Fishery Data Series No. 15-37

Fishery Investigations along the Proposed Ambler Road Corridor, 2014

by

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November 2015

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

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
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	ã
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	â
trademark	ä
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, c^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	³
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)	a
probability of a type II error (acceptance of the null hypothesis when false)	b
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA REPORT NO. 15-37

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by

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ABSTRACT

In 2009, the state of Alaska began studying the feasibility of a potential road to the Ambler Mining District located in the northwestern region of the state. One potential route, the Brooks East Corridor, was selected for field studies in preparation for the National Environmental Policy Act (NEPA) process. The proposed corridor crosses several rivers including the Koyukuk and Alatna rivers located on the eastern end of the corridor near Bettles/Evansville and the Kobuk River on the western end of the corridor. In 2013, the Alaska Industrial Development and Export Authority (AIDEA) contracted the Alaska Department of Fish and Game (ADF&G) to conduct fisheries assessments in water bodies in and along the proposed corridor. This report describes 3 separate studies of various fisheries along the proposed corridor.

Study 1: This study was designed to collect information on the locations of seasonal habitats of freshwater fishes and their movements within the Upper Koyukuk River drainage in the vicinity of the proposed road crossing over a 14-month period using radiotelemetry. A total of 237 radio tags were deployed July–September 1, 2014 in the upper mainstem Koyukuk River and its tributaries around Bettles. The number of radio tags deployed by species included Arctic grayling *Thymallus arcticus* (n = 137), northern pike *Esox lucius* (n = 17), burbot *Lota lota* (n = 56), broad whitefish *Coregonus nasus* (n = 4), humpback *Coregonus pidschian* (n = 19), and sheefish *Stenodus leucicthyes* (n = 4). An emphasis was placed on Arctic grayling because they were assumed to be the most widespread and prevalent of all freshwater species, they can be readily sampled, and Arctic grayling commonly require a wide range of habitat types. A total of 11 aerial surveys were flown between August 2014 and August 2015. The seasonal locations and movements exhibited by all species demonstrated the importance of main channels, tributaries, and connected off-channel waters that support important habitats year round and underscored the dynamic nature of fish movements between these waters seasonally. Moreover, evidence indicated that discrete spawning stocks for all species exist throughout the study area, such as the spawning population of Arctic grayling in the Malamute Fork, as well as demonstrating the potential of spawning aggregations that are partially composed of fish migrating from outside the study area.

Study 2: This study was designed to collect baseline information about the current status of aquatic communities and habitat in lake systems along the proposed Ambler Road corridor. Four lakes (Birch Hill Lake, Heart Mountain Lake, Sleeper Lake, and Nutuvuki Lake) along the proposed Ambler Road corridor were sampled during the 2014 field season. Sampling was conducted July 7–13, 2014. Fish, water quality, and bathymetric data were collected. Northern pike were captured in all 4 study lakes. Northern pike ranged in size from 32 to 575 mm FL. One slimy sculpin (80 mm FL) was captured in Sleeper Lake; 1 burbot (35 mm TL), 3 lake trout (510-540 mm FL), and 1 ninespine stickleback (40 mm TL) were captured in Nutuvuki Lake. Recorded water temperature did not exceed 21° C in any of the lakes. Nutuvuki Lake and Sleeper Lake were clear with no color, Birch Hill Lake was ferric, and Heart Mountain Lake was humic. Secchi readings for all lakes ranged from 1.75 to 4.75 m and total alkalinity ranged from 11 to 130 mg CaCO3/L.

Study 3: This study used sonar techniques to enumerate the spawning abundance of sheefish *Stenodus leucichthys* in the Kobuk River. Two DIDSON (Dual frequency Identification Sonar) side-scanning sonars were used from 15 September through 6 October 2014 to enumerate outmigrating sheefish from their spawning grounds. All recorded images of sheefish migrating up- and downstream were counted for every hour of every day in the sampling period. The final count of outmigrating sheefish was 8,511. The spawning abundance was less than expected because high water and early ice flows made conditions such that the sonars could not be positioned in a manner that allowed for full coverage of the river bottom. A future sonar site was located that will allow for one sonar to be placed on each side of the river to ensure complete coverage of the river profile.

Key words: Ambler Road Corridor, Koyokuk River, John River, Wild River, North Fork Koyukuk River, Birch Hill Lake, Heart Mountain Lake, Sleeper Lake, Nutuvuki Lake, Kobuk River, Arctic grayling, burbot, northern pike, humpback whitefish, broad whitefish, sheefish, sonar, radiotelemetry.

INTRODUCTION

In 2009, the state of Alaska began studying the feasibility of a potential road to the Ambler Mining District located in the northwestern region of the state. The Alaska Department of Transportation and Public Facilities (ADOT&PF) was tasked with the preliminary work to identify, design, and potentially construct an access and transportation corridor that would connect the Dalton Highway (Haul Road) to the mining district. When ADOT&PF evaluated potential routes, there were initially eight corridors being considered; however, only one of those routes, the Brooks East Corridor, was selected for field studies in preparation for the National Environmental Policy Act (NEPA) process. The proposed corridor crosses several rivers including the Koyukuk and Alatna rivers located on the eastern end of the corridor near Bettles/Evansville and the Kobuk River on the western end of the corridor. In 2013, the Alaska Industrial Development and Export Authority (AIDEA) contracted the Alaska Department of Fish and Game (ADF&G) to conduct fisheries assessments in water bodies in and along the proposed corridor. A portion of that work included systematic sampling of fish and fish habitat within the Koyukuk, John, and Wild rivers and was conducted by the Division of Habitat (Scannell 2015). AIDEA also contracted the Division of Sport Fish to conduct fisheries sampling in rivers and lakes within the proposed corridor, and this report summarizes three separate studies conducted during 2014. Additional contract work concerning anadromous fish surveys throughout the corridor was conducted by ABR Inc. Environmental Research and Services (Lemke et al. 2013). Other fisheries inventory or assessment studies in waters within the corridor are extremely limited and outdated.

STUDY 1: FISH ASSEMBLAGES AND THEIR HABITAT USAGE IN THE KOYUKUK RIVER DRAINAGE

INTRODUCTION

Study 1 was done in collaboration with the Division of Habitat and included several objectives; 4 objectives have already been reported on by Scannell (2015). These objectives were as follows: 1) identify fish species assemblages in water bodies along the corridor; 2) collect fish samples to determine fish population characteristics and life history traits including length/age, age at maturity, diet, and fecundity; 3) measure water chemistry (pH, conductivity, turbidity, temperature); and 4) take invertebrate samples to qualitatively and quantitatively identify lower trophic level productivity.

The remaining portions of Study 1 were directed at collecting information on the seasonal habitats of resident fish species inhabiting the Upper Koyukuk River drainage using radiotelemetry over a 14-month period. The study area included tributaries and mainstem portions of the Koyukuk River, Middle and North Fork Koyukuk rivers, and the John River in the vicinity of Bettles. To investigate seasonal habitats, an emphasis was placed on Arctic grayling *Thymallus arcticus* because they were assumed to be the most widespread and prevalent of all freshwater species, they can be readily sampled, and Arctic grayling commonly require a wide range of habitat types. For example, an Arctic grayling may easily travel 70 km over the course of a year by spawning in a small tundra stream during spring, feeding in a first-order mountainous creek during summer, and overwintering in large rivers. Other migratory freshwater species of interest included northern pike *Esox lucius*, burbot *Lota lota*, and whitefish species; (sheefish *Stenodus leucicthyes*, broad whitefish *Coregonus nasus* and humpback whitefish

Coregonus pidschian). Prior to this study, information on resident fishes inhabiting the Upper Koyukuk drainage was minimal because of its remote geography and relatively small consumptive uses by sport, commercial, and subsistence fishers.

OBJECTIVES

1. Use radiotelemetry to document seasonal locations of mature-sized Arctic grayling (≥330 mm fork length [FL]) captured in the mainstem Koyukuk River and its tributaries during late summer/early fall 2014 with an emphasis on documenting overwintering and spawning areas.
2. Use radiotelemetry to document seasonal locations of other fish species that may be prevalent (northern pike, sheefish, burbot, or whitefish spp.) in the mainstem Koyukuk River during 2014 (summer and fall) with an emphasis on documenting overwintering and spawning areas.

METHODS

The generalized field schedule for 2014 consisted of the following:

1. June 9–12, preparing and testing equipment and methods near Bettles;
2. July 1–14, sampling the mainstem Koyukuk River including deployment of radio tags in prevalent resident fishes;
3. July 29–Aug 10, deploying radio tags in Arctic grayling within Koyukuk River tributaries; and
4. Aug 28–Sept 8, sampling of the mainstem Koyukuk River, which included deployment of radio tags in resident fishes.

To facilitate sampling and the distribution of radio tags, the mainstem portions of major rivers within the study area were divided into 9 study sections (each ~10 km in length), and distributed across portions of the Koyukuk River, Middle and North Fork Koyukuk rivers, and the John River (Figure 1). In general, the area included 170 river kilometers (rkm), and approximately every other 10 km of river was sampled. This division of the sampling area helped to ensure that a large geographic area was sampled, that the amount of area (i.e., a 10-km section) could be reasonably sampled in a given day, and that all habitat types were encountered and sampled.

In the mainstem sections, a combination of boat electrofishing and baited hoop traps were used to capture fish. In the tributary streams, a helicopter was used to access sampling locations for Arctic grayling and hook-and-line gear was used to capture fish. During planning, aerial images were used to locate 22 potential sampling locations across 16 tributary streams for the deployment of radio tags in Arctic grayling during August (Figure 2). These candidate tributaries were selected based on their proximity to the proposed road and to detect a broad range of possible movements. Fish of mature size were targeted during sampling to help maximize detection of probable spawning areas.

Standardized telemetry practices were employed. For all fish species, radio tags were surgically implanted using Aqui-S 20E for anesthesia and following the basic surgical methods detailed by Brown (2006) and Morris (2003). The transmitters used for this project were Lotek coded tags with motion sensors. Radio tags had a 14-month operational life and operated on 4 frequencies between 149.500 and 149.999 MHz with individual transmitters digitally coded for identification.

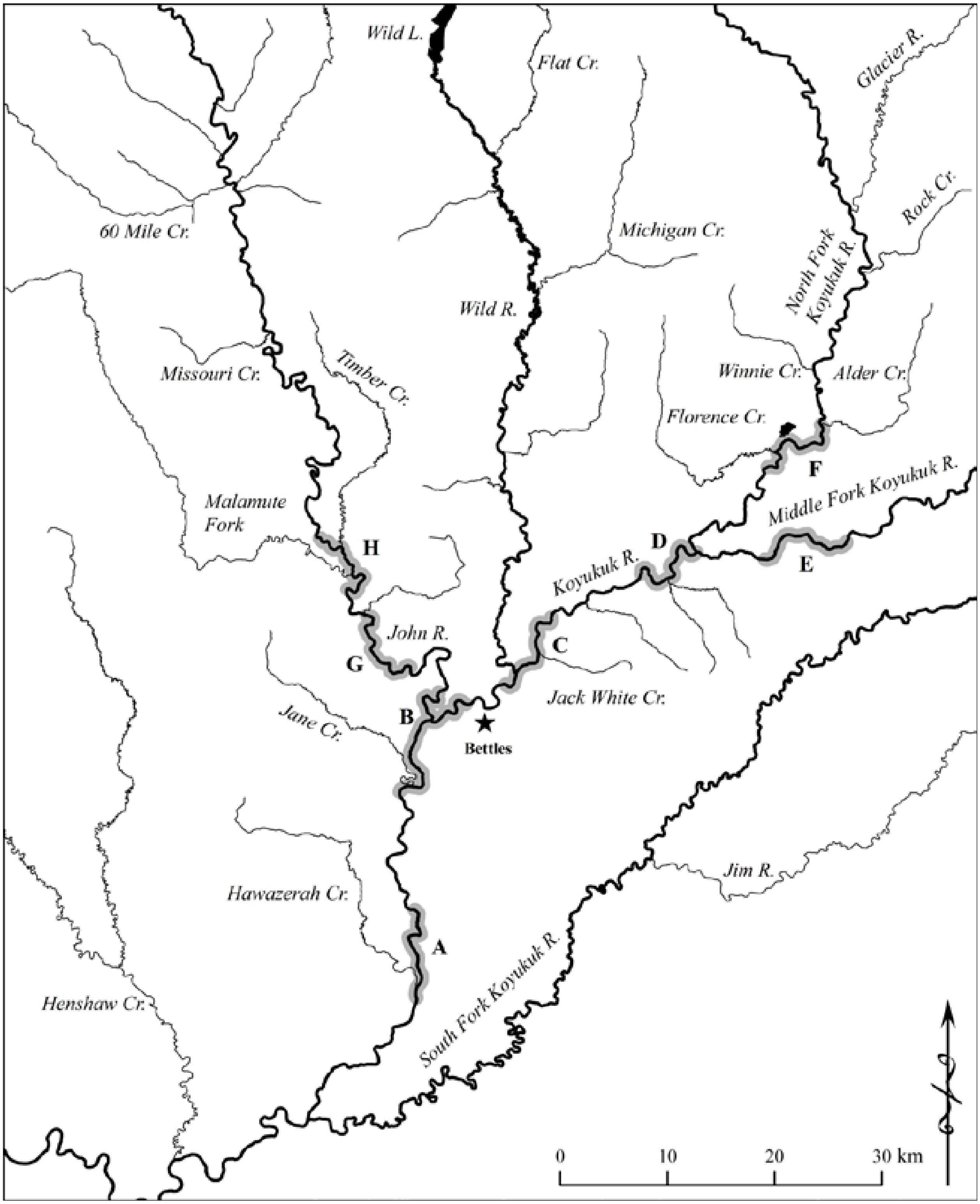

Figure 1.–Koyukuk River sampling area with mainstem sampling sections (A–H) highlighted.

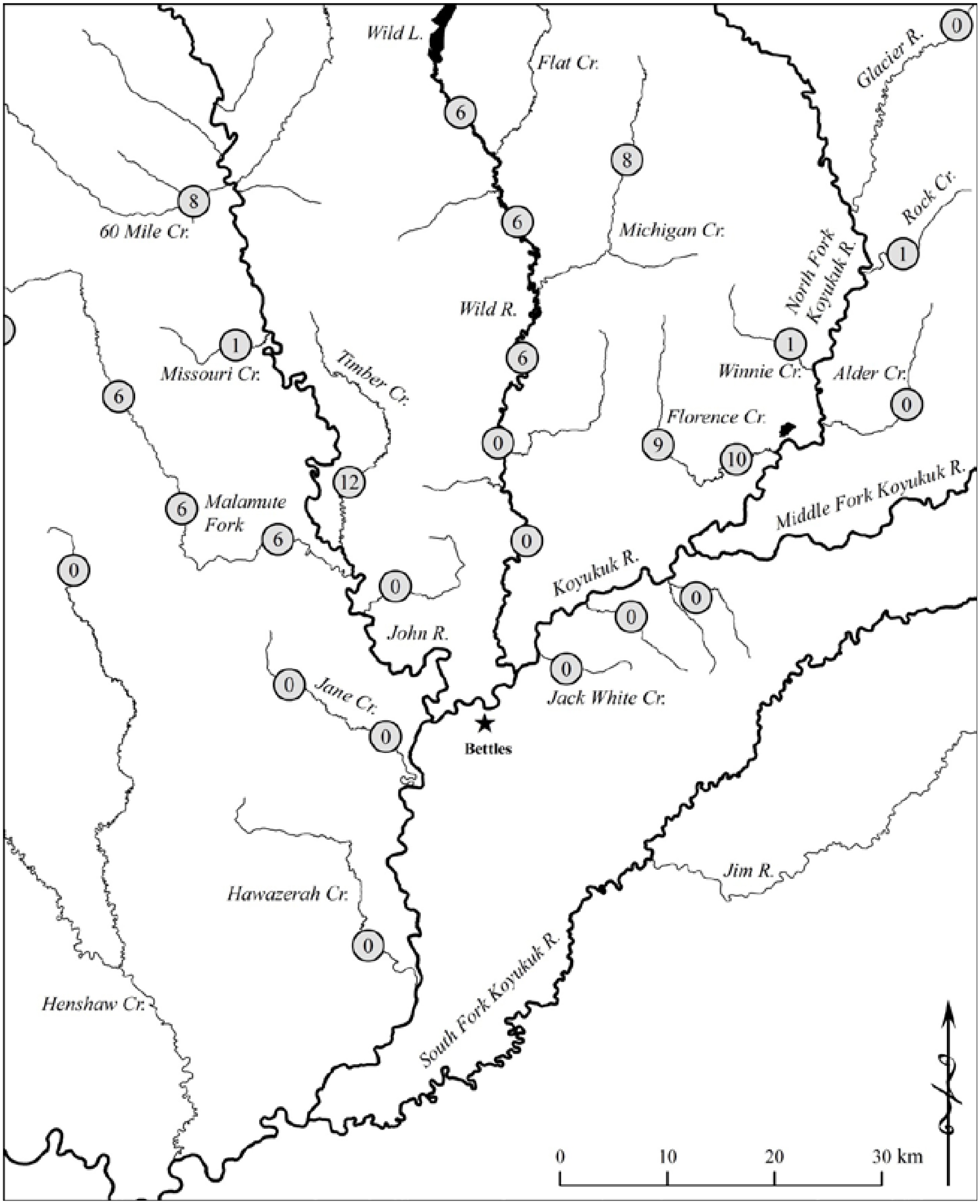

Figure 2.–Locations of tributaries sampled for Arctic grayling with a helicopter. Circles represent all areas investigated or sampled, and numbers indicate the number of radio tags deployed into Arctic grayling.

Tracking flights were conducted using a fixed-wing aircraft and a Lotek SRX 600 receiver with an internal GPS that recorded time and location data. Over a 14-month period, surveys were conducted to coincide with periods before and after major movements to spawning, overwintering, and summer feeding areas. The aerial surveys extended from Allakaket to Coldfoot, including all tributaries, the Wild River drainage and the lower ~100 km of the John and North Fork Koyukuk rivers. The accuracy of locations was within a 0.5-km radius.

In 2014, aerial surveys were conducted on 25 September, 1 October, and 13 December. In 2015, surveys were on 1 and 3 February, 30 March, 7 May, 20 May, 2 June, and 1 August. The February flights were assumed to best represent the burbot spawning period, the June flight best corresponded to the spawning periods for Arctic grayling and northern pike, and the October flight best corresponded to potential spawning periods for sheefish, humpback whitefish, and broad whitefish.

Seasonal distributions of fish were described and summarized by plotting coordinates of all located fish deemed to be alive at the time of the survey onto a digitized map of the drainage using the program ArcGIS. To help visualize geographic differences in seasonal habitat use, the plotted locations by survey were color-coded by their original tagging area. For example, on a given survey, the locations of all fish originally tagged in Florence Creek were represented by green circles and fish tagged in Timber Creek were represented by blue circles. Each colored dot only represented a fish judged to be alive at the time of the survey. Fish that did not survive the initial tagging were removed from all maps, including the map depicting original tagging locations.

Patterns in fish locations were then used to infer behavior and habitat use, and aggregations of fish would identify potentially significant habitats such as spawning and overwintering. Because sample sizes of surviving tags were relatively small for most species, a single dot could represent an important spawning area, although with far less certainty than if 3 fish were in close proximity (i.e., <3 km).

The fate of each fish (i.e., dead, alive, or not located) by survey was determined by examining the movement history and data provided by the motion sensors. Reviewing the movement history of each radiotagged fish was required because the motion sensor sometimes did not accurately reflect the fate of a tagged fish during a given survey. The history of sensor recordings for each fish was then examined to decipher when and if the fish had died, and its fate was corrected for subsequent surveys. For example, a fish with an inactive signal for one or more surveys that later made significant movements and emitted an active signal was considered alive for the inactive period. Conversely, when a fish emitted an active signal intermittently, all the while exhibiting no detectable movement throughout the tracking history, it was considered dead at the time when the first of consecutive inactive signals occurred. By the end, all fish were classified as alive, dead, or missing.

RESULTS AND DISCUSSION

A total of 237 fish were radiotagged during the July, August, and September sampling trips (Table 1 and 2). Inferences on fish movements and seasonal habitats were based on the number of surviving fish at each survey. The life expectancy of the radio tags was 14 months, but after ~12 there appeared to be an abnormally large decline in the number of fish located, suggesting that the radio tags had ended their expected life prematurely. In general, annual survival rates of radiotagged fish were within expected ranges (~30%-70%) for a given species.

Table 1.–Number of fish radiotagged by water body and species in the Koyukuk River study area, 2014 .

Water body	Arctic grayling	Burbot	Broad Whitefish	Humpback Whitefish	Northern Pike	Sheefish	Total
60 Mile Creek	8						8
Florence Lake Creek	19						19
John River	1	6	4	3	8	3	25
Mainstem Koyukuk (Upper)	36	35			8	1	82
Malamute Fork	18						18
Middle Fork Koyukuk		9					10
Michigan Creek	8						8
Missouri Creek	1						1
North Fork Koyukuk	12	6		16	1		35
Rock Creek	1						1
Timber Creek	12						12
Wild River	18						18
Wild River Mouth	2						2
Winnie Creek	1						1
Total	137	56	4	19	17	4	237

Table 2.–Mean length and range of fish radiotagged, by species, in the Koyukuk River study area, 2014.

Species	Number of fish	Mean length (mm FL)	Length range (mm FL)
Arctic Grayling	137	348	293 – 447
Burbot	56	562	435 – 930
Broad whitefish	4	524	483 – 537
Humpback whitefish	19	407	315 – 465
Sheefish	4	597	556 – 625
Northern Pike	17	643	476 – 950

ARCTIC GRAYLING

Arctic grayling migrate seasonally. Their migrations vary in duration, occur within a river and among rivers, and often involve homing to specific areas (Reed 1964; Tack 1980; Ridder 2000; Buzby and Deegan 2000; Gryska 2006). During autumn, Arctic grayling tend to vacate tributaries and upper portions of drainages because of the impending loss of habitat during winter, when river discharge reaches annual lows and some streambeds go dry while others freeze to the bottom. For winter, Arctic grayling seek out habitat that minimizes energy expenditure (e.g., low-velocity water), has physio-chemically suitable water (e.g., adequate depth and oxygen, and no frazzle ice), and provides cover from predators (e.g., overhead ice; Cunjak 1996). As winter ends, Arctic grayling begin their migrations to spawning areas, often located nearby, just before and after breakup. After spawning, Arctic grayling redistribute to summer feeding areas often located in the headwater tributaries. For approximately 2–4 months in the summer and 6–8 months in the winter, Arctic grayling are relatively stationary as they occupy their seasonal habitats (Fish 1998; Gryska 2006). The occupation of spawning areas is short term (about 2 weeks) and a dynamic part of the migration from winter habitats to summer habitats. This same generalized pattern of seasonal habitat use was observed in the Koyukuk study area (Appendices A1-B8).

Most Arctic grayling tagged in tributaries began vacating their summer feeding areas during September. Overwintering areas were mostly concentrated downstream of their respective tributaries in main river channels. Migration distances to overwintering areas were varied, but generally localized and relatively short (<30 km). Maximum distances recorded between tagging and overwintering areas were ~90 km for fish tagged in Timber Creek, ~120 km for those in the Malamute Fork Creek, and ~80 km for those tagged in Florence Creek. Upriver spawning migrations had been initiated by the March 30 aerial survey, with peak spawning occurring near the June 2 aerial survey. Spawning was widely distributed and strong fidelity to their initial tagging location was observed during spawning and summer feeding the following year. This fidelity suggested that populations are likely defined, and should be protected, at the scale of a tributary, such as the Malamute Fork or Timber Creek.

Fish tagged in the mainstem portions of the Koyukuk, John, and North Fork Koyukuk rivers in general showed small downstream movements to mainstem overwintering habitats. Upriver migrations to spawning habitats had been initiated by the end of March and most moved into tributaries for spawning and summer feeding. Interestingly, fish tagged upstream of the Wild River tended to move into tributaries of the North Fork Koyukuk River, whereas fish tagged downstream of the Wild River tended to migrate to the John River drainage. This tendency may be in part attributed to the fact that most (~90%) of these fish were tagged in September and they may have already vacated their tributary streams in route to fall or winter habitats.

For fish that remained in the mainstem Koyukuk River year round, their movements may be explained by two possibilities. The first is that the mainstem Koyukuk River provided suitable spawning, summer feeding, and overwintering habitat year round. The second may be that these fish did not spawn the following spring due to being immature, lacked fitness for sufficient gonadal development, or were affected by the transmitter.

As has been observed in other telemetry studies, there is always a small fraction (i.e., <10%) of a population that are far ranging and possibly establishing new territories, as has been observed in the Tanana Drainage (Gryska *In prep*). For example, one fish tagged in the lower Koyukuk River was located near the Jim River the following year, and another fish that was tagged in the upper Koyukuk River mainstem summered in Rock Creek the following year.

During deployment of radio tags, several candidate streams were identified for sampling grayling, but either no Arctic grayling were observed or fish were of insufficient size for tagging (Figure 2). For example, no Arctic grayling >330 mm FL were captured in upper Henshaw Creek. Although many streams were not represented with radio tags, it is noted that based on field observations and known life histories, most small first-order tributaries are likely to support various life-history stages of Arctic grayling, at least seasonally.

This study demonstrated that all waters including first-order tributaries probably provide seasonal habitats (rearing, spawning, and summer feeding) for discrete populations of Arctic grayling. The mainstem portions of the Wild, John, North Fork, Middle Fork, and Koyukuk rivers provide overwintering habitat that supports mixed spawning stocks, as well providing migration corridors between all seasonal habitats year round.

BURBOT

The few telemetric studies on burbot in Alaska demonstrated that movements can be highly variable and difficult to predict for a given river system. Evenson (1994) radiotagged 55 burbot and found ranges of small burbot (<450 mm FL) to be less variable (<40 river km) compared to larger fish (5–255 river km), with all fish most active during freeze-up and ice-out. In the Kuskokwim River, burbot were tagged near Sleetmute during fall, and most of these fish made large migrations between breakup and spawning. They started between Bethel and Aniak and ended near McGrath, migrating up to ~800 km (Albert and Wuttig *In prep*).

The largest movements in this study were associated with spawning where a general upriver migration was observed between late summer and mid-winter (Appendix C1–C8). It is believed the survey on 2 February best represents probable spawning areas (Appendix C3). Burbot in the John, North Fork Koyukuk, and Middle Fork Koyukuk rivers tended to remain in their respective drainage for spawning, whereas burbot tagged in the mainstem Koyukuk River dispersed most widely using all the major tributaries. The largest observed spawning movements were for fish bound for the upper Wild River, a distance of ~ 120 km. This was a relatively modest distance compared to spawning migrations observed on the Kuskokwim River.

This study demonstrated that spawning for burbot is widespread, potentially occurring outside of the search area, and that moderately sized tributaries such as the Wild River can afford significant spawning habitats. Any aggregations of two or more radiotagged burbot during the February survey likely represented a significant spawning area. For example, the mouth of Michigan Creek in the Wild River and the North Fork Koyukuk River downstream of Florence Lake Creek were particularly notable.

From the spawning period to breakup, burbot appeared to slowly shift back downstream to their original tagging areas, displaying a generalized pattern of fidelity to their summer feeding areas, with several exceptions. For example, one burbot tagged in the lower Koyukuk river mainstem during September migrated to Fish Creek the following summer, a distance of approximately 90 km. This particular fish was tagged on 1 September and may have already been en route to its upriver spawning area, thereby demonstrating the potential of fish from areas well outside of the study area moving in to spawn. The least amount of movements was observed during summer between the June and August surveys when fluvial burbot are relatively sedentary (Evenson 1994, McPhail and Paragamian 2000).

SHEEFISH, HUMPBACK WHITEFISH, AND BROAD WHITEFISH

The life histories of sheefish, humpback whitefish, and broad whitefish in Alaska are similar in that they spawn in rivers during fall (i.e., late September/early October), exhibit either localized (<100 km) or extensive (>1,000 km) migrations to spawning areas, may seasonally utilize brackish waters as juveniles or adults, and exhibit fidelity to spawning areas and summer feeding areas (Alt 1979, Brown 2000, Brown 2006, Brown et al. 2007, Dupuis 2010, Morrow 1980, Scott and Crossman 1973, Stuby 2012). All three species are known to share the same river reaches for spawning, as has been observed in the Tanana and Chatanika rivers near Fairbanks (Andy Gryska, Fisheries Biologist, Alaska Department of Fish and Game, Fairbanks, personal communication).

In general, catches of sheefish, broad whitefish, and humpback whitefish while using boat electrofishing were very low (Scannell 2015). Despite these small sample sizes, the telemetry and catch data did indicate the existence of at least 3–4 possible spawning areas within the study area; one for humpback whitefish in the lower North Fork Koyukuk River, one for broad whitefish in the lower John River, and possibly a combined spawning area for all three species in the mainstem Koyukuk River downstream of the John River (Appendices D1–D9). For all three species, the aerial survey on October 1 was in closest proximity to peak spawning (Appendix D2).

For humpback whitefish, the majority of radiotagged fish were captured in an unnamed, connected slough opposite of Florence Creek (14 out of 17 total radiotagged fish). Of these, nearly all surviving fish migrated only a short distance (i.e., <15 km) upstream by October 1, remaining in the lower portions of the North Fork Koyukuk River for the year, and exhibiting some measure of fidelity to this unnamed slough the following summer. One fish migrated a considerable distance (>50 km) up the North Fork Koyukuk River by October 1, suggesting the presence of an additional spawning area farther upstream. On October 1, the 2 remaining humpback whitefish were below the mouth the John River in the vicinity of other sheefish and broad whitefish, indicating another potentially significant spawning reach for all 3 species.

Only 3 humpback whitefish were tagged in the John River but all made notable spawning migrations. Two made upriver migrations indicating potential spawning areas in the John River, and the third moved to the suspected spawning area downstream of the John River to where 2 humpback whitefish from the Florence Creek area had migrated.

For broad whitefish, the telemetry and catch data indicated the existence of a small population of broad whitefish that utilizes the lower John River for spawning, and downriver areas, such as the Alatna River, Fish Creek or beyond, for overwintering and summer feeding. During early fall (29 August–1 September), a total of 4 broad whitefish were radiotagged in the lower John River where a notable cluster (i.e., >20 fish) was encountered (~5 km from its mouth). The absence of broad whitefish during July and the presence of this cluster in fall, combined with the telemetry data, strongly suggested that during August, broad whitefish migrated from outside the study area to a spawning area located in the lower John River. Two broad whitefish survived to overwintering and were observed in the lower Alatna River in late March. One of these survivors appeared to have migrated to summer feeding areas downstream of Allakaket and eventually outside of the search area. The other survivor was last seen in the lower Fish Creek just after ice-out in mid-May.

Catch data indicated that sheefish are present in the study area during midsummer, including the lower North Fork Koyukuk River, but probably in very low densities (Scannell 2015). Three radiotagged sheefish were located in the loose aggregations of humpback and broad whitefish downstream of the John River, strengthening the possibility of shared spawning area. By February, only one fish was observed overwintering within the study area, and after breakup in late May, 2 were observed in or near the mouth of Fish Creek. Sheefish are highly migratory, but the limited evidence collected in this study indicated a relatively small and regional population, unlike those in the Yukon River that migrate to brackish waters.

The juvenile least cisco *Coregonus sardinella* captured during July sampling using a beach seine in the North Fork Koyukuk River provided strong evidence that spawning for this species probably occurs in the lower portions (i.e., 30 km) of the river. Whitefish species are often found spawning in the same river reach, such as has been observed in the Chatanika, Tanana, and Yukon rivers. Thus, the spawning area utilized by the radiotagged humpback whitefish may also be utilized by least cisco.

NORTHERN PIKE

Northern pike spawn in spring just after ice-out, typically in shallow waters with emergent vegetation, which for river populations is found in connected sloughs and lakes, and typically return to the same spawning area annually (Morrow 1980). Telemetric studies on riverine northern pike show that movements can be highly variable and difficult to predict for a given river system. In the Nowitna River, approximately half of the 70 radiotagged northern pike migrated to the mainstem Yukon River to overwinter for ~6 months, whereas the other half traveled up to ~160 km upstream to riffle-pool sections of the Nowitna River where higher dissolved oxygen concentration were likely present (Scanlon *In prep*). The Nowitna study is in contrast to the Chena River, where all radiotagged northern pike remained in the lower 37 km of the river and displayed only small local movements (e.g., <5 km) from the spawning areas near where they were tagged (Pearse 1994).

In the Koyukuk River, northern pike generally displayed only small localized movements, similar to that of the Chena River (Appendices E1–E4). They tended to overwinter in the mainstem Koyukuk River and returned to the same habitat (side channels and tributary mouths) in which they were captured and tagged for spawning or summer feeding. In general, there is very little interconnected off-channel habitat, such as large oxbow lakes, for northern pike to utilize in spring for spawning and for summer feeding, which underscores the importance of these few available habitats. Densities of northern pike in the study area were in general very low.

CONCLUSION

Despite the limited sample sizes, the movements exhibited by all species demonstrated the importance of main channels, tributaries, and connected off-channel waters that support important habitats year round and underscored the dynamic nature of fish movements between these waters seasonally. Moreover, evidence indicated that discrete spawning stocks for all species exist throughout the study area, such as the spawning population of Arctic grayling in the

Malamute Fork, as well as demonstrating the potential of spawning aggregations that are partially composed of fish migrating from outside the study area.

STUDY 2: INVESTIGATIONS OF AQUATIC COMMUNITIES AND HABITAT IN LAKE SYSTEMS

INTRODUCTION

This project was designed to collect baseline information about the current status of aquatic communities and habitat in lake systems along the proposed Ambler Road corridor. For many lakes in Interior Alaska, species and habitats have not been investigated, documented, or, in some cases, sampled in over 50 years. Lakes and fish populations within this corridor may be impacted by road construction, increased public use after construction, and future resource development.

Fish information, water quality, and bathymetry data are needed to assist state and federal agencies in developing management plans, assessing the impacts of current or proposed development, issuing permits, and monitoring changes in aquatic systems over time. In addition to documenting species and habitat, these sampling actives will help ADF&G Sport Fish Division area managers identify new angling opportunities.

Fish Populations

Basic fish population information is needed to document native species present, their size and age range, and their overall condition. This information is used by biologists and managers to identify critical habitats, fish distributions, the current status of fish communities, and fish populations that require further study. Length compositions are used in management models to establish harvest guidelines. Age information is used to gauge the impacts of harvest over time and to identify stocks that are particularly vulnerable to increased angling pressure. Basic fish population information is also used to identify new angling opportunities and to respond to public inquires.

Water Quality

Water quality data is needed to help biologists interpret fish sample results; identify the habitat needs, usage, and limitations of fish species; monitor habitat changes over time; and plan more detailed fishery or habitat research. Water quality information such as dissolved oxygen and temperature is useful when evaluating fish species' presence or absence and is used to establish fish sampling protocol in future studies such as appropriate capture gear and sample locations.

Bathymetric Maps

Bathymetric maps are used to describe a lake's physical characteristics. A bathymetric map is used to calculate several measurements such as surface area, maximum length and width, mean depth, maximum depth, shoreline length, shoreline development, and volume. Documentation of the physical attributes of a lake can be used to monitor changes, such as lake succession and water level, and to identify attributes (e.g., deep vs. shallow) that may limit fish presence or habitat. Additionally, volumetric calculations from bathymetric data are often required before permits for water resource use and extraction are issued.

OBJECTIVES

Fish Populations

Objective 1: Survey selected lakes to determine fish species present, characterize the size range of the fish captured, and describe the overall appearance and condition of captured fish.

Objective 2: Determine the age of 2–5 fish from each specified length category for captured game fish species >150 mm in length. Length categories will be increments of 50 or 100 mm depending on species. Game fish species include Arctic grayling, burbot, lake trout, northern pike, and whitefish.

Water Quality

Objective 3: Measure water clarity, temperature, dissolved oxygen, pH, total dissolved solids, specific conductivity, and alkalinity.

Bathymetric Maps and Other Lake Characteristics

Objective 4: Survey the lake bottom to obtain depth, longitude, and latitude data for producing bathymetric maps.

Objective 5: Describe the lake watershed and the immediate surroundings, such as tree/shrub cover, and inlets and outlets.

Objective 6: Photograph the lake and surrounding area from north and south locations and, if flown into a lake, take aerial photographs of the lake and surrounding area.

METHODS

Four lakes (Birch Hill Lake, Heart Mountain Lake, Sleeper Lake, and Nutuvuki Lake) along the proposed Ambler Road corridor were sampled during the 2014 field season (Table 3, Figure 3). Sampling was conducted July 7–13, 2014. Fish, water quality, and bathymetric data were collected.

Table 3.–Location and description of lake morphometrics for 2014 study lakes along the proposed Ambler Road corridor.

	Birch Hill Lake	Heart Mountain Lake	Nutuvuki Lake	Sleeper Lake
Lat (WGS 84)	66.92446	67.12128	66.989305	67.049155
Long (WGS 84)	-151.418	-152.523	-154.723957	-153.522377
Elevation (m)	210	334	192	260
Surface area (ha)	28.6	79.6	1,535.5	36.9
Shoreline length (m)	2,776	8,186	23,895	3,004
Volume (m^3)	473,592	4,662,260	329,600,991	1,316,147
Maximum depth (m)	5.2	22.0	52.6	10.4
Mean depth (m)	1.8	3.8	9.2	2.4

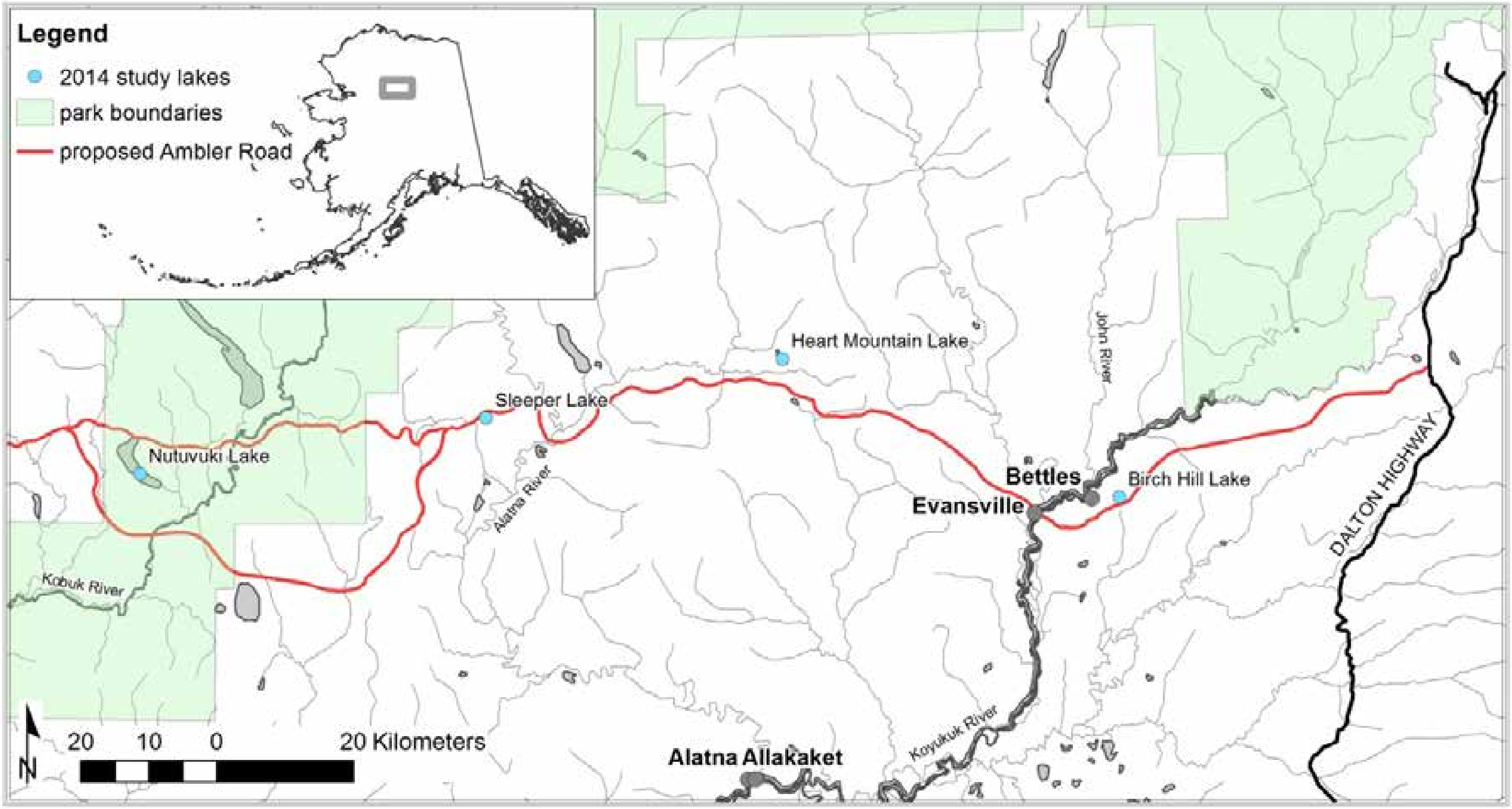

Figure 3.–Location of 2014 study lakes along the proposed Ambler Road corridor.

Fish Populations

Fyke nets, tangle nets, and minnow traps were used to sample fish populations in each lake. The amount of capture gear and duration of sampling was based on lake size and is summarized in Table 4. Captured fish were measured to the nearest mm fork length (FL) or total length (TL), depending on the species, and visually inspected for signs of parasites and disease.

Table 4.–Amount of capture gear and duration of sampling used to capture fish in 2014 study lakes along the proposed Ambler Road corridor.

	Birch Hill Lake	Heart Mountain Lake	Nutuvuki Lake	Sleeper Lake
Nights	2	3	3	2
Fyke Nets	4	4	8	4
Tangle Nets	1	2	2	1
Minnow Traps	4	4	6	4

Water Quality

Water quality parameters were measured at two stations in each lake. Water color, Secchi reading, and total alkalinity were recorded at one sample station in each lake; and specific conductivity, pH, TDS, temperature, and dissolved oxygen were recorded at depth at two sample stations in each lake.

Bathymetric Maps and Other Lake Characteristics

Study lakes were surveyed for bathymetry data and peripheral watershed features were documented. Position and depth data for bathymetry mapping were collected with a Lowrance HDS-5 sonar unit equipped with a GPS receiver. Data were collected by first following the shoreline in a small skiff within 5 m of shore where adequate depth (>0.5 m) allows. After surveying the shoreline the rest of the lake will be surveyed along multiple circular transects, spaced equidistance apart paralleling the shoreline and decreasing in size until the middle of the lake is reached. The number of transects will be determined by lake size and by the variability of the lake bottom. Collected data will be used to generate lake maps using Arc Map 3D Spatial Analyst.

The terrestrial surroundings (up to 5 m from shore) were documented. This included documenting inlets and outlets and noting the general vegetation types present (e.g., sedge, shrub willow, deciduous, coniferous).

A minimum of two photographs were taken at each lake, one from the south shore looking north and one from the north shore looking south.

RESULTS AND DISCUSSION

Fish Populations

Northern pike were captured in all 4 study lakes. Northern pike ranged in size from 32 to 575 mm FL. One slimy sculpin (80 mm FL) was captured in Sleeper Lake and 1 burbot (35 mm TL), 3 lake trout (510-540 mm FL), and 1 ninespine stickleback (40 mm TL) were captured in Nutuvuki Lake. All fish appeared to be in good condition and had no external signs of parasite or disease. Basic summary statistics for fish captured in 2014 study lakes are represented in Table 5.

Water Quality

Recorded water temperature did not exceed 21° C in any of the lakes. Nutuvuki Lake and Sleeper Lake were clear with no color, Birch Hill Lake was ferric, and Heart Mountain Lake was humic. Secchi readings for all lakes ranged from 1.75 to 4.75 m and total alkalinity ranged from 11 to 130 mg $CaCO_3$/L. Values observed for these and other water quality parameters measured during July 2014 sampling are summarized in Table 6.

Table 5.–Basic summary statistics for fish captured in 2014 study lakes along the proposed Ambler Road corridor.

	Birch Hill	Heart Mountain	Nutuvuki	Sleeper
Northern pike *Esox lucius*				
Mean length (mm)	364	120	114	58
Standard Error	21	28	40	2
Median	346	67	65	57
Mode	-	-	65	54
Minimum	340	51	38	32
Maximum	405	320	575	145
Count	3	10	13	43
Slimy sculpin *Cottus cognatus*				
Mean length (mm)	-	-	-	80
Standard Error	-	-	-	-
Median	-	-	-	80
Mode	-	-	-	-
Minimum	-	-	-	80
Maximum	-	-	-	80
Count	-	-	-	1
Burbot *Lota lota*				
Mean length (mm)	-	-	35	-
Standard Error	-	-	-	-
Median	-	-	35	-
Mode	-	-	-	-
Minimum	-	-	35	-
Maximum	-	-	35	-
Count	-	-	1	-
Lake trout *Salvelinus namaycush*				
Mean length (mm)	-	-	522	-
Standard Error	-	-	9	-
Median	-	-	515	-
Mode	-	-	-	-
Minimum	-	-	510	-
Maximum	-	-	540	-
Count	-	-	3	-
Ninespine stickleback *Pungitius pungitius*				
Mean length (mm)	-	-	40	-
Standard Error	-	-	-	-
Median	-	-	40	-
Mode	-	-	-	-
Minimum	-	-	40	-
Maximum	-	-	40	-
Count	-	-	1	-

Bathymetric Maps and Other Lake Characteristics

Lakes ranged in size from 28.6 to 1,535.5 ha, in maximum depth from 5.2 to 52.6 m, and in elevation from 192 to 334 m. Lake morphometrics for 2014 study lakes are summarized in Table 3. Bathymetric maps generated from collected depth data are shown in Figures 4–7. Aerial and ground photographs of the lakes are available at http://www.adfg.alaska.gov/index.cfm?adfg=fishingSportStockingHatcheries.lakesdatabase.

Study lakes were surrounded by rolling hills with both coniferous and deciduous trees present; coniferous trees were more abundant. Inlets and outlets were observed at three lakes: Birch Hill Lake, Nutuvuki Lake, and Sleeper Lake. Birch Hill Lake had a small outlet at the north end that flowed into the Koyukuk River. Nutuvuki Lake had an outlet at the south end that flowed into the Kobuk River and multiple inlets at the north end. Sleeper Lake had one outlet that flowed into Helpmejack Creek and the Alatna River, one small inlet located on the western shore, and several small inlets that flowed from a lowland bog on the eastern shore. Heart Mountain Lake did not appear to have inlets or outlets at the time of sampling.

Table 6.–Range of physical and chemical water quality parameters recorded in 2014 study lakes along the proposed Ambler Road corridor. Data were recorded July 8–12, 2014.

	Birch Hill Lake	Heart Mountain Lake	Nutuvuki Lake	Sleeper Lake
water color	ferric	humic	clear	clear
Secchi reading (m)	1.75	2.75-4.13	3.88	4.75
total alkalinity (mg/L CaCO3)	11	62	29	130
specific conductivity (µS/cm)	35-40	157-295	84-89	307-612
pH	6.2-6.9	6.0-8.4	7.1-7.5	7.3-7.8
TDS (ppm)	0.023-0.026	0.100-0.189	0.053-0.059	0.199-0.398
temperature (°C)	15.5-20.4	3.3-20.7	4.7-18.8	5.2-17.8
dissolved oxygen (mg/L) [a]	5.1-8.1	0.0-10.5	9.5-11.3	0.5-12.2
maximum depth sampled (m)	2.5	13	15	9.75

[a] Dissolved oxygen saturation exceeded 100% in some areas during July 2014 sampling. We do not typically see values greater than 100% in Interior Alaska lakes; however, super saturation of oxygen in water can occur during photosynthesis or when abrupt changes in temperature, salinity, or air pressure occur. These high readings may be a result of natural processes or due to a faulty oxygen probe.

Figure 4.–Bathymetric map for Birch Hill Lake, July 2014.

Figure 5.–Bathymetric map for Heart Mountain Lake, July 2014.

Figure 6.–Bathymetric map for Nutuvuki Lake, July 2014.

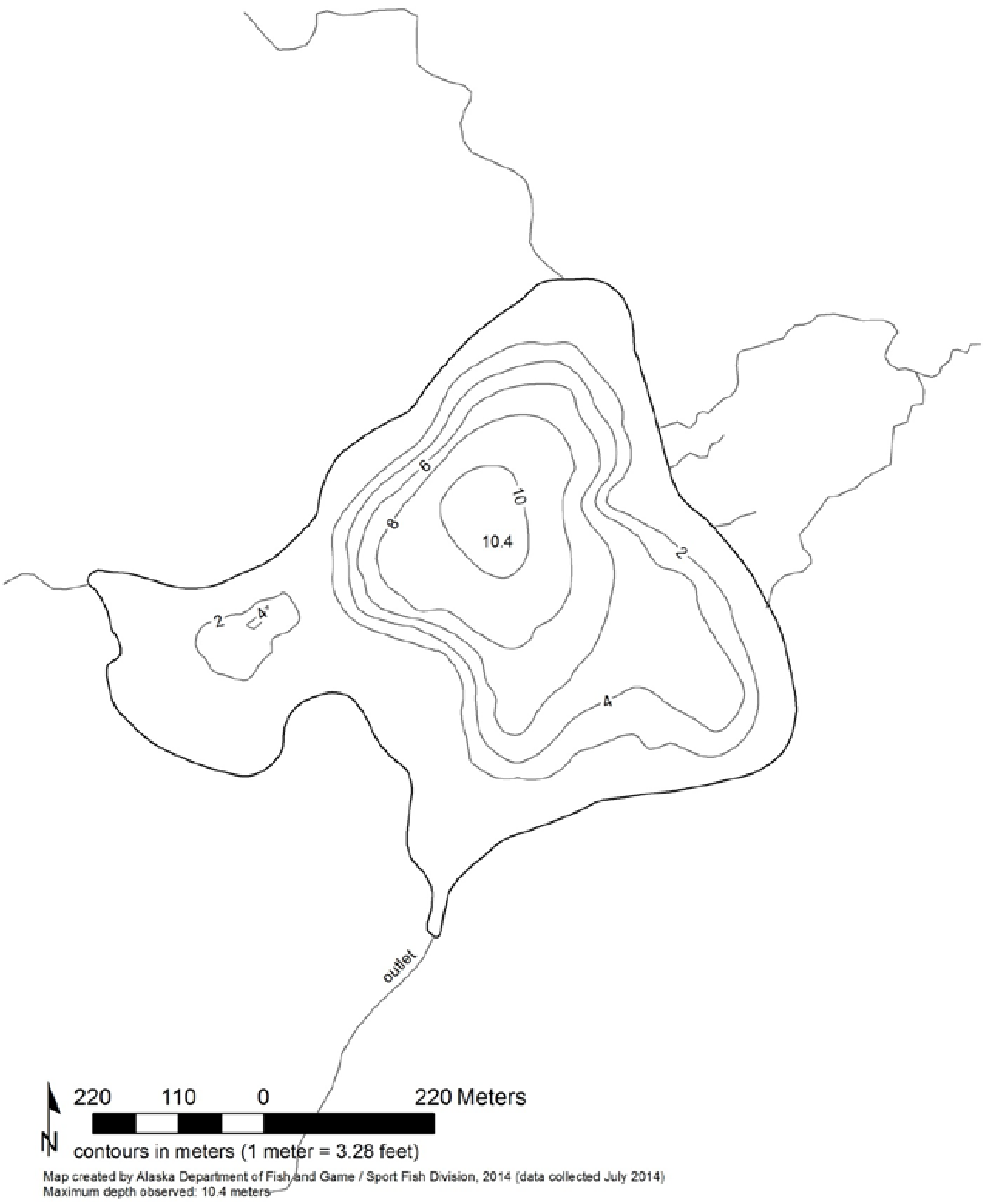

Figure 7.–Bathymetric map for Sleeper Lake, July 2014.

STUDY 3: SPAWNING ABUNDANCE OF KOBUK RIVER SHEEFISH

INTRODUCTION

Sheefish, or inconnu *Stenodus leucichthys,* are an extremely important resource in northwest Alaska. Their importance stems from their extensive use as a subsistence food, their value as a commercial resource, and their reputation as a trophy sport fish (Georgette and Loon 1990). The Kobuk River sheefish population supports inriver subsistence and sport fisheries along with winter subsistence and commercial fisheries that occur in Hotham Inlet and Selawik Lake (Figure 8). Sheefish harvested in Hotham Inlet and Selawik Lake are a mixed stock composed of the only 2 known spawning populations in the region, the Selawik and Kobuk river populations (Alt 1987). The exploitation of these stocks is poorly understood due to incomplete estimates of total annual harvest, unknown stock composition in the mixed stock winter fisheries, and unknown total exploitable stock abundance.

An understanding of these basic elements is necessary to describe the population dynamics of each stock and identify sustainable harvest levels. Because sheefish are iteroparous and known to skip a year after spawning, estimates of spawning frequency are critical in determining whole population estimates. Recent studies have led to a better understanding of spawning frequency and timing, which may be coupled with a sonar assessment of spawning abundance to derive an estimate of total stock abundance. If the spawning frequency strategies are sporadic and a total stock abundance cannot be derived, then the counts of spawning abundance would provide a reliable index of the stock's status.

OBJECTIVE

The objective of this study was to use DIDSON sonar techniques to enumerate the abundance of outmigrating mature sheefish near the village of Kobuk from 15 September through 15 October 2014.

METHODS

Two sonar units (DIDSON) were placed on the north side of the Kobuk River near the lower boundary of the known spawning areas on an inclined gravel bar that stretches across the river to the southside cut bank (Figure 8). This type of river profile is preferred to ensure ensonification of the entire area where fish are migrating. Low frequency settings that allow for up to 40 m of the area to be ensonified were used to maximize coverage of the river profile. One sonar was set up to ensonify the first 30 m of the river and the other sonar was set up to ensonify the remainder of the river. Images were recorded 24 h a day over the course of the outmigration, which was approximately 30 days.

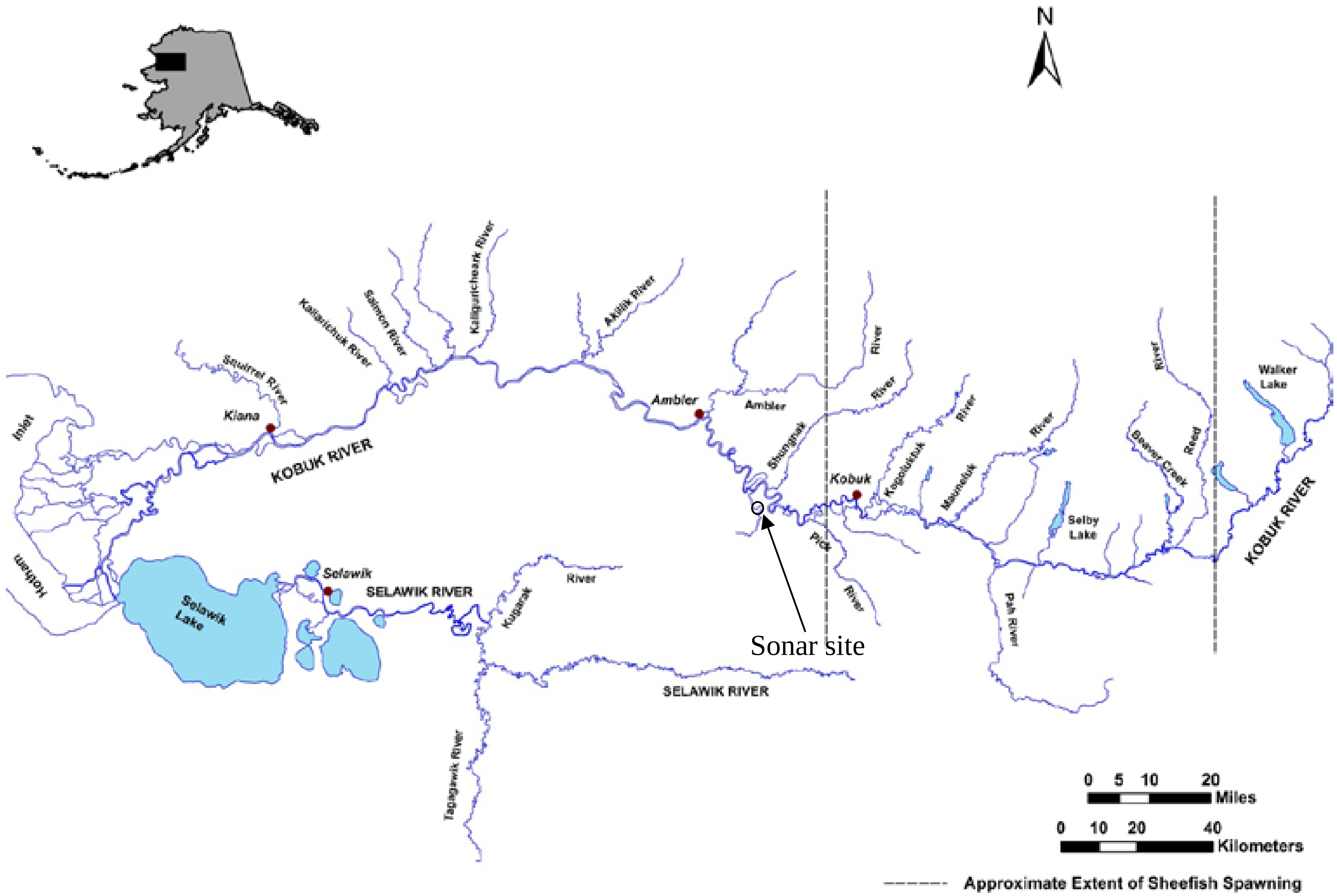

Figure 8.–A map of the Kobuk and Selawik river drainages including the sonar site and surrounding communities.

All targets measuring ≤650 mm in total length (TL) were culled from the analysis because the length composition of spawning sheefish in the Kobuk River indicated there are no mature sheefish smaller than 650 mm TL (Savereide *In prep*).

A beach seine (200 ft long x 8 ft deep) was used to ensure all fish in the ensonified area were actually sheefish.

Daily estimates of abundance were determined inseason by expanding the number of targets counted for a portion of every hour. A census of spawning abundance was completed postseason by counting the total number of targets over the entire outmigration.

RESULTS

A total of 8,511 mature sheefish were enumerated from 15 September to 5 October 2014 (Figure 9). Each sonar recorded all hours of each day within the sampling period. Early river ice on the eve of 5 October forced the crew to remove the sonar units and demobilize camp.

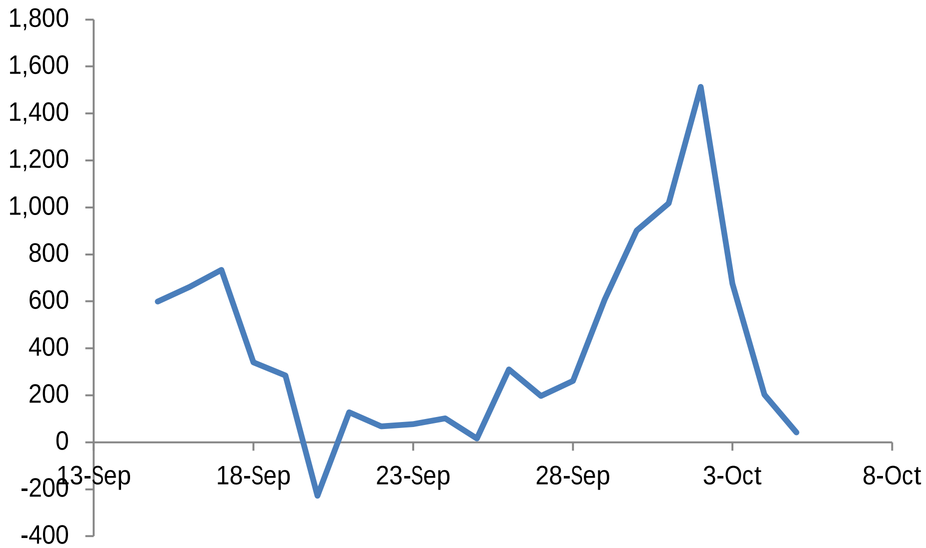

Figure 9.–Daily counts of outmigrating sheefish (a negative number indicates more fish went upstream that day than downstream).

One beach seine haul near the sonar site was conducted each day over the first 10 days of sampling and indicated that nearly all fish (>92%) recorded on the DIDSON images were sheefish (Table 7).

Table 7.–Total catch per daily seine haul.

Date	Sheefish	Arctic Grayling	Whitefish
15-Sep	6	1	1
16-Sep	12	1	1
17-Sep	21	1	0
18-Sep	24	1	0
19-Sep	25	0	1
20-Sep	18	0	2
21-Sep	16	1	0
22-Sep	15	2	1
23-Sep	19	0	0
24-Sep	24	0	0

DISCUSSION

Previous studies and local knowledge have established that sheefish in the Kobuk River tend to reach spawning areas upstream of Kobuk village from mid-July to late August and leave those same areas from late September to mid-October (Alt 1987, Taube and Wuttig 1998, Savereide *In prep*). In addition, Savereide (*In prep*) has shown that anywhere from 18% to 49% of Kobuk River sheefish exhibit sequential year spawning, including males and females. This evidence suggests that deriving total stock abundance estimates of mature sheefish are unlikely when 51% to 82% may skip spawn in any particular year. For these reasons, an annual enumeration of the sheefish outmigration from their spawning grounds using sonar methodology would be necessary to provide a reliable index of the total stock abundance.

Previous spawning abundance estimates based on mark–recapture techniques have ranged from 32,000 to 40,000 sheefish (Taube and Wuttig 1998). After enumerating 20 days of recorded DIDSON images of outmigrating sheefish, the total count was only 8,511 sheefish, which is not even half of what was expected. However, high water, early ice, and a thalweg that was deeper than expected limited our ability to ensonify the majority of the river, especially the thalweg, which, based on Selawik River sonar studies (R.F. Hander, Fish Biologist U.S.F.W.S., Fairbanks, personal communication), is known to be the preferred corridor of migrating sheefish. Based on these circumstances it is likely more than half of the outmigration was not enumerated.

Despite the fact the entire outmigration corridor was not ensonified, the ability to obtain a reliable count of the spawning abundance is possible. Based on the beach seine catches and the length composition of mature sheefish, the majority of fish in the ensonified area are sheefish and if not, they can easily be culled from the count. In addition, the project biologist and crew surveyed another sonar location downstream where a DIDSON can be placed on each side of the river to obtain full images of the river profile, including the thalweg. The gradient of the river bottom in this area is more conducive to sonar techniques and will provide a more complete enumeration of the entire outmigration.

ACKNOWLEDGEMENTS

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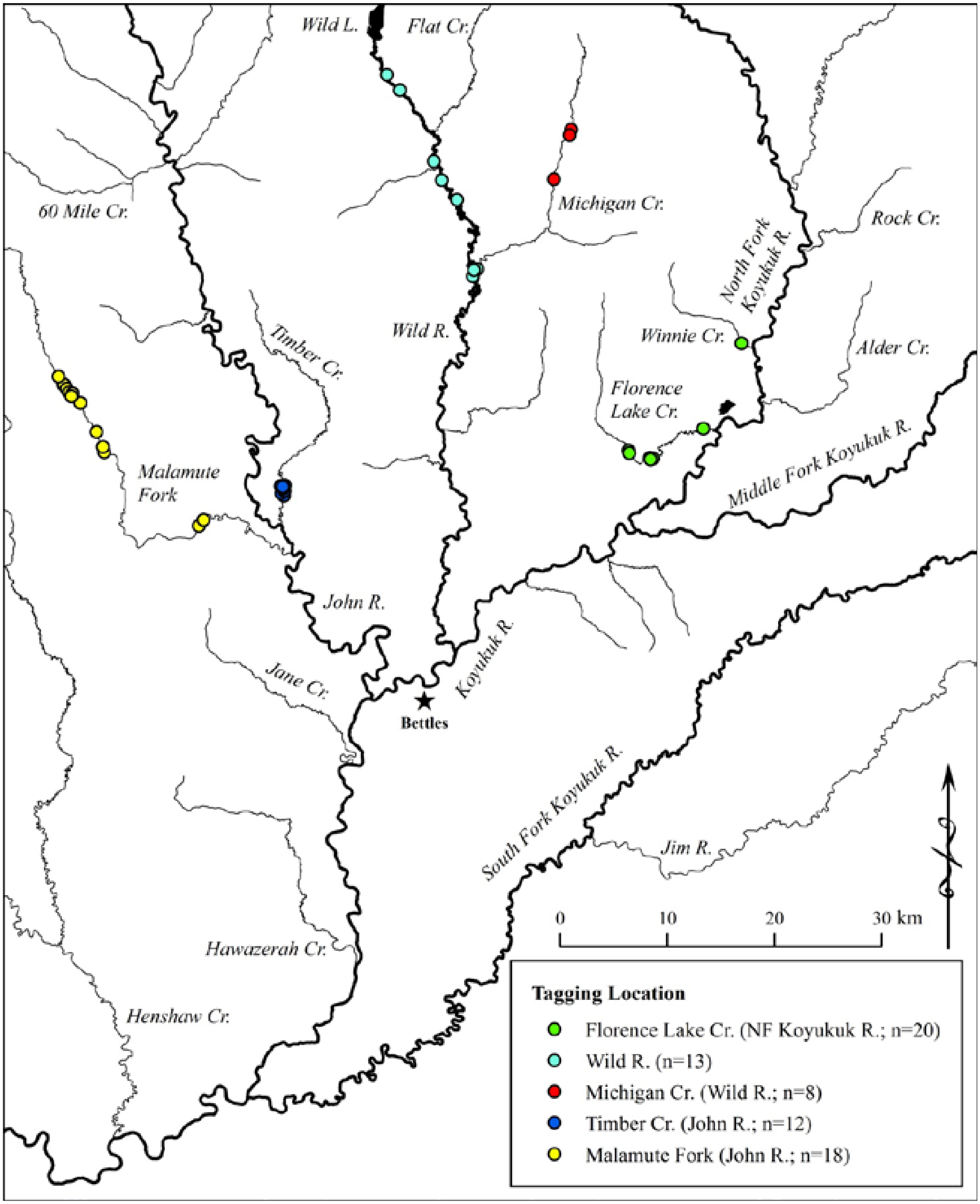
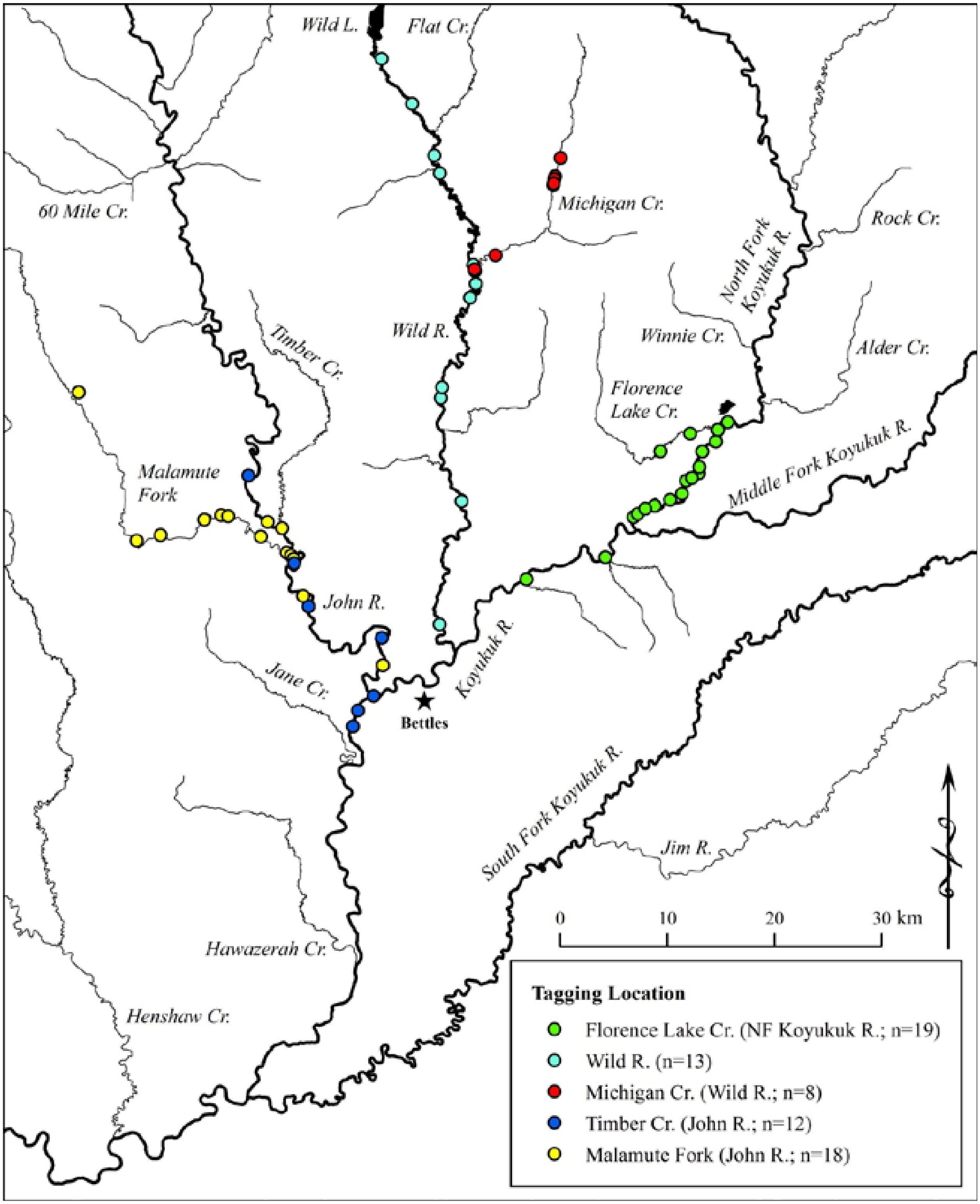
APPENDIX A:
LOCATIONS OF RADIOTAGGED ARCTIC GRAYLING CAPTURED IN TRIBUTARIES WITHIN THE KOYUKUK STUDY AREA

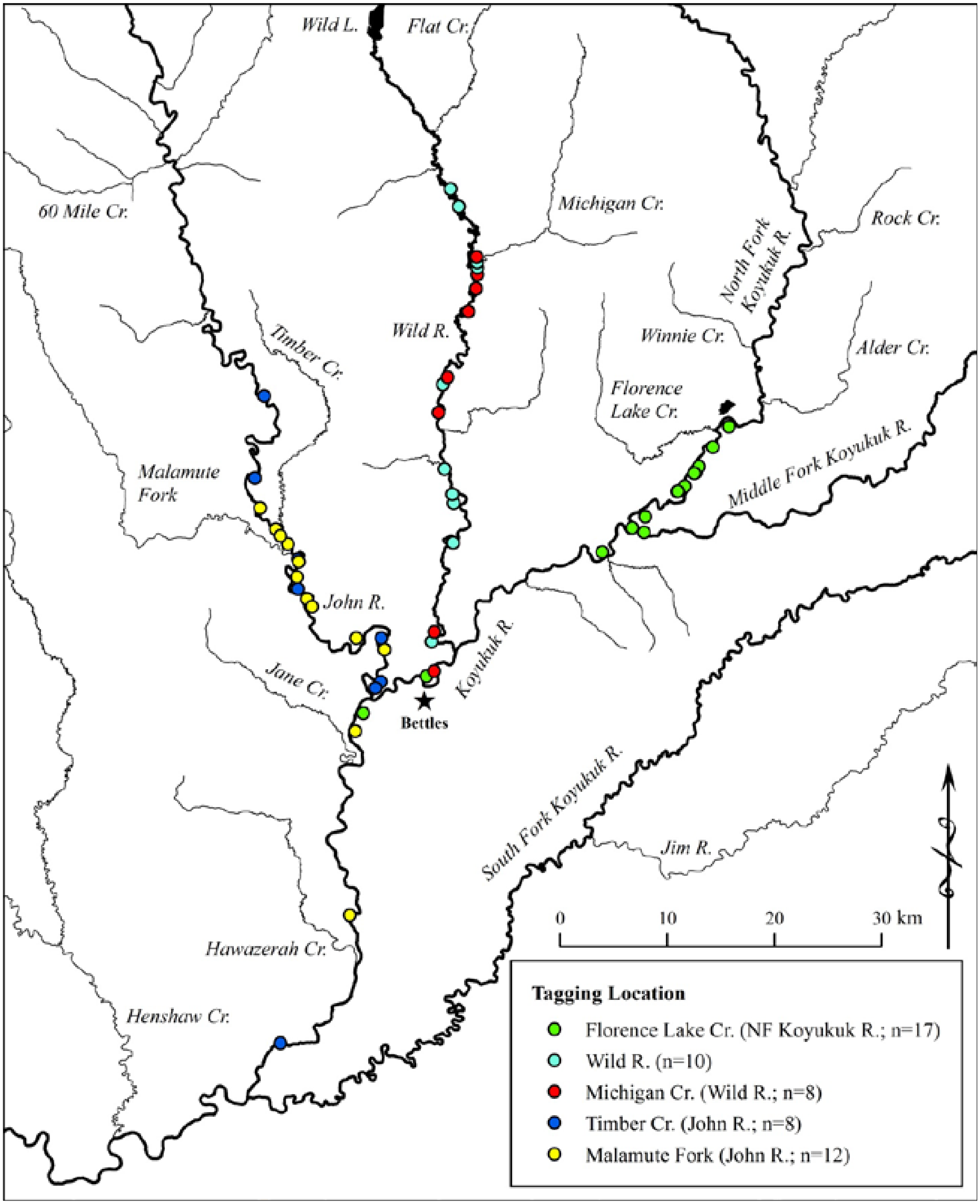
Appendix A1.–Tagging locations for Arctic grayling sampled in tributaries within the Koyukuk study area, 2014. Colors depict a general tagging area and the total number of surviving radiotagged fish are labeled parenthetically in legend.



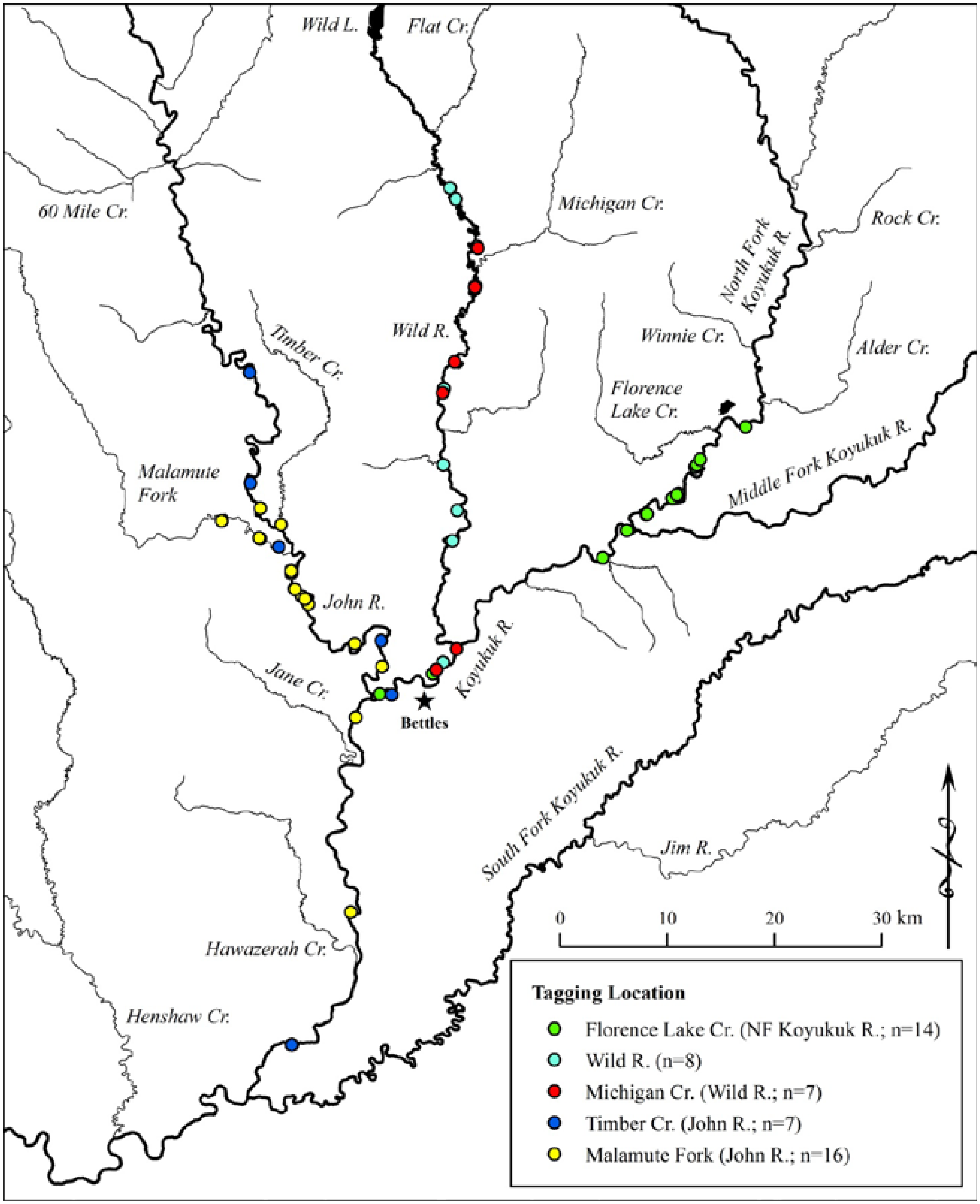
Appendix A2.–Locations of radiotagged Arctic grayling on 25 September 2014 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



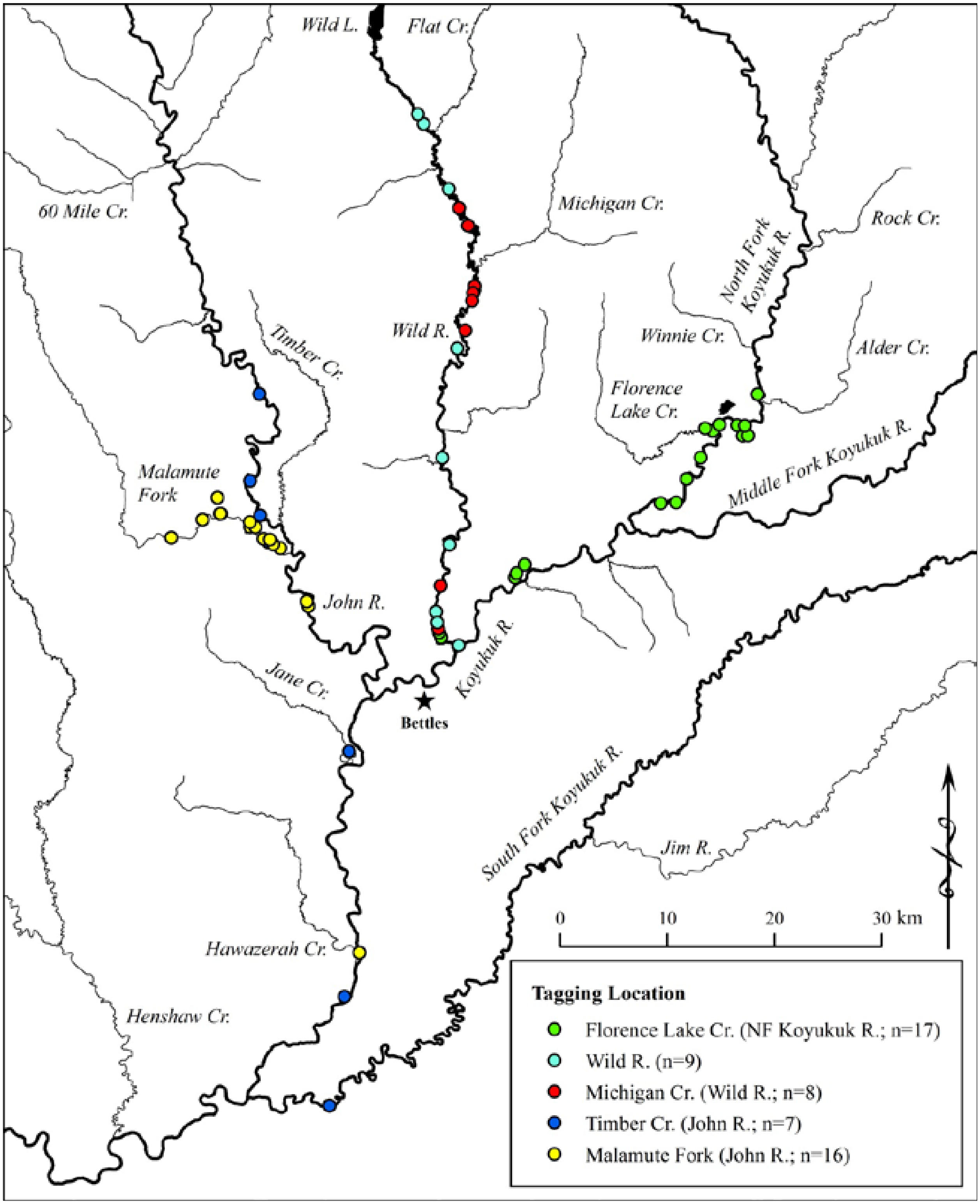
Appendix A3.–Locations of radiotagged Arctic grayling on 1 February 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



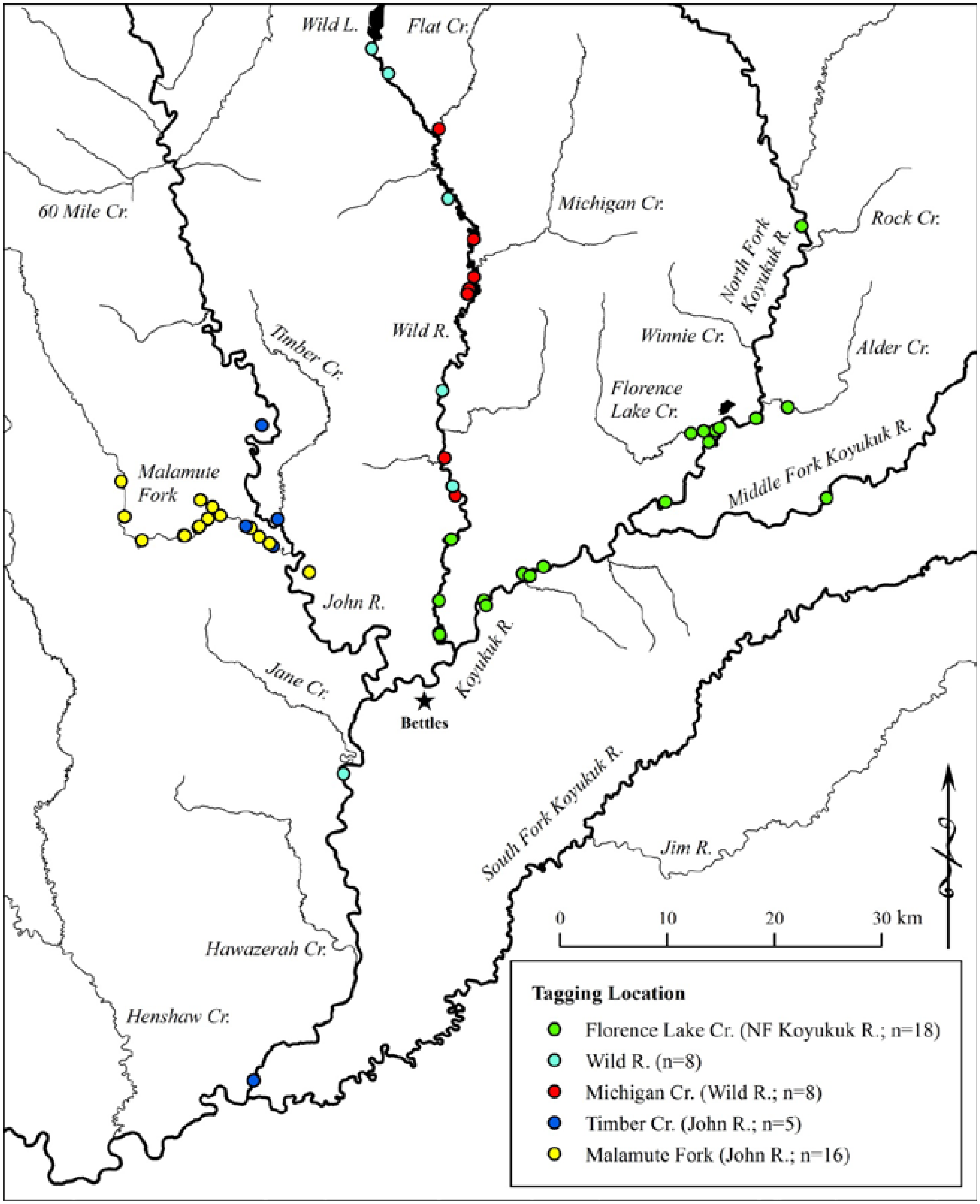
Appendix A4.–Locations of radiotagged Arctic grayling on 30 March 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



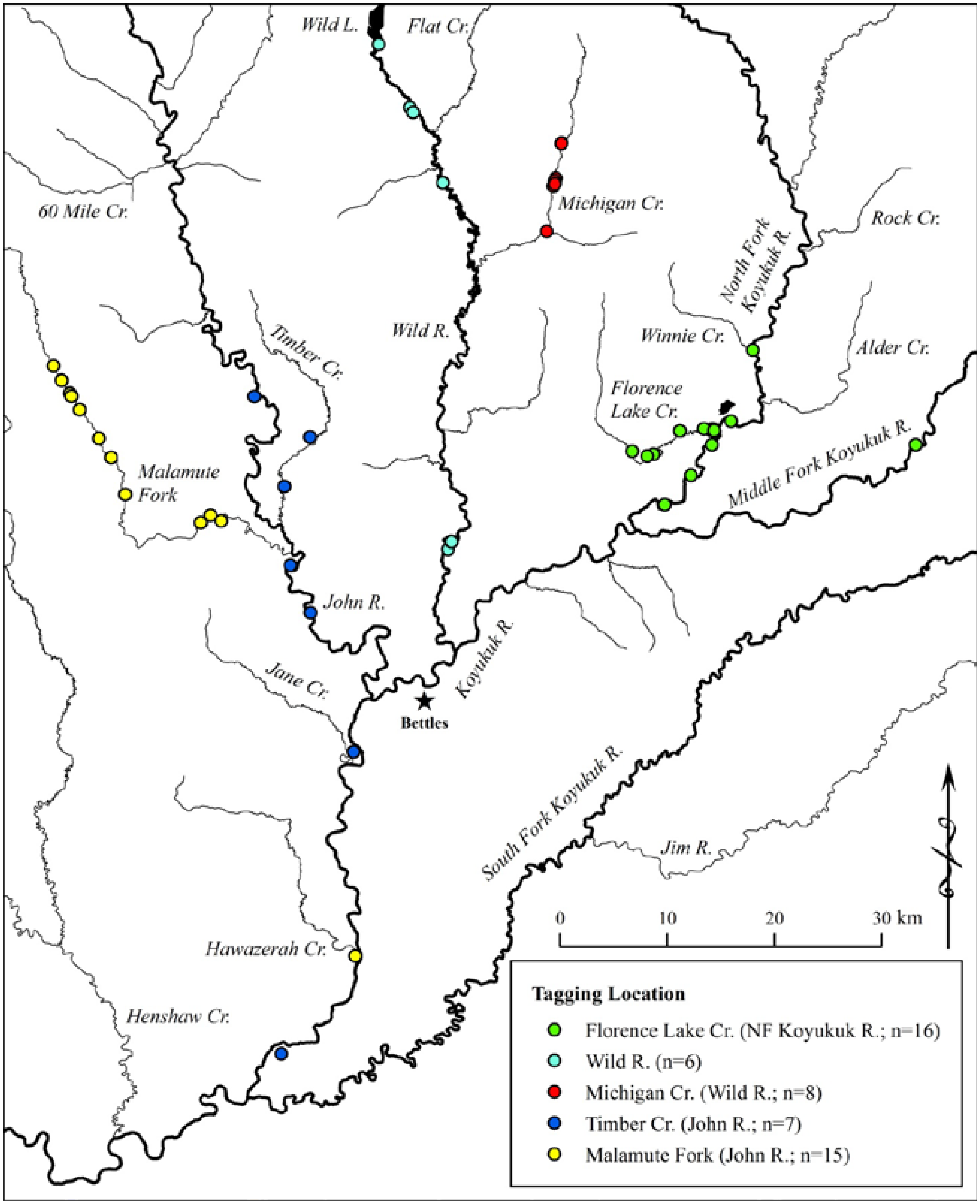
Appendix A5.–Locations of radiotagged Arctic grayling on 7 May 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



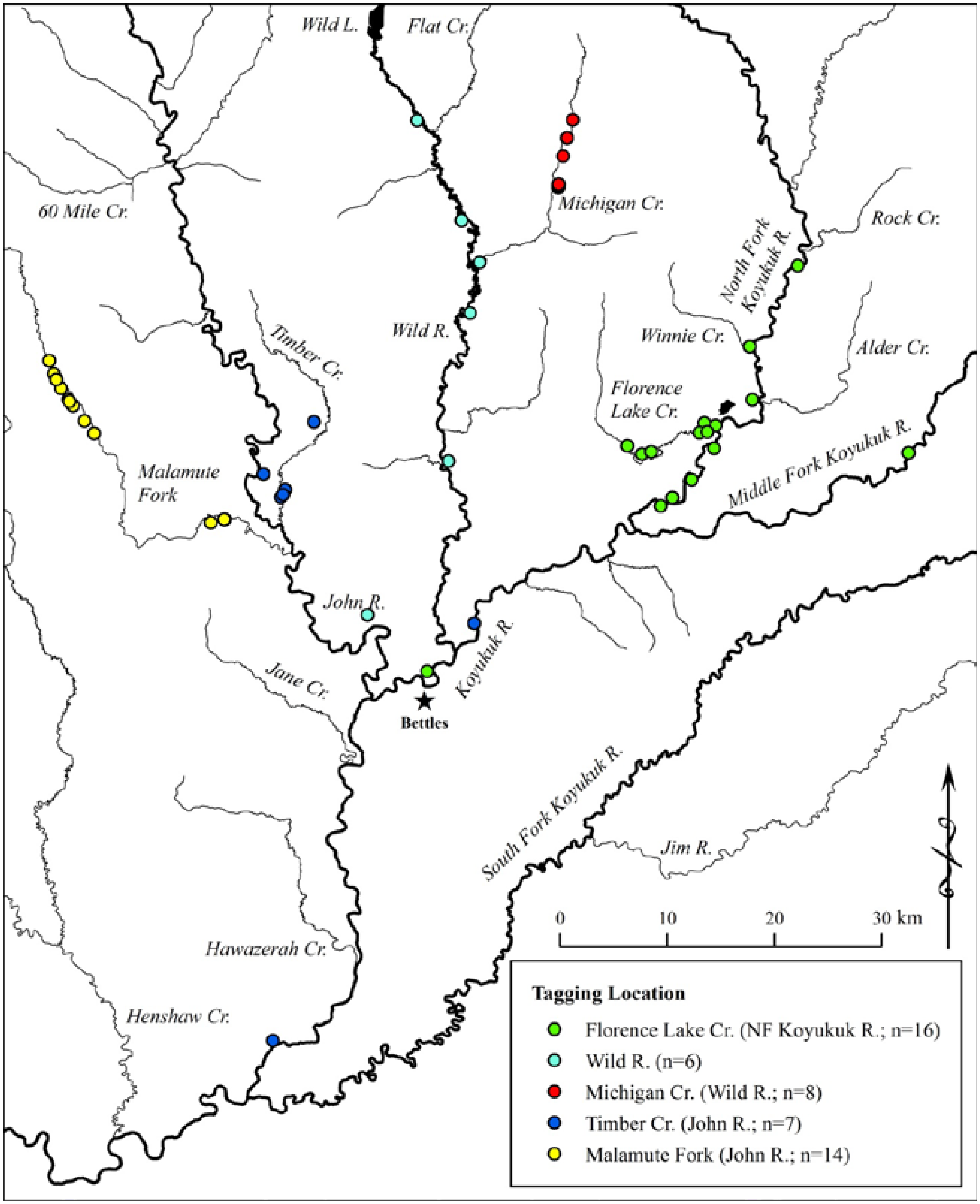
Appendix A6.–Locations of radiotagged Arctic grayling on 20 May 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix A7.–Locations of radiotagged Arctic grayling on 2 June 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

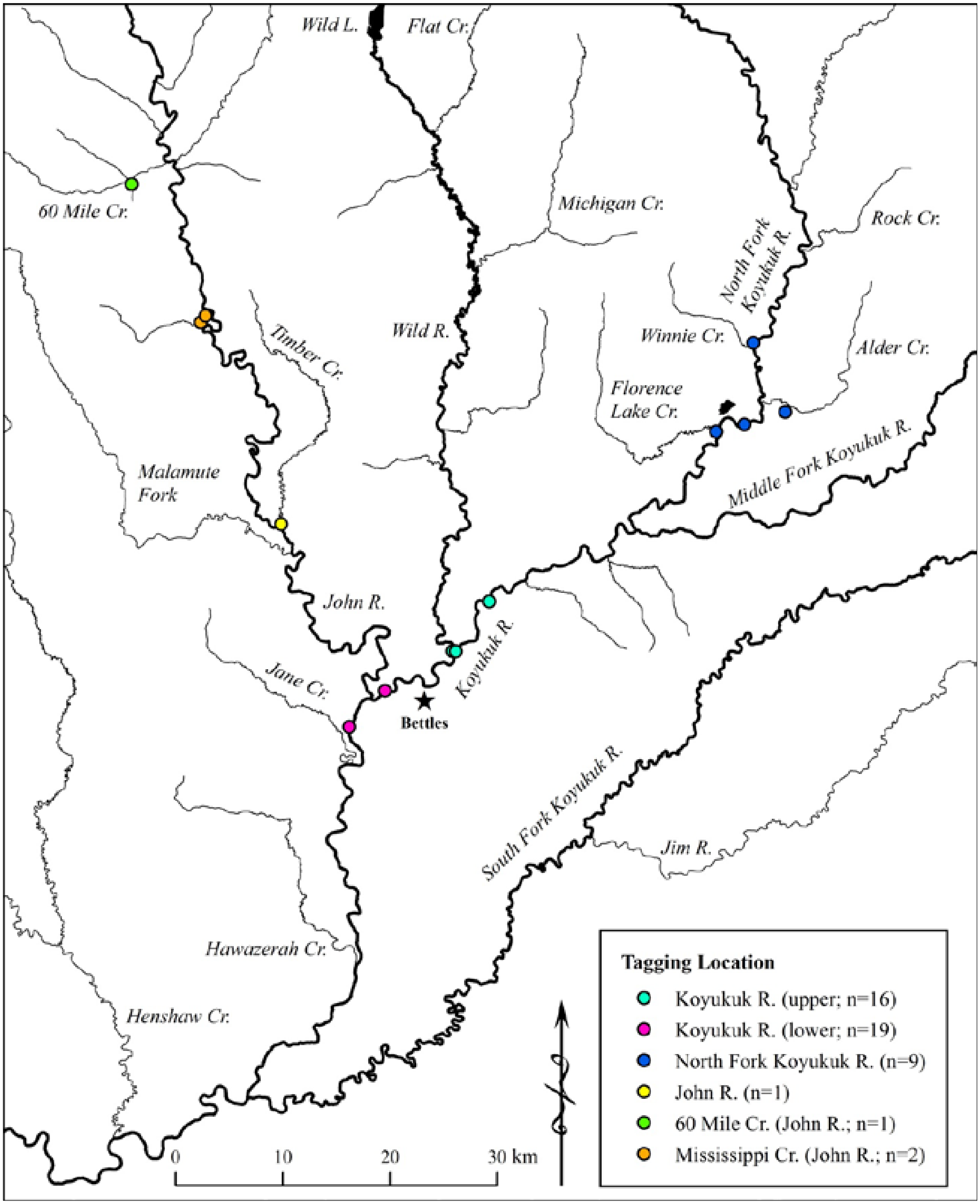


Appendix A8.–Locations of radiotagged Arctic grayling on 1 August 2015 sampled in tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

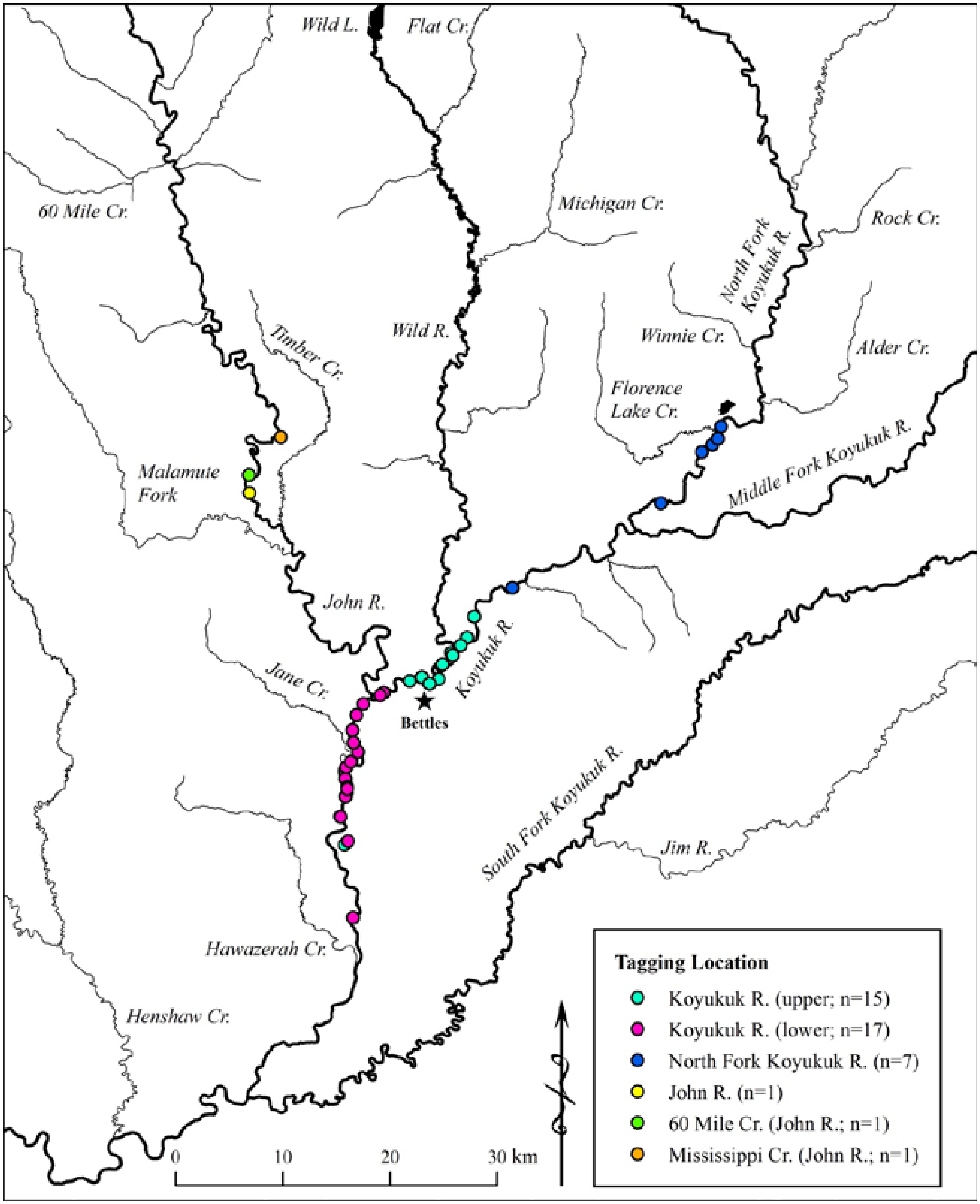


APPENDIX B:
LOCATIONS OF RADIOTAGGED ARCTIC GRAYLING SAMPLED IN THE MAINSTEM REACHES AND TRIBUTARIES WITHIN THE KOYUKUK STUDY AREA

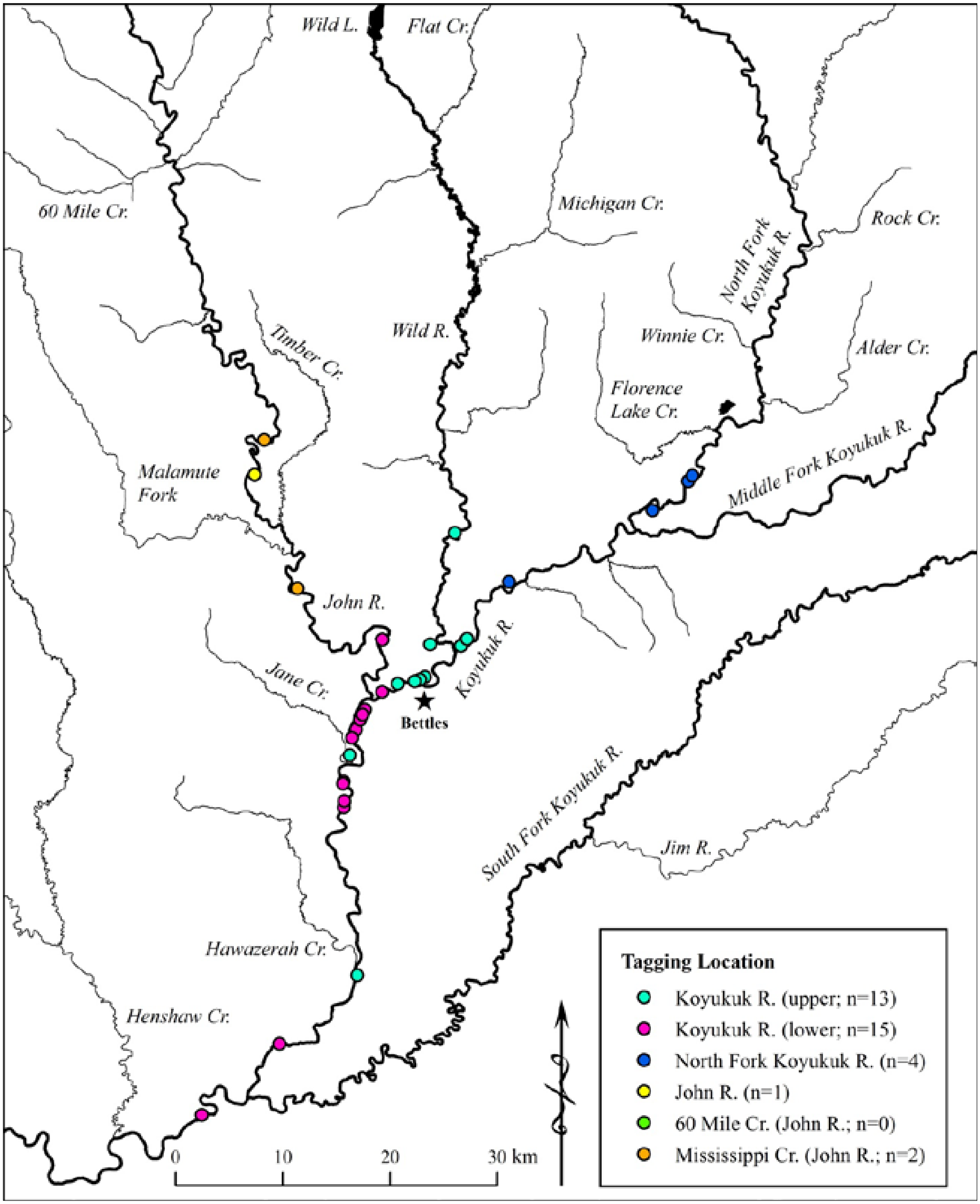
Appendix B1.–Tagging locations for Arctic grayling sampled in mainstem reaches and tributaries within the Koyukuk study area, 2014. Colors depict a general tagging area and the total number of surviving radiotagged fish are labeled parenthetically in legend.



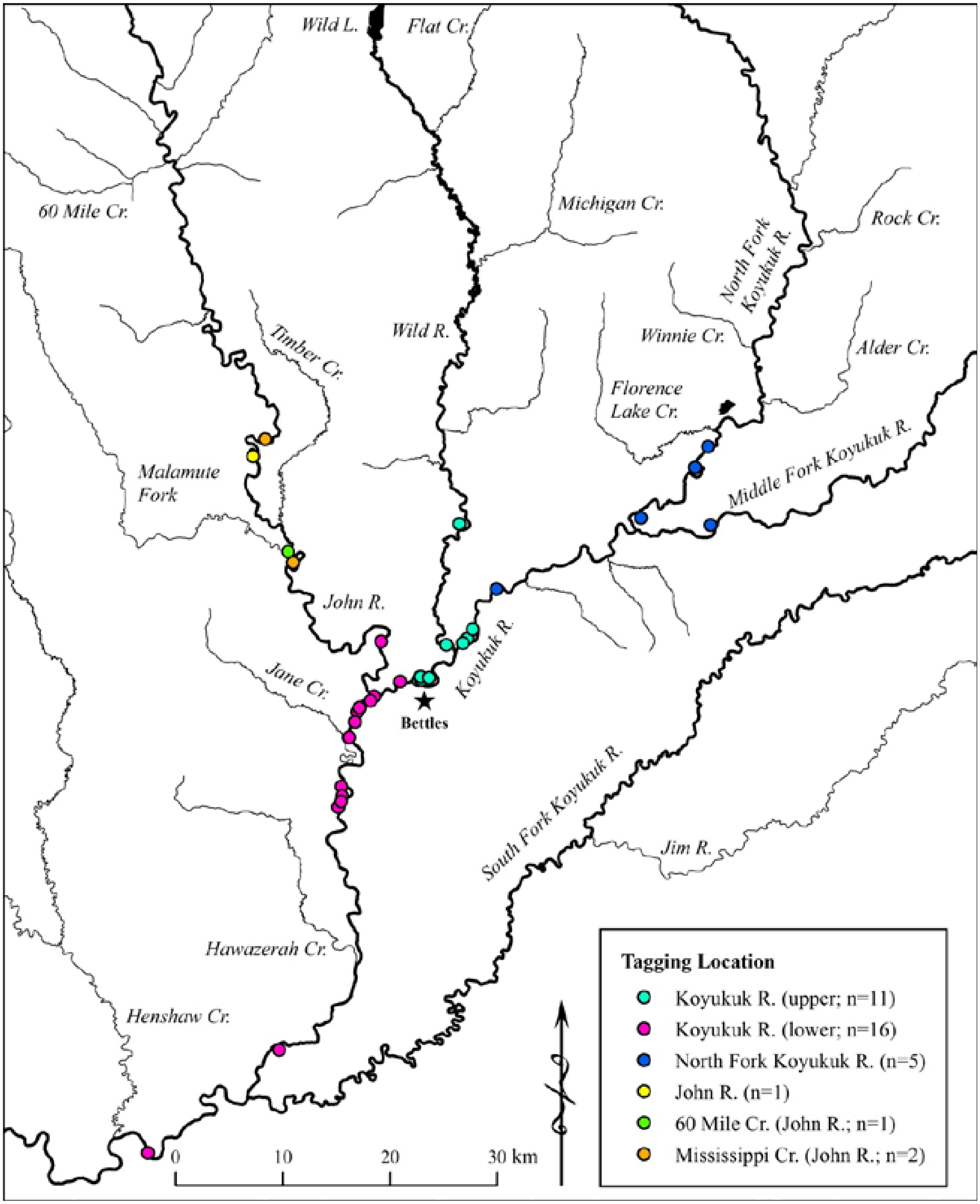
Appendix B2.–Locations of radiotagged Arctic grayling on 25 September 2014 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



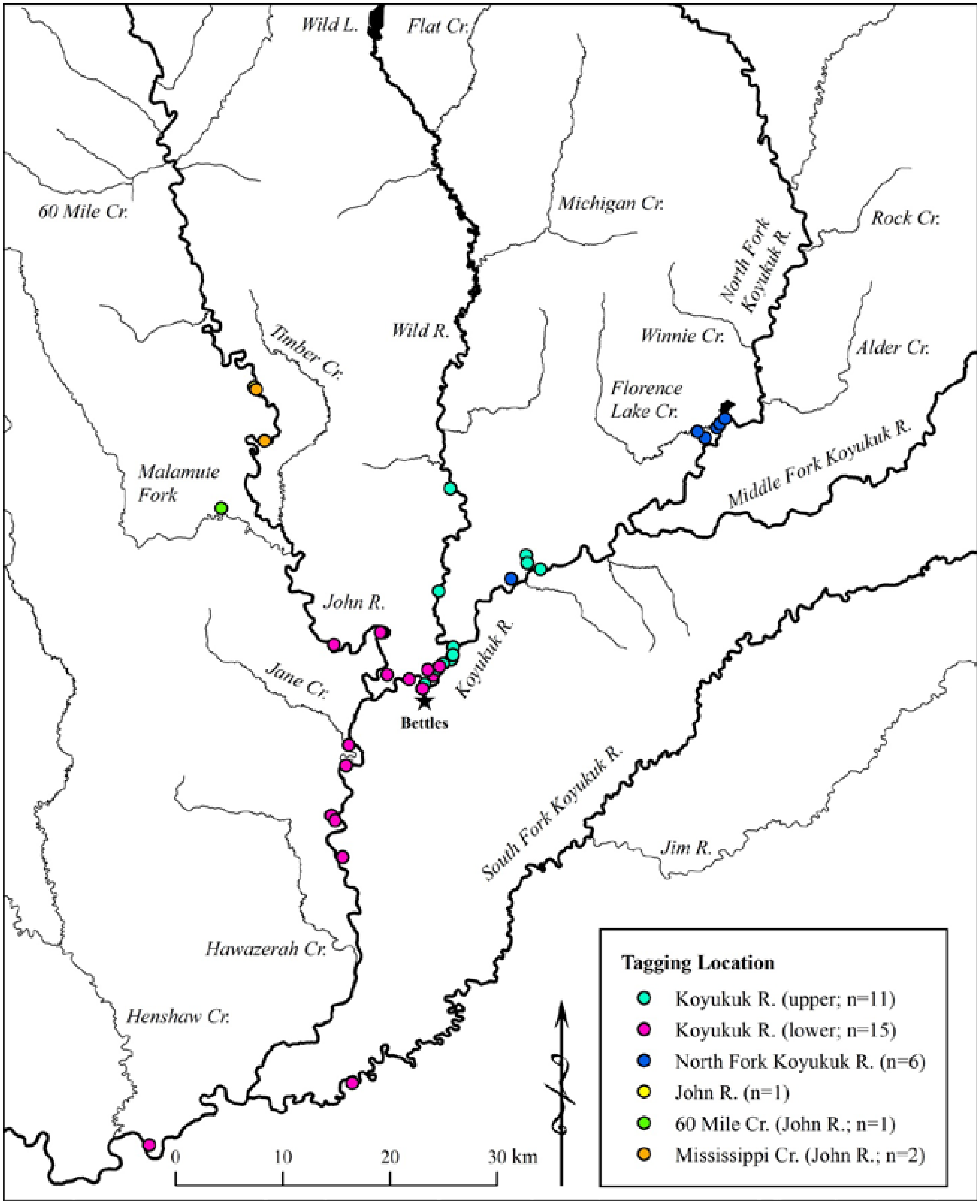
Appendix B3.–Locations of radiotagged Arctic grayling on 1 February 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



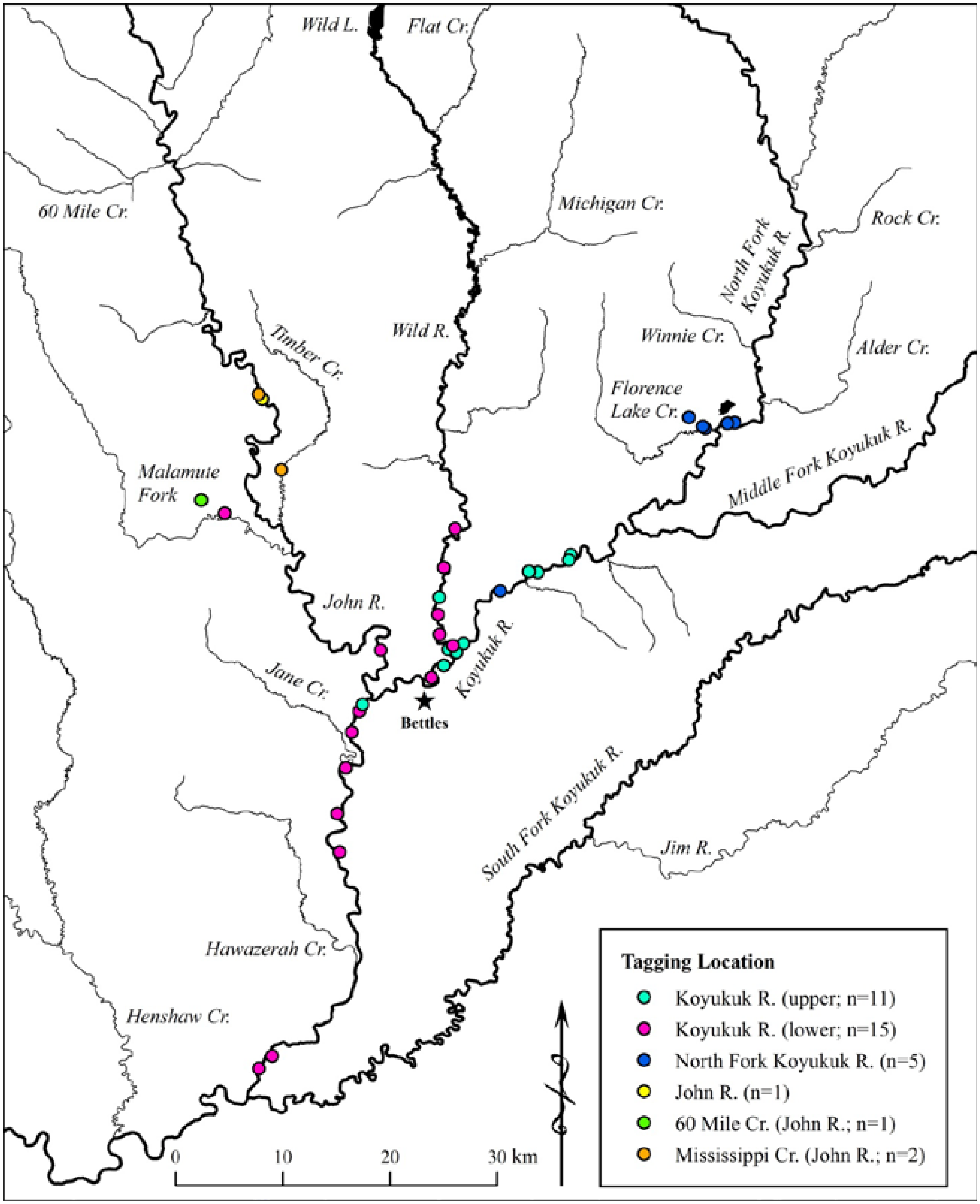
Appendix B4.–Locations of radiotagged Arctic grayling on 30 March 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



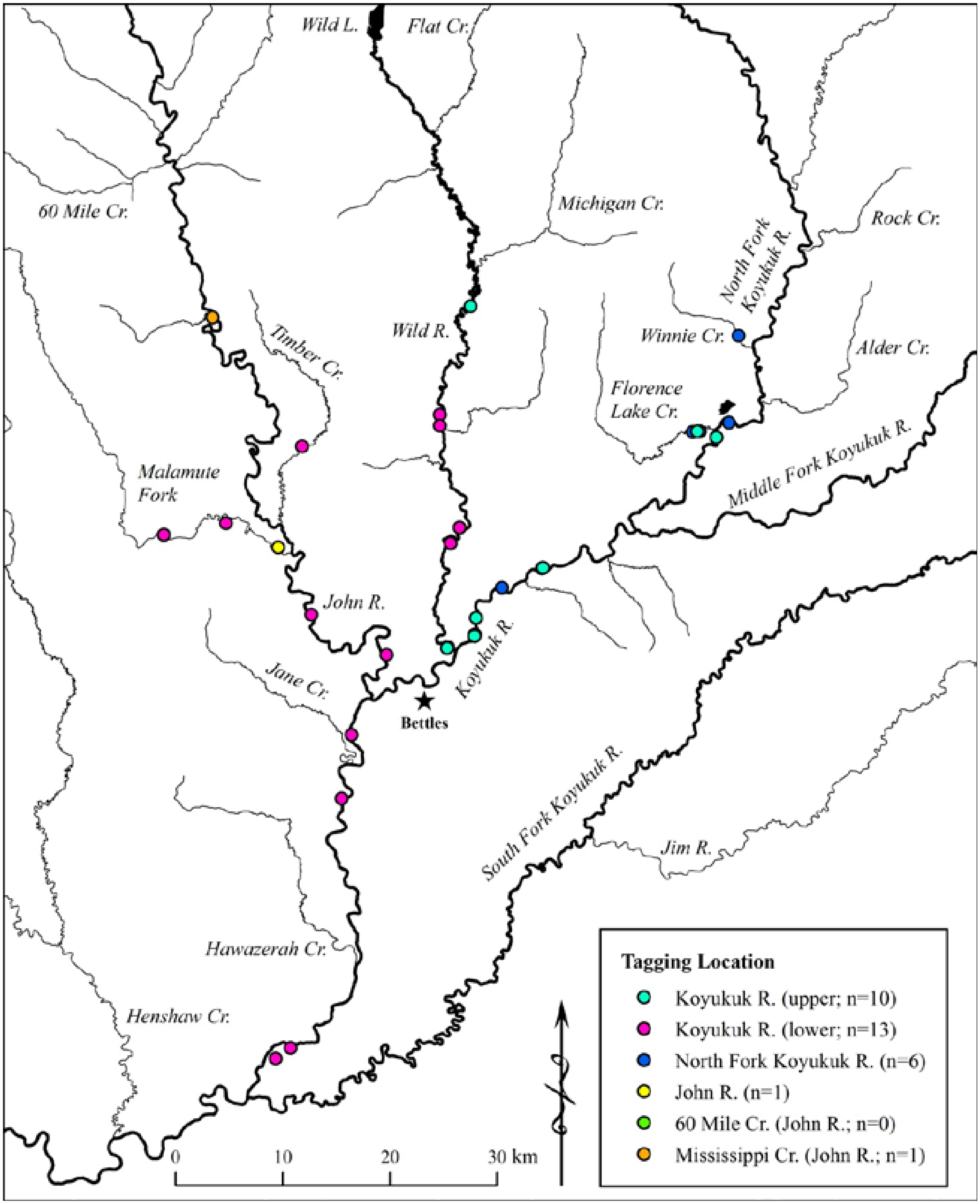
Appendix B5.–Locations of radiotagged Arctic grayling on 7 May 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



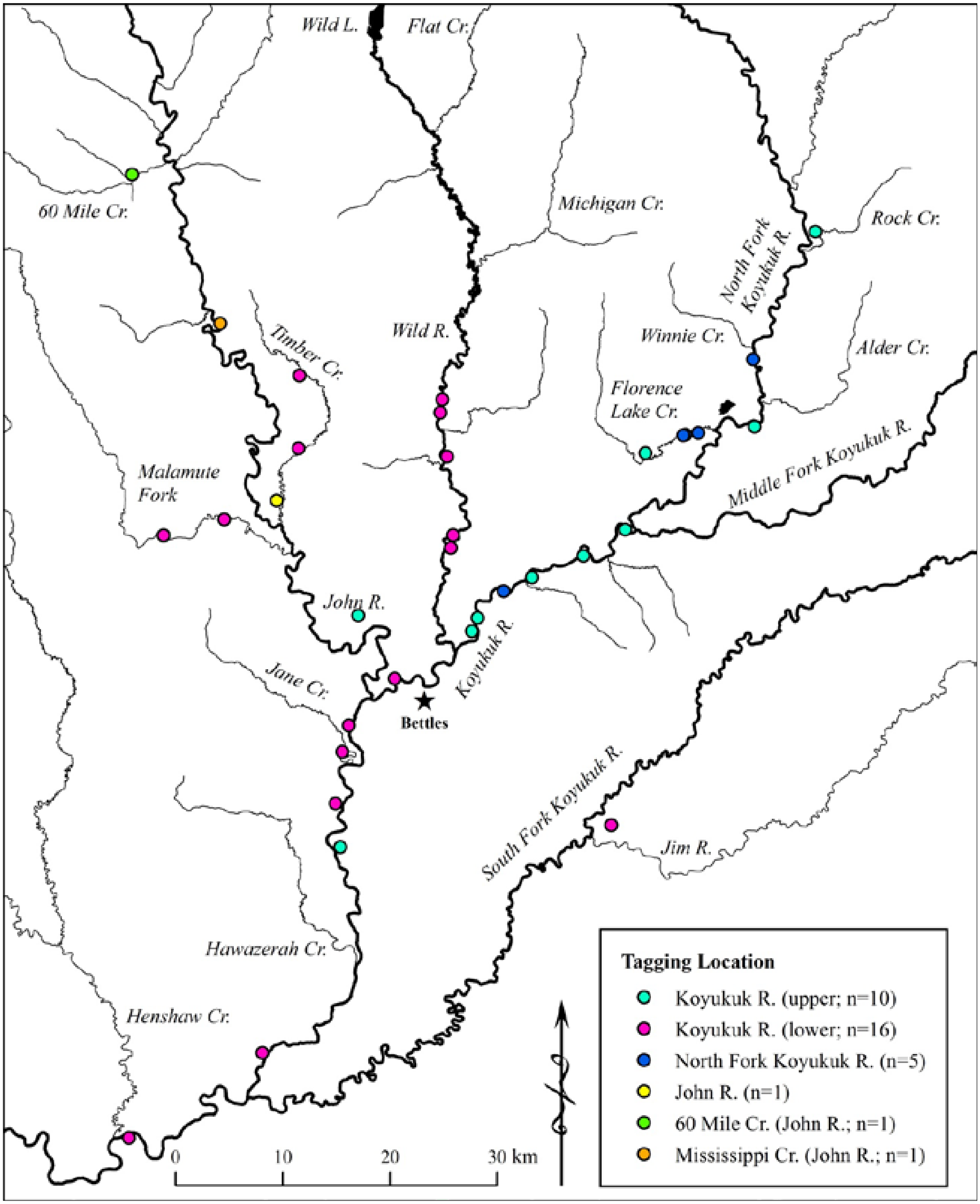
Appendix B6.–Locations of radiotagged Arctic grayling on 20 May 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix B7.–Locations of radiotagged Arctic grayling on 2 June 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

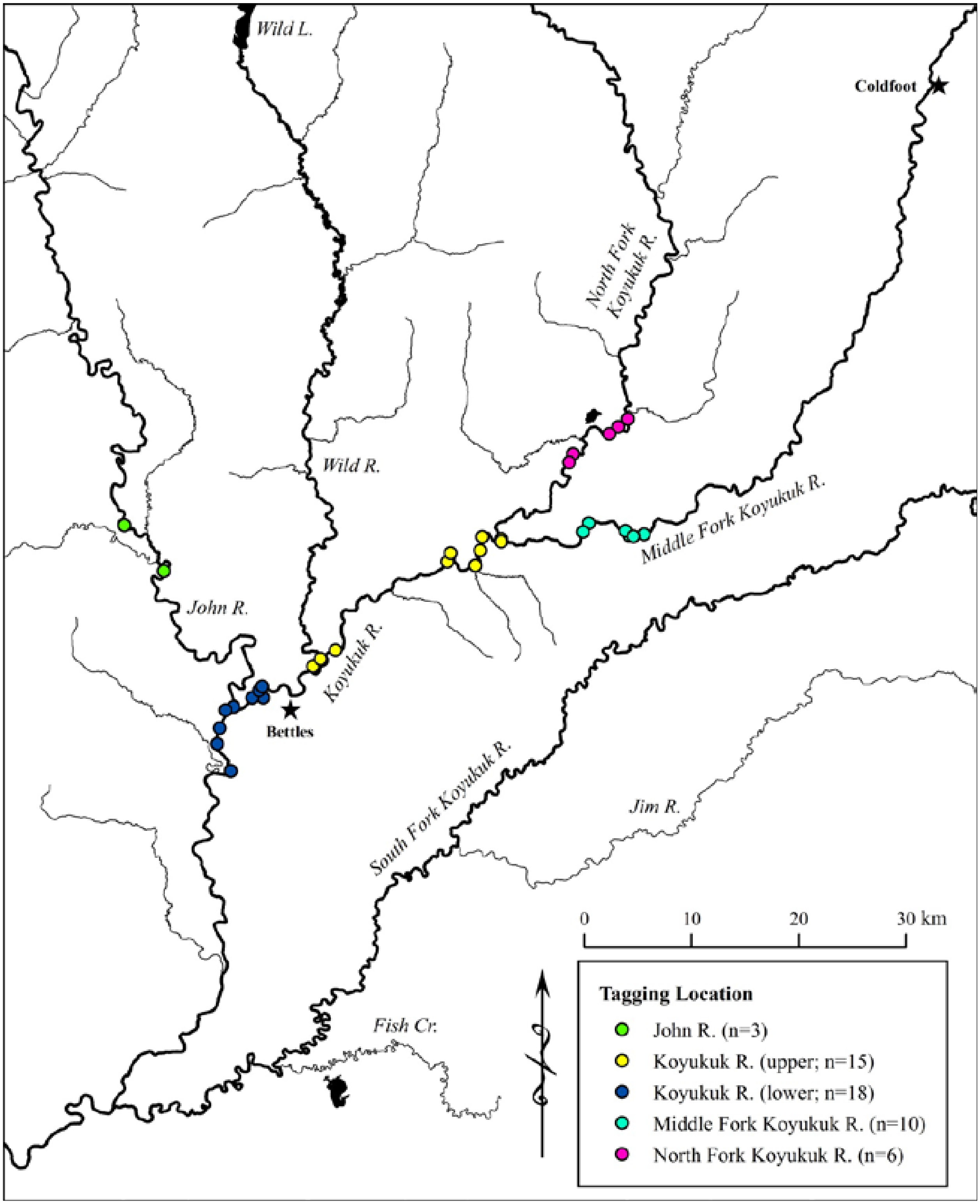


Appendix B8.–Locations of radiotagged Arctic grayling on 1 August 2015 sampled in mainstem reaches and tributaries within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

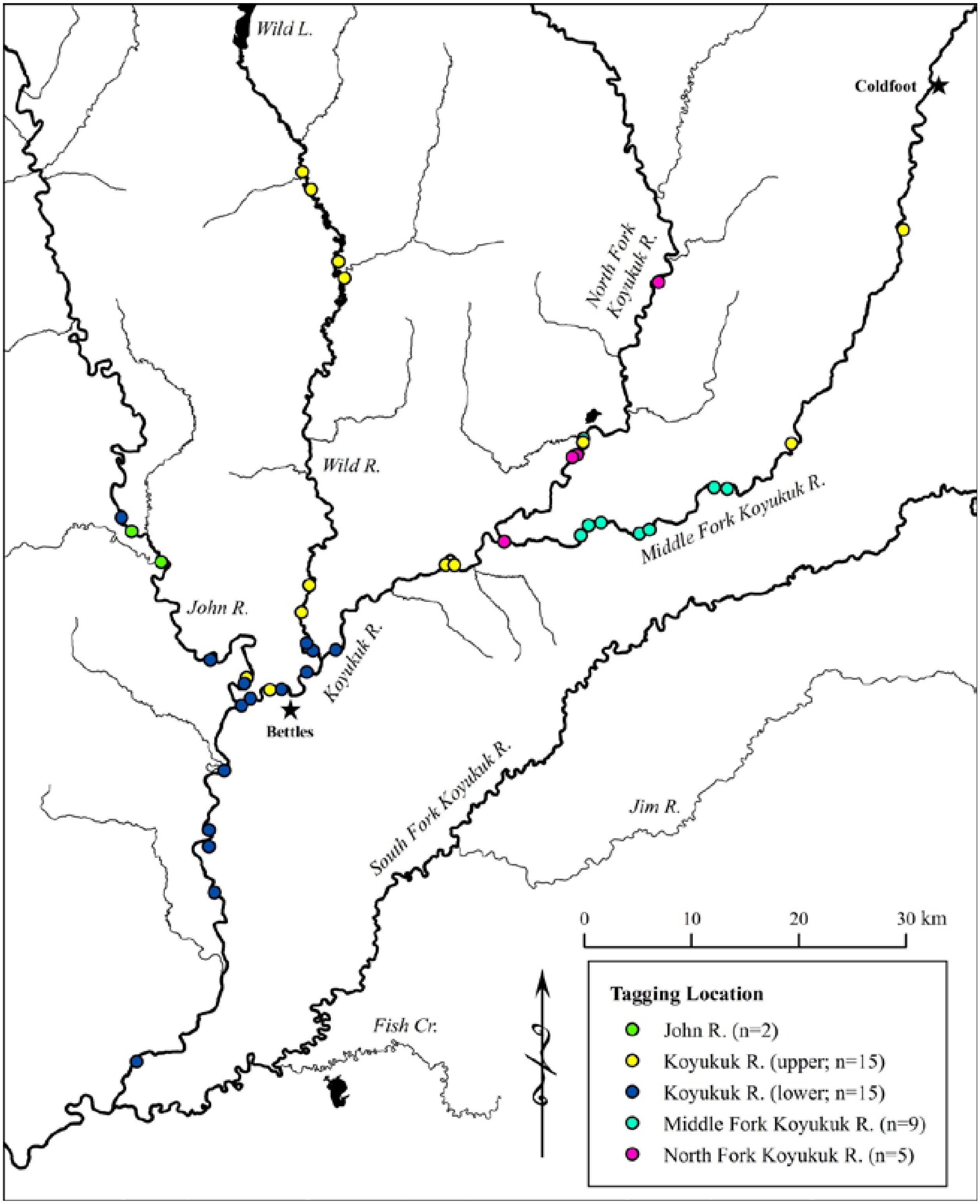


APPENDIX C:
LOCATIONS OF RADIOTAGGED BURBOT SAMPLED IN THE MAINSTEM REACHES WITHIN THE KOYUKUK STUDY AREA

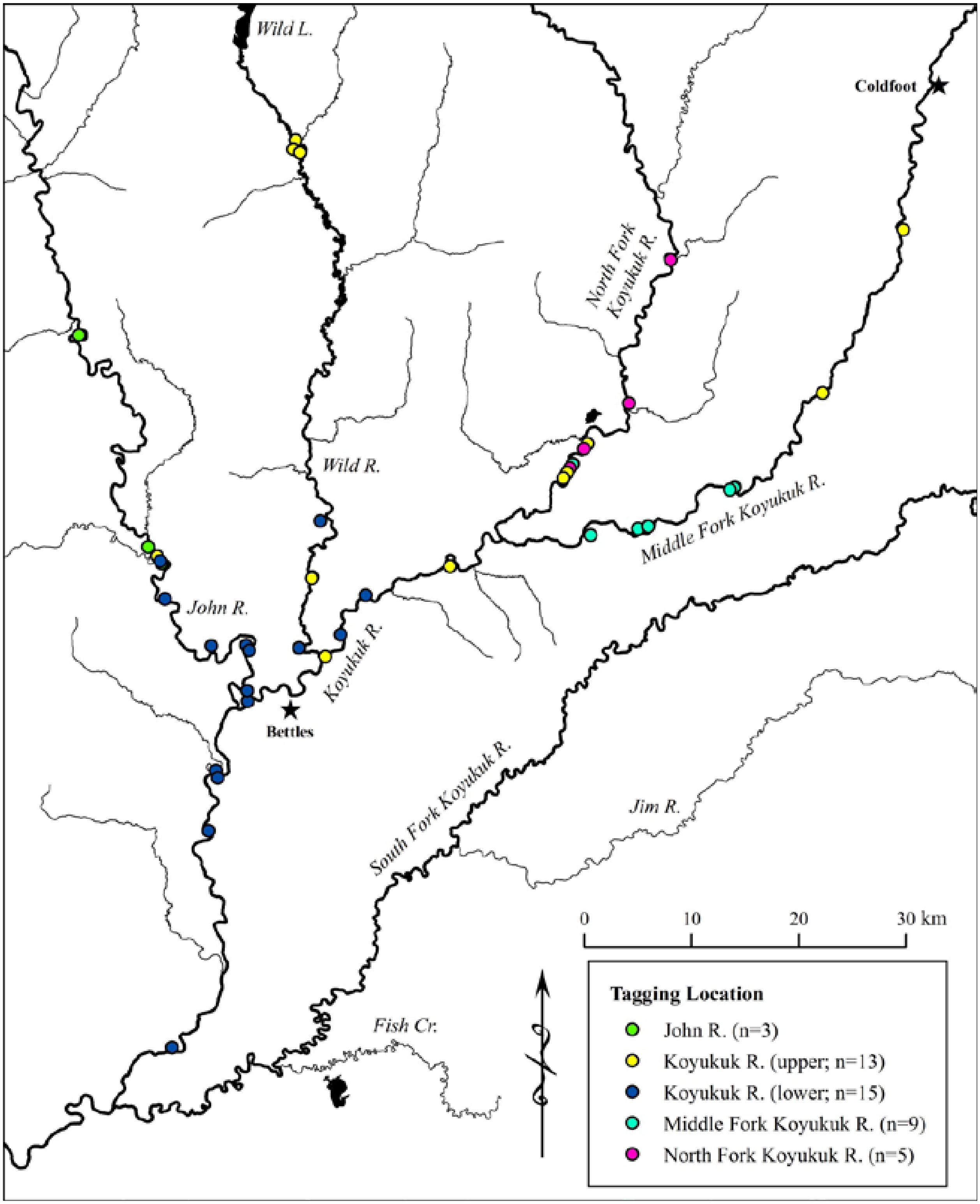
Appendix C1.–Tagging locations for burbot sampled in mainstem reaches within the Koyukuk study area, 2014. Colors depict a general tagging area and the total number of surviving radiotagged fish are labeled parenthetically in legend.



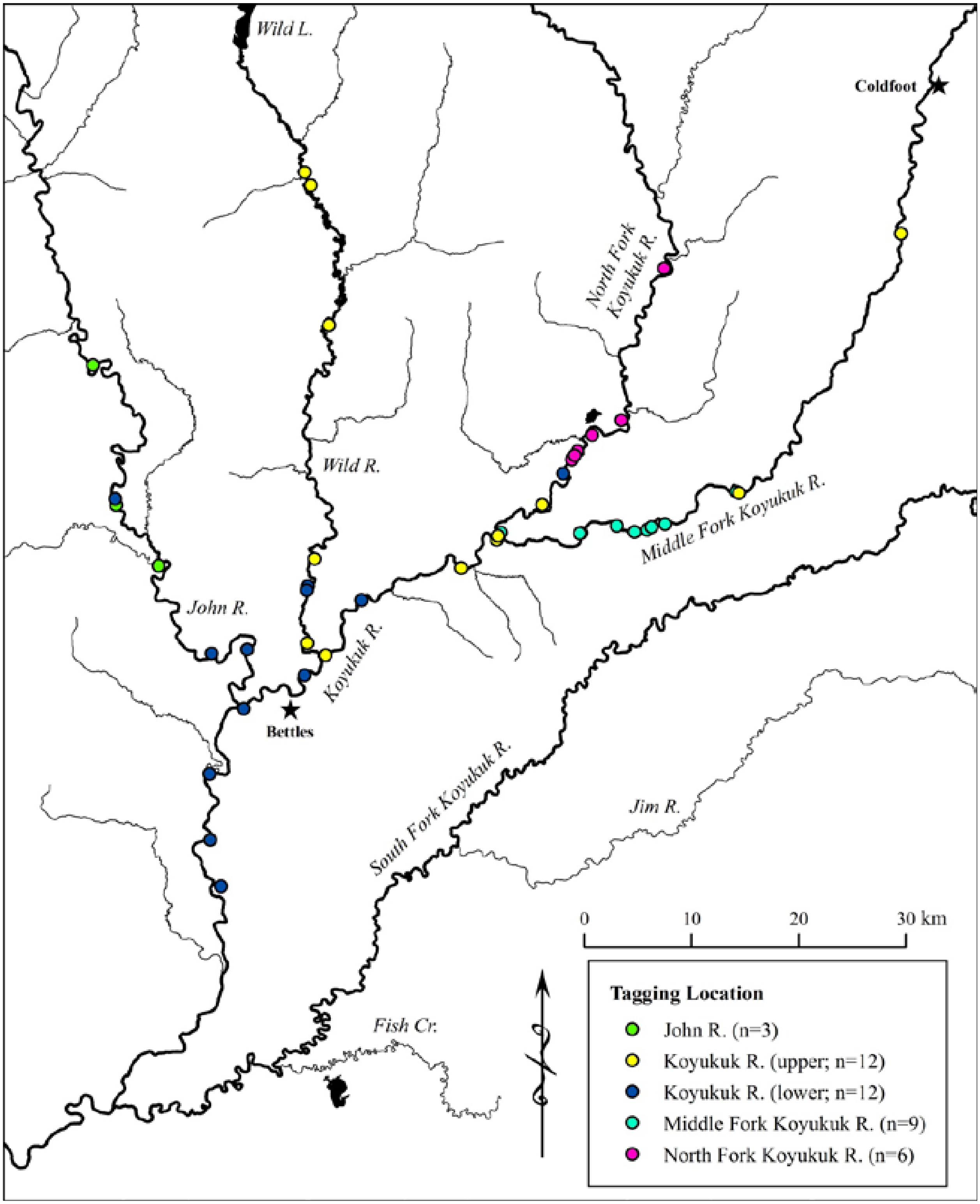
Appendix C2.–Locations of radiotagged burbot on 13 December 2014 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



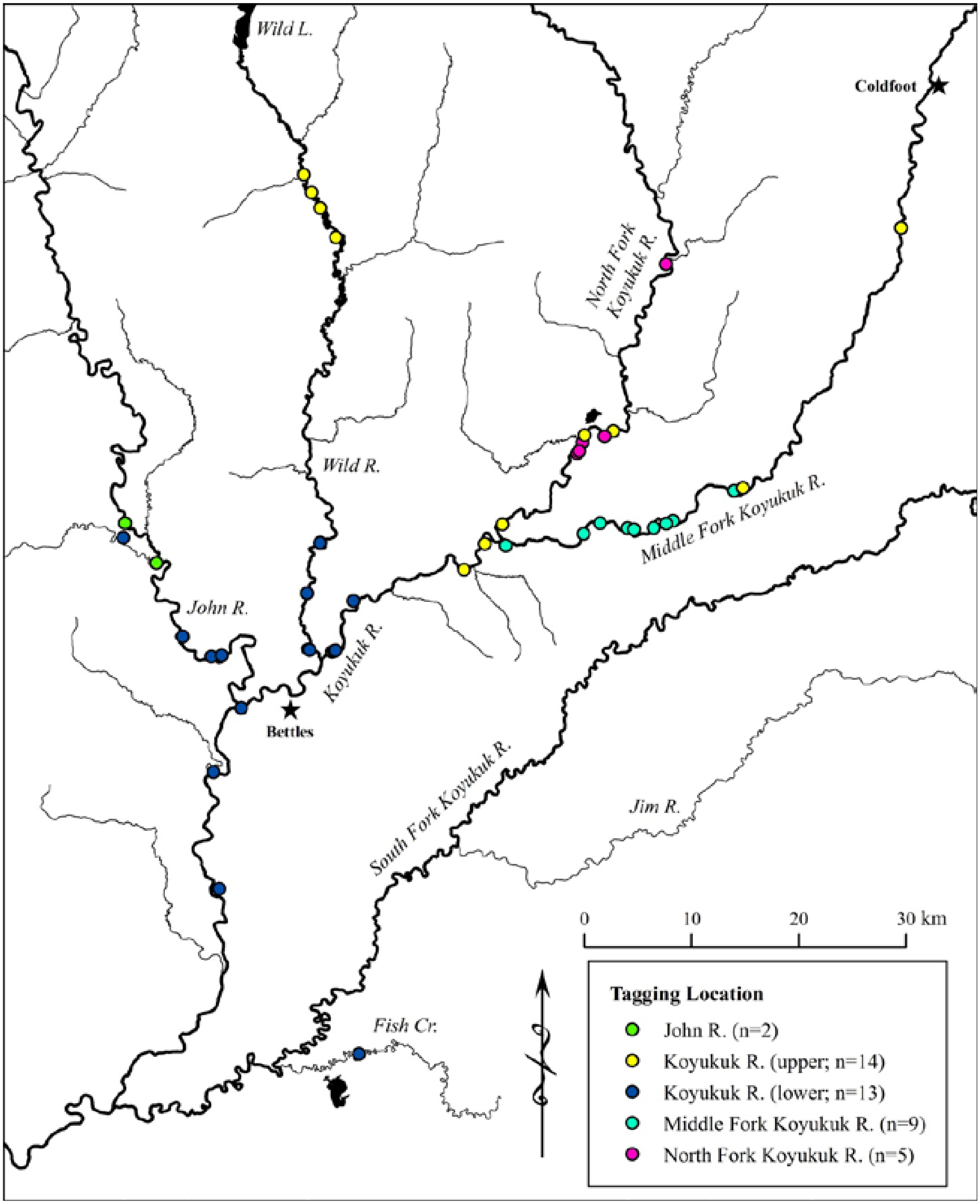
Appendix C3.–Locations of radiotagged burbot on 1 and 3 February 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



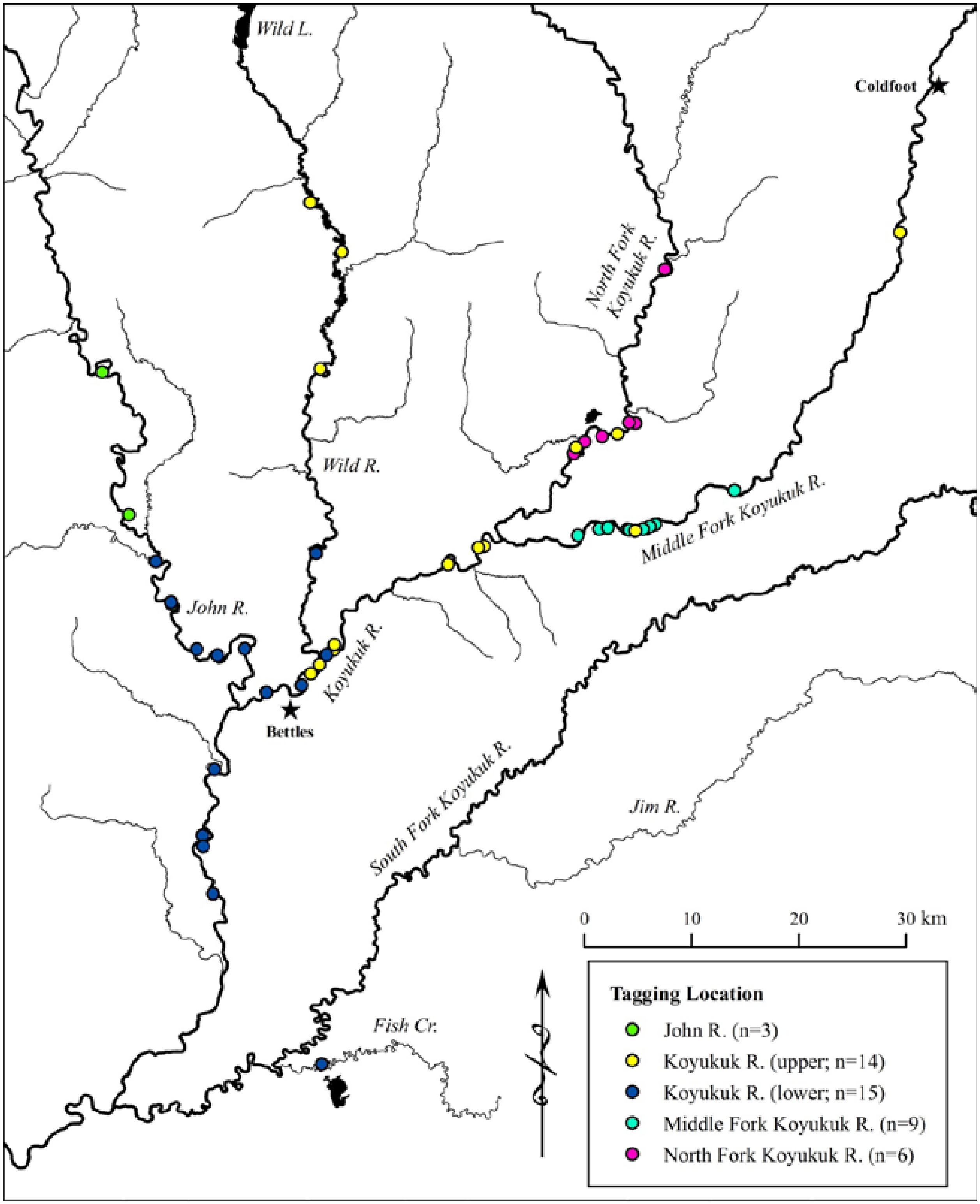
Appendix C4.–Locations of radiotagged burbot on 30 March 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



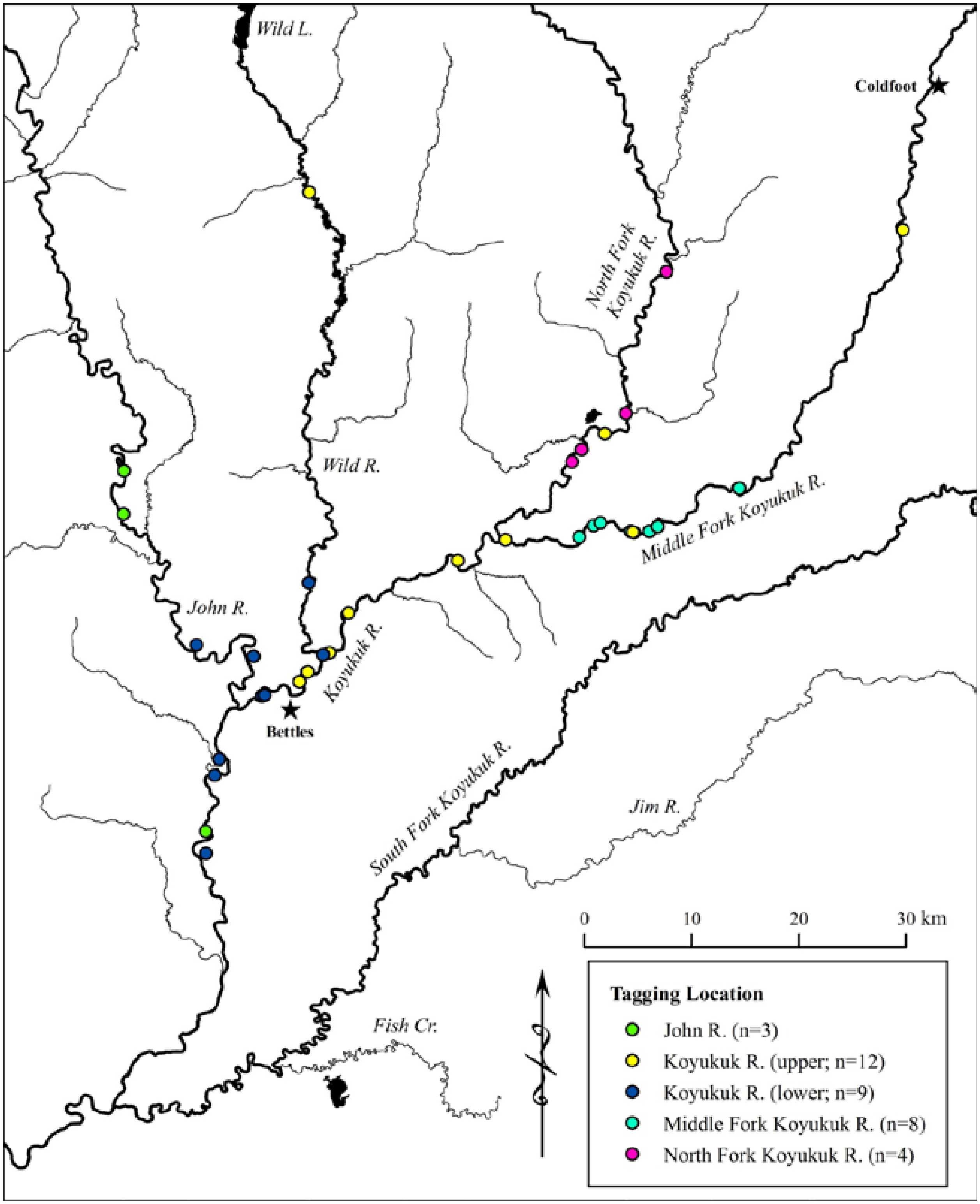
Appendix C5.–Locations of radiotagged burbot on 7 May 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



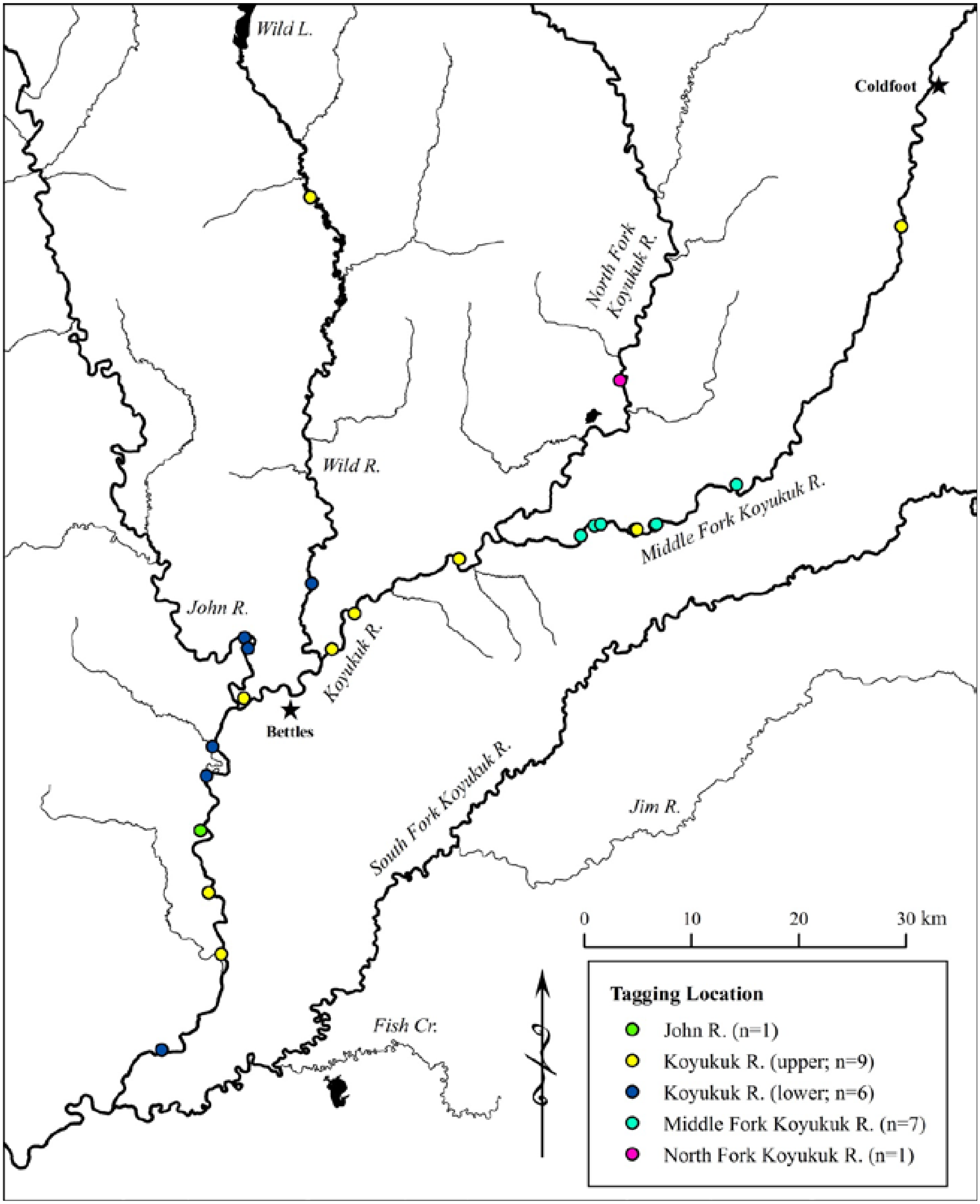
Appendix C6.–Locations of radiotagged burbot on 20 May 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix C7.–Locations of radiotagged burbot on 2 June 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

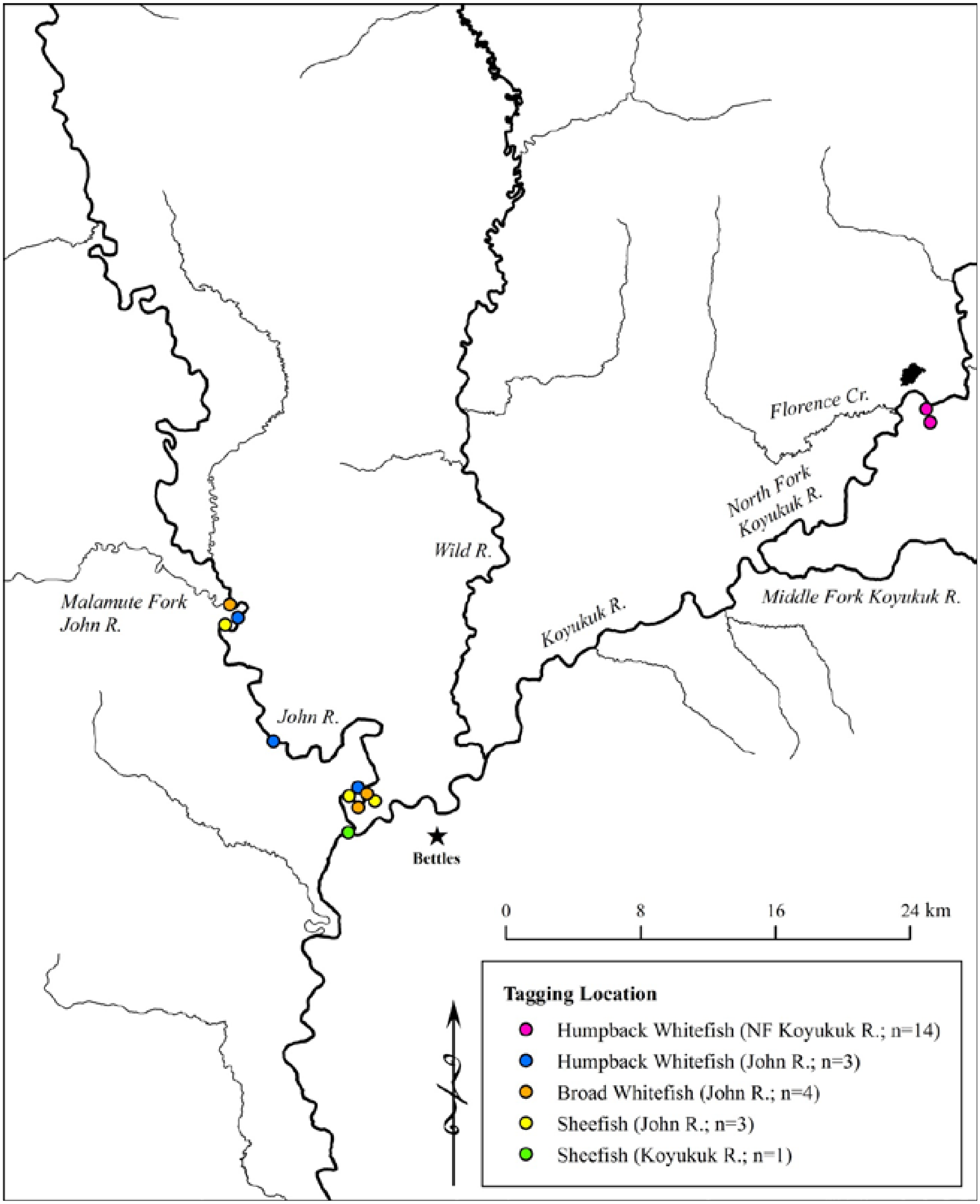


Appendix C8.–Locations of radiotagged burbot on 1 August 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

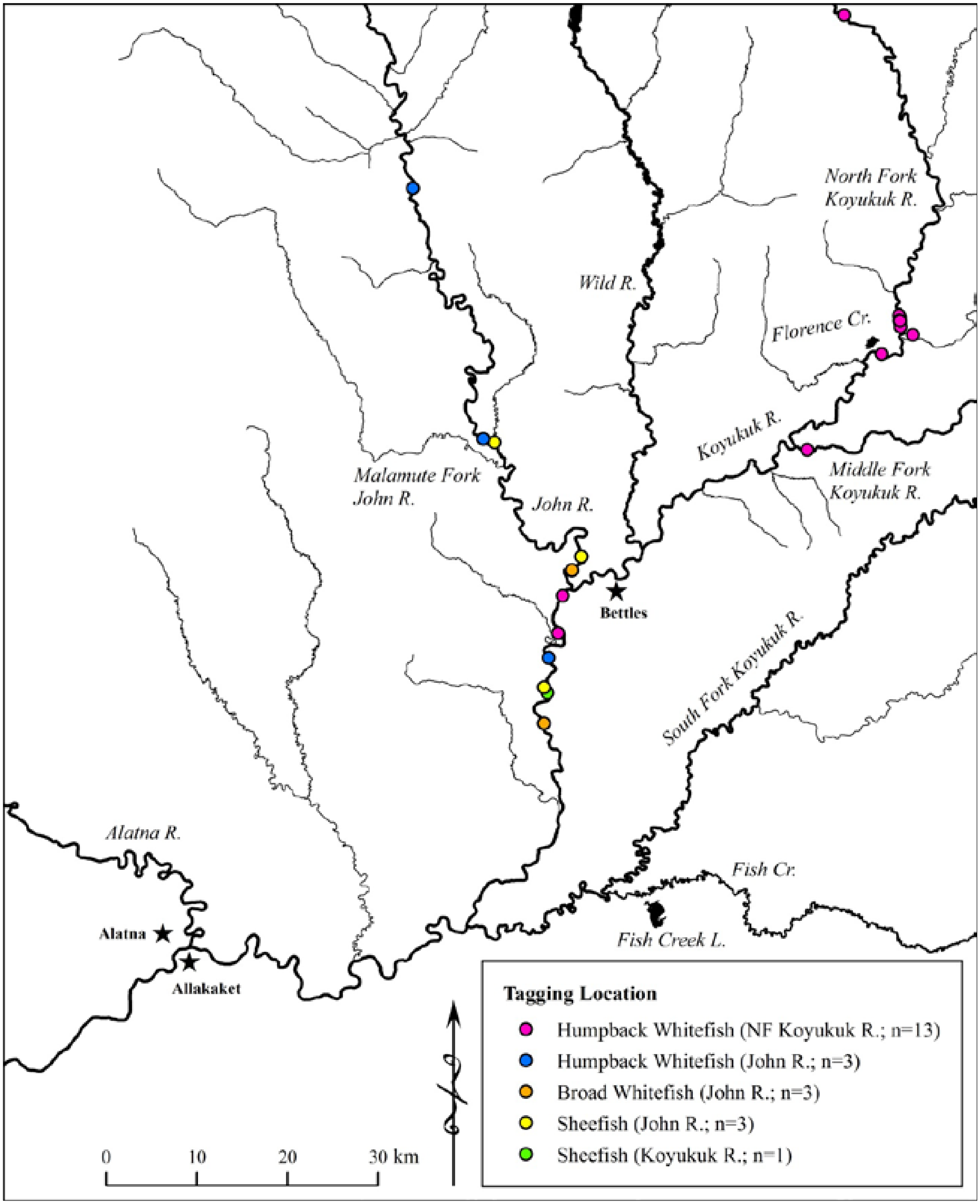


APPENDIX D:
LOCATIONS OF RADIOTAGGED WHITEFISH SAMPLED IN THE MAINSTEM REACHES WITHIN THE KOYUKUK STUDY AREA

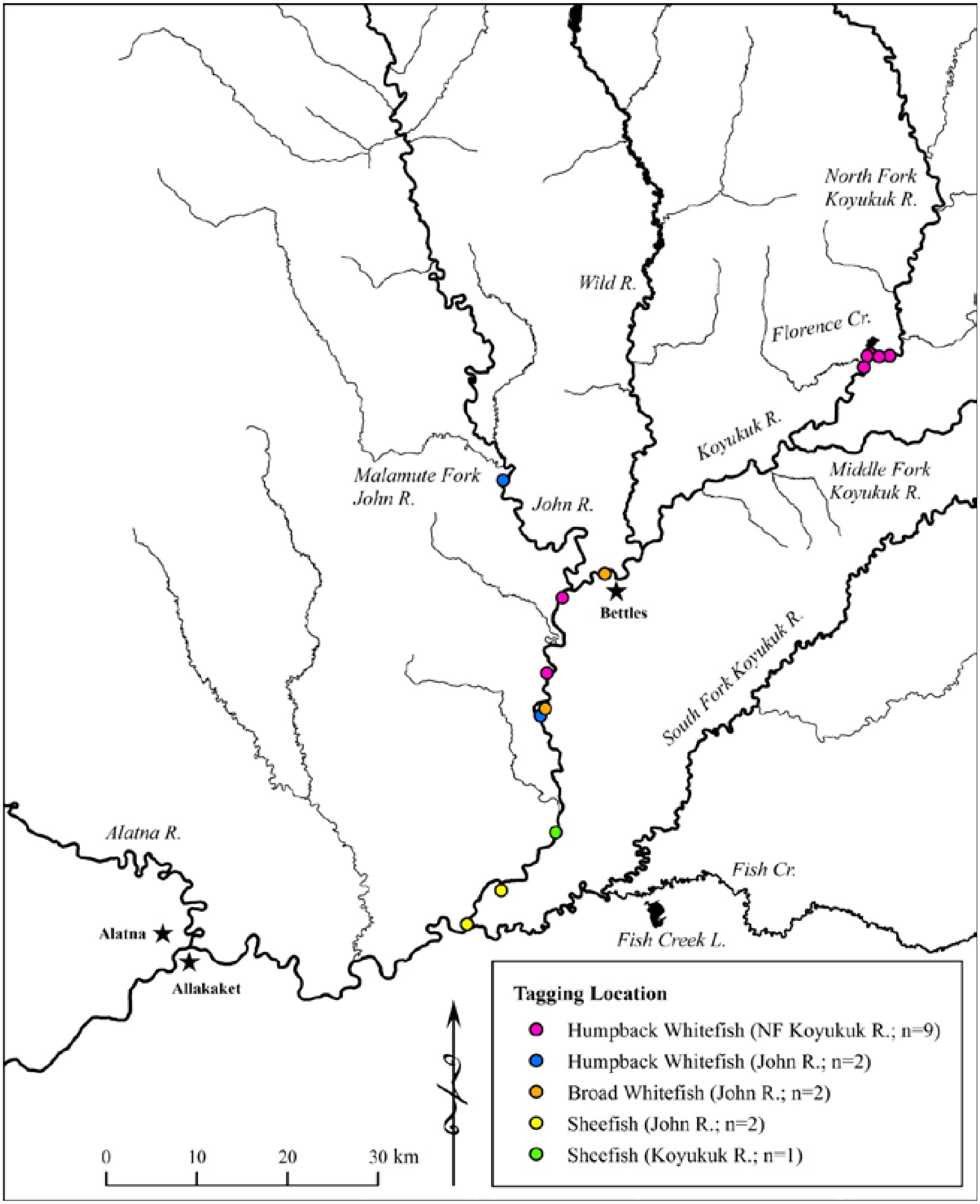
Appendix D1.–Tagging locations of whitefishes sampled in mainstem reaches within the Koyukuk study area, 2014. Colors depict a general tagging area and the total number of surviving radiotagged fish are labeled parenthetically in legend.



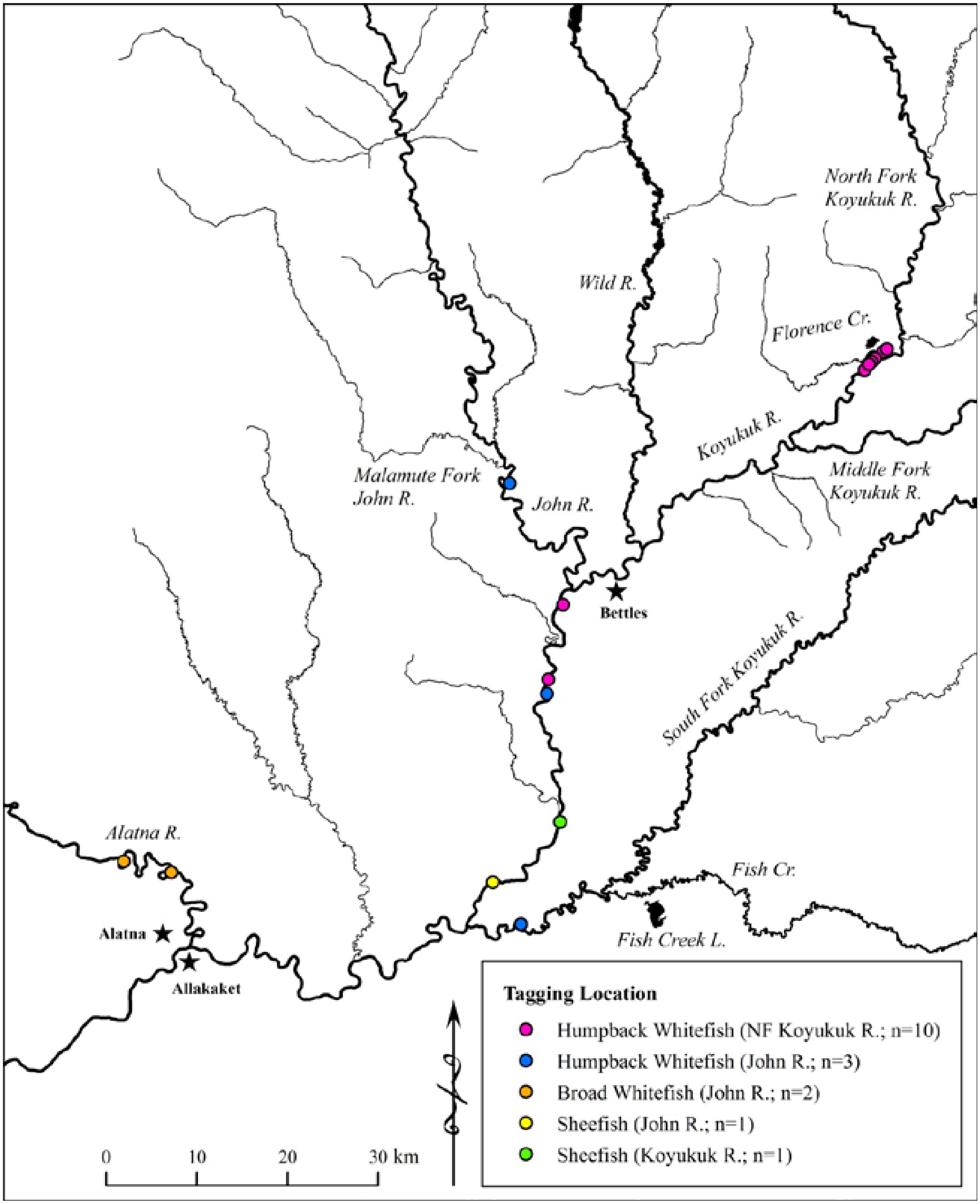
Appendix D2.–Locations of radiotagged whitefishes on 1 October 2014 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



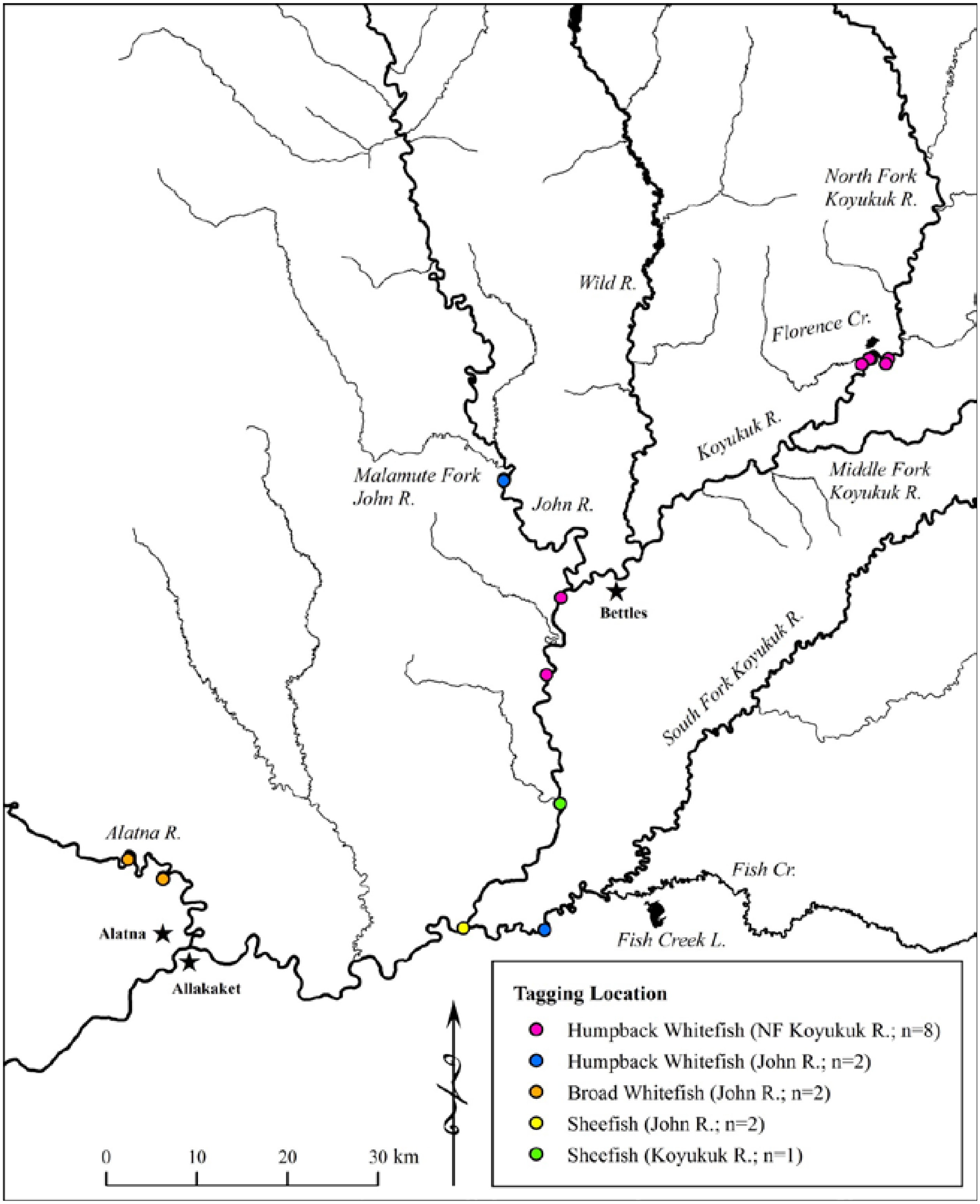
Appendix D3.–Locations of radiotagged whitefishes on 13 December 2014 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



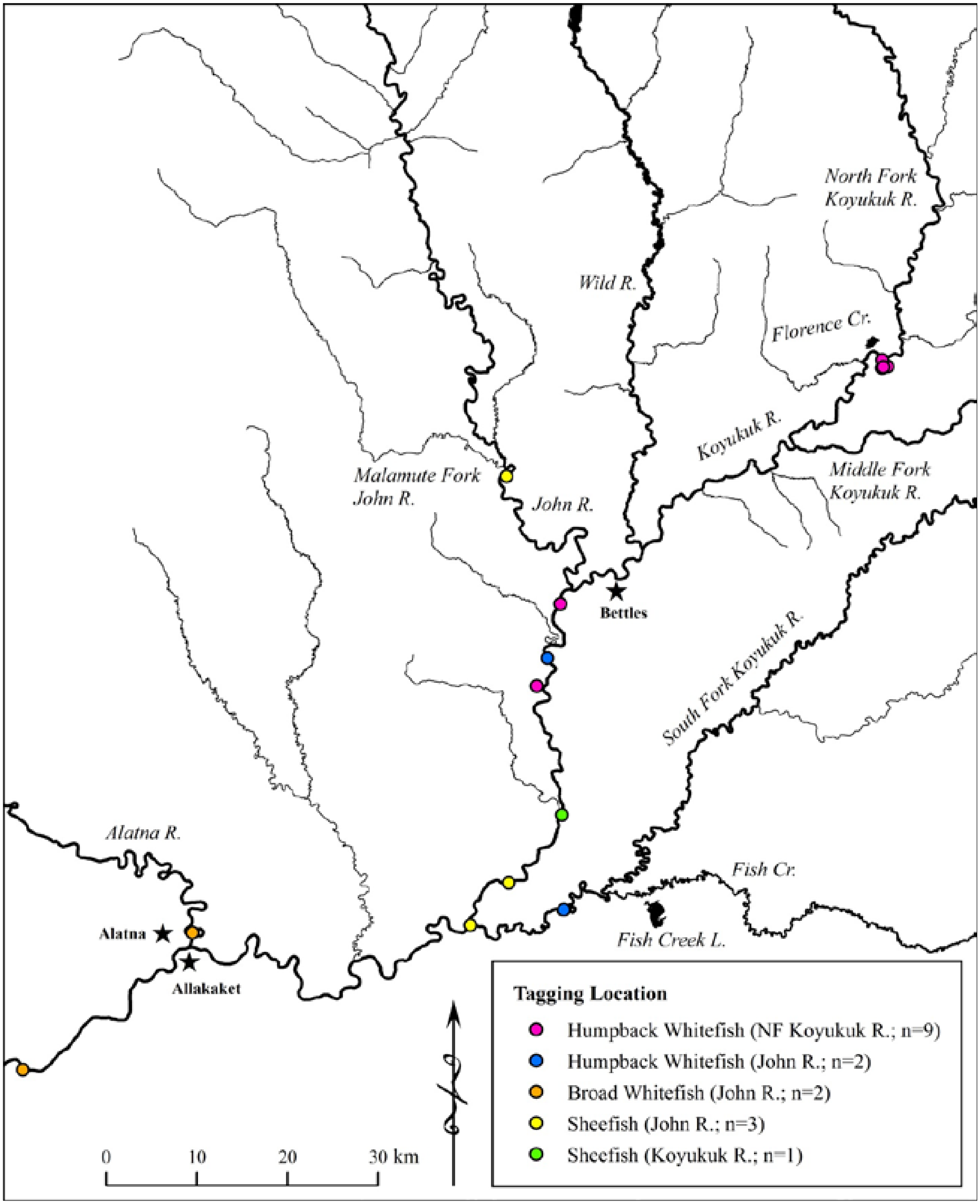
Appendix D4.–Locations of radiotagged whitefishes on 1 February 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



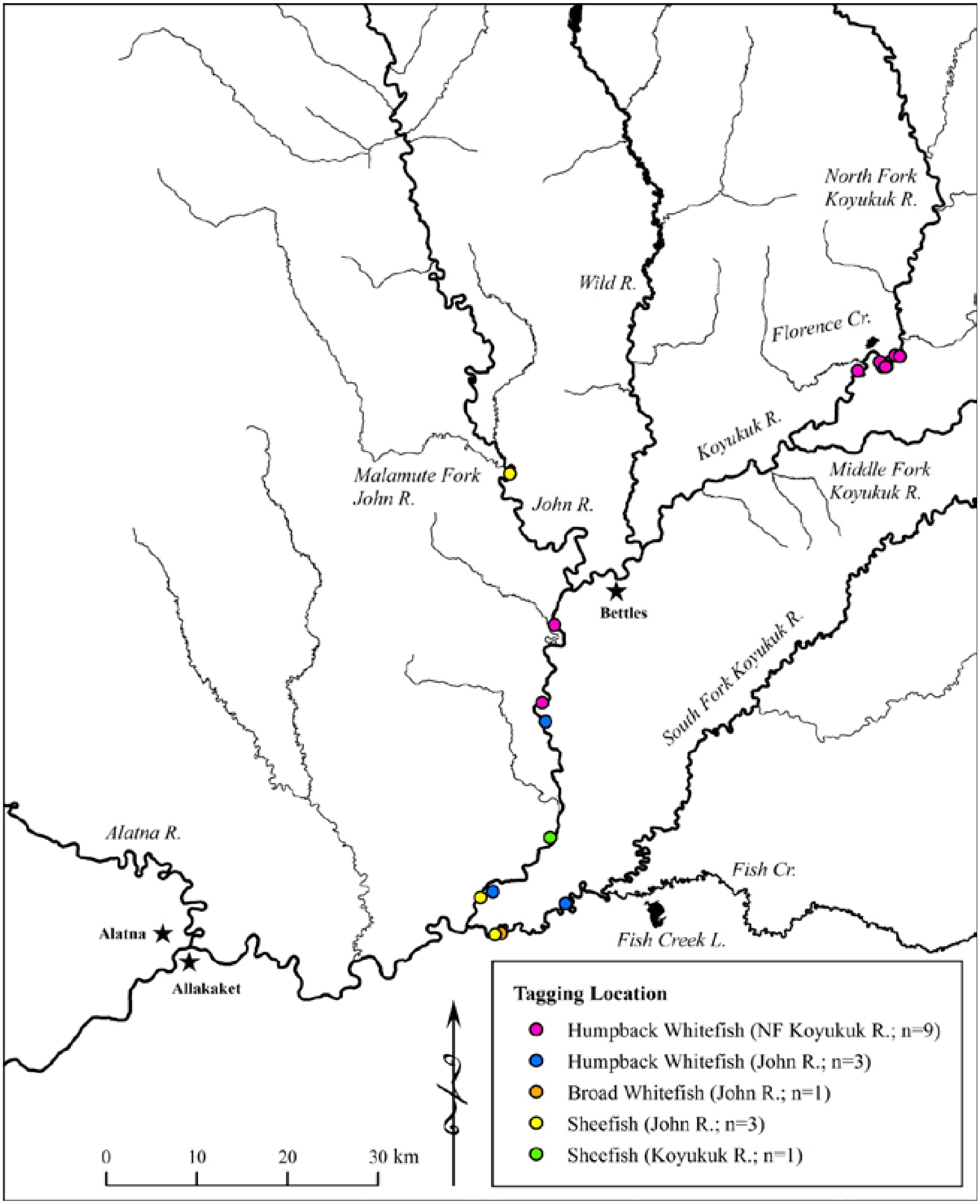
Appendix D5.–Locations of radiotagged whitefishes on 30 March 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



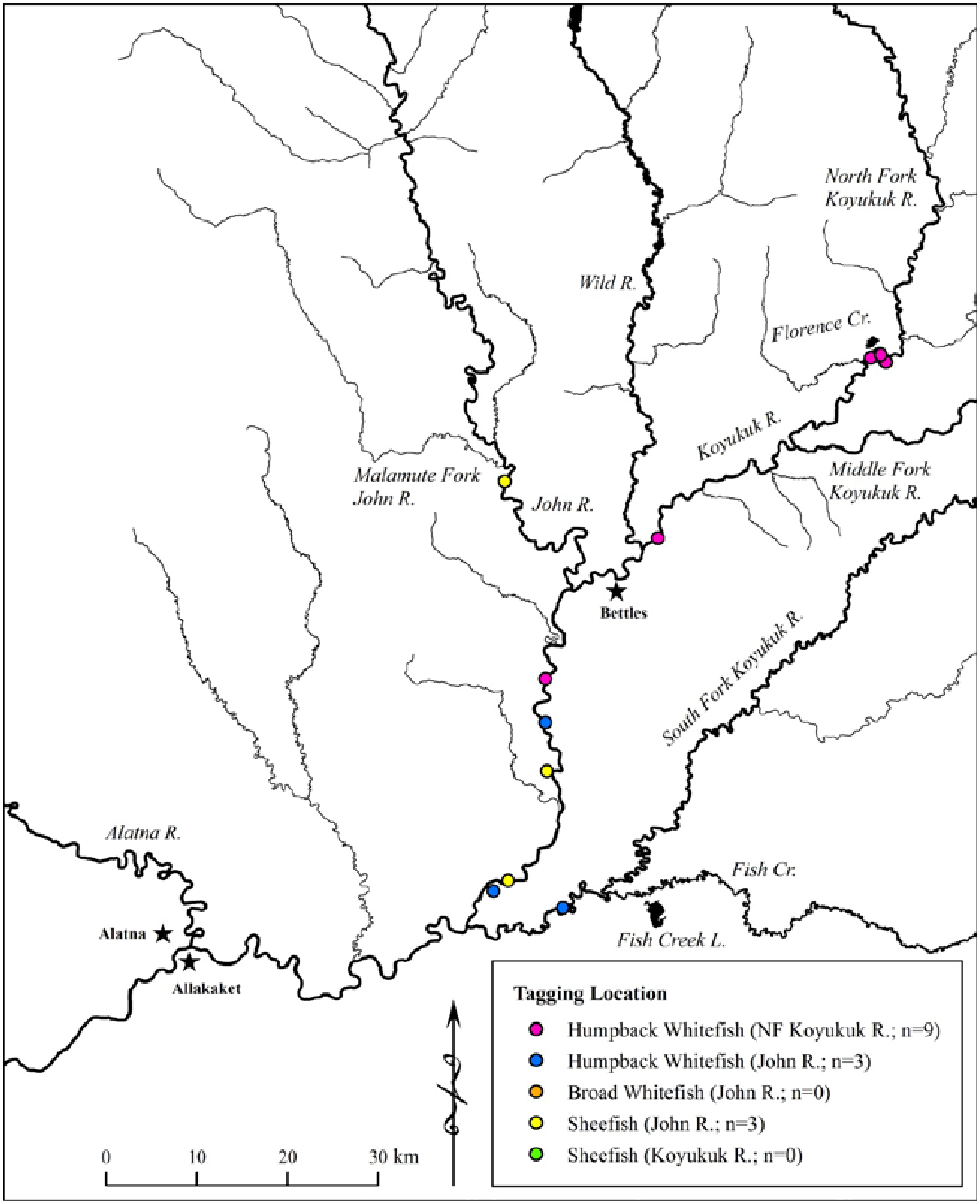
Appendix D6.–Locations of radiotagged whitefishes on 7 May 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



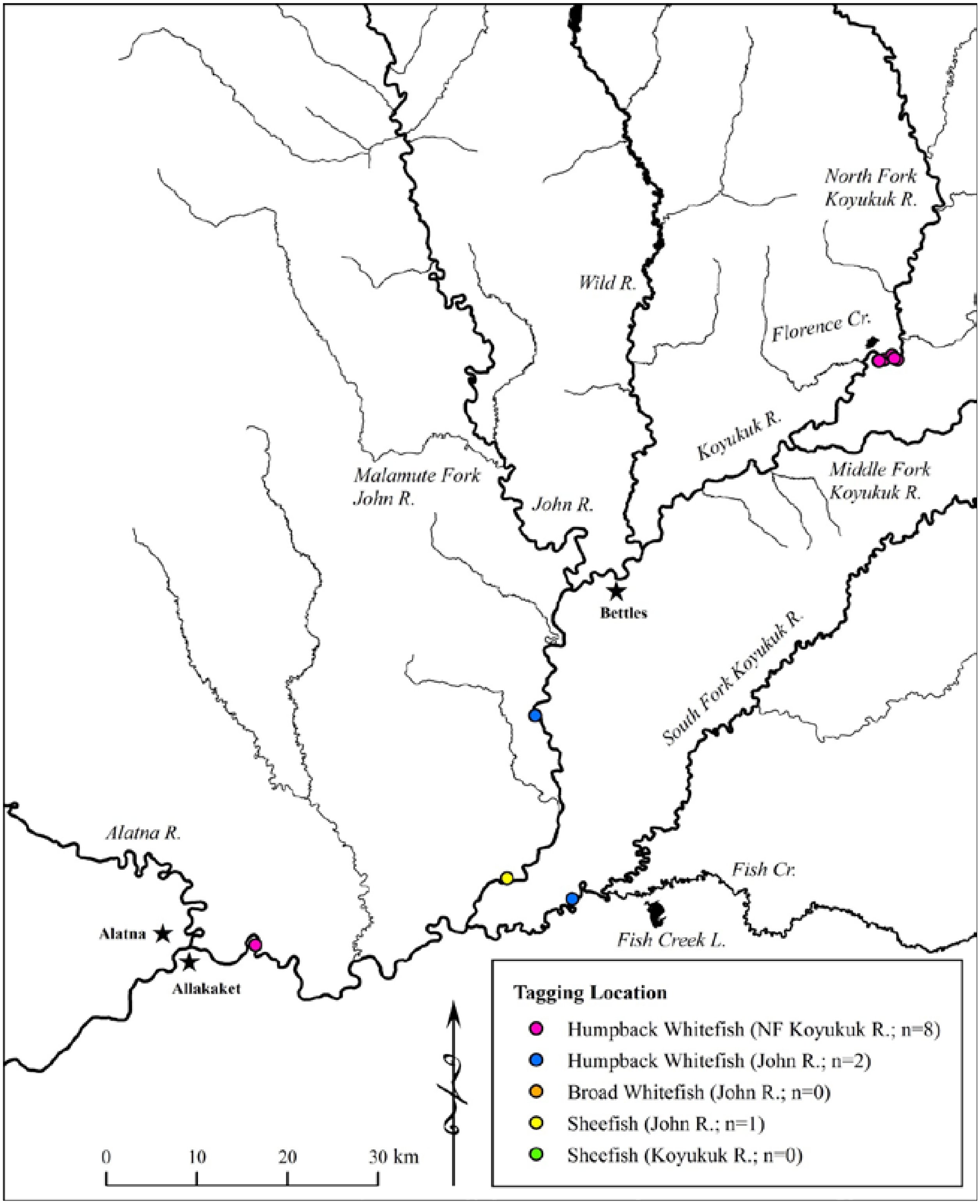
Appendix D7.–Locations of radiotagged whitefishes on 20 May 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix D8.–Locations of radiotagged whitefishes on 2 June 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

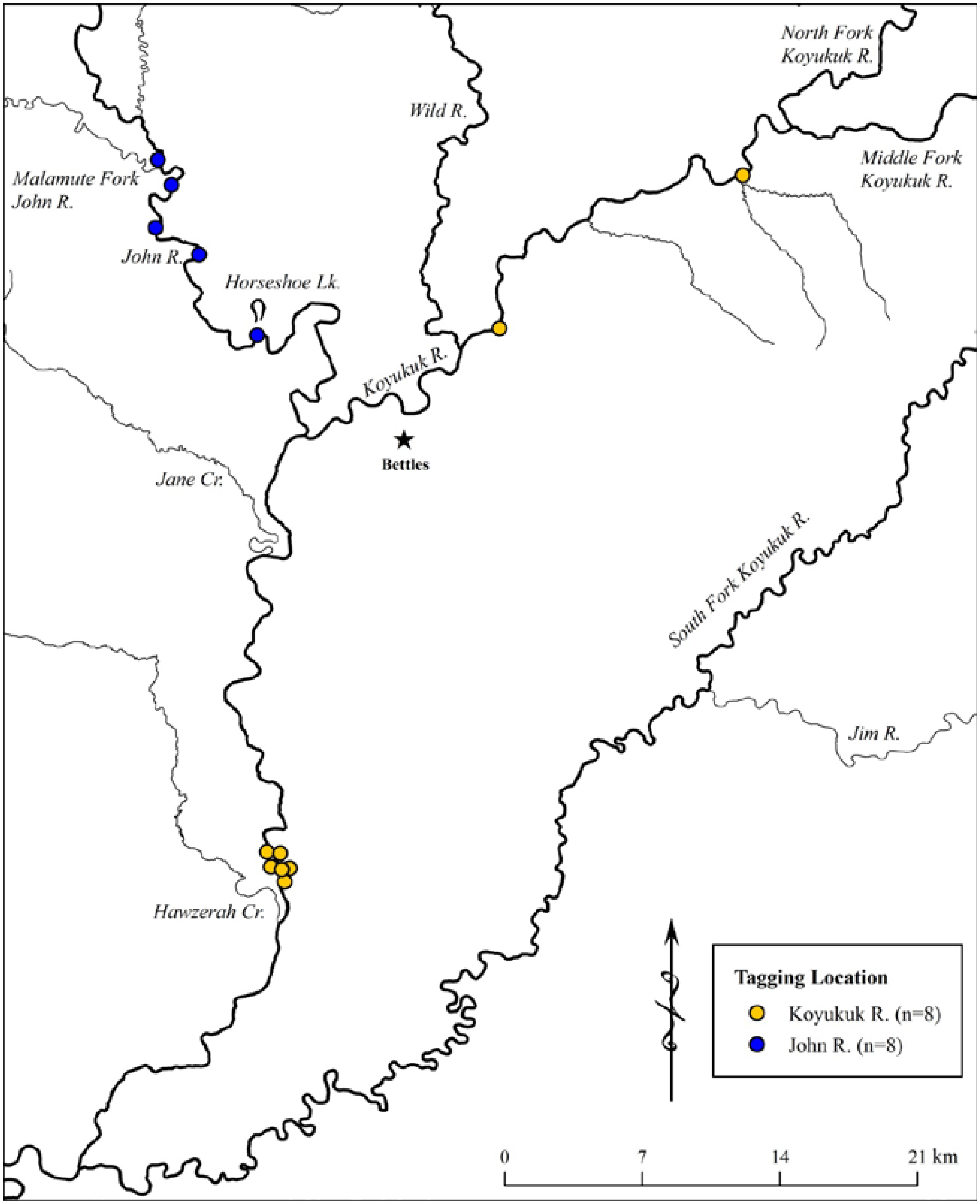


Appendix D9.–Locations of radiotagged whitefishes on 1 August 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.

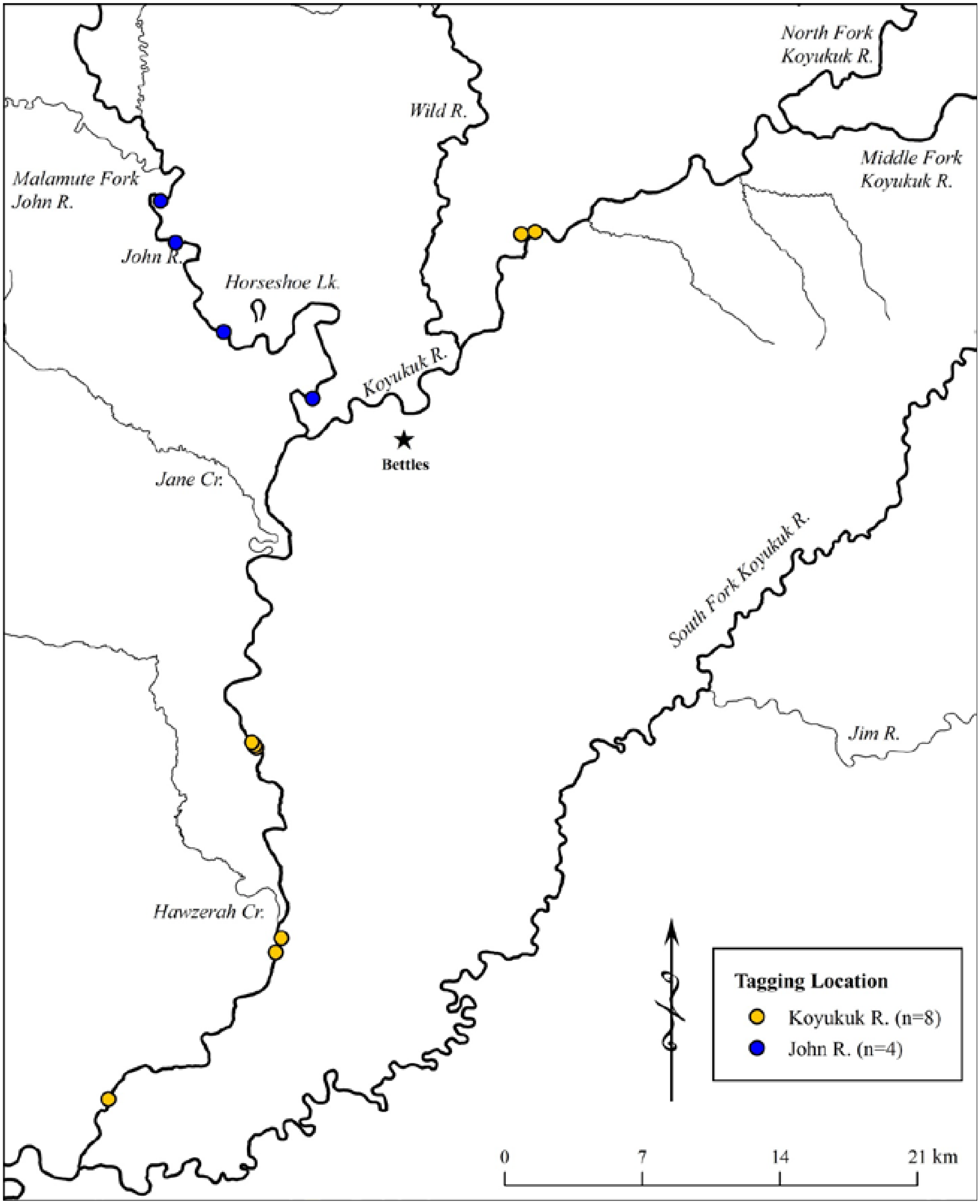


APPENDIX E:
LOCATIONS OF RADIOTAGGED NORTHERN PIKE SAMPLED IN THE MAINSTEM REACHES WITHIN THE KOYUKUK STUDY AREA

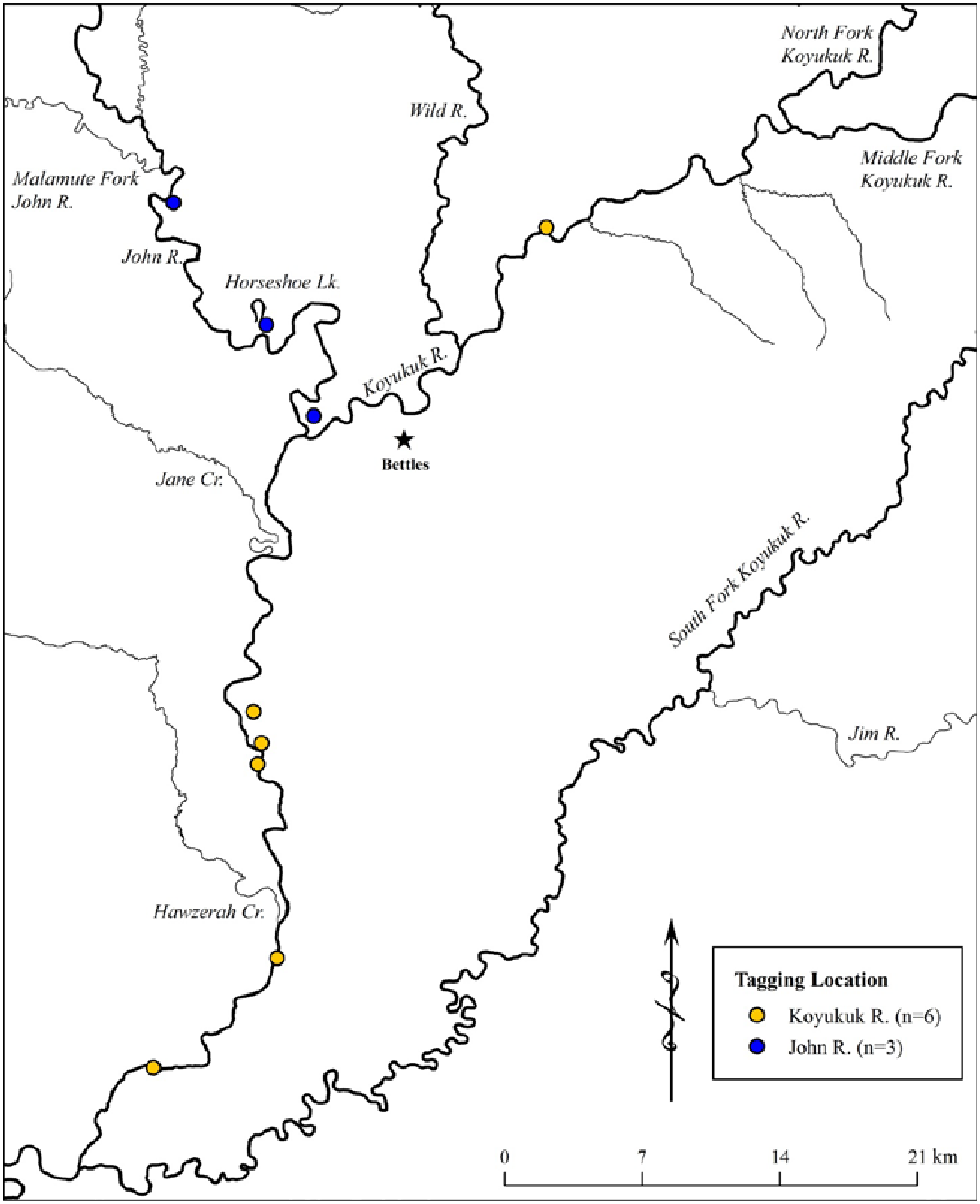
Appendix E1.–Tagging locations for northern pike sampled in mainstem reaches within the Koyukuk study area, 2014. Colors depict a general tagging area and the total number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix E2.–Locations of radiotagged northern pike during fall 2014 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix E3.–Locations of radiotagged northern pike on 1 February 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.



Appendix E4.–Locations of radiotagged northern pike on 2 June 2015 sampled in mainstem reaches within the Koyukuk study area. Colors depict original tagging areas and the number of surviving radiotagged fish are labeled parenthetically in legend.