep	U	562	AH
18	2009	11 Sep	U	146	AH
19	2009	11 Sep	F	613	IR
20	2009	11 Sep	U	5	HM
21	2009	11 Sep	U	5	GM
22	2009	11 Sep	U	0	HM
23	2009	24 Sep	U	133	AH
24	2009	24 Sep	U	245	UM
25	2009	25 Sep	U	6	HM
26	2009	25 Sep	U	336	C
27	2009	25 Sep	U	0	HM
28	2009	25 Sep	U	53	HM
29	2009	25 Sep	U	35	HM

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Table 7.–Page 2 of 2.

Floy tag number	Year of transmitter implant	Date of transmitter implant	Sex [a]	Days of postimplant survival	Fate code [b]
30	2009	28 Sep	U	273	C
31	2009	28 Sep	U	633	RA
32	2009	29 Sep	F	595	IR
33	2009	29 Sep	F	596	IR
34	2009	29 Sep	U	632	RA
35	2009	29 Sep	M	394	GM
36	2009	29 Sep	U	0	HM
39	2009	2 Oct	U	588	RA
1078	2010	15 Apr	M	545	EM
1079	2010	16 Apr	F	397	IR
1080	2010	20 May	F	37	AH
1081	2010	20 May	U	343	UM
1082	2010	20 May	U	281	AH
4792	2010	28 Oct	M	200	IR
4793	2010	28 Oct	M	202	IR
4794	2010	28 Oct	M	201	IR
4795	2010	28 Oct	U	0	HM

[a] “M” means male, “F” is female, and “U” is unknown sex.

[b] Fate code definitions are as follows:

“GM” is a gillnet mortality or fish that died as a result of accidental gillnet capture.

“EM” is an entanglement net mortality or a fish that died as a result of accidental entanglement net capture.

“AH” is an angler harvest or a fish that was harvested by a sport angler and reported to ADF&G.

“UM” is an unknown mortality or a fish that died due to unknown causes at 60 days postsurgery or longer.

“C” is a censored fish or one that was never located after its release.

“HM” is a handling mortality or a fish that died less than 60 days after capture and not associated with angler harvest or net recapture.

“IR” is an intentional recapture or a fish that was intentionally captured and sacrificed near the end of the study.

“RA” is a fish that remained alive at the end of the study.

“SR” is a shed radio transmitter or a live fish that expelled its radio transmitter during the study.

[c] Two study fish received Floy tags with identical numbers (#004) so one was arbitrarily designated as Floy tag #004.1 to avoid confusion during data analysis.

Table 8.–Summary of short- and long-term mortality rates of study fish.

Term	Description	Number of fish	Percentage
Within 60 days postrelease			
	Total number of study fish	45	100%
	Suspected handling mortality	12	27%
	Mortality by angler harvest or net recaptures	4	9%
	Total number of mortalities	16	36%
Overall summary [a]			
	Total number of study fish [b]	45	100%
	Mortality not attributed to harvest or net recaptures (includes suspected handling mortality and unknown causes)	21	47%
	Mortality by angler harvest or net recapture	10	22%
	Total number of mortalities	31	69%

[a] Includes mortalities that occurred any time during the study.

[b] One study fish (Floy Tag #4) lost its radio tag and its long-term mortality status is unknown, although it was captured alive 212 days after being radiotagged.

DISCUSSION

STUDY-FISH MORTALITIES

Our study-fish mortality rates were high and capture or handling stress is the most likely primary cause. During the initial collection of study fish, low gillnet catch rates prompted us to fish gillnets overnight and unattended to meet our collection needs. In addition, some study fish were held for up to 24 hours in a net pen after collection. Despite attempting to select only fish that had little or no visible sign of injury for use in this study, an unknown number may have experienced serious capture or surgery related injury, causing delayed mortality.

The short-term mortality rate (36% survived less than 60 days after release) of our study fish was near the higher end of short-term mortality rates experienced in other similar Alaskan studies (0% to 43%) (Joy and Burr 2004; Roach 1998b; Scanlon 2009; Taube and Lubinski 1996). In our study, 31 of 45 study fish (69%) died or disappeared before completion of the 20-month study period. Long-term mortality rates experienced by other similar studies in Alaska have ranged from 45% to 55% (Scanlon 2009; Taube and Lubinski 1996). In total, 5 study fish (11%) died from angler harvest and another 5 (11%) died from accidental net recapture, resulting in a combined 22% loss of study fish due to human-related causes. Two study fish disappeared during the study from unknown causes. Because nearly half of the nonharvest mortality experienced during this study occurred within 60 days postrelease, our capture and handling stress was probably excessive. Unattended gillnetting should be avoided as a means to collect fish for future telemetry studies.

ACCURACY OF STUDY-FISH LOCATION WAYPOINTS

Study-fish locations associated with tracking signal strengths of 135 or greater (with a standardized receiver gain setting of 7) were deemed to be less than or equal to 120 ft of the true fish location. This assumption was based on field trials using a tethered radio transmitter submerged in calm shallow water and also by visual observations of study fish during tracking surveys. When we received signal strengths at or exceeding 135 during open water periods, it was not uncommon to visually spot the study fish or its wake within 10 m of the tracker. Variables affecting radio transmitter signal strength (i.e., depth, lake waves, geography, and antennae orientation; Bookhout 1996) could confound the use of signal strength to estimate distance from study fish and therefore accuracy of congregation locations. Regardless, our graphic representations of northern pike congregation sites (fish located within 120 feet of each other; Figures 4–6) provide a reasonable tool for targeting sites of congregation for removal purposes.

SPAWNING

Our data suggest that most adult northern pike in Stormy Lake are annual spawners; this is based on our observation that every northern pike greater than 400 mm in length and assessed for spawning condition by dissection during the spring was in spawning condition. The 2 northern pike dissected in the fall had gonadal development consistent with being ready to spawn during the upcoming spring.

Spawning site fidelity may exist in this population; each study fish that was available for detection during 2 spawning seasons was detected at one or more very similar locations during both spawning periods (Figures 13–24). However, fidelity to habitat (vegetation beds) was prevalent rear-round for most study fish, so the primary reason for site utilization during the spawning period remains speculative.

MANAGEMENT IMPLICATIONS

This project successfully identified year-round northern pike congregation sites, including those located during the spawning period (Figures 4–6). Some study fish were found near the outlet creek in Area 1 during the spawning period (Figures 13–15, 17, 19, and 20), and although no study fish were detected entering the creek itself during any period, non-study northern pike were visually observed in the outlet creek just upstream of the ADF&G maintained net barrier during spring tracking surveys. The presence of spawning northern pike in or near the outlet raised concern that drifting eggs or larval northern pike could pass through the porous fish barrier (fabric fyke net) and expose the remainder of the Swanson River drainage to northern pike invasion.

Since this study concluded, ADF&G secured the funding and permits needed to eradicate invasive northern pike from Stormy Lake. The eradication project was designed to treat the lake and outlet creek with a fish pesticide (rotenone), and the treatment was executed in September of 2012. Knowledge of where most study fish congregated in Stormy Lake was useful in planning the eradication project. With a better understanding of the areas in Stormy Lake where northern pike tended to concentrate, we designed the rotenone application to ensure these areas, typically heavy vegetation beds, were thoroughly treated and we acquired specialized watercraft (surface drive and an airboat) and high-pressure pump delivery systems to improve our coverage of rotenone to these congregation areas. We later weighted our posttreatment evaluation efforts (eDNA sampling and gillnet surveys) by heavily targeting these congregation sites to detect potentially surviving northern pike. The prevalence of nonstudy northern pike, including study fish, near the lake outlet during the spawning period underscored the importance of treating the outlet creek with rotenone to kill any juvenile northern pike that may have passed through the fabric mesh of our fish barrier at the lake outlet. Periodic posttreatment net surveys from 2013 to

2017 never detected a northern pike in Stormy Lake, suggesting the treatment was successful at removing the entire northern pike population.

During this movement study, we detected many northern pike congregation sites, and when viewed collectively, it is clear that most northern pike habitat utilization is in association with the lake's major visible macrophyte beds (Figures 4–6). Future efforts to detect or control invasive northern pike in similar waterbodies should target these areas for maximum efficiency.

ACKNOWLEDGEMENTS

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APPENDIX A: NETTING SURVEYS CONDUCTED IN STORMY LAKE BY ADF&G IN 2009 AND 2010

Appendix A1.–Stormy Lake gillnet survey catches during 2009 and 2010.

Year	Date	Net ID	Hours of net effort	Catch			
				Northern pike	Arctic char	Rainbow trout	Longnose sucker
2009	14 May	1	1.6	0	0	0	0
2009	14 May	2	1.5	2	0	0	3
2009	14 May	3	1.5	0	0	0	0
2009	14 May	4	1.5	0	0	0	1
2009	14 May	5	1.5	1	0	0	0
2009	14 May	6	1.5	0	0	0	0
2009	14 May	7	1.3	0	0	0	3
2009	14 May	8	1.3	2	0	0	0
2009	14 May	9	1.4	2	0	0	1
2009	14 May	10	1.4	2	0	0	2
2009	14 May	11	1.4	2	0	0	0
2009	14 May	12	1.5	0	0	0	0
2010	26 Oct	1	26.0	0	0	0	0
2010	26 Oct	2	26.0	1	0	0	0
2010	26 Oct	3	25.9	0	0	0	0
2010	26 Oct	4	25.9	0	0	0	0
2010	26 Oct	5	25.8	0	0	0	0
2010	26 Oct	6	25.7	0	0	0	0
2010	26 Oct	7	25.7	0	0	0	1
2010	26 Oct	8	25.6	2	0	0	1
2010	27 Oct	9	22.2	1	0	0	0
2010	27 Oct	10	22.1	0	0	0	0
2010	27 Oct	11	22.1	0	0	0	0
2010	27 Oct	12	22.1	0	0	0	0
2010	27 Oct	13	22.0	0	0	2	0
2010	27 Oct	14	22.0	1	0	0	0
2010	27 Oct	15	22.0	0	0	1	0
2010	27 Oct	16	21.9	3	0	0	0
2010	27 Oct	17	20.7	0	0	0	0
2010	27 Oct	18	20.7	0	0	0	0
2010	27 Oct	19	20.7	1	0	0	0
2010	27 Oct	20	20.6	0	0	0	0
		Total	483.1	20	0	3	12

Note: Gillnets were made with floating hanging lines and bottom lead lines and all were 120 ft in length, 6 ft deep, and composed of 6 different monofilament mesh panels in the following sizes: 0.75 in, 1 in, 1.25 in, 1.50 in, 1.75 in, and 2.0 in.

APPENDIX B: SURGERY DATA

Appendix B1.–Radio transmitter implantation surgery data listed in the order that fish were released.

Date	Floy tag number	Radiotag frequency [a]	Pulse code [b]	Fork length (mm) [c]	Sex [d]	Anesthesia induction time [e]	Surgery duration	Recovery time [f]	Total time of anesthesia influence [g]	Lake water temperature (°C)	Lake capture area [h]
8 Sep 2009	1	152.043	16	642	U	0:05:00	0:05:36	0:04:46	0:15:22	12	1
8 Sep 2009	2	152.043	17	459	U	0:03:56	0:06:21	0:14:28	0:24:45	12	1
8 Sep 2009	3	152.043	18	544	U	0:03:17	0:04:56	0:10:50	0:19:03	12	2
9 Sep 2009	4	152.043	19	505	M	0:05:52	0:05:19	0:18:00	0:29:11	13	1
9 Sep 2009	5	152.043	20	500	U	0:03:13	0:04:18	0:09:24	0:16:55	13	1
9 Sep 2009	6	152.043	21	500	U	0:04:18	0:04:02	0:10:55	0:19:15	13	2
9 Sep 2009	7	152.043	22	482	U	0:04:37	0:04:34	0:17:45	0:26:56	13	3
10 Sep 2009	8	152.043	22	713	M	0:04:17	0:04:53	0:11:55	0:21:05	10	3
10 Sep 2009	9	152.043	23	601	U	0:04:45	0:06:45	0:16:45	0:28:15	10	3
10 Sep 2009	10	152.043	24	635	U	0:03:23	0:03:52	0:08:30	0:15:45	10	3
10 Sep 2009	11	152.043	26	593	U	0:03:50	0:07:36	0:08:21	0:19:47	10	4
10 Sep 2009	12	152.073	16	670	U	0:04:48	0:04:53	0:14:00	0:23:41	10	4
10 Sep 2009	14	152.073	17	632	M	0:03:54	0:08:06	0:12:49	0:24:49	10	4
11 Sep 2009	16	152.073	18	702	U	0:04:30	0:03:37	0:14:14	0:22:21	11	4
11 Sep 2009	17	152.073	19	487	U	0:03:00	0:05:33	0:11:46	0:20:19	11	4
11 Sep 2009	18	152.073	20	518	U	0:03:02	0:05:53	0:12:24	0:21:19	11	4
11 Sep 2009	19	152.073	21	627	F	0:04:12	0:06:29	0:14:53	0:25:34	11	4
11 Sep 2009	20	152.073	22	658	U	0:03:33	0:05:56	0:13:59	0:23:28	11	5
11 Sep 2009	21	152.073	23	576	U	0:03:33	0:07:35	0:13:18	0:24:26	11	6
11 Sep 2009	22	152.073	24	585	U	0:03:05	0:09:00	0:12:02	0:24:07	11	6
24 Sep 2009	23	152.073	26	625	U	0:05:00	0:06:45	0:20:00	0:31:45	7	5
24 Sep 2009	24	152.133	16	581	U	0:03:45	0:06:27	0:13:55	0:24:07	7	5
25 Sep 2009	25	152.133	17	586	U	0:02:27	0:07:03	0:13:00	0:22:30	7	5
25 Sep 2009	26	152.133	18	601	U	0:04:30	0:06:05	0:28:00	0:38:35	7	6
25 Sep 2009	27	152.133	19	533	U	0:02:55	0:05:01	0:16:15	0:24:11	7	2
25 Sep 2009	28	152.133	20	504	U	0:02:50	0:05:58	0:13:23	0:22:11	7	4
25 Sep 2009	29	152.133	21	480	U	0:03:07	0:07:03	0:15:15	0:25:25	7	5
28 Sep 2009	30	152.133	19	570	U	0:04:25	0:05:38	0:15:31	0:25:34	6	1
28 Sep 2009	31	152.133	22	404	U	0:03:58	0:08:17	0:12:20	0:24:35	6	1

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Appendix B1.–Page 2 of 2.

Date	Floy tag number	Radiotag frequency [a]	Pulse code [b]	Fork length (mm) [c]	Sex [d]	Anesthesia induction time [e]	Surgery duration	Recovery time [f]	Total time of anesthesia influence [g]	Lake water temperature (°C)	Lake capture area [h]
28 Sep 2009	30	152.133	19	570	U	0:04:25	0:05:38	0:15:31	0:25:34	6	1
28 Sep 2009	31	152.133	22	404	U	0:03:58	0:08:17	0:12:20	0:24:35	6	1
29 Sep 2009	32	152.073	23	430	F	0:04:30	0:05:30	0:11:04	0:21:04	6	4
29 Sep 2009	36	152.133	23	611	U	0:03:08	0:06:35	0:13:16	0:22:59	6	3
29 Sep 2009	35	152.133	26	540	M	0:04:49	0:11:21	0:18:06	0:34:16	6	5
29 Sep 2009	33	152.073	16	670	F	0:04:50	0:09:15	0:16:20	0:30:25	6	5
29 Sep 2009	34	152.133	24	610	U	0:06:02	0:08:09	0:23:10	0:37:21	6	5
2 Oct 2009	39	152.043	26	645	U	0:05:16	0:06:43	0:16:01	0:28:00	7	4
15 Apr 2010	1078	152.073	26	505	M	0:09:50	0:06:15	0:52:00	1:08:05	3	1
16 Apr 2010	1079	152.073	20	678	F	0:08:00	0:06:00	0:40:00	0:54:00	3	1
20 May 2010	1080	152.043	23	625	F	0:05:00	0:07:00	0:02:00	0:14:00	9.5	1
20 May 2010	1081	152.043	17	450	U	0:06:00	0:07:00	0:04:00	0:17:00	9.5	1
20 May 2010	1082	152.133	23	450	U	0:04:00	0:10:00	0:01:00	0:15:00	9.5	1
20 May 2010	4.1	152.073	22	520	M	0:05:00	0:19:00	0:00:30	0:24:30	9.5	1
28 Oct 2010	4793	152.043	23	495	M	0:08:00	0:07:00	0:10:15	0:25:15	5	4
28 Oct 2010	4794	152.133	26	482	M	0:07:00	0:06:30	0:07:15	0:20:45	5	4
28 Oct 2010	4795	152.043	21	543	U	0:06:30	0:06:15	0:17:15	0:30:00	5	6
28 Oct 2010	4792	152.043	19	419	M	0:07:30	0:06:30	0:11:00	0:25:00	5	1

[a] Radio tag frequency is in MHz.

[b] Each radio tag within a frequency could be identified by a unique radio pulse code.

[c] "FL" means fork length measurement from end of snout to fork of tail.

[d] Identification of sex was only attained for fish killed and examined later in the project; minimal fall gonad development made ascertaining sex during radiotag implant surgery difficult.

[e] Time in minutes the fish was placed in anesthesia prior to surgery.

[f] Approximate time postsurgery it took for fish to regain equilibrium.

[g] Total time fish was under the influence of anesthesia including induction, surgery, and recovery.

[h] Stormy Lake capture areas depicted in Figure 2.

APPENDIX C: STUDY FISH BIOLOGICAL DATA

Appendix C1.–Biological records and summary information for study fish.

Radiotag															
Freq.	Pulse code	Used for >1 fish	Floy tag no.	Release date	Last known date fish was alive	Min. days survival post-surgery	Final status	Fork length at capture (mm)	Fork length at recap. (mm) [a]	Length change (mm)	Sex	Spawning assessment[b]	Initial capture area	Recap. area	Comments[c]
152.043	16	N	1	09/08/09	12/17/10	465	Died	459					1		TRN
152.043	17	Y	2	09/08/09	05/11/10	245	Died	450					1		TR
152.043	17	Y	1081	05/20/10	04/28/11	343	Died	544					1		TRN
152.043	18	N	3	09/08/09	10/27/10	414	Died	544					2		TRN
152.043	19	Y	4	09/09/09	08/18/10	251	[d]	505	NA		M		1		TR
152.043	19	Y	4792	10/28/10	05/16/11	200	Sacrificed	419	407	-12	M	PS on 05/16/11	1	1	TR
152.043	20	N	5	09/09/09	10/01/09	22	Died	500					1		TRN
152.043	21	Y	6	09/09/09	05/27/10	260	Died	500					2		TR
152.043	21	Y	4795	10/28/10	10/28/10	0	Died	543					6		TRN
152.043	22	Y	7	09/09/09	09/10/09	1	[e]	482	482	0			3		TR
152.043	22	Y	8	09/10/09	10/12/11	762	Sacrificed	713	748	35	M	Gonads ripening	3	4	TR
152.043	23	Y	9	09/10/09	09/16/09	6	Died	601					3		TR
152.043	23	Y	1080	05/20/10	06/26/10	37	Angler harvest	625	NA		F	PS on 05/20/10	1		TR
152.043	23	Y	4793	10/28/10	05/18/11	202	Sacrificed	495	492	-3	M	PS on 05/18/11	4		TR
152.043	24	N	10	09/10/09	08/27/10	351	Died	635					3		TRN
152.043	26	Y	11	09/10/09	09/16/09	6	Died	593					4		TR
152.043	26	Y	39	10/02/09	05/13/11	588	Remained alive in lake	645					4		TRN
152.073	16	Y	12	09/10/09	09/29/09	19	[e]	670	NA				4		TR
152.073	16	Y	33	09/29/09	05/18/11	596	Sacrificed	670	683	13	F	PS on 05/18/11	5	5	TR
152.073	17	N	14	09/10/09	05/17/11	614	Sacrificed	632	650	18	M	PS on 05/17/11	4	5	TR
152.073	18	N	16	09/11/09	10/16/09	35	Died	702					4		TRN
152.073	19	N	17	09/11/09	03/27/11	562	Angler harvest	487	NA			Unk.	4		TR

-continued-

Appendix C1.–Page 2 of 3.

Radiotag															
Freq.	Pulse code	Used for >1 fish	Floy tag no.	Release date	Last known date fish was alive	Min. days survival post-surgery	Final status	Fork length at capture (mm)	Fork length at recap. (mm) [a]	Length change (mm)	Sex	Spawning assessment[b]	Initial capture area	Recap. area	Comments[c]
152.073	20	Y	18	09/11/09	02/04/10	146	Angler harvest	518	NA			Unk.	4		TR
152.073	20	Y	1079	04/16/10	05/18/11	397	Sacrificed	678	711	33	F	PS on 05/18/11	1	5	TR
152.073	21	N	19	09/11/09	05/17/11	613	Sacrificed	627	661	34	F	PS on 05/17/11	4	5	TR
152.073	22	Y	20	09/11/09	09/16/09	5	Died	658					5		TR
152.073	22	Y	4.1	05/20/10	05/18/11	363	Sacrificed	520	515	-5	M	PS on 05/18/11	1	5	TR
152.073	23	Y	21	09/11/09	09/16/09	5	[e]	576					6		TR
152.073	23	Y	32	09/29/09	05/17/11	595	Sacrificed	430	570	140	F	PS on 05/17/11	4	5	TR
152.073	24	N	22	09/11/09	09/11/09	0	Died	585					6		TRN
152.073	26	Y	23	09/24/09	02/04/10	133	Angler harvest	625	NA			Unk.	5		TR
152.073	26	Y	1078	04/15/10	10/12/11	545	Accidental char net catch	505	572	67	M	Gonads ripening	1	4	TR
152.133	16	N	24	09/24/09	05/27/10	245	Died	581					5		TRN
152.133	17	Y	25	09/25/09	10/01/09	6	Died	586					5		TRN
152.133	18	N	26	09/25/09	08/27/10	336	Disappeared	601					6		TRN
152.133	19	Y	27	09/25/09	09/25/09	0	Died	533					2		TR
152.133	19	Y	30	09/28/09	06/28/10	273	Disappeared	570					1		TRN
152.133	20	N	28	09/25/09	11/17/09	53	Died	504					4		TRN
152.133	21	N	29	09/25/09	10/30/09	35	Died	480					5		TRN
152.133	22	N	31	09/28/09	06/23/11	633	Remained alive in lake	404					1		TRN
152.133	23	Y	36	09/29/09	09/29/09	0	Died	611					3		TR
152.133	23	Y	1082	05/20/10	02/25/11	281	Angler harvest	450	NA			Unk.	1		TR

-continued-

Appendix C1.–Page 3 of 3.

Radiotag															
Freq.	Pulse code	Used for >1 fish	Floy tag no.	Release date	Last known date fish was alive	Min. days survival post-surgery	Final status	Fork length at capture (mm)	Fork length at recap. (mm) [a]	Length change (mm)	Sex	Spawning assessment[b]	Initial capture area	Recap. area	Comments[c]
152.133	24	N	34	09/29/09	06/23/11	632	Remained alive in lake	610					5		TRN
152.133	26	Y	35	09/29/09	10/27/10	394	[e]	540	575	35	M	Gonads ripening	5		TR
152.133	26	Y	4794	10/28/10	05/17/11	201	Sacrificed	482	480	-2	M	PS on 05/1711	4	5	TR

[a] “NA” means not available.

[b] “PS” means postspawning condition observed on date given; “unk.” means unknown.

[c] “TRN” means radio transmitter was never recovered; “TR” means radio transmitter was recovered.

[d] The study fish (Floy Tag #4) lost its radio tag; the radio tag was recovered and redeployed in a new study fish (Floy Tag # 4292). Original study fish (Floy Tag #4) was recaptured in June of 2010.

[e] Accidently caught and killed in a gillnet.