To: Fred DeCicco, ADF&G, Sport Fish Division, Fairbanks, AK.

From: Jack Dean, P.O. Box 428, Sterling, Ak. 99672 3/9/00

Subject: Arctic(Taranetz)char in South Central Alaska

This letter will bring you up to date on my char chase in the Upper Cook Inlet and Kodiak Island areas of Alaska. Tables 1. to 4. list the populations of Arctic char known to me at this time.

Char distributions in the Susitna Valley seem to be better known than other areas of South Central Alaska. The Palmer office appears to have located most of their Arctic char populations.

Benka Lake is land locked but only three miles east of the Susitna River. How Arctic char gained access to this lake is unknown. Al Havens believes they were stocked. It is possible is that they have been there a long time. Arctic char were identified in the initial lake survey in the early 1960's. If they were stocked, what lake served as the source? There were no other known nearby sources of Arctic char. It has only been in the past 15 years that the Big Lake char were positively identified as Arctic char.

The opportunity to learn the affinities of the Benka Lake char may have been lost. ADF&G has stocked Benka Lake annually since 1990 with char from Lake Aleknagik near Bristol Bay.

Mirror and Flat Lakes are connected to Big Lake by a creek. In 1987 a 24.6 inch char that weighed 4.3 pounds was taken by an angler from Flat Lake.

Never-Never Lake is also in the Big Lake basin. This lake maintains an intermittent outlet to Big Lake and also contains large char. A gill net set on August 24, 1988 took only two char. These fish were 24.0 and 24.3 inches in fork length.

Sara Lake is land locked but just a short walk from Flat Lake. Fifteen Arctic char were taken in a gill net set in Sara Lake in 1988. These char ranged in fork length from 10.1 to 14.2 inches.

Al Havens (personal communication) reported that char up to 14 pounds have been taken from Big Lake by anglers. The largest char caught during the July 1987 fishing derby was 25.1 inches long and weighed 7.53 pounds. The 1989 derby winner was 26.2 inches long.

With the exception of Sara Lake every char lake in the Big Lake basin has unusually large Arctic char compared to all other South Central populations. These char are up to three times larger than the largest fish reported elsewhere in this area of Alaska. This size discrepancy suggests that the Arctic char from the Big Lake area survived the Wisconsin glaciation in a separate refugium or entered Big Lake from Knik Arm of Cook Inlet.

Northern pike have been reported in Big Lake. If pike become well established they could have a detrimental effect on the resident and anadromus fish populations. In other South Cental lakes where pike have become abundant they have decimated the rainbow trout populations. Big Lake is the first South Central Arctic char lake where pike have apparently become established. Their effect on the Arctic char won't be known for some time.

Another concern at Big Lake is possible eutrophication from residential development. A study by Paul Wood in 1983-84 determined that a dissolved oxygen deficit developed in the hypolimnion during both summer and winter.

Most of what I've learned about Arctic char on the Kenai National Wildlife Refuge came from lake survey reports and fishing in the Swanson River watershed. Arctic char, usually listed as Dolly Varden in the the older reports, have been recorded in 50 lakes on the refuge. My wife and I have caught Arctic char in a couple of unsurveyed lakes. They are probably present in several more unsurveyed lakes. My quess is that the actual total is somewhere near 55 lakes where Arctic char occur or occurred in the Swanson River watershed.

In Table 2. I've listed the lakes where I believe Arctic char are reproducing on the refuge. This list is rather subjective and no doubt will be revised in the furure. It's based primarily on old lake survey reports. If a lake is near the top of its watershed, and has a viable char population, they are obviously reproducing in the lake.

There are about 15 lakes where only a few char were captured during the initial lake survey. In some cases these lakes have been resurveyed. If few or no char were taken during a second test netting this suggests little or no reproduction is taking place in that lake. In a few lakes char appear to be present as strays from nearby lakes where spawning is successful. Of course the lake surveys have to be looked at with a critical eye. If the lake was surveyed in July or August, and the nets were set in shallow water, Arctic char could have been present but remained undetected in the hypolimnion.

The only current threat to any of these refuge char lakes could occur in a year or two when Marathon Oil Company drills gas wells near Finger and Wolf Lakes.

In the early 1960's Larry Engel of the ADF&G studied the summer depth distribution of the Arctic char in East finger Lake. John Tobin and Doug Palmer of the FWS sampled East Finger, Middle Finger and Falcon Lakes in 1993. They determined age and growth rates of 99 char using otoliths.

The Swanson River watershed contains 80 percent of the known Arctic char lakes in this part of the state. This one watershed probably holds at least one fourth of the Arctic char lakes in Alaska. With the exceptions of road accessible Dolly Varden and East Finger Lakes little more than cataloging has occurred here. No spawning areas have been located. No one has ever captured a young of the year or a yearling Arctic char in this watershed. These char are heavily parasitized but we don't know what species of parasites they're hosting. We don't know if people could become parasitized by eating cold smoked char.

Arctic char are the aquatic equivalent of the canary in the coal mine. They are the first fish species to suffer from habitat alterations or competition from non-native fishes. They will probably be the first fish species to be impacted on the Kenai Peninsula by global climate change. The need for a better understanding of our resident lake char is apparent.

The fish in Cooper Lake have been listed as Dolly Varden for at least 40 years. Our limited sampling last fall provided the first evidence of Arctic char in this lake. Hopefully state or federal fishery biologists will obtain adequate samples this year for meristic and genetic analysis.

Between 1973 and 1990 Cooper Lake was sampled four times with variable mesh gill nets. During these sampling efforts 453 char were captured. Only three char measuring 16 inches or more in length were collected. In a lake of this size there were far fewer medium sized char than expected.

Our limited sample in November found sexually mature dwarf Arctic char only 9-10 inches long. Cooper Lake, to my knowledge, contains the only dwarf Arctic char population in South Cental Alaska.

Char Lake was sampled for the first and only time in 1970 by ADF&G. The biologists who did the test neting reported catching 24 Arctic char. In this little 10 acre lake, that drains into Cooper Lake, 29 percent of the char were over 14 inches in fork length compared to only 3 percent of similiar sized char in the much larger reservoir downstream. Winter water level withdrawals for power generation may be impacting a portion of the lake spawning Arctic char population in Cooper Lake.

As soon as the ice goes out this spring I plan to fish Char Lake to determine if it is still populated with Arctic char.

Last week retired state fishery biologist Larry Larson and I had lunch with glacial geologist Dick Reger. His maps indicated that there were unglaciated areas on the Kenai Peninsula during the Wisconsin glaciation. There were also several ice dammed lakes that formed during this period. These lakes or one of the unglaciated areas in the Caribou Hills or corridors north and south of the Kenai River may have served as fish refugiums. The lake trout present in Tustumena Lake and in the Kenai River lakes may have survived the last glaciation in one of these refugiums. The Arctic char in the Swanson River watershed and in Cooper Lake may also have survived the last glacial maximum in one or more unglaciated area on the west side of the Kenai Peninsula.

Portions of the Southwestern side of Kodiak Island are documented to have remained ice free during the last glacial maximum (Mann and Peteet,1994). This area probably served as the refugium for the Arctic char present in Karluk and Frazer Lakes. Dolly Varden are also present in both lakes.

A genetic study of both species in Karluk Lake by Tony Gharrett et al,1991 showed evidence of introgression of Arctic char genes into the Dolly Varden. In spite of this mixing of genes both species have maintained their separate identities in this lake. Gharrett was unable to determine if gene flow had occurred from the Dolly Varden to the Arctic char.

Several other sizeable lakes in this part of the island have been studied for their contribution to the commercial salmon fishery. Little work, however, has been done to determine the presence of Arctic char in these lakes. Its quite likely that both char species occur together in other lakes in this area.

Lakes where Arctic char may occur iclude:

Akalura Lake	1,210 acres, 72 feet deep
Horse Marine Lake	222 acres, 94 feet deep
Red Lake	2,075 acres, 148 feet deep
Upper Station L.	1,951 acres, 230 feet deep
Four smaller lakes north of Larsen Bay.	

Hopefully these lakes will be sampled in the not too distant future to determine if one or more species of char are present.

I haven't been able to find any information on the Arctic char lake in the Shumigan Islands that Dr. Morrow listed in his 1980 paper on Dolly Varden. His coordinates place this lake on Nakai Island.

The pyloric caeca and gill raker counts I've found for this area are shown in Table 5.

Table 6. was included for those Alaskan's who do not believe that Dolly Varden and Arctic char are valid species.

I hope the information in this letter is a step towards a better understanding of the distribution of Arctic char in the Upper Cook Inlet-Kodiak Island area. It seems ironic that the Arctic char of this area appear to the least studied group in Alaska while surrounded by over half the states citizens.

Your comments and suggestions would be appreciated, Fred.

cc: Kenai NWR
Dr. Behnke
Kodiak NWR

Table 1. Known Arctic char lakes in the Susitna Valley.

Lake	Surface Acres	Maximum Depth	Conduct-ivity	Elevation	Heaviest Arctic char	Land-locked	Watershed	Geographic location
Benka	123	75'	41	525'	3.00 lbs.	Yes	Susitna R.	62°11'N-150°15'W
Big	2,495	89'		142'	14.00	No	Fish Ck.	61°31'N-149°59'W
Flat	296	44'		142'		No	Fish Ck.	61°31'N-150°30'W
Mirror	44	34'		142'		No	Fish Ck.	61°32'N-149°58'W
Never-Never	31	30'		145'		No	Fish Ck.	61°31'N-149°59'W
Sara	44	50'		145'		Yes	Fish Ck.	61°31'N-149°59'W
Total acres	3,033							

Table 2. Lakes in the Swanson River watershed where Arctic char reproduction is believed to be taking place.

Lake	Surface acres	Maximum depth	Conduct-ivity	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Anertz	33	26'		238'	1.50 lbs.		
Canoe #2				190	3.94		
Channel	97	50'		237'	0.94		
Chick				245'			
Chum	8	23'		225'			
Dog	23	57'		225'	1.63		
Dolly Varden	242	95	34	240'	2.60		$60^{o}43'$N-$150^{o}46'$W
Drake	165	105		233'			
Duckling	73	78		233'	1.37		
Eider	113	58		235'	1.00		$60^{o}49'$N-$150^{o}26'$W
Falcon	238	56	20	260'	1.88	Yes	$60^{o}47'$N-$150^{o}23'$W
Finger, East	72	48	23	235'	2.37	Yes	$60^{o}39'$N-$150^{o}52'$W
Finger, Middle	180	88	28	225'	1.65	Yes	$60^{o}38'$N-$150^{o}53'$W
Finger, South	220	100+		240'	3.00	Yes	
Fish	66	61	36	210'	2.10		$60^{o}43'$N-$150^{o}43'$W
Gavia	293	31		203'			
Grus	193	33		170'	1.10	?	
Ice	78	60		157'	2.55		
King	490	61	133	207'	2.25		$60^{o}48'$N-$150^{o}19'$W
Konchanee	224	78		207'	1.00		
Kuviak	70	52		255'	0.88		
Llerum	26	35		210'	0.79		
Lonely	52	47		215'	0.94		
Lost	47	65		260'	1.06	?	
Lure	40	37		217'	1.19		
Norak	173	57		183'	1.94		
Olsjold	48	29		233'	1.04		
Polski	15	35		243'			
Sabaka	75	58		242'	1.28		

Table 2. Continued.

Lake	Surface acres	Maximum depth	Conductivity	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Skookum	45	60'		243'	3.60 lbs.		
Snag	306	37'	68	195'	1.01		60°49'N-150°41'W
Stormy	390	50		56'	2.45		
Swanson	320	41		184'	2.50		
Waterfowl	77	46		210'	2.00		
Wolf	88	42	30	125'			60°40'N-150°54'W
Woods	40	25		240'	2.63		
Total acres	4,620+						

Table 3. Known Arctic char lakes in the Kenai River watershed.

Lake	Surface acres	Maximum depth	Conductivity	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Char	10	22		1,250	1.58		60°23'N-149°43'W
Cooper	1,990	450+	71	1,168	1.80		60°24'N-149°46'W
Total acres	2,000						

Table 4. Known Arctic lakes on Kodiak Island.

Lake	Surface acres	Maximum depth	Conductivity	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Frazer	4,100	193		353'			57°15'N-154°10'W
Karluk	9,728	413		368'	3.19		57°23'N-154°03'W
Total acres	13,828						

Table 5. Pyloric caeca and gill raker counts of Arctic char from Upper Cook Inlet and Kodiak Island areas of Alaska.

Lake	Watershed	Year	Number of fish	Pyloric caeca mean	Pyloric caeca range	Number of fish	Gill rakers mean	Gill rakers range	Source
Big	Fish Ck.	1987	166	46.1	35-57	72	25.4	19-28	Havens
Sara	Fish Ck.	1988	13	44.4	39-53	13	25.2	24-27	ADF&G
Never-Never	Fish Ck.	1988	2	44.5	43-46	2	24.5	24-25	ADF&G
East Finger	Swanson R.	1964	19	45.8	39-59				Engle
Falcon	Swanson R.	1993	2	37.5	37-38	6	24.0	22-26	Tobin
Middle Finger	Swanson R.	1993	3	46.7	45-49	1	24		Tobin
Cooper	Kenai R.	1999	6	39.8	35-45	6	23.0	22-24	Dean
Karluk	Karluk R.	1943	60	45.6	30-64	70	23.4	21-26	DeLacy
Karluk	Karluk R.	1961	32	44.3	35-57	32	23.6		McPhail
Karluk	Karluk R.	1980	7	46.2	39-49	7	23.1	21-25	Morrow
Frazer	Dog Salmon Ck.	61	54	42.9	36-55	54	24		Mcphail
Shumigan Islands		1980				1	23		Morrow
Totals			364		30-64	264		19-28	

Table 6. Morphological, life history and genetic differences between the southern subspecies of Dolly Varden and Arctic char.

Characteristic	Dolly Varden	Arctic char
Caudal fin	Slightly forked	Moderately forked
Caudal peduncle depth	Thicker	Thinner
No. of gill rakers	Mean 18 Range 15-22	Mean 23 Range 21-26
No, of vertebra	Mean 62	Mean 65
Pyloric caeca	Mean 30 Range 21-39	Mean 45 Range 30-64
Spots on the side	Small, more than 50	Less than 50 spots. Some spots larger than the pupil of the eye.
Color of eggs	Orange	Pale yellow
Swim bladder	Transparent, thin walled	Opaque, pinkish and tough
Parasites	Sparsely parasitized	Heavily parasitized
Habitat	Lakes, streams or anadromus	Lake resident
Spawning	Stream spawner	Lake spawner
Preferred water temperature	50-55^{o}F.	45-50^{o}F.
Chromosome Karyotypes 2N	82	78
Metacentric-submetacentric	8 pair	10 pair
acrocentric	66	58
No. of arms	98	98

This information taken from DeLacy and Morton, 1943 and Cavender, 1980.

ARCTIC CHAR IN SOUTHCENTRAL ALASKA

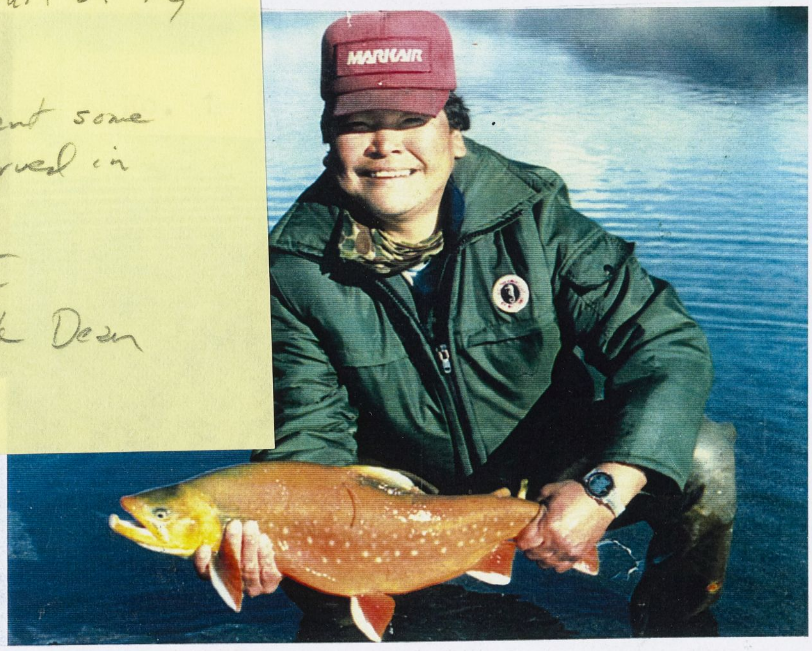
A Status Report

Bob,
Here's the fruit of my winters labor.

Do you still want some specimens preserved in formalin?

Jack Dean

N...



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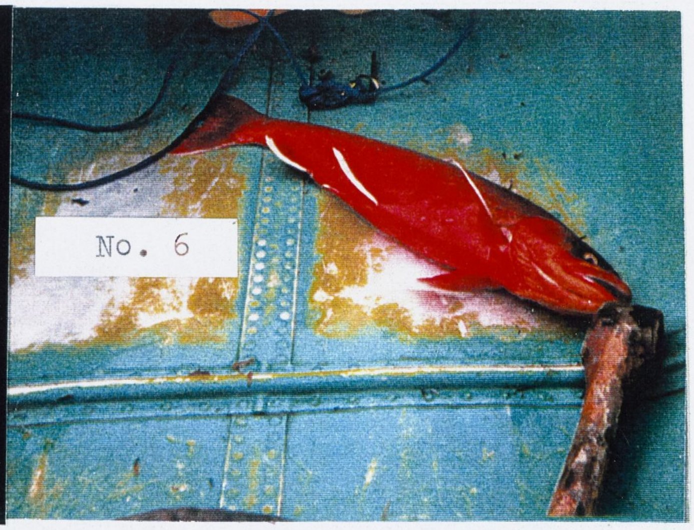


No. 6

ARCTIC CHAR IN SOUTHCENTRAL ALASKA

A Status Report


No. 2

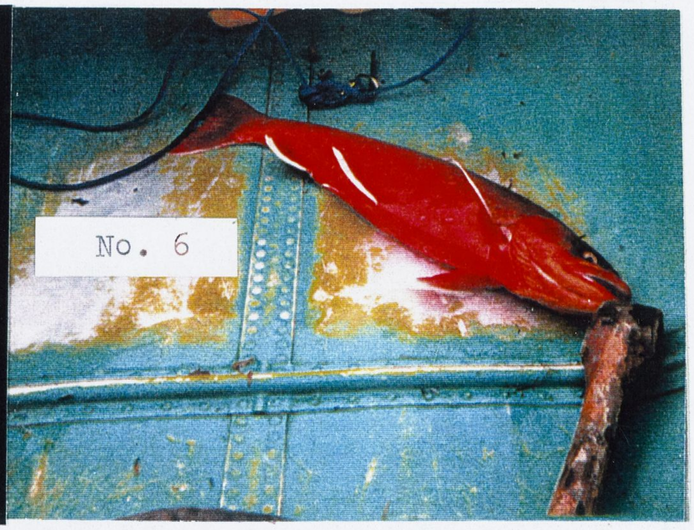
No. 1


No. 3

No. 4


No. 5


No. 7


No. 6

ARCTIC CHAR IN SOUTHCENTRAL ALASKA
A Status Report
by
Jack Dean
Fishery Biologist (Retired)

Southcentral Alaska is home to three species of char. Dolly Varden are the most widespread and successful of the three chars in this part of the state. They occur as anadromus , resident stream and lake dwellers. Lake trout occur in about 20 lakes in the Matanuska-Susitna and Kenai Peninsula Borough's. This species does not occur on Kodiak Island. Arctic char are the least known of the three species of char. Arctic char are often confused with Dolly Varden and occasionally confused with lake trout. The intent of this report is to better acquaint the reader with the status and distribution of Arctic char in the Cook Inlet-Kodiak Island areas of Alaska.

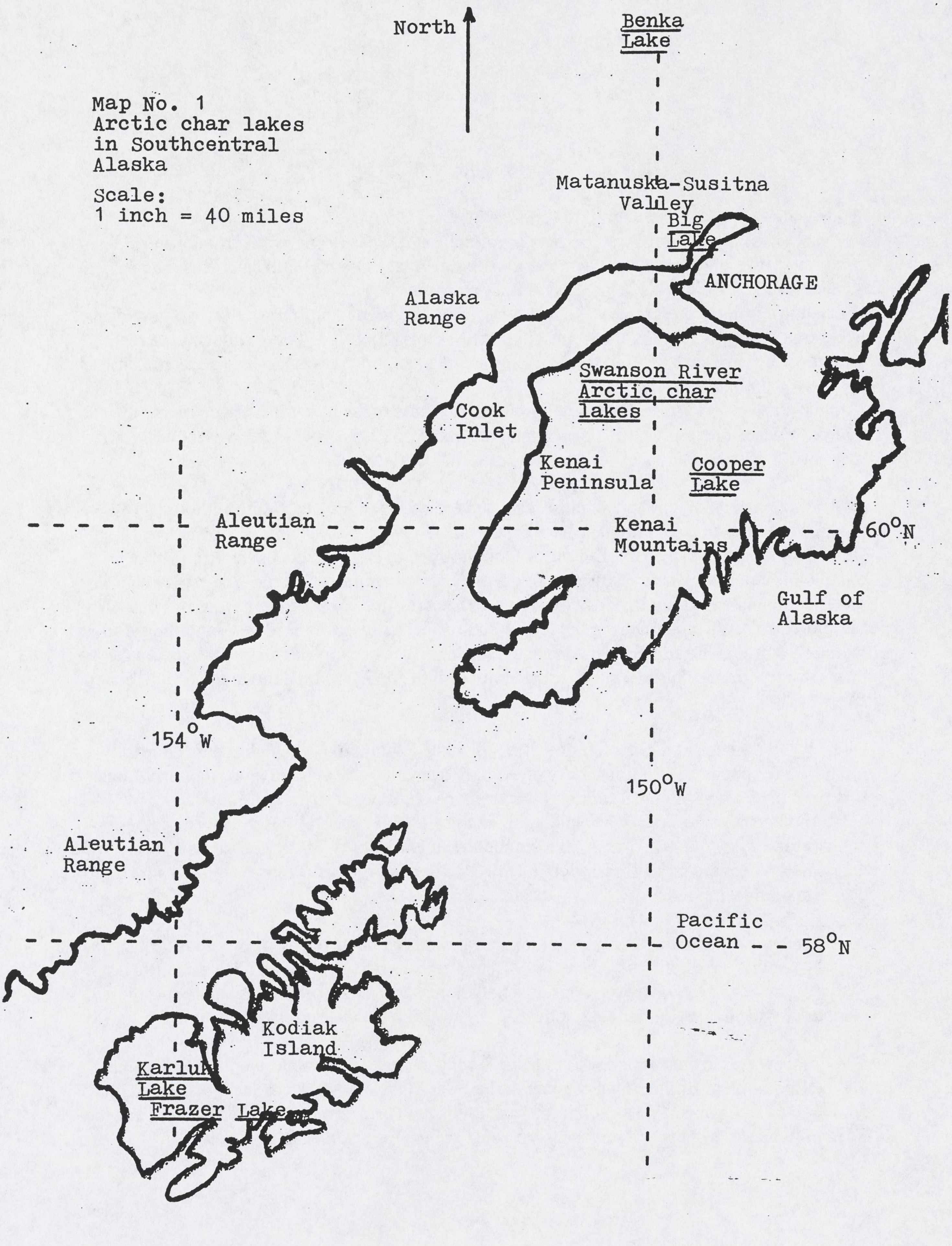
Arctic char were more than likely anadromus in this area in the past when the climate and marine water temperatures were cooler than they are now. The populations present today are most likely glacial relicts.

Dolly Varden and Arctic char are closely related look- a- like species. Some authorities believe they separated from a common ancestor over a million years ago. Others, notably several Russian authorities, consider all forms of Dolly Varden to be members of the Arctic char complex. Here in Alaska the situation has been confusing to many people. For many years fishery biologists working in northern and northwestern Alaska called the anadromus char of those regions Arctic char. During the late 1980's they were discovered to be the northern form of the Dolly Varden. In southcentral Alaska the tendency has been to call all char, except lake trout, Dolly Varden. This has led to considerable confusion in areas where both closely related species occur.

DeLacy and Morton, in 1943, were the first biologists to point out that both Arctic char and Dolly Varden occurred in Karluk Lake on Kodiak Island. On the Kenai Peninsula Larry Engel was the first the first biologist to report the presence of Arctic char in East Finger Lake in 1964. Other biologists working in this area continued to call local char Dolly Varden. This situation persists to this day. Dolly Varden Lake, on the Kenai National Wildlife Refuge, as a result, was misnamed. There are no Dolly Varden in Dolly Varden Lake. This lake is populated with Arctic char and a few rainbow trout.

Arctic char have a circumpolar distribution in the northern hemisphere. They occur further north than any other species of fresh water fish. There are five or six subspecies. The scientific name of the Arctic char in southcentral Alaska is Salvelinus alpinis taranetzi. This subspecies was named after the noted Russian taxonomist A.Y.Taranets who worked in Siberia in the 1930's.

The Taranets Arctic char is believed to have become separated from more northerly populations by the Bering Land Bridge. This connection between Asia and Alaska existed, off and on, for 50,000 to 60,000 years . At its maximum extent this land bridge was nearly a 1,000 miles wide. Today the Taranets subspecies of the Arctic char occurs from southeastern Siberia to


North
Benka Lake
Map No. 1
Arctic char lakes
in Southcentral
Alaska
Scale:
1 inch = 40 miles
Matanuska-Susitna
Valley
Big
Lake
ANCHORAGE
Alaska
Range
Swanson River
Arctic char
lakes
Cook
Inlet
Kenai
Peninsula
Cooper
Lake
Aleutian
Range
Kenai
Mountains
60°N
Gulf of
Alaska
154°W
150°W
Aleutian
Range
Pacific
Ocean
58°N
Kodiak
Island
Karluk
Lake
Frazer Lake

southwestern and southcentral Alaska.

One reason for the confusion between Dolly Varden and Arctic char is the fact that the two species are quite similar in appearance. The differences between the two species is shown in Table 1. The most obvious external differences are the fewer but larger spots, the forked tail and the narrower caudal peduncle of the Arctic char. The most difinitive method to separate these two species is to count their gill rakers and pyloric caeca (finger like projections on the stomach). These counts are difficult to do in the field and are best done in the laboratory.

There are seven photo's of Arctic char on the cover of this report to give the reader an idea of their appearance;

Photo 1. Wilber Bavila with a 12 pound pre spawning Arctic char from Kagati Lake on the Togiak National Wildlife Refuge.

Photo 2. A male Arctic char in spawning color from a lake on the Kenai National Wildlife Refuge.

Photo 3. An Arctic char from Cooper Lake on the Chugach National Forest. Note the forked tail and the narrow caudal peduncle.

Photo 4. Six Arctic char from Cooper Lake. The two small char with faint parr marks were sexually mature at a length of 9 to 10 inches.

Photo 5. A large spotted Cooper Lake Arctic char. This one also shows a forked tail and a narrow caudal peduncle.

Photo 6. Spawning male from a lake on the Kenai National Wildllife Refuge.

Photo 7. Another Cooper Reservoir Arctic char. This photo was provided by the Seward Office of the Chugach National Forest.

This status report is mostly based on information collected from natural resource agencies such as the Alaska Department of Fish and Game (ADF&G), the U.S. Fish and Wildlife Service (USFWS) , the U.S. Forest Service (USFS) and numerous technical reports some of which are listed in the bibliography.

MATANUSKA-SUSITNA VALLEY

<u>Benka lake</u>

Char distributions in the Matanuska-Susitna Valley are better known than in other areas of southcentral Alaska. The Palmer Office of the ADF&G appears to have located most of their Arctic char lakes.

Table 1. Morphological, life history and genetic differences between the southern subspecies of Dolly Varden (*Salvelinus malma lordi*) and the Taranetz subspecies of Arctic char (*S. alpinus taranetzi*)

Characteristic	Dolly Varden	Arctic char
Caudal (tail) fin	Slightly forked	Moderately forked
Caudal peduncle depth	Thicker	Thinner
No. of gill rakers	Mean 18 Range 13-22	Mean 23 Range 21-26
No. of vertebrae	Mean 62	Mean 65
Pyloric caeca	Mean 29 Range 21-39	Mean 45 Range 30-64
Spots on the side	Small, more than 50	Less than 50 spots. Some spots larger than the pupil of the eye.
Color of eggs	Orange	Pale yellow
Swim bladder	Transparent, thin walled	Opaque, pinkish and tough
Scales along lateral line	Mean 243	Mean 217
Liver color	Dark maroon	Pale brownish
Parr marks in mature adults	8-12	8-15
Parasites	Sparsely parasitized	Heavily parasitized
Habitat	Lakes, streams and anadromus	Lake resident
Spawning	Streams	Lakes
Preferred water temperature	50-55°F.	45-50°F.
Chromosome karyotypes 2N	82	78
Metacentric-submetacentric	8 pair	10 pair
Acrocentric	66	58
No. of arms	98	98

Sources: DeLacy and Morton, 1943, McPhail, 1970 and Sternberg, 1987.

Benka Lake is land-locked. The lake is only three miles east of the Susitna River (Map 2). It is the only known Arctic char lake in this large watershed. How Arctic char gained access to this lake is unknown. Former Sport Fishery Supervisor Al Havens (personal communication) believes they were stocked. It is possible they have been here a long time. Arctic char were identified in the initial lake survey of Benka Lake in the early 1960's. Fish from that survey were sent to the University of British Columbia for identification. If Benka Lake was stocked with Arctic char in the 1940's or 1950's, what lake served as the source? There were no other nearby sources of Arctic char. Arctic char were not positively identified in Big Lake, the most likely source, until 1987. Big Lake is 58 miles by road from Benka Lake.

Benka Lake was initially stocked by the ADF&G with 12,400 (100 per surface acre) coho salmon fingerlings in 1967. Stocking of this species continued every other or every third year until 1978 (Table 2). Then the stocking of coho salmon became a nearly annual event until 1994. During this period a total of 290,261 coho (silver) salmon fingerlings were stocked. Stocking of this species was terminated in 1995 because salmon fishing was never good enough to attract many anglers. .

Benka Lake supported a good Arctic char population from 1968 to 1977. An average of 44 char (range 34 to 51) were taken in three open water gill netting operations during this period. Then the population collapsed. Only 12 char were captured in 10 test netting operations from 1979 to 1991. In 1990 12,300 Arctic char of Bristol Bay origin from Lake Aleknagik were stocked for the first time. They were stocked again in 1991. Three overnight gill net sets on October 7, 1993 took seven two year old char, probably from the 1991 stocking, and two four year old char. The larger char, with fork lengths of nearly 16 inches, were more than likely survivors of the original Arctic char population.

Because of several additional stockings of char of Lake Aleknagik origin and the near collapse of the population in the late 1970's, the opportunity to learn the affinities of the original char has most likely been lost.

The reason for the collapse of Benka Lake's char population is unknown. There are several possible causes. Winterkill (oxygen depletion) has been mentioned as a likely reason. This seems unlikely in an oligotrophic (nutrient poor) lake with an average depth of 32 feet and a maximum depth of 75 feet unless some form of pollution was indicated. Predation on young of the year char by coho salmon could have contributed to the collapse. Arctic char are easy to catch with sport fishing gear when concentrated on their spawning grounds. If anglers had located the spawning grounds, they could have contributed to the decline. Poachers with gill nets could also have decimated the spawning population.

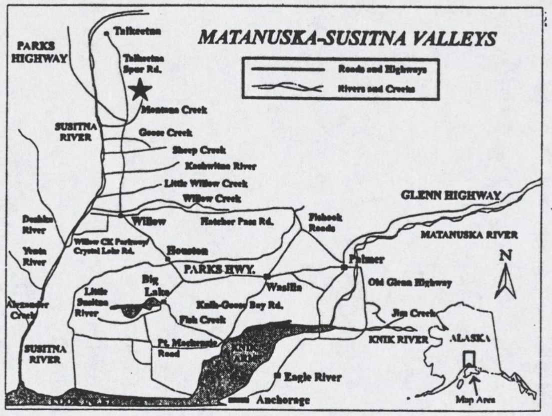
Recent creel census data indicates that Benka Lakes Arctic char population is still depressed in spite of repeated stocking. This lake is scheduled to be stocked with both fingerling and catchable sized char this year.

<u>Big Lake</u>

This lake provides the states largest ice fishery and one of the larger harvests of Arctic char.

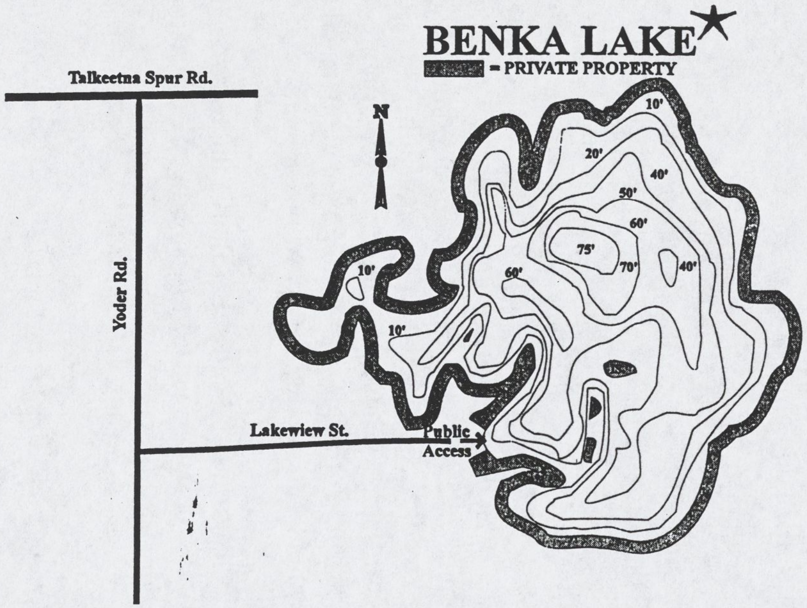
MATANUSKA-SUSITNA VALLEYS STOCKED LAKES SERIES

State of Alaska
Department of Fish and Game
Sport Fish Division
1800 Glenn Hwy #4
Palmer, AK 99645
(907) 746 -6300



Map No. 2.

BENKA LAKE★



U.S.G.S. Map Ref.	Talk. A-1, T24N R4W, S9,10	Geographic Location	62°11'15"N, 150°00'15"W
Elevation	525'	Surface Acres	123
Volume	3,894 Acre Ft.	Maximum Depth	75'
Mean Depth	32'	Shoreline Length	3.6 Miles
Surveyed	8/19/75 ADFG	Year 1st Stocked	1967
Game Fish Present	Arctic Char		

BENKA LAKE PUBLIC ACCESS: Mile 98.7 Parks Hwy. East on Talkeetna Spur Rd. 3.1 miles to Yoder Rd. Right on Yoder Rd. 0.6 mile to Lakeview Street. Left on Lakeview Street 0.7 mile to parking area and undeveloped boat launch. **NOTE**: Limited public access. Majority of lake shoreline is privately owned. Please respect private

Table 2. Benka Lake stocking, creel census and netting summary.

STOCKING ACCESS: same as public access
STOCKING METHOD: truck

LAKE: Benka
ACRES: 123

Year Stocked	Species	Number Stocked	Stocking Density (fish/a)	Stocking Size	Effort (angler days)		Number Harvested (H) or Caught (C): Landlocked Salmon	Rainbow Trout	Arctic Grayling	Arctic Char/ Lake Trout	Fish/ Angler-Day
1992	AC	12,300	100	8.6g	427	H					0.00
						C					0.00
1993	SS	12,230	99	9.4g	735	H	45	20			0.10
	AC	12,300	100	7.8g		C	268	20			0.41
1994	SS	12,300	100	7.9g	23	H					0.00
	AC	12,300	100	8.7g		C					0.00
1995	AC	12,300	100	10.2g	55	H	0				0.00
						C	59				1.07
1996	AC	12,300	100	9.9g	588	H	0				0.00
						C	66				0.11
1997					1,410	H	201				0.14
						C	201				0.14
1998	AC	752	6	135.2g		H					
						C					

TEST NET SAMPLING

Date	Species	Age Class	#	Range(mm)	Avg	C/GNHr
10/7/93	SS	0,2	104	103-250	150	1.40
"	AC	2,4	9	170-440	250	0.12
"	RT	7	1	554	554	0.01

FTP: 97A-0007 ARCTIC CHAR CATCHABLE
97A-0007 ARCTIC CHAR FINGERLING

COMMENTS: Benka Lake was first stocked by ADFG in 1967 with coho salmon (SS), which were stocked again in 1970, 1974, 1976, 1978, 1981-1982, and 1984-1985. SS and rainbow trout (RT) fingerlings were stocked in 1986, SS from 1987-1989, SS and Arctic char (AC) fingerlings in 1990-1991, AC in 1992, and SS and AC in 1993. Benka Lake is landlocked. The access to this lake is a via a gravel road that ends in a turn-around circle that just tangents the lake (as of 4/94 Larry Erie is working on this with a landowner). Reported SWHS fishing effort, harvest, and catch has been none to poor. As coho salmon growth in this lake has never been good enough to draw much fishing effort, SS stocking has been discontinued after 1994. Scheduled for annual stocking of 12,300 Arctic char fingerling from 1999-2003 and 1,000 Arctic char catchables in 2000 and 2002.

Species abbreviations:

SS = coho (silver) salmon

RT = rainbow trout

AC = Arctic char

Between 1977 and 1986 Big Lake provided an average of 13,100 angler days. The harvest during this 10 year period averaged 6,840 Arctic char, 5,371 rainbow trout and 542 coho salmon. The char harvest rate was 0.52 per angler day. Arctic char were not only the largest contributors to the harvest but also grew much faster and reached a substantially larger size than the rainbow trout in Big Lake. Seven year old rainbow trout were only 12 inches long while Arctic char of the same age were 18.8 inches long (Havens).

Until recently the char in Big Lake were considered to be Dolly Varden. Pyloric caeca were counted on 166 fish and gill rakers counted on 72 in 1987. This analysis proved that the char in Big Lake were not Dolly Varden but were Arctic char (Tables 1 and 5).

Big Lake's Arctic char population has received the most attention in the Cook Inlet area. A creel census in 1987 showed that October produced the best fishing of the year with a catch rate of 0.63 char per hour. Early winter fishing was nearly as good. December was the second best month with a catch rate of 0.58 char per hour. Winter catch rates declined each month thereafter to only 0.05 char per hour in April. Summer catch rates were all below 0.1 char per hour through September with a dramatic improvement in early October.

An age and growth study of Big Lakes Arctic char indicated an average growth of 2.15 inches per year (Table 6). Growth in length was fastest between ages three to seven when it averaged 2.45 inches per year. The oldest char in this study was 11 years old.

Fyke nets fished in Big Lakes inlet and outlet captured only two Arctic char between April and June, 1987. This netting effort showed that Big Lake char rarely entered moving water.

Al Havens (personal communication) reported that char up to 14 pounds have been caught from Big Lake by anglers. The largest char caught during the July 1987 fishing derby was 25.1 inches long and weighed 7.53 pounds. The 1989 derby winner was 26.2 inches long.

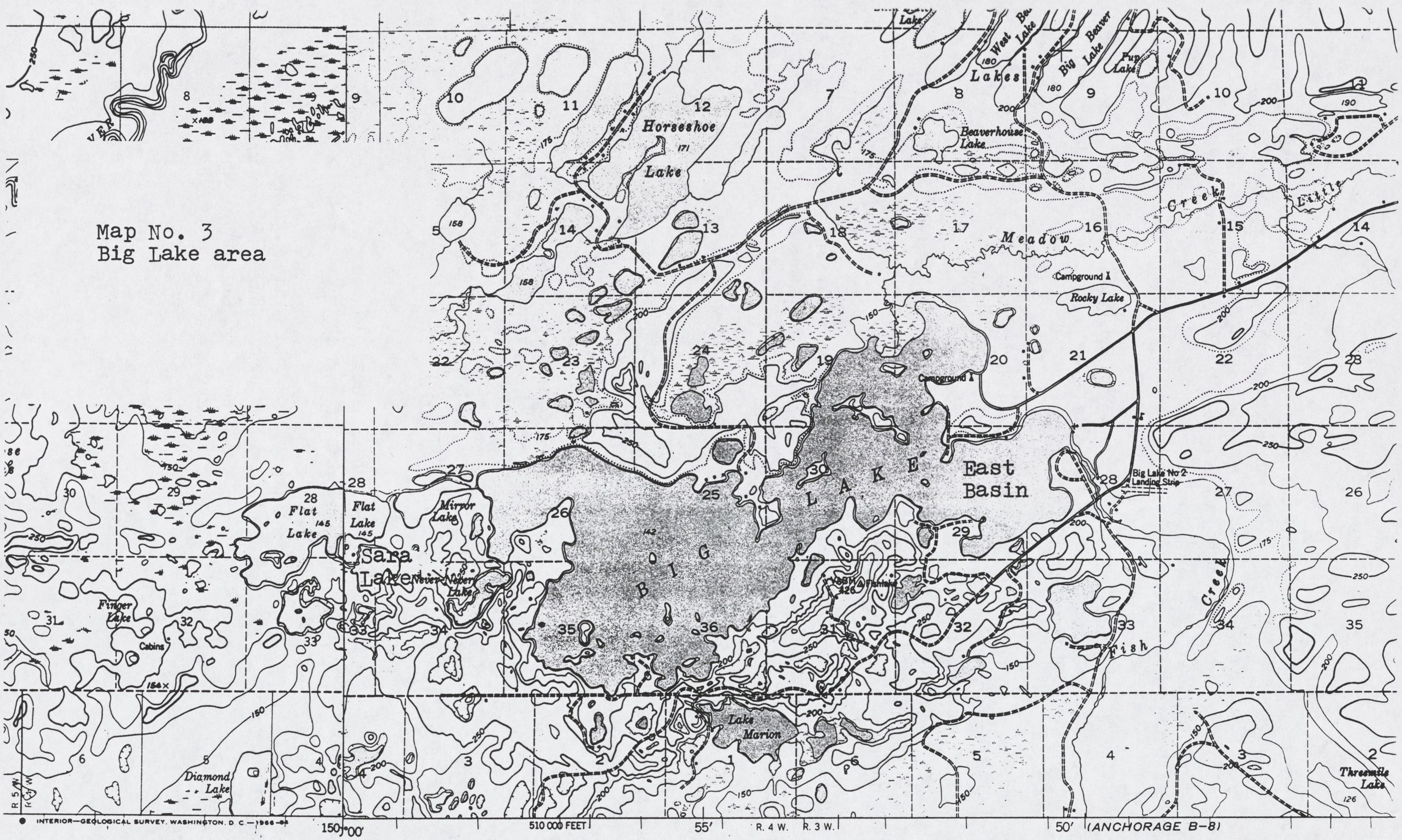
Mirror and Flat Lakes are connected to Big Lake by a creek (Maps 3, 5 and 6 and Table 3). In 1987 a 24.6 inch char that weighed 4.3 pounds was taken from Flat Lake by an angler.

Never-Never Lake is also in the Big Lake basin. This lake maintains an intermittent outlet to Big Lake and also contains large char. A gill net set on August 24, 1988 took only two char. These fish were 24.0 and 24.3 inches in fork length.

Sara Lake is land locked but just a short walk from Flat Lake. Fifteen Arctic char were taken in a gill net set in this lake in 1988. These char ranged in fork length from 10.1 to 14.2 inches.

With the exception of Sara Lake every char lake in the Big Lake basin has unusually large Arctic char compared to all other southcentral populations. These char are up to three times larger than the largest fish reported elsewhere in this area of Alaska. This size discrepancy suggests that the Arctic char from the Big Lake area survived the Wisconsin glaciation in a separate refugium or entered Big Lake from the sea after the glaciers receded.

Map No. 3
Big Lake area



ROAD CLASSIFICATION

Medium-duty ———— Light-duty ————

Unimproved dirt - - - - - - -

◯ State Route

ION

TYONEK (C-1), ALASKA

N6130—W15000/15X22.5

1958

MINOR REVISIONS 1965

Mapped, edited, and published by the Geological Survey

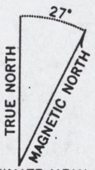
Control by USGS, USC&GS, and USCE

Topography by photogrammetric methods from aerial photographs taken 1949, field annotated 1950. Map not field checked

Universal Transverse Mercator projection, 1927 North American datum
10,000-foot grid based on Alaska coordinate system, zone 4
1000-meter Universal Transverse Mercator grid ticks, zone 6, shown in blue

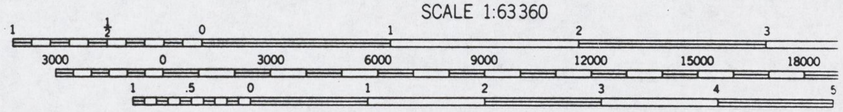
Gray land lines represent unsurveyed and unmarked locations predetermined by the Bureau of Land Management
Folios S-2, and S-13, Seward Meridian

Swamps, as portrayed, indicate only the wetter areas, usually of low relief as interpreted from aerial photographs



APPROXIMATE MEAN DECLINATION, 1950

SCALE 1:63360



CONTOUR INTERVAL 50 FEET

DOTTED LINES REPRESENT 25-FOOT CONTOURS

DATUM IS MEAN SEA LEVEL

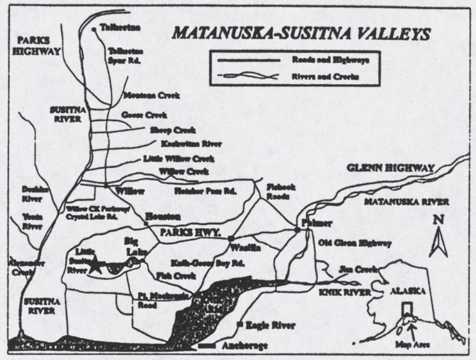
FOR SALE BY U. S. GEOLOGICAL SURVEY

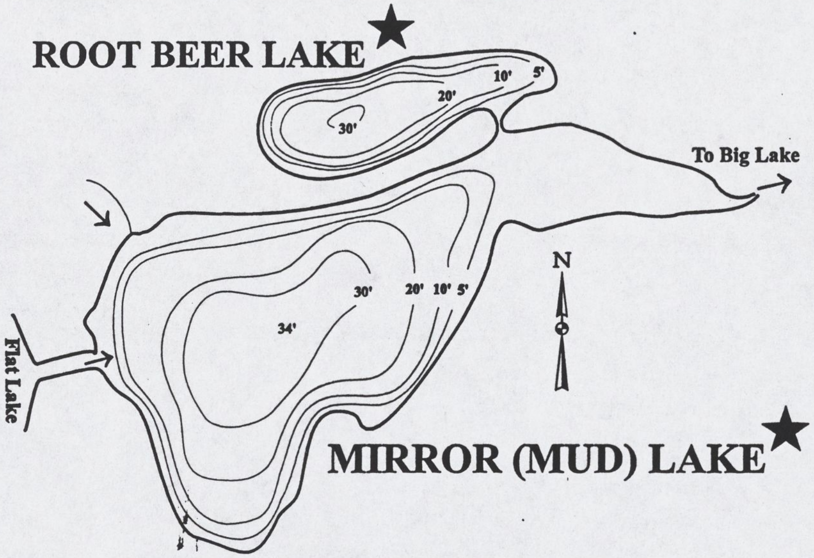
FAIRBANKS, ALASKA 99701, DENVER, COLORADO 80225, OR WASHINGTON, D.C. 20

Map No. 5

SOUTHCENTRAL LAKES MAP SERIES

State of Alaska
Department of Fish and Game
Sport Fish Division
1800 Glenn Hwy #4
Palmer, AK 99645
(907) 746 - 6300





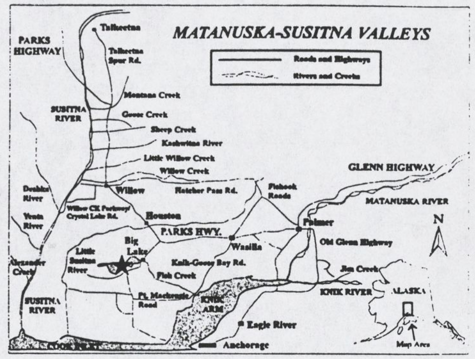
U.S.G.S. Map Ref.	Anch. C-8, T17N, R4W, S27	Geographic Location	61°32'N, 149°58'W
Elevation	142'	Surface Acres	44
Volume	660 Acre Ft.	Maximum Depth	34'
Mean Depth	15'	Shoreline Length	1.4 Miles
Game Fish Present	Rainbow Trout, Arctic Char, Burbot, Whitefish, Sockeye Salmon, Coho Salmon		

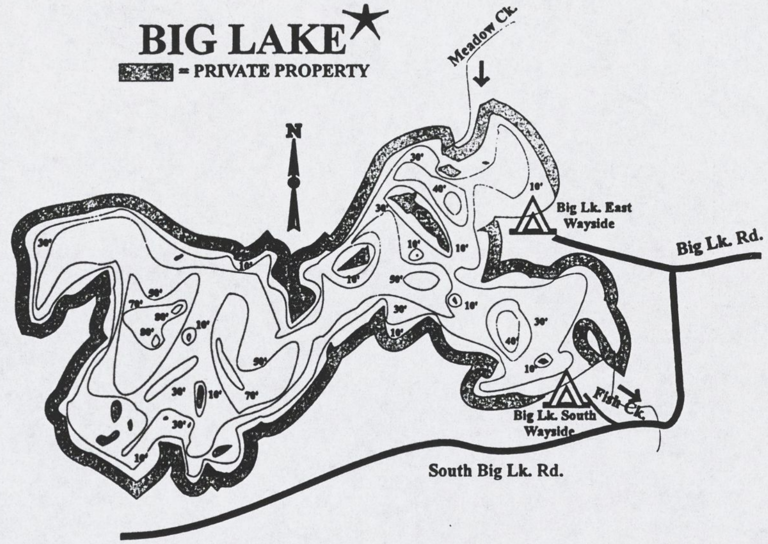
MIRROR LAKE PUBLIC ACCESS: The primary access to Mirror Lake is by boat from Big Lake, access for Big Lake located at Big Lake South State Wayside, accessed from Mile 52.3 Parks Hwy. West on Big Lake Rd. 3.6 miles to "Y". Left at "Y" on South Big Lake Rd. 1.7 miles to Big Lake South Wayside with camping and boat launch. Fees charged. NOTE: Limited public access. Majority of lake shoreline is privately owned. Please respect private property. Keep lake and access sites free of litter.

Map No.4

MATANUSKA-SUSITNA VALLEYS STOCKED LAKES SERIES

State of Alaska
Department of Fish and Game
Sport Fish Division
1800 Glenn Hwy #4
Palmer, AK 99645
(907) 746 - 6300





U.S.G.S. Map Ref.	Anch. C-8, T17N, R3W, S31	Geographic Location	61°31'45"N, 149°59'00"
Elevation	142'	Surface Acres	2,495 Acres
Volume	90,723 Acre Ft.	Maximum Depth	89'
Mean Depth	30'	Shoreline Length	26.0 Miles
Surveyed	1974 ADFG	Year 1st Stocked	1988 RT
Game Fish Present	Rainbow Trout, Arctic Char, Silver Salmon, Burbot		

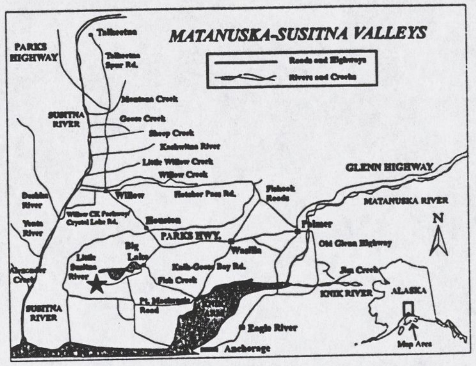
BIG LAKE PUBLIC ACCESS: Mile 52.3 Parks Hwy. West on Big Lake Rd. 3.6 miles to "Y". Right at "Y" on North Shore Drive for 1.6 miles to Big Lake East Wayside with camping, picnic tables, toilet facilities and developed boat launch. Fees required for camping and launching. Or left at "Y" on South Big Lake Rd. 1.7 miles to Big Lake South Wayside on the right with camping, picnic tables, toilet facilities and developed boat launch. Fees required for camping and launching.

6

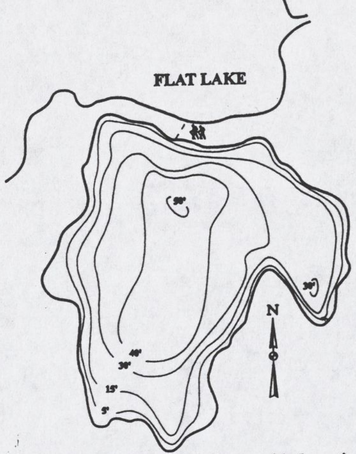
Map No. 7

SOUTHCENTRAL LAKES MAP SERIES

State of Alaska
Department of Fish and Game
Sport Fish Division
1800 Glenn Hwy #4
Palmer, AK 99645
(907) 746 - 6300



SARA LAKE ★



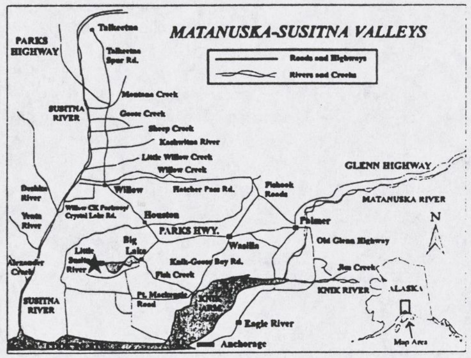
U.S.G.S. Map Ref.	Tyonek C-1, T17N, R4W, S33	Geographic Location	61°31'N, 149°59'W
Elevation	145'	Surface Acres	44
Volume	1,140 Acre Ft.	Maximum Depth	50'
Mean Depth	26.1'	Shoreline Length	1.2 Miles
Game Fish Present	Arctic Char		

SARA LAKE PUBLIC ACCESS: Access is from Flat Lake. Left after entering Flat Lake from connecting channel, approximately 0.3 mile along shoreline to a 50' ROW easement with an undefined trail leading over the small ridge to Sara Lake. The primary access to Flat Lake is by boat from Big Lake, access for Big Lake located at Big Lake South State Wayside, accessed from Mile 52.3 Parks Hwy. West on Big Lake Rd. 3.6 miles to "Y". Left at "Y" on South Big Lake Rd. 1.7 miles to Big Lake South Wayside with camping and boat launch. Fees charged. **OR:** Continue on South Big Lake Rd. 6.0 miles to Purintan Road. Right on Purinton Rd. 1.6 miles to canal between Mirror and Flat Lakes. **NOTE:** Limited public access. Majority of lake shoreline is privately owned. Please respect private property. Keep lake and access sites free of litter.

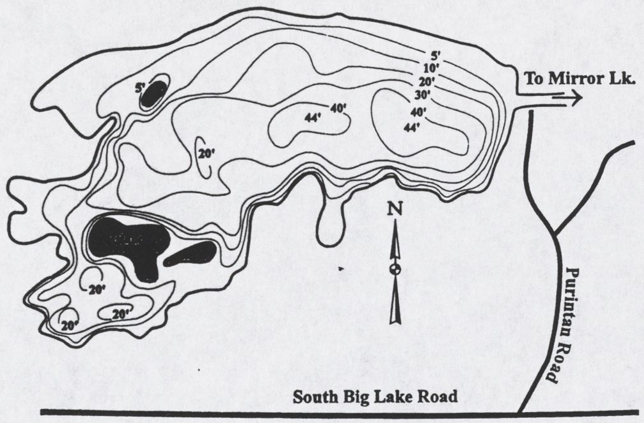
Map No. 6

SOUTHCENTRAL LAKES MAP SERIES

State of Alaska
Department of Fish and Game
Sport Fish Division
1800 Glenn Hwy #4
Palmer, AK 99645
(907) 746 - 6300



FLAT LAKE ★



U.S.G.S. Map Ref.	Tyonek C-1, T17N, R4W, S28	Geographic Location	61°31'N, 150°30'W
Elevation	142'	Surface Acres	296
Volume	5,407 Acre Ft.	Maximum Depth	44'
Mean Depth	18.3'	Shoreline Length	5.1 Miles
Game Fish Present	Rainbow Trout, Arctic Char, Coho Salmon, Sockeye Salmon, Whitefish, Burbot		

FLAT LAKE PUBLIC ACCESS: The primary access to Flat Lake is by boat from Big Lake, access for Big Lake located at Big Lake South State Wayside, accessed from Mile 52.3 Parks Hwy. West on Big Lake Rd. 3.6 miles to "Y". Left at "Y" on South Big Lake Rd. 1.7 miles to Big Lake South Wayside with camping and boat launch. Fees charged. **OR:** Continue on South Big Lake Rd. 6.0 miles to Purintan Road. Right on Purinton Rd. 1.6 miles to canal between Mirror and Flat Lakes. **NOTE:** Limited public access. Majority of lake shoreline is privately owned. Please respect private property. Keep lake and access sites free of litter.

Table 3. Known native Arctic char lakes in the Matanuska-Susitna Valley.

Lake	Surface acres	Maximum depth	Conductivity mhos	Elevation	Heaviest Arctic char	Landlocked	Watershed	Geographic location
Benka	123	75'	41	525'	3.00 lbs.	Yes	Susitna R.	62°11'N-150°15'W
Big	2,495	89'	110	142'	14.00	No	Fish Ck.	61°31'N-149°59'W
Flat	296	44'		142'		No	Fish Ck.	61°31'N-150°30'W
Mirror	44	34'		142'		No	Fish Ck.	61°32'N-149°58'W
Never-Never	31	30'		145'		No	Fish Ck.	61°31'N-149°59'W
Sara	44	50'		145'		Yes	Fish Ck.	61°31'N-149°59'W
Total	3,033 acres							

Table 4. Swanson River watershed lakes where Arctic char have been collected.

Lake	Surface acres	Maximum depth	Conductivity mhos	Elevation	Heaviest Arctic char	Landlocked	Month-Year Surveyed 1st yr.	Month-Year Surveyed 2nd yr.	No. of Arctic char captured 1st yr.	No. of Arctic char captured 2nd yr.
Anertz	33	26'		238'	1.50 lbs.	No	8/65		28	
Canoe No. 1	100	28'		185'	4.55	No	10/54	6/84	7	2
Canoe No. 2	37	73'		191'	3.94	No	10/64		10	
Canoe No. 3	28	19'		191'	1.27	No	10/64		1	
Channel	97	50'		233'	0.94	No	6/65	89	21	40
Contact	20	29'		201'	2.51	No	10/64	8/74	3	14
Cygnet	53	40'		210'	3.08	No	8/74		2	
Dog	23	57'		225'	1.63	No	7/65		7	
Dolly Varden	242	95'	34	244'	2.60	No	7/60	6/83	32	105
Drake	165	105'		234'	0.60	No	8/65		1	
Duckling	73	78'		234'	1.37	No	7/71		8	
Eider	113	58'		235'	1.00	No	7/65	7/76	19	12
Falcon	238	56'	20	260'	1.88	Yes	7/65	10/93	29	65
Finger, East	72	48'	23	235'	2.33	Yes	7/64	6/83	30	13
Finger, Middle	180	88'	28	225'	1.65	Yes	6/84	10/93	20	18
Finger, South	220	100'+		241'	3.00	Yes	7/64	9/75	1	13
Finger, West	73	42'		225'	2.52	Yes	7/64	10/93	16	0
Fish	66	61'	36	211'	2.10	No	7/61	7/83	7	17
Gavia	293	31'		205'	1.16	No	7/64	8/74	22	0
Gene	310	36'		201'	2.12	No	7/65	6/76	3	8

Table 4. Continued.

Lake	Surface acres	Maximum depth	Conductivity mhos	Elevation	Heaviest Arctic char	Landlocked	Month-Year Surveyed 1st yr.	Month-Year Surveyed 2nd yr.	No. of Arctic char captured 1st yr.	No. of Arctic char captured 2nd yr.
Grus	193	33'		170'	1.10 lbs.	?	7/71		13	
Ice	78	60'		158'	2.55	No	6/71	8/76	24	1
King	490	61'	133	208'	2.25	No	6/71	8/84	12	30
Konchanee	224	78'		208'	1.00	No	7/64	8/74	0	1
Kuviak	70	52'		253'	0.88	No	6/65		9	
Llerum	26	35'		204'	0.79	No	10/76		9	
Lonely	52	47'		225'	0.94	No	6/65		25	
Lost	47	65'		260'	1.06	Yes	6/65		7	
Lure	40	37'		217'	1.19	No	6/65		12	
Martin	75	40'		201'	0.89	No	7/78		1	
Norak	173	57'		185'	1.94	?	6/71		13	
Nuthatch	16	22'		204'	1.38	No	7/70	7/76	1	0
Olsjold	48	29'		233'	2.31	No	9/65	8/76	6	5
Paddle	97	41'	96	225'	1.43	No	6/65	6/83	55	3
Pond	23	30'		216'	1.44	No	6/65		4	
Pot	10	20'		216'	1.69	No	6/65		5	
Sabaka	75	58'		228'	1.28	No	9/65		14	
Skookum	45	60'		244'	3.60	No	9/65	7/74	24	1
Snag	306	37'	68	195'	1.01	No	8/84		5	
Spinner	11	27'				No	9/65		1	
Spruce	134	33'	90	201'	0.81	No	10/64	7/74	1	1
Stormy	390	50'	39	56'	3.44	No	6/66	10/84	23	4
Swanson	320	41'		184'	2.50	No	7/65		9	
Trout	193	57'		201'	0.75	No	7/64	8/74	2	1
Waterfowl	77	46'		211'	2.00	No	7/65		15	
Wilderness	155	31'		205'	2.91	No	6/71	8/84	1	5
Wolf	88	42'		195'		No	9/82		36	
Woods	48	25'		240'	2.63	No	6/65		11	
Wyrob	32	60'		261'	1.62	No	9/65		1	
Total	5,972									

Table 5. Pyloric caeca and gill raker counts of Arctic char from the Upper Cook Inlet and Kodiak Island areas of Alaska.

Lake	Watershed	Year	Number of fish	Pyloric caeca mean	Pyloric caeca range	Number of fish	Gill rakers mean	Gill rakers range	Source
Big	Fish Creek	1987	166	46.1	35-57	72	25.4	19-28	Havens
Sara	Fish Creek	1988	13	44.4	39-53	13	25.2	24-27	ADF&G
Never-Never	Fish Creek	1988	2	44.5	43-46	2	24.5	24-25	ADF&G
Finger, East	Swanson River	1964	19	45.8	39-59				Engel
Falcon	Swanson River	1993	2	37.5	37-38	6	24.0	22-26	Tobin, Palmer
Finger, Middle	Swanson River	1993	3	46.7	45-49	1	24		Tobin, Palmer
Cooper	Kenai River	1999	6	39.8	35-45	6	23.0	22-24	Dean, Larson
Karluk	Karluk River	1943	60	45.6	30-64	70	23.4	21-26	DeLacy, Morton
Karluk	Karluk River	1961	32	44.3	35-57	32	23.6		McPhail
Karluk	Karluk River	1980	7	46.2	39-49	7	23.1	21-25	Morrow
Frazer	Dog Salmon Ck.	1961	54	42.9	36-55	54	24		McPhail
Totals, averages or range			354	45.2	30-64	263	24.2	19-28	

Table 6. Age and growth of Arctic char in southcentral Alaska.

Lake	Year	Fork length in inches - age in years: I	II	III	IV	V	VI	VII	VIII	IX	X	XI	Number aged
Big	1987	5.2	7.0	9.0	11.5	13.7	16.5	18.7	19.9	20.7	22.7	23.7	
		4	23	142	101	69	47	43	46	19	10	2	506
E. Finger	1993			10.8	11.4	13.3	13.6		18.3				
				11	10	5	1		1				28
M. Finger	1993			5.6	10.5	11.4	13.2	12.3					
				2	3	10	2	1					18
Falcon	1993			9.4	11.7	12.6	14.1	13.7					
				1	16	23	9	4					28
Cooper	1962		7.0	9.0	11.2	13.6	14.8	16.5					190
Average growth		5.2	7.0	9.1	11.5	13.2	16.0	18.2	19.9	20.7	22.7	23.7	

The last glacial period ended here about 9,500 years ago (Reger and Pinney). The Arctic char native to the Matanuska-Susitna Valley have shown little tendency to colonize adjacent waters. Benka Lake is the only lake known to support Arctic char in the Susitna River watershed. The char native to Big Lake are still confined to lakes connected to it or not over a quarter of a mile away. This species has shown little tendency at range expansion since the end of the last major (Wisconsin) glaciation.

Northern pike have been reported in Big Lake (Table 7). In other southcentral lakes where pike have become abundant they have decimated rainbow trout populations. Big Lake is the first southcentral Arctic char lake where pike are known to have become established. Their effect on the Arctic char probably won't be known for some time.

Other species that coexist with Arctic char in Big Lake include rainbow trout, coho and sockeye salmon, burbot, longnose sucker, round whitefish, slimy and prickly sculpin, three and ninespine stickleback and Arctic lamprey (Havens).

By the mid 1980's there were over 500 private lake front cabins and residences, two state waysides, a commercial campground, two marinas, seven restaurants and three motels on Big Lakes shoreline. These facilities disposed of human wastes primarily with individual on-site septic systems. In addition to the concern about the presence of northern pike there are also concerns about eutrophication (enrichment) of Big Lake from residential and commercial development.

Concern about the eutrophication of Big Lake led to a two year study by hydrologist Paul Woods of the U.S. Geological Survey. His study showed both winter and summer oxygen depletions in the lakes deeper basins. These oxygen depletions were most severe during August and September each year.

Suitable summer habitat for Arctic char in this area is not well known. Most salmonid species do best in oxygen concentrations of 5 parts per million (p.p.m.) or more. I assume this requirement includes Arctic char. We know this species is cold adapted. My guess is that summer habitats suitable for Arctic char include water temperatures of 39 to 55 degrees F. and dissolved oxygen levels of 5 p.p.m. or more.

In the east basin during August and September, 1983 oxygen levels below a depth of 33 feet were less than 5 p.p.m.. For a short time in September water temperatures in the east basin exceeded 55 degrees F. above a depth of 26 feet. If my Arctic char habitat requirements are reasonably accurate, they should have been restricted to a band of water only seven feet wide at that time of the summer. If nutrient loading from human activities intensifies and oxygen depletions extend higher into the water column, east basin may become ~~poor~~ summer habitat for Arctic char. Warmer water temperatures could also reduce the useable char habitat zone in the east basin. Most lakes with good Arctic char populations are deep, cold, nutrient poor and have chlorophyll a levels of 2.3 micrograms or less. A second report by Paul Woods recommended that the east basin be reclassified as mesotrophic (moderate level of nutrients) based on mean chlorophyll a determinations of 4.96 micrograms per liter in 1983 and 2.81 micrograms per liter in 1984.

Fortunately the deeper western basin was not as affected by low oxygen levels. In that basin during 1983 the minimal habitat zone was about 20 feet wide and extended from a depth of 30 feet down to 50 feet.

A state salmon and trout hatchery located on Meadow Creek, Big Lake's principle tributary, operated from 1975 to 1992. Effluents from the hatchery probably contributed to the enrichment load. The sockeye salmon escapement goal for Big Lake is 50,000 fish. Unusually large escapements in the mid 1980's and mid 1990's may also have added to the enrichment problem at Big Lake (Figure 1).

During the years from 1992 to 1997 annual fishing pressure on Big Lake declined to 9,370 angler days (Table 7). The harvest of Arctic char declined from 6,840 in the ten years between 1977 and 1986 to 1,713 in the 1990's. Fortunately anglers only harvested 40 percent of the char they caught in the 1990's.

Concerns about the declining catch of Arctic char in Big Lake prompted the Alaska Board of Fisheries to reduce the daily and possession limit from five char to one char 20 inches or more in length. In addition the Fisheries Board approved regulation changes that limited the winter fishery ,when many char are caught, to unbaited, single hook artificial lures.

In 1989 ADF&G began stocking selected lakes with Arctic char of Lake Aleknagik origin. This year 11 deeper lakes with be stocked in the Matanuska-Susitna Valley. Three lakes will also be stocked to enhance sport fishing opportunities in the Anchorage area. .

KENAI PENINSULA

Swanson Arctic char lakes

The Swanson River is a small, bog stained, low gradient river . It drains a 277 square mile watershed on the Kenai lowlands into Cook Inlet. This watershed contains more lakes than any other watershed on the Kenai National Wildlife Refuge. There are 125 named lakes and as many unnamed ponds. Ninety one of the named lakes have been test netted by the ADF&G or the USFWS.

The Swanson River Oil Field is located on four square miles of refuge land close to the Swanson River. In recent years there have been oil and produced water spills from this field. In the 1970's and 1980's there were problems with polychlorinated biphenyls (PCB) contamination.

The Swanson River watershed is home to every known Arctic char lake on the refuge. These lakes are listed in Table 4. Stormy Lake in Captain Cook State Park and Dolly Varden Lake on the refuge are the only road accessible lakes. Aircraft landings are permitted on 15 of the char lakes. The other char lakes are accessible on foot or by canoe during the summer. Eleven lakes are available to snowmobilers

Table 7. Big Lake stocking, creel census and netting summary.

STOCKING ACCESS: same as public access
STOCKING METHOD: truck

LAKE: Big
ACRES: 2,894

Year Stocked	Species	Number Stocked	Stocking Density (fish/a)	Stocking Size	Effort (angler days)		Number Harvested (H) or Caught (C): Landlocked Salmon	Rainbow Trout	Burbot	Arctic Char/ Lake Trout	Fish/ Angler-Day
1992	RT	299,131	103	1.2g	11,545	H	1,979	2,090	110	2,597	0.58
						C	3,483	5,296	178	6,202	1.30
1993	RT	612	0	738.0g	8,446	H	2,566	2,073	278	1,812	0.76
						C	2,817	4,845	439	4,686	1.46
1994					9,987	H	2,004	2,260	279	1,489	0.58
						C	2,768	5,502	299	5,086	1.34
1995					6,888	H	209	1,365	110	1,228	0.42
						C	1,053	3,502	237	2,964	1.13
1996					9,649	H	578	1,884	44	1,340	0.40
						C	3,819	6,232	80	3,819	1.45
1997					9,702	H	389	1,745	252	1,809	0.43
						C	1,396	5,352	361	3,226	1.07
1998						H					
						C					

TEST NET SAMPLING

Date	Species	Age Class	#	Range(mm)	Avg	C/FNHr
6/21/88	RT	1-5	360	118-433	198	0.91
"	AC	1-8	70	189-584	426	0.18

Also LNS, SS, RS, RWF not recorded

FTP: OPEN DRAINAGE: NO BIG LAKE RAINBOW TROUT AVAILABLE

COMMENTS: Big Lake was first stocked with Big Lake strain rainbow trout (RT) by ADFG in 1988 then stock annually with Big Lake RT fingerling from 1989-1992; the remaining Ft. Richardson BDC Big Lake strain bro stock were stocked in 1993. We did increase the total number of RT in Big Lake through our stocking a hopefully more spawners will equate to a reasonable number of harvestable fish over time. During October 199 Board of Fisheries meetings, the Arctic char bag and possession limits were lowered to one per day, one possession with a minimum length requirement of 20 inches. Also, a special provision was established that requir the use of unbaited, single-hook, artificial lures from November 1 through April 30. There have been reports Northern pike catches in the last several years. If the Northern pike become well established there could be detrimental effect on the other fishery populations.

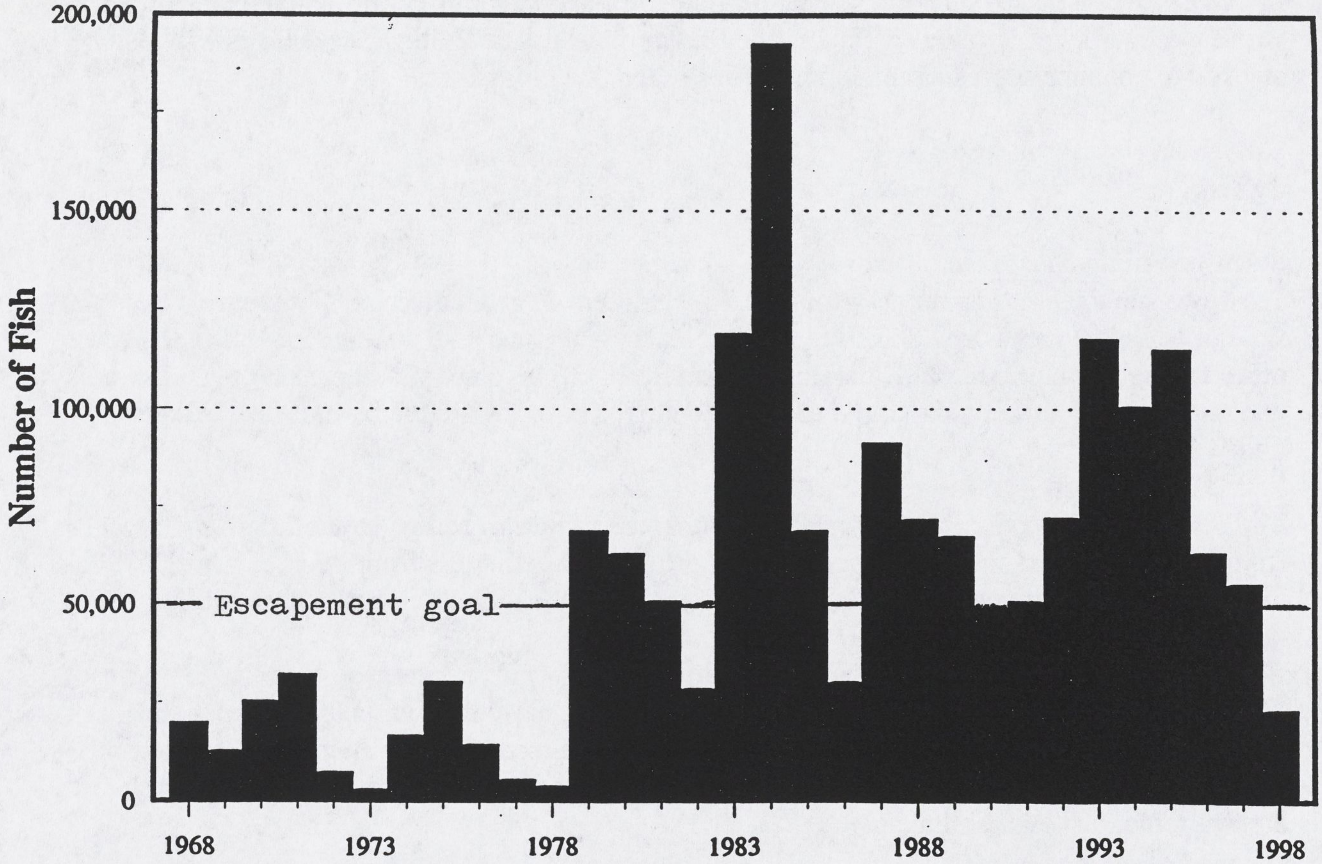


Figure 1. Sockeye salmon escapements into Fish Creek (Big Lake).

Most of my first hand knowledge of Arctic char has come from fishing one-third of these lakes. These are the char waters I am most familiar with. These fish were not identified as Arctic char until 1964 when state fishery biologist Larry Engel started counting pyloric caeca and gill rakers. Prior to that time everyone considered these fish to be Dolly Varden.

Arctic char , usually listed as Dolly Varden in the older reports, have been recorded from 49 lakes in the Swanson River watershed (Map 8). My wife and have caught char in two named lakes that have not been test netted. A red tailed char was observed in an unnamed lake when it followed a lure to the canoe but did not bite. This species is more than likely present in several other unsurveyed lakes on the refuge. Arctic char are believed to be reproducing in two-thirds of the lakes listed in Table 4. They are apparently present from downstream drift in lakes where reproduction appears to be lacking.

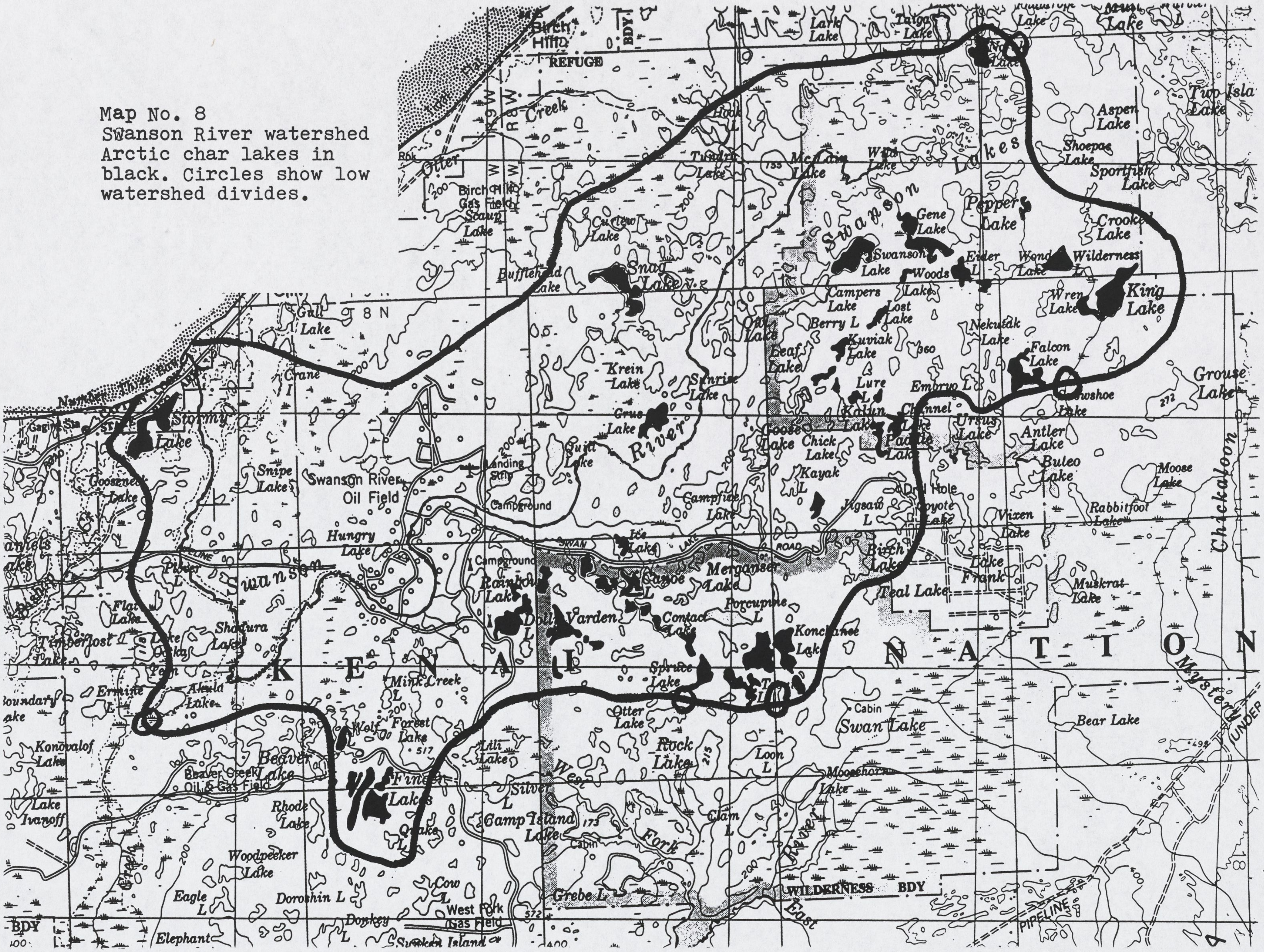
In one third of the lakes only a few char were captured during the initial lake survey. In some cases these lakes have been resurveyed. If few or no char were taken during a second test netting this suggests that little or no reproduction is taking place in the lake. Of course the lake surveys have to be looked at with a critical eye. If the lake was surveyed in July or August, and the nets set in shallow water, Arctic char could have been present but remained undetected in the hypolimnion (deep water layer).

In southcentral Alaska Arctic char are near the southern limit of their range. The critical time of the year in this area occurs during the summer months. They must have access to cold water with adequate oxygen levels to survive. Some of the deeper, nutrient poor lakes on the Kenai Peninsula provide this type of essential habitat. In order to maintain viable populations, they must also have suitable in lake gravel spawning areas deep enough to avoid freezing.

Lowland refuge lakes normally freeze over by late October and remain frozen until early May. During the summer, surface water temperatures seldom exceed 70 degrees F. Fish in spawning color are seen in October when ripe char have been taken near the end of the month. Spawning appears to occur in late October or early November about the time these lakes freeze over. Spawning males are a golden color with large pink spots and white edged ventral fins. They are strikingly beautiful in appearance. They are also heavily parasitized. Common loons nest on most char lakes and are a likely link in the life cycle of the parasites. These char feed on snails, sticklebacks, sculpins and aquatic insects. The largest Arctic char reported during lake surveys weighed 4.55 pounds (Table 4). Most of the char my wife and I catch weigh less than a pound. I consider a two-pounder a big one and a three pound specimen trophy sized. Swanson Arctic char share every lake with threespine stickleback. Other species that occur in some of the lakes include rainbow trout, longnose sucker, coho and sockeye salmon, coastrange sculpin and Arctic lamprey.

The Wisconsin glaciation ,that occurred from 9,500 to 25,000 years ago, covered most of southcentral Alaska. Studies by glacial geologist Reger and Pinney indicated that parts of the rain shadowed western Kenai Peninsula remained unglaciated. The Caribou Hills were one of the areas that remained ice free. In addition, there is evidence of several ice dammed lakes. Cook Inlet was filled with glacial ice until 16,500 years ago. Most of this ice originated from

Map No. 8
Swanson River watershed
Arctic char lakes in
black. Circles show low
watershed divides.



glaciers flowing from the Alaska Range and the Chugach Mountains. This ice blocked the outlet of the Kenai River and diverted its flow south into the Kasilof River. The outlet of the Kasilof River was also blocked by glaciers and flowed into one of the ice dammed lakes. The Swanson River was also diverted by coastal ice. Where it now turns to the north, the Swanson River was diverted south down the present channel of Beaver Creek becoming a tributary of the Kenai River. In spite of these harsh environmental conditions, freshwater fish probably survived in one or more glacial refugiums on the Kenai Peninsula.

The presence of lake trout, as an example, is evidence that this species survived the Wisconsin glaciation on the Kenai Peninsula. This char is intolerant of salt water. It is unlikely that lake trout invaded the Kenai and Kasilof Rivers from the sea.

Arctic char have been collected in only two areas on the Kenai Peninsula. An isolated population was found last fall in Cooper Lake in the Kenai River watershed. The center of distribution on the Kenai Peninsula is the lowland Swanson River watershed.

There is a low divide separating Gavia Lake in the Swanson River watershed from Long Lake that straddles the divide between the Swanson and Moose Rivers. According to the Kenai (C-2) NW 1:25,000 USGS map a fish would have to climb only seven feet to reach Long Lake from Gavia Lake. Long Lake (55 acres) is deep enough, with a maximum depth of 37 feet, to provide both summer and winter habitat for Arctic char. There is no evidence that Arctic char have crossed this divide. The species was described as a poor jumper by Scott and Crossman which might explain their inability to colonize adjacent watersheds. There is a low marshy divide east of Falcon Lake. Unnamed streams are shown to drain this marsh north towards the Swanson River and south towards the Chickaloon River. There is no evidence that char have crossed this low divide either. There are several other low divides (Map 8) around the rim of the Swanson River basin that Arctic char are not known to have surmounted.

There are 22 lakes in the adjacent Moose River watershed with maximum depths of 30 feet or more. Many of these lakes appear suitable for Arctic char but this species has never been reported in this basin. In the Chickaloon River watershed there are five lakes with maximum depths of 44 to 84 feet. Arctic char have not been reported from this watershed. There are deep lakes to the north of the Swanson River in the adjacent Bedlam, Pincher and Seven Egg Creek watersheds. Reportedly these lakes remain free of Arctic char.

In the 1930's 4,220 Arctic char were tagged at Karluk Lake on Kodiak Island (DeLacy). The author concluded: “With few exceptions the tagged charr after approximately one year of liberty were recovered in the every place they had been tagged”. This lack of movement and poor jumping ability are no doubt important reasons for the restricted range of this species in southcentral Alaska.

The picture that emerges is that the Swanson Arctic char have not expanded their distribution to adjacent watersheds on the Kenai Peninsula. Even within the Swanson River watershed, they do not appear to have accessed all suitable lakes. This information further suggests that Arctic char did not migrate into the Swanson River from the sea, at least not since the end of the Wisconsin glacial period. If they had come in from the sea, they should be present today in most of the deeper lakes throughout the Kenai Peninsula. Their present limited distribution suggests they survived the last glaciation in a local refugium and have not extended their range beyond the Swanson River watershed on the Kenai National Wildlife Refuge..

During the summers of 1967 and 1968, the ADF&G conducted a vertical gill netting study in East Finger Lake. The purpose of the study was to determine why Arctic char were a minor part of the summer sport fishery while contributing substantially to the fall, winter and spring sport fish harvest. During the two summers, 89 percent of the char were caught in water colder than 55 degrees F. This study determined that the char occupied the colder mid-water and bottom depths during the summer but rose to surface layers in the fall where they became readily available to the sport fishery.

This study also determined that mature females ranged in fork length from 11.6 to 14.3 inches. Mature males were somewhat larger and ranged from 14.8 to 16.3 inches. Only 35 percent of the char over 11.6 inches in fork length were mature suggesting the species was an alternate year spawner.

Fecundity was also determined for 29 mature females. The number of eggs varied from 413 in a 12 inch char to 870 in a 13.9 inch female. This relationship was expressed by the formula $Y=3.64X - 591.1$ where Y is the egg count and X is the fork length of the female in millimeters.

In 1987 the USFWS collected Arctic char from East Finger and Dolly Varden Lakes and Dolly Varden from the Fox River. These fish were sent to the University of Wisconsin at Milwaukee. Geneticists from this university have published several reports that include fish from one or both of these lakes. The first report in my possession (Phillips et al, 1992) indicated the Swanson Arctic char were different at one restriction site for ribosomal DNA from Arctic char collected in Arctic Canada and Maine. The Swanson Arctic char were two restriction sites different from the southern form of the Dolly Varden collected at two locations in Alaska and three restriction sites different from Arctic char from Scotland and Norway.

A second report by Leder and Phillips in 1998 using char from East Finger Lake showed they grouped with Arctic char from Bristol Bay in one test. In another test the East Finger Lake char grouped with Arctic char from eastern Siberia and Arctic Canada. In a third test the East Finger Lake fish were different from all other groups of Arctic char and Dolly Varden tested.

A third genetic paper by Phillips et al in 1999 again indicated differences between the Kenai Arctic char and Arctic char from northern Canada and the southern form of the Dolly Varden. These authors concluded that their results can be considered preliminary until additional genetic data on char has been obtained.

Except for the studies done by the ADF&G at East Finger Lake little more than cataloging has occurred on the Kenai Peninsula. No spawning areas have been described. No one has captured a young of the year Swanson Arctic char. These char are heavily parasitized but we don't know what species of parasites they're hosting. We don't know if people could become parasitized by eating under cooked char.

Several Swanson char lakes appear to support little biological productivity. These lakes have clear water but scanty shallow water aquatic vegetation. They are usually located at or near the top of a small watershed. Duckling, Middle and South Finger and Sabaka Lakes are representatives of this type of nutrient poor lake. Sustainable harvest levels appear to be low. Such lakes may not be able to support more than a minimal level of exploitation without suffering a decline in productivity. If sport or subsistence fishing pressure increases it may be necessary to determine sustainable harvest levels, not only for these lakes, but also for the more productive char lakes.

The only current threat to any of the Kenai National Wildlife Refuge Arctic char lakes could occur in a year or two when Marathon Oil Company drills for natural gas near Middle Finger and Wolf Lakes.

Cooper Lake

Prior to 1959 Cooper Lake was a natural lake in the Chugach National Forest. At that time it had a surface area of 1,990 acres and was over 400 feet deep (Table 8). The lake was 5 miles long and nearly a mile wide (Map 9). It was nestled between two mountains at an elevation of 1,168 feet. Eight tributaries drained several small glaciers on north facing slopes. Five mile long Cooper Creek drained from the north end of the lake to the Kenai River. The lower reaches of Cooper Creek served as a spawning area for rainbow trout and several species of salmon. Water levels in Cooper Lake were most likely relatively stable and probably fluctuated only one or two feet during the year. I have taken the liberty of referring to the resident char as Arctic char in this section on Cooper Lake. My reason for doing so will be explained later.

Cooper Lake is a unique char lake. With the exception of nearby Char Lake, it lies at a higher elevation than any other lake populated with Arctic char in southcentral Alaska. It is also the deepest lake. This lake is 82 miles from Cook Inlet making it and its tributary lake the farthest Arctic char lakes from the sea in the Cook Inlet-Kodiak Island area.

Before impoundment there was a steep incline on Cooper Creek that prevented other species of fish from reaching Cooper Lake. How char and sculpins reached this mountain lake is a mystery. There are four possible avenues of access. The first one is Cooper Creek where conditions had to be different in the past than they are now to allow fish passage. Another possibility is that they made their way up from Kenai Lake and crossed the saddle between the two lakes. A third possibility is access across the saddle to the west between Cooper and Upper Russian Lake. Another possibility is access up the Resurrection River from the Seward area.

If fish reached Cooper Lake from Kenai Lake, they should be present in the ~~small~~ lakes on both sides of the saddle between the two lakes. Arctic char were found on the west side of the divide when Char Lake (10 acres, 22 feet deep) was surveyed by the ADF&G in 1970 (Table 8). There were no fish in Rainbow Lake (then known as Fetus Lake) (15 acres, 26 feet deep) on the east side of the
divide when it was sampled by ADF&G in 1970. The presence of fish in the small lake on the

Table 8. Known Arctic char lakes in the Kenai River watershed.

Lake	Surface acres	Maximum depth	Conduct-ivity mhos	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Char	10	22'		1,250'	1.58 Lbs.	Yes*	60°23'N-149°43'W
Cooper	1,990	450'+	71	1,168'	2.42	Yes*	60°24'N-149°46'W
Total	2,000 acres						

* Fish can get out of both lakes but they cannot get in.

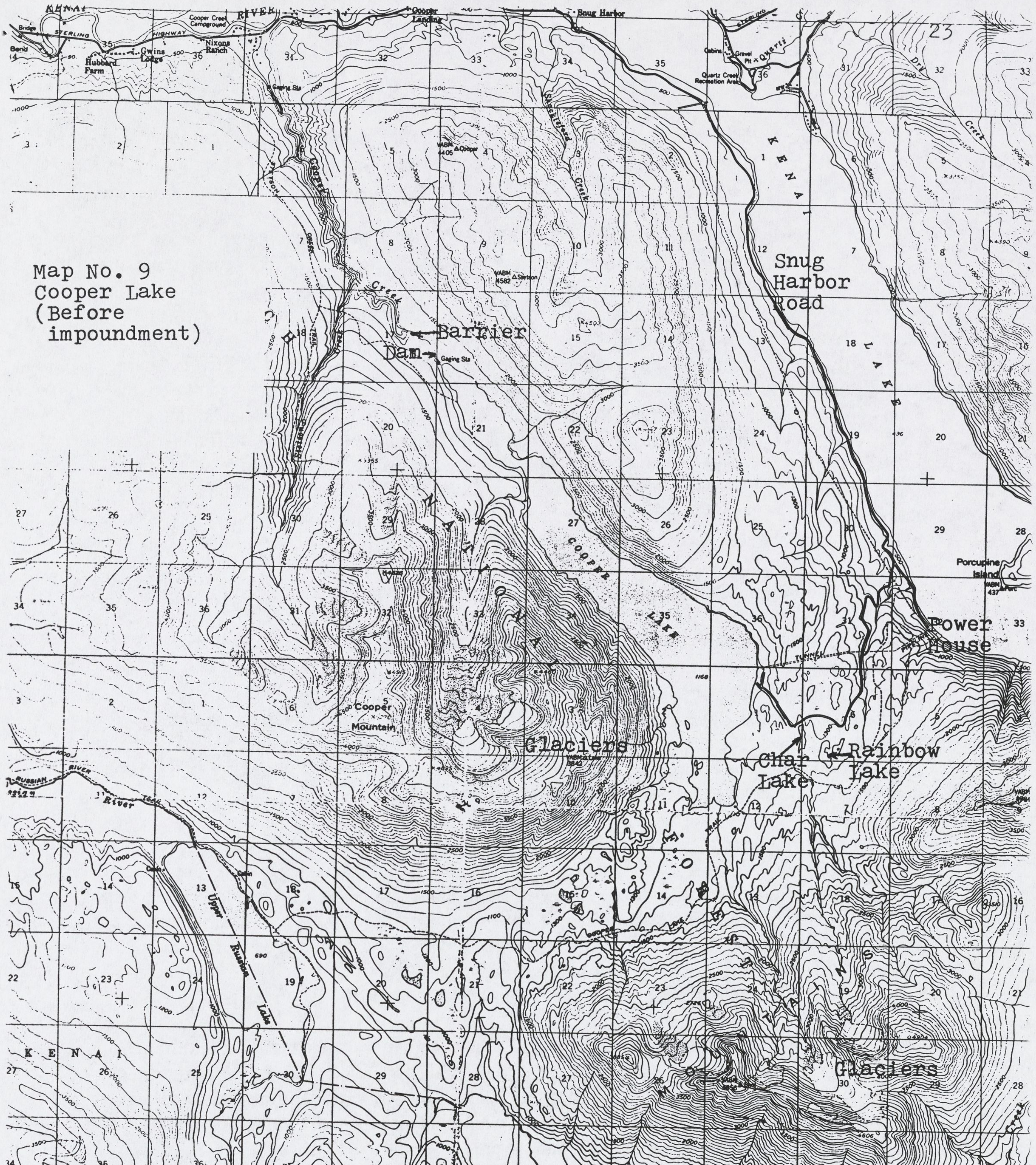
Table 9. Known Arctic char lakes on Kodiak Island.

Lake	Surface acres	Maximum depth	Conduct-ivity mhos	Elevation	Heaviest Arctic char	Land-locked	Geographical location
Frazer	4,100	193'	52	353'		*	57°15'N-154°10'W
Karluk	9,728	413'	71	365'	3.19 Lbs.	No	57°23'N-154°03'W
Total	13,828 acres						

* There was a water falls at Frazer Lakes outlet that has been bypassed by a fish ladder.

Table 10.
Dolly Varden/Char samples from Cooper Lake, 11/22/99.
Collectors: Pattie Berkhahn (ADF&G), Vickie Davis (FWS), Jack Dean (Retired FWS), Mark Wegner
Collection Method: Nets
Disection: Vickie Davis, Jack Dean, Larry Larson (ADF&G)

Genetics Sample #	Fork Length	Wt. (grams)	Sex	Maturity	Gill Raker Cnt.	Pyloric C.	Spots	Stomach	Color
1	320	620	M	Non Spawn	23	43	Large	Eggs	Yellow on Belly
2	230	114	M	Sperm	23	38	Small		14 Parr Marks, small spots
3	419	815	M	Undeveloped	22	41	Large	Snails	Light Colored
4	217	100	F	Developed Eggs	23	37	Small & 1 lg		14 Parr Marks
5	410	610	M	Weakly Developed Testes	24	45	Large	Snails & Eggs	Yellow on Belly
6	424	810	M	Non Spawn	23	35	Large	Snails	Light Colored



Map No. 9
Cooper Lake
(Before
impoundment)
Barrier
Dam
Snug
Harbor
Road
Power
House
Char
Lake
Rainbow
Lake
Glaciers
Glaciers
Cooper Mountain
Cooper Landing
Snug Harbor
Porcupine Island
Upper Russian Lake

west side of the saddle but not in the small lake on the east side suggests fish did not reach Cooper Lake from Kenai Lake unless they subsequently died out in Rainbow Lake. Steep gradients (Map 9) also make fish passage from Kenai Lake unlikely.

Arctic char accessing Cooper Lake from the Resurrection River would likely be an anadromus form. Access from this route also seems unlikely because the east side of the Kenai Mountains receives several times more precipitation than the rain shadowed western side. Today the east side of the Kenai Mountains is far more heavily glaciated than the west side. Presently there are several tide water glaciers on the east side of the mountain but none on the west side. It has only been a few hundred years since Exit Glacier melted back from the Resurrection River. During the Wisconsin glaciation this glacier and several others filled the valley with ice that more than likely prevented fish from reaching the headwaters of the Resurrection River. If Arctic char reached Cooper Lake using this route, they should also be present in lower elevation lakes such as Bear, Golden Fin or Meredian Lakes. Unless the char in this area have been misidentified there are no known Arctic char populations on the east side of the Kenai Mountains. If char climbed 1,200 or 1,300 feet into the mountains to reach Cooper Lake, they should have been able to reach more accessible lakes at lower elevation on the east side of the Kenai Peninsula.

A final possibility is damming by glaciers across the narrows near the north end of Cooper Lake. (Map 9). This could have raised the lake level and caused Cooper Lake to overflow to the west through a saddle to the Resurrection River. Lowell Glacier and other glaciers could have blocked the river valley and created an ice dammed lake. When this lake filled it would have spilled to the north into Upper Russian Lake. Char and sculpins could have migrated up the Kenai River, reached Upper Russian Lake via the Russian River, entered the ice dammed lake,and then moved up the headwaters of the Resurrection River to Cooper Lake. If this theory is correct there may be Arctic char in Upper Russian Lake. A fish sampling effort in this lake could lend credence to or invalidate this theory.

Char Lake is about a mile by stream from Cooper Lake. The elevation of this little lake is between 1,250 and 1,300 feet or about 100 feet higher than Cooper Lake before its outlet was dammed. Char Lake is tributary to an unnamed stream that drains into Cooper Lake. Because of steep gradients fish may have had a difficult time climbing nearly 100 feet to reach Char Lake. If Cooper Lakes normal outlet to the north was blocked by local glaciers fish could have easily reached Char Lake if it became inundated by high water levels. The presence of Arctic char in Char Lake may be evidence of much higher water levels in Cooper Lake in the past.

None of the potential access routes for char and sculpins were probably available until most of the large glaciers melted back from this part of the Kenai Mountains. Char and sculpins must have been the first and only species to colonize Cooper Lake by whatever route they traveled. Shortly thereafter the window must have closed excluding all other species of resident fish from reaching Cooper Lake until stocking programs were initiated in 1984. It is not known when the window to Cooper Lake opened or when it closed. It's possible the endemic char and sculpins have remained isolated in Cooper Lake since the end of Wisconsin glaciation 9,500 years ago.

Earlier in this report Benka Lake was described as the only known lake with an Arctic char population in the Susitna River Valley. At Big Lake resident char have not spread to any lake not directly connected to that lake or over a quarter of a mile from it. In the Swanson River watershed, the stay at home resident char have not spread to adjacent drainages or even inhabited all suitable lakes within this same basin. The picture that emerges is of a char species that rarely enters streams and has shown little tendency to stray.

How did a sedentary species follow melting glaciers 82 miles up the Kenai River and then climb nearly 1,200 - 1,300 feet into the Kenai Mountains to reach Cooper Lake? The char that made that successful journey probably had a different genetic makeup from the immobile Arctic char that occurs elsewhere in the Upper Cook Inlet area. Hopefully samples from representative lakes will be collected and analyzed this year to determine if genetic differences exist among the widely separated relict Arctic char populations in southcentral Alaska.

In 1959 Chugach Electric Association built a 70 feet earth fill dam across Cooper Creek at the outlet of Cooper Lake. This dam increased the surface area to 3,100 acres at spillway level. The dam also created 112,000 acre feet of useable storage. A tunnel, 11 feet in diameter and nearly two miles long, carried water to a power plant on Kenai Lake where two 10,500 horse power turbines that were connected to two generators of 7500 kw capacity each. Snug Harbor road was constructed to access the power plant and Cooper Lake. Cooper Reservoir filled and spilled in 1961. Water level fluctuations since 1959 are shown in Figure 2.

Once power generation began all run-off from Cooper Reservoir into Cooper Creek ceased. As a result stream flow in Cooper Creek declined about 80 percent and summer water temperatures decreased by 6 to 8 degrees F. What had formerly been a rainbow trout and salmon spawning area in lower Cooper Creek was no longer attractive to these species. Dolly Varden, however, continued to use the stream as a spawning area.

The USFWS conducted a pre-impoundment fishery survey in 1955. Unfortunately that report has not been located. A one month creel census by the USFWS in 1962 reported that 826 anglers caught 3,665 char for an average of 4.43 fish per angler. This is considered excellent fishing for resident species even by Alaskan standards. A 1964 report by the U.S. Fish and Wildlife Service suggested that the reservoirs fish population was perhaps in better condition than before impoundment but no evidence was offered to support this claim.

The initial post-impoundment gill netting of Cooper Lake by the ADF&G in 1973 indicated that Cooper Reservoir was populated primarily with small char averaging 8.7 inches in fork length (Table 12). A second gill netting effort in 1983 showed an improvement in mean size to 10.3 inches.

In 1984 ADF&G stocked Cooper Lake with 125,586 fingerling Chinook salmon. After a year or two when these salmon left the reservoir through the outlet tunnel to the power plant. ADF&G began stocking rainbow trout in 1987 in an effort to enhance the sport fishery. This program continued until 1994 (Table 11). During that period over 1.6 million rainbow trout fry and fingerlings were stocked. There is evidence that rainbow trout are now spawning succesfully in

Figure 2. Cooper Reservoir water level fluctuations, July 1959 through October 1999.

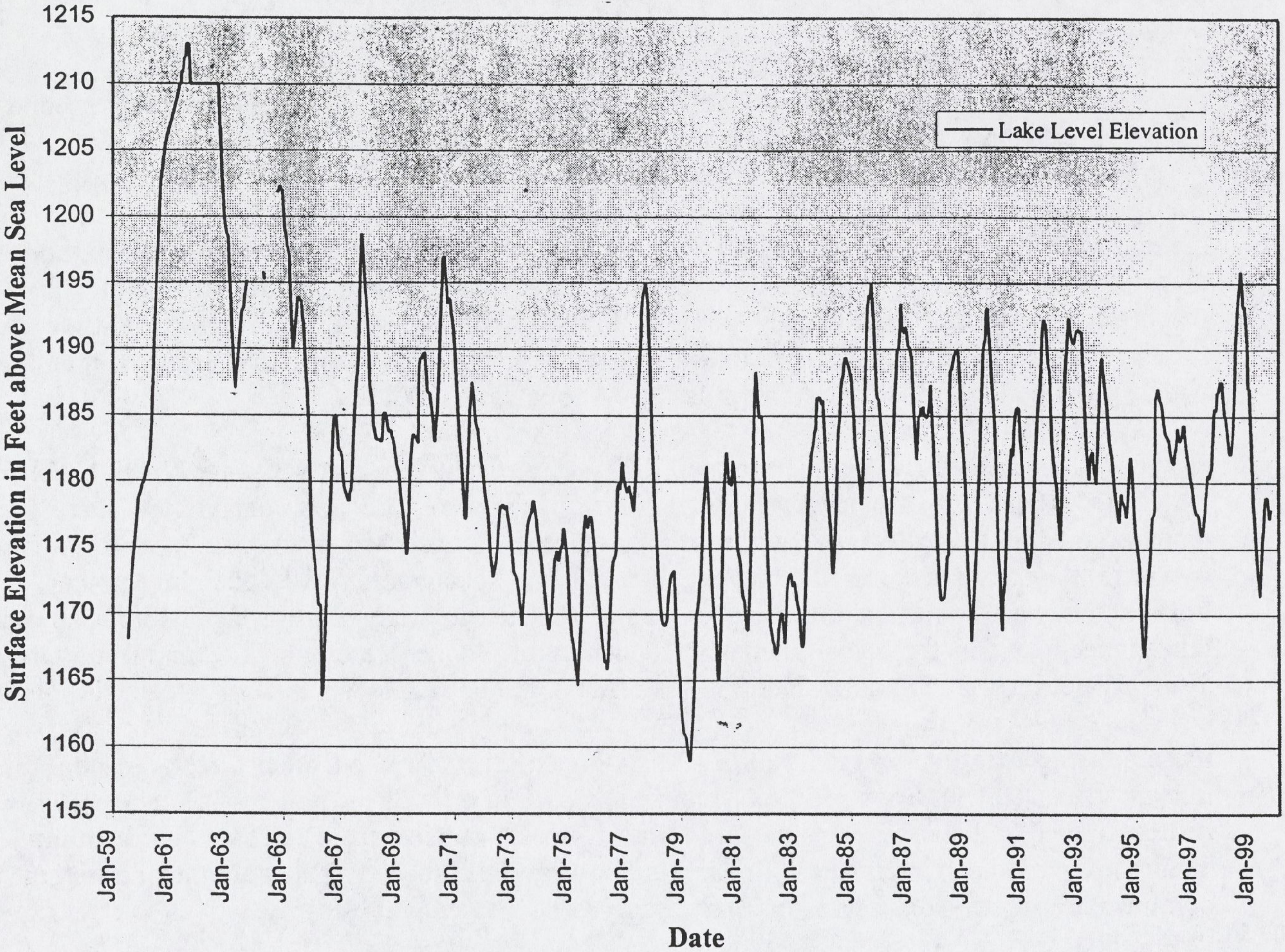


Table 11. Fish stocking summary, Cooper Lake, 1984 to 1994.

Trip Date	Species	Number Released	Hatchery	Stock	Brood year	Age	Weight (grams)
6/12/84	chinook	125586	Trail Lake	Quartz Cr.	1983	fingerling	2.3
6/23/87	rainbow tr.	421700	Ft Richardson	Swanson R.	1987	fed fry	0.15
6/23/87	rainbow tr	84200	Ft Richardson	Big Lake	1987	fed fry	0.15
6/23/89	rainbow tr	275569	Ft Richardson	Swanson R.	1989	fed fry	0.17
8/02/90	rainbow tr	50000	Ft Richardson	Swanson R.	1990	fingerling	1.3
6/12/91	rainbow tr	250000	Ft Richardson	Swanson R.	1991	fed fry	0.1
6/25/92	rainbow tr	259848	Ft Richardson	Swanson R.	1992	emerg. fry	0.25
6/10/93	rainbow tr	97251	Ft Richardson	Swanson R.	1993	emerg. fry	0.2
6/10/93	rainbow tr	161700	Ft Richardson	Big Lake	1993	emerg. fry	0.2
7/22/94	rainbow tr	24728	Ft Richardson	Swanson R.	1994	fingerling	1.29
7/22/94	rainbow tr	15023	Ft Richardson	Swanson R.	1994	fingerling	2.5

Records provided by ADF&G

the reservoir's tributary streams.

The gill netting CPUE's (catch per unit of effort) listed in Table 12 for Cooper Lake are much higher than any other Arctic char population in this part of Alaska. The fluctuating CPUE's and mean lengths obtained by ADF&G do not show obvious trends. The low CPUE's for char in the 1990's are probably the result of sampling during the warmest part of the summer when surface waters are avoided by most Arctic char and gill net catches of that species are reduced.

I took the liberty of combining the four years of results obtained by the ADF&G. The CPUE's were converted from numbers of fish per hour to pounds caught per hour. The results were compared with several other char populations. The results are shown in Table 14. These results support the conclusion that Cooper Lake supports an abundant population of mostly small char.

The results of two minnow trapping efforts by the USFS are shown in Table 13. The CPUE was nearly identical both years. The CPUE was 0.46 coastrange sculpins in 1992 and 0.48 sculpins in 1994.Minnow trapping results from lakes supporting Swanson Arctic char populations in the early 1980's showed similar catch rates for coastrange sculpins. The mean CPUE from 10 lakes was 0.50 sculpins per hour with a range of 0.08 to 1.68. This sampling method indicated that Cooper Lake supports a moderately abundant sculpin population. This species seldom grows longer than four inches (Morrow). Food habit observations on Cooper Lake by the ADF&G showed that sculpins had been eaten by 10 percent of the 114 char stomachs checked in 1983 and 1984. The smallest char that had eaten a scuplin was 10.1 inches in fork length. Most of the sculpin eaters were over 12 inches long.

Available age and growth results for Cook Inlet area char populations are shown in Table 6. In 1962 the Cooper Lake char were growing slower than the Big Lake char but growing as well as or a little better than the char in three Swanson lakes. The six char collected in 1999, a rather small sample, show similar growth to the 1962 study. Obviously a larger number of Cooper Lake char need to be aged to make a meaningful comparison.

A temperature profile taken by the limnology section of ADF&G on August 6, 1999 is shown in Figure 3. The north basin had higher water temperatures than the deeper main basin. An oxygen profile taken this same day showed excellent levels at all depths tested (Figure 4).

A three hour gill netting effort by the ADF&G and the USFWS on November 22, 1999 produced some surprising results. Only six char were captured (Table 10). Pyloric caeca and gill raker counts showed they were Arctic char. This was the first evidence of their occurrence in this lake. Even more surprising was evidence that there were two forms of Arctic char present. This limited sample also brought into question the presence of Dolly Varden in this lake. The need for a much larger sample to more fully substantiate the presence of Arctic char and to determine if Dolly Varden are present is apparent.

The two, small sexually mature Arctic char we caught in November, 1999 were unlike any mature Arctic char I'd seen before. These little char were both ripe. Eggs were easily expelled from the little female and milt was running from the little male. They were subsequently

Table12..Gill netting results, Cooper Reservor, 1977 to 1999.

Date	Agency	No. of nets	Species	Number caught	CPUE*	Average length	Length range	Average weight	Heaviest fish lbs.	No. over 12 inches
8/29/73	ADF&G	4	Char	115	1.22	8.9"	4.5-14.4"	0.26	1.25	6
6/21/83	ADF&G	5	Char	152	1.55	10.3	5.5-16.1	0.39	1.44	26
6/21/84	ADF&G	3	Char	150	2.86	10.2	5.0-16.3	0.35	1.21	12
9/25/90	ADF&G	3	Char	243	2.23	7.7	4.7-11.5			
			Rainbow**	4	0.05	6.1	5.1- 7.7			
7/10/91	USFS	2	Char	51	0.84	9.6	5.1-16.2			
7/10/92	USFS	2	Char	24	0.55	12.8	8.3-18.6		2.42	14
			Rainbow	4	0.09	12.8	11.6-15.2		1.10	2
8/18/94	USFS	3	Char	1	0.01	5.1				
			Rainbow	29	0.43	11.8	4.9-15.3		1.54	19
11/22/99	ADF&G	3	Char	6	0.67	13.3	8.5-16.7	1.12	1.78	4
	USFWS		Rainbow	6	0.67					
		Total	Char	742						
		Total	Rainbows	43						

* Catch per unit (hour) of effort
** Rainbow trout

Table13..Minnow trapping results, Cooper Reservoir, 1992 and 1994.

Date	Agency	No. of traps	Total hrs. fished	Species	Number caught	CPUE*	Length range
7/10/92	USFS	10	222.1	Sculpin**	102	0.46	
				Rainbow	2		4.9-5.0"
				Char	1		2.8
8/18/94	USFS	28	612.5	Sculpin	296	0.48	
				Rainbow	14	0.02	2.2-6.1
				Char	1		2.1

* Catch per unit (hour) of effort
** Coastrange sculpin

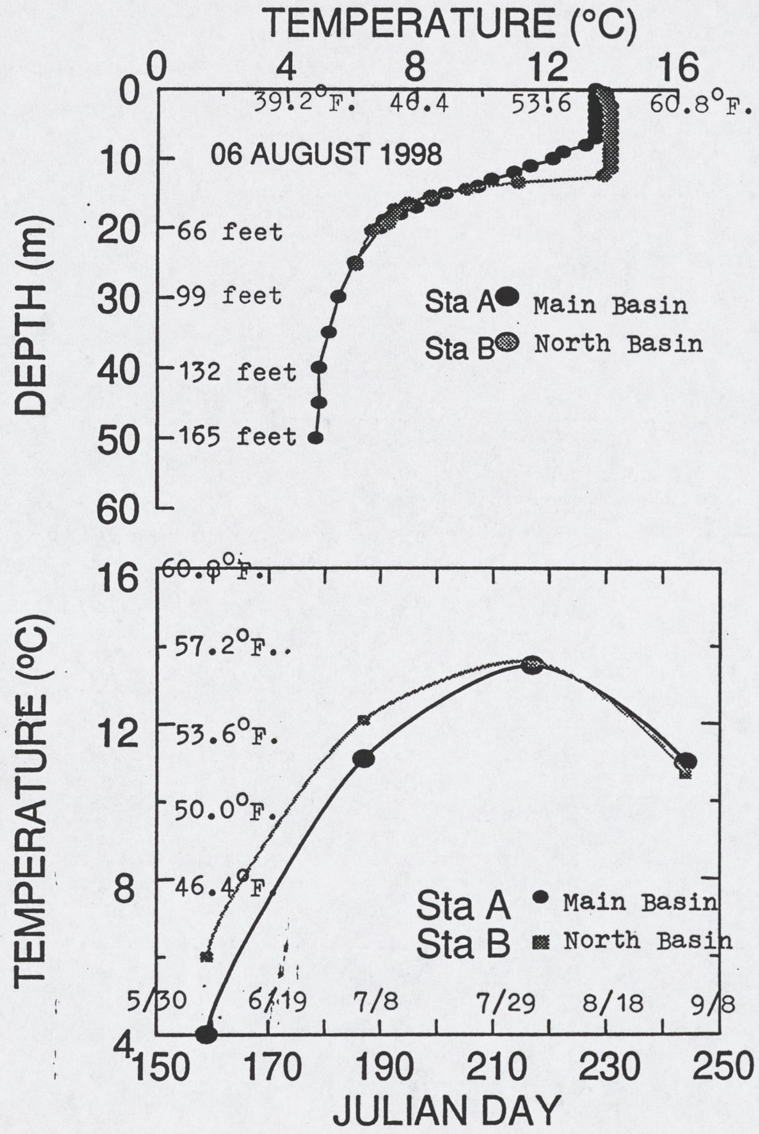


Figure 3. Vertical temperature profile at time of maximum heat content showing pronounced density stratification in the shallower basin (Sta B); and (B) plot of temperature at 1-m during June-September in Cooper Lake, 1998..

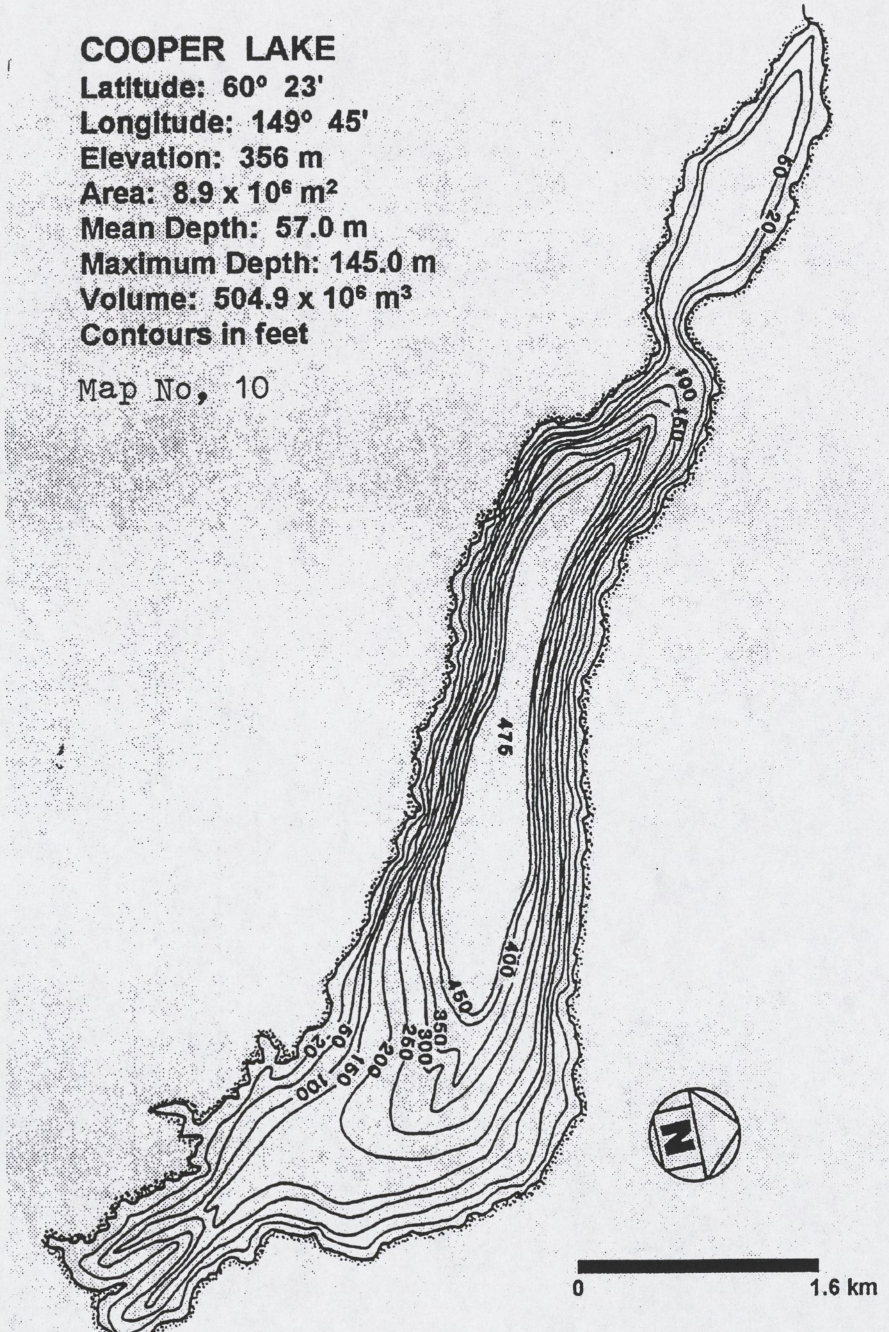


Table 14. Comparable gill netting results, Arctic char populations, Cook Inlet area, Alaska.

Lake	Dates	Gill Net Hours	Char Caught	Av. Weight Pounds	Catch per Unit (hour) of effort Numbers	Catch per Unit (hour) of effort Weight
Benka	68 to 77	156.0	132	0.51	0.85	0.43
Big	1987	767.5	277	1.31	0.36	0.47
E. Finger	10/18/93	54.3	29	0.69	0.53	0.36
M. Finger	10/18/93	43.2	18	0.52	0.42	0.22
Falcon	10/7/93	60.4	65	0.77	1.08	0.83
Dolly Varden	6/7/83	208.0	105	0.70	0.50	0.35
Dolly Varden	9/26/83	200.0	162	0.70	0.81	0.57
Norak	6/9/71	40.0	13	1.03	0.33	0.34
Char	7/31/70	50.0	24	0.98	0.48	0.47
Cooper	73 to 90	353.0	660	0.27	1.87	0.51
Total or average		1,932.4	1,485	0.61	0.77	0.47

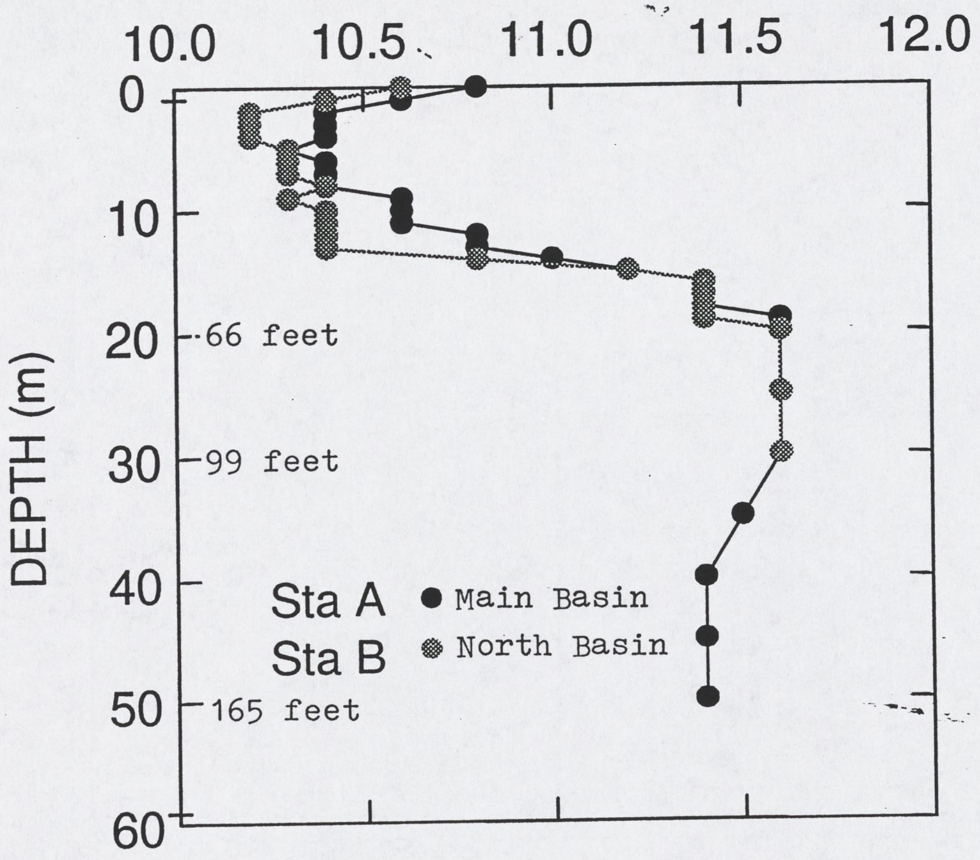


Figure 4. Vertical distribution of dissolved oxygen concentration (mg L^{-1}) during August in Cooper Lake, 1998.

determined to be three years old by the Kenai Fishery Resource Office of the USFWS..

My literature search suggested that these little, parr marked, mature char were dwarfs. Dwarf Arctic char are a common occurrence in Europe but have seldom been described in North America. The available evidence suggests they are unique in the upper Cook Inlet area and only occur in Cooper Lake in this part of Alaska.

Research in Norway (Hindar) suggests that anadromus Arctic char are an extremely plastic species. This plasticity is an asset that allows different morphological forms to develop to utilize the available habitats and food resources of the nutrient poor cold water lakes they inhabit. Large deep lakes offer the best conditions for more than one form of Arctic char to develop. In northern Norwegian lakes some of the char remain anadromus along with a normal sized resident form and a deep water dwarf resident form. These forms are more likely to develop where Arctic char are the dominant species. As species are added to a lake a phenomenon known as niche compression takes place. Since Arctic char prefer colder water than other freshwater species they are forced into the deeper waters. The other species take over the warmer more productive shallow waters. In these cases, even in deep lakes, more than one form of Arctic char is unlikely to be present.

The fish population of Karluk Lake on Kodiak Island, for example, includes several species of salmon, rainbow trout, Dolly Varden and Arctic char. (DeLacy, McPhail and Morrow). This lake is 413 feet deep and would be a likely candidate for the presence of more than one form of Arctic char. Karluk Lake is the most studied lake in Alaska. Niche compression has probably occurred here since only one form of Arctic char has been reported from this deep lake.

The ADF&G conducts and annual statewide creel census by mailing out questionnaires to a representative sample of sport fishermen. This data is used to generate fishing pressure estimates for he more popular lakes and streams. During most years a lake or stream on the Kenai Peninsula has to provide nearly 350 angler days to make the list of named lakes and rivers. Since 1981 Cooper Lake has never had enough fishing pressure to make the list. This in stark contrast to the creel census conducted in 1962. At that time 826 anglers were estimated in one month. Fishing pressure now is less than 350 angler days for the entire year indicating little use of a road accessible, clear water mountain reservoir.

Water level fluctuations have averaged 12 feet per year (Figure 2). The Chugach Power Association has the facilities in place to fluctuate water levels 51 feet from an elevation of 1,159 to 1,210 feet. Research in European Arctic char lakes shows this species has a strong fidelity to customary spawning areas. In The location of Arctic char spawning areas in this reservoir is mostly unknown. We did discover evidence that dwarf Arctic char were spawning on a rubble covered slope within 200 yards of the outlet structure on November 22, 1999. Normal sized Arctic char may spawn at a different time and place in Cooper Lake. The reservoir is normally drawn down in the winter when Arctic char eggs would be incubating and partially refilled in the summer from snow melt and rainfall. The impact of winter draw downs on Arctic char spawning success is unknown. Groups of char utilizing spawning areas at a elevation of 1,170 feet would be impacted nearly every other year (Figure 2). Those char spawning at depths below an elevation of 1,160 feet would seldom have their eggs affected by winter draw downs.

Char Lake

Char Lake was test netted for the first and only time by the ADF&G in 1970. The biologists who did the netting reported catching 24 Arctic char. In this little 10 acre lake, 29 percent of the char sampled were over 14 inches in fork length compared to only 3 percent of similar sized char in the much larger Cooper Lake downstream. Char Lake should be resampled to see if it is still populated by Arctic char that on average are 3.5 times heavier than the char in Cooper Lake. The char in both lakes are presumed to be of the same genetic stock.

The Cooper Lake hydro project will be coming up for relicensing by the Federal Energy Regulatory Commission in 2007. The ADF&G, the USFWS and the USFS are reviewing the project to see if its undesirable fishery impacts can be reduced.

KODIAK ISLAND

Karluk and Frazer Lakes

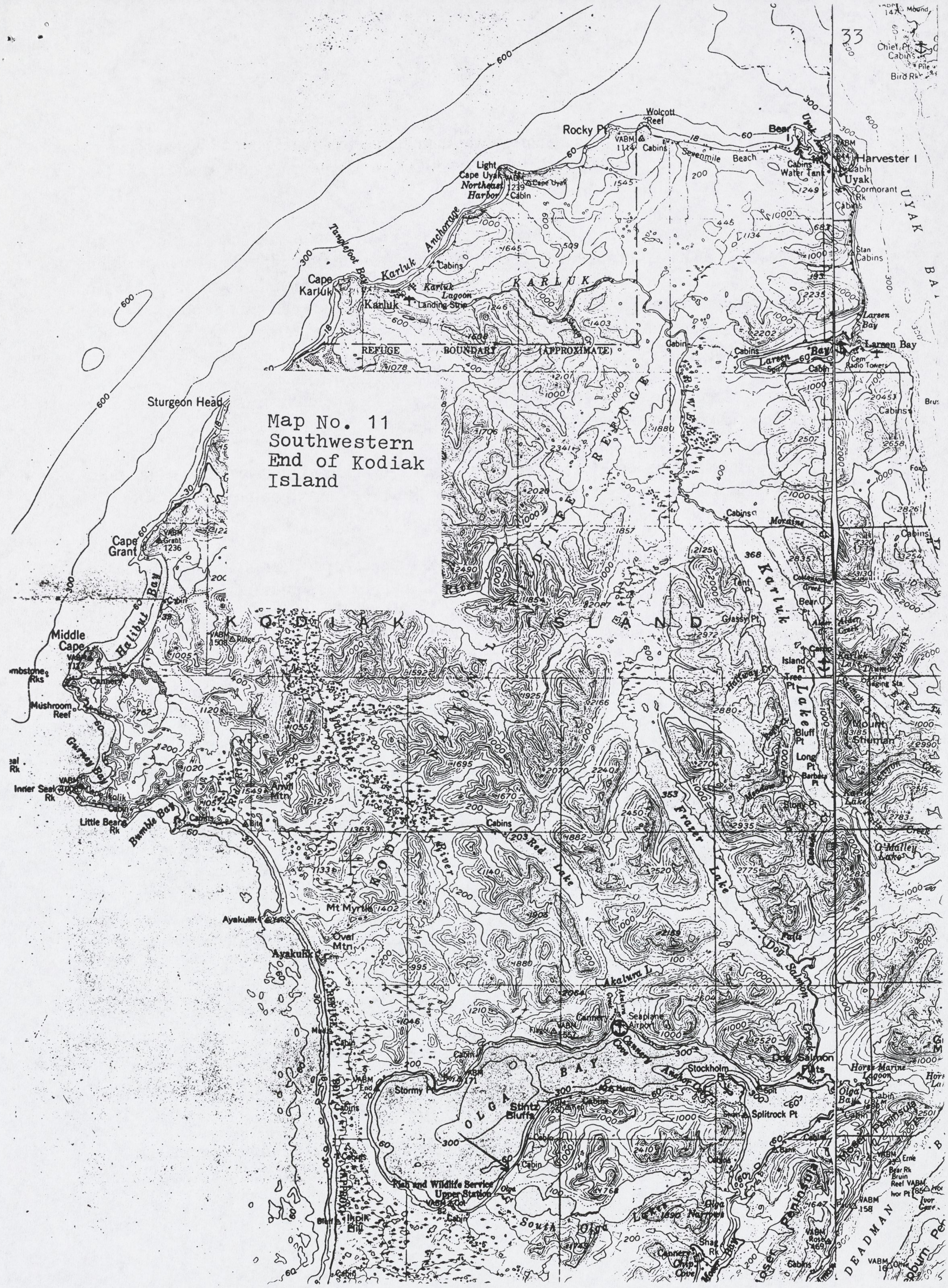
Karluk Lake, with a surface area of 9,728 acres, is by far the largest lake with an Arctic char population in southcentral Alaska (Table 9). It is also the second deepest lake with a maximum depth of 413 feet. This lake is usually iced over from mid December until April. Usual summer surface temperatures range from 55 to 59 degrees F (Hartman).

The Arctic char in Karluk Lake are a lake resident form. They have access to the sea via the Karluk River but remain in the lake year around (DeLacy and Morton). They are the most abundant species taken in gill nets and are commonly taken in nets set as deep as 200 feet. One eight inch Arctic char was taken in a net set at 300 feet. In June they feed primarily of insects. In July they move to stream mouths to feed on drifting salmon eggs and other food dislodged by spawning salmon. Later they feed on disintegrating salmon carcasses. Arctic char in shallow feed quite heavily on sticklebacks. Sculpins, salmon fingerlings and young char were also present occasionally present in stomachs. In September they feed on insects again.

Anadromus Dolly Varden coexist with Arctic char in Karluk Lake. Dolly Varden migrate out of the lake from late May through June. They return from the sea from mid July until September. Average time at sea is about 60 days The other species occurring in Karluk Lake include five species of Pacific salmon, rainbow trout, threespine and ninespine stickleback and coastrange sculpin (McPhail)

My only visit to Karluk Lake was in late June, 1987. The eight Arctic char I caught on flashy spoons had an average weight of 1.06 pounds.

Karluk Lake is the most studied lake in Alaska. Most of the studies have been directed at restoring the sockeye salmon runs to their their former abundance. Most of what we know about Arctic char in this lake came from studies by DeLacy and Morton in 1943 and by McPhail in 1969. The most recent study by Gharrett et al in 1991 investigated the genetic differences between Dolly Varden and Arctic char. This study showed evidence of introgression of Arctic



Map No. 11
Southwestern
End of Kodiak
Island

char genes into the Dolly Varden. Gharrett was unable to determine if gene flow had occurred from Dolly Varden into the Arctic char. In spite of this mixing of genes both species have maintained their separate identities.

Nearby Frazer Lake is also populated with both Dolly Varden and Arctic char (Table 9). A 31 foot waterfalls on its outlet stream prevented the Dolly Varden from migrations to and from the sea. In this lake Arctic char coexisted with lake resident Dolly Varden. In the 1980's a fish ladder was built around the falls to allow salmon access to the lake. The endemic fish population of Frazer Lake consisted of rainbow trout, Dolly Varden, Arctic char, threespine stickleback and coastrange sculpin.

On Kodiak Island Arctic char coexist with both the anadromus and resident forms of Dolly Varden providing good evidence of the validity of both species.

Portions of the southwestern side of Kodiak Island are documented to have remained ice free during the last glacial maximum (Mann). This area most likey served as a refugium for the Arctic char present in Karluk and Frazer Lakes.

Karluk and Frazer Lakes are the only ones known to support Arctic char on this island. This species probably occurs in several other lakes in this area. Earlier in this report it was shown that Arctic char occur in only a few restricted areas in the Matanuska-Susitna and Kenai Peninsula Borough's. This species has shown little tendency to colonize adjacent waters. If this same pattern holds true on Kodiak Island then Arctic char should be restricted to the glacial refugium at the southwestern end of this island. Until further studies are carried out here the distribution of this species on this island will remain largely unknown.

Potential Arctic char lakes include:

Akalura Lake	1,210 acres,	72 feet deep
Horse Marine Lake	222 acres,	94 feet deep
Red Lake	2,075 acres,	148 feet deep
Upper Station Lake	1,951 acres,	230 feet deep

Two smaller unnamed lakes north of Larsen Bay.

My wife and I spent the month of June, 1987 at Portage on the Karluk River as volunteers for Kodiak National Widllife Refuge. Local residents from Larsen Bay told us they fish for brown trout in a lake four miles to the north. Brown trout do not occur on Kodiak Island but Arctic char often are an olive tan or brownish color. This unnamed lake is in the Karluk River watershed and could be supporting an Arctic char population. Another unnamed lake occurs a quarter of a mile further north. Both lakes would appear worth investigating for the presence of Arctic char (Map 11).

Questions

With the exceptions of studies at Karluk, Big and East Finger Lakes Arctic char remain mostly unstudied in southcentral Alaska. Because of the lack of attention many unanswered questions remain. Some of these questions are as follows:

Why do the Big Lake Taranets char get two to three times heavier than all other Arctic char in southcentral Alaska? Are the Big Lake char genetically different from the other isolated populations?

Why haven't Arctic char in the Swanson River watershed colonized adjacent lakes in the Moose and Chickaloon River watersheds? At one time the Swanson River was a tributary of the Kenai River. Why didn't Arctic char colonize the Moose River from the Kenai River? What species of parasites occur in Swanson Arctic char? Can humans become infected by eating undercooked char? What are the sustainable harvest levels from these nutrient poor lakes?

How did Arctic char and coastrange sculpins get into Cooper Lake? Are Arctic char present in downstream lakes in the Kenai River watershed? How many species of char occur in Cooper Lake? How many morphological forms of Arctic char are present in this lake? If dwarf Arctic char evolved in Cooper Lake why aren't they present in other deep lakes in southcentral Alaska? At what depth and when do Arctic char spawn in Cooper Lake? What impacts are water level fluctuations having on the reservoirs fish and aquatic invertebrates?

How many lakes on Kodiak Island support Arctic char populations? Are dwarf Arctic char present in any of the islands deeper lakes? Are the Kodiak char genetically different from the populations in the Cook Inlet area?

What are the relationships of the southcentral Taranets char to populations in the Bristol Bay area and in southeastern Siberia? Which of the other recognized subspecies of Arctic char is the Taranets char most closely related to?

Concerns

There are two concerns at Big Lake. One is about the potential impacts from an expanding northern pike population. Pike are known to be effective predators of other fish species. The other concern is the impact from increased eutrophication as the human presence around the lake shore increases.

The primary cause for concern in the Swanson River watershed is the potential impact from hazardous material spills associated with the oil and gas industry. Fortunately every lake in this watershed is in public ownership within Captain Cook State Park and the Kenai National Wildlife Refuge. Many of the Arctic char lakes are further protected by wilderness status since they are within the Swan Lake and Swanson River Canoe Systems.

At Cooper Lake the primary concern is the impact of water level fluctuations for hydro power generation. Water level fluctuations can affect a lake spawning species such as Arctic char. Fluctuating water levels also reduce the productivity of benthic invertebrates that provide most of the food for the char. Another concern is the stocking of non-indigenous species to enhance the sport fishery that may have been degraded by water level fluctuations.

The lakes on the southwestern side of Kodiak Island are in a roadless area that can best be reached by aircraft. Since most of these lakes are within the Kodiak National Wildlife Refuge, the protection of the native Arctic char populations should be assured. Habitats and fish populations have been manipulated, however, to benefit the sockeye salmon commercial fishery. These activities have included fish way construction, lake fertilization and sockeye salmon stocking. The impacts of these alterations on resident fish populations have not been evaluated.

Arctic char are the aquatic equivalent of the canary in the coal mine. They are the first fish species to suffer from habitat alterations or competition from non-native fishes. The need for a Citizens Char Watch appears warranted. Such a group could keep an eye out for unwise developments that could impact the native Arctic char and bring them before the public for review and discussion. This species is fun to catch and is a strong fighter for its size with lots of endurance. It's a beautiful fish in spawning color and is also good eating. It's part of our natural heritage and deserves to be better known, appreciated and perpetuated throughout its native range in southcentral Alaska.

Finally I hope the information in this report is a step towards a better understanding of the distribution and status of Arctic char in southcentral Alaska. It seems ironic that the Arctic char of this area appear to be one of the least known groups in Alaska while surrounded by over half of the states citizens.

Contributors

Most of the information in this report was provided by the Palmer and Soldotna Offices of the ADF&G, and the Kenai Fishery Resource Office of the USFWS. Individuals who were especially helpful included Craig Baer, Patty Berkhahn, Fred DeCicco, Jim Edmundson, and Larry Larson of the ADF&G; Ted Bailey, Vicki Davis and Mark Wegner of the USFWS; Dave Blanchet and Larry Winter of the Forest Service; Robert Behnke of Colorado State University and glacial geologist Dick Reger. This report would not have been possible without their cooperation and assistance. I would like to take this opportunity to thank everyone who contributed to this project.

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P.O. Box 428
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June, 2000

Bibliography

DeLacy, A.C. 1941. Contributions to the life histories of two Alaskan charrs, Salvelinus malma (Walbaum) and Salvelinus alpinus (Linneaus). PH.D. Thesis. Univ. of Wash. 114 p.

DeLacy, A.C. and W.M. Morton. 1943. Taxonomy and habits of the charrs, Salvelinus malma and Salvelinus alpinus of the Karluk draingae system. Trans. Am. Fish. Soc. 72: 79-91.

Edmundson, J. July 27, 1999. Letter to Mr. Eric Johanson of the the U.S. Forest Service about the limnology of Cooper Lake. 16 p.

Engel, L.J. 1969. Inventory and cataloging of Kenai Peninsula, Cook Inlet and Prince William Sound draingaes and fish stocks. Fed. Aid F-9-1, Rpt. No. 7-A.

Gharrett, T. J. , A. Goto and F. Yamazaki. 1991. A note on the genetic contrasts of sympatric Dolly Varden (Salvelinus malma) and Arctic char (S. alpinus) in the Karluk River system, Alaska. In Fumio Yamazaki (Editor) Reproduction biology and population genetics of Dolly Varden (Salmonidae). Survey of the Ministry of Education. Science and Culture of Japan, during 1987 - 1990.

Hartman, W.L. and R.L. Burgner. 1982. Limnology and fish ecology of sockeye salmon nursery lakes of the world. Journ. Fish. Res. Bd. of Canada, Vol. 29, No.6, 699-715.

Havens, A.C. 1988. Evaluation of enhancement efforts for sport fisheries for rainbow trout and Arctic char in Big Lake, Alaska, 1987. Fish Data Ser. No. 63. Alaska Dept. of Fish and Game. Div. of Sport Fish, Juneau, Alaska. 40 p.

Hindar, K. and B. Jonsson. 1982. Habitat and food segregation of dwarf and normal Arctic char (Salvelinus alpinus) from Vangsvatnet Lake, western Norway. Can. J. Fish. Aquat. Sci: 39, 1030-1045.

Leder, E.H. and R.B. Phillips. 1998. Phylogenetic analysis of Salvelinus alpinus and Salvelinus malma in the north Pacific based on ribosomal ITS1 and growth hormone 2 intron sequences. Proceedings of the 8th and 9th ISACF workshops on Arctic char, 1996 and 1998. Institute of Freshwater Reserach, S-170 11 Drottningholm, Sweden. 151-156.

Mann, D.H. and D.M. Peteet. 1994. Extent and timing of the last glacial maximum in southwestern Alaska. Quaternay Reserch vol 42, No. 2, 136-148.

McPhail, J. D. 1961. A systematic study of the Salvelinus alpinus complex in North America. J. Fish. Res. Bd. Can., 18 (5), 793-816.

Morrow, J. E. 1980. The freshwater fishes of Alaska.

Morrow, J. E. 1980. Analysis of the Dolly Varden charr, Salvelinus malma of northwestern North America and northestern Siberia. In: E.K. Balon (ed) Charrs , Salmonid fishes of the genus Salvelinus. 323-338. Junk Publ. The Hague.

Phillips, R.B., L.I. Gudex, K.M. Westrich and A.L. DeCicco. 1999. Combined pylogenetic analysis of ribosomal ITS1 sequences and chromosome data support three subgroups of Dolly Varden char (Salvelinus malma). Can. J. Fish. Aquat. Sci. 56: 1504-1511.

Phillips, R.B., K. A, Pleyte and M. R. Brown. 1992. Slamonid phylogeny inferred from ribosomal DNA restriction maps. Can. J. Fish. Aquat. Sci. 49: 2345-2353.

Reger, R.D. and D.S. Pinney. 1996. Late Wisconsin glaciation of Cook Inlet Region with emphasis on the Kenai lowland and implications for early peopling. In Davis N.Y. and Davis W.E. eds. Adventures through time: Readings in the anthrology of Cook Inlet, Alaska: Anchorage, Cook Inlet Historical Society. 15-35.

Reger, R.D. and D.S. Pinney. 1997. Last major glaciation of Kenai lowland, Alaska. Alaska Geological Society, 1997. 54-67.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Bd. Can. Bull. 184. 966 p.

Sternberg, R. 1987. Freshwater gamefish of North America. Prentice Hall Press. New York, NY. 54-55.

Tobin, J.H. III and D.E. Palmer. 1997. Fishery and limnological surveys of 25 lakes on the Kenai National Wildlife Refuge, Alaska, 1993. U.S. Fish and Wildlife Service. Alaska Fisheries Data Series No. 97-3. 51 p.

Woods, P.F. 1985. Limnology of Big Lake, southcentral Alaska, 1983-84. U.S. Geological Survey.

Woods, P.F. 1986. Deep-lying chlorophyll maxima at Big Lake: Implications for tropic state classification of Alaska lakes. 19-20. In Proceedings: Cold water Hydrology. American Water Resources Association. Bethesda, Maryland 29811.

Mr. Jack Dean
P.O. Box 428
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Dear Jack,

Your status report on southcentral Alaskan charr is a most valuable summary and synthesis. Now, if you can get more people enthused over this rare, beautiful, and mysterious fish, an Alaskan chapter of the Arctic Charr Fanatics Society could be started.

Jennifer Nielsen, who, along with Ruth Phillips, have used a diversity of molecular genetic techniques, on salmonid fishes, is now with the USGS Alaskan Biological Science Center in Anchorage. I talked to her recently about getting involved with Alaskan charr. Evidently she has to follow the funding in regards to what fish she works with. If you have extra copies of your status report you can send one to Jennifer and encourage her to informally associate with your charr interest group. Interest leads to obsession, then to fanaticism to learn more about charr.

Phylogenetically, the northern Dolly Varden may share a more recent common ancestor with S. alpinus than it does with the southern Dolly Varden. Both of the former have 78 chromosomes whereas the southern Dolly Varden has 82. In Europe, the marble trout, S. marmoratus is more closely related to some S. trutta than those trutta are to other trutta.

No doubt all of the Kenai charr are the Taranetz form, morphologically identical to those of Kamchatka and Chukota (23-25 rakers, 40-45 caeca—gill raker shape, short, stout, blunt, is distinctive from both Dolly Varden and other S. alpinus. I suspect drawf, deepwater populations exist with "normal" charr in lakes with sufficient depth and volume to select for evolutionary micro fragmentation.

The boundary between Taranetz charr and "high arctic" charr (with 25-30 rakers) isn't known with any certainty in Alaska. Is there an area of overlap? Of sympatry with reproductive isolation?

Also for northern and southern Dolly Varden. I caught sea-run northern Dolly Varden (20-23 gill rakers) on south side of Alaskan Peninsula. Also, in 1957, I sampled resident northern Dolly Varden in Susitna drainage from Willow Creek about 50 miles from Anchorage. Where is boundary between northern and southern Dolly Varden? Area of overlap? Sympatry? The Taranetz charr in the Far East occurs only with the northern Dolly Varden. It is strictly lake resident on Kamchatka but typically anadromous on Chukota. Strange that no sea-run forms of Arctic charr have been documented in Alaska (anadromy known from Mackenzie River eastward).

Sincerely,

Bob Behnke

Cc:

Dr. Jennifer Nielsen

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Bob Behnke

Cc:

Dr. Jennifer Nielsen

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From: JandM60@aol.com
Date: Sat, 11 Mar 2000 22:31:08 EST
Subject: Jim
To: fwb@cnr.colostate.edu
X-Mailer: AOL 5.0 for Windows sub 67

Bob,

Just in case you haven't heard --

Jack McIntyre

James W. 'Jim' Mullan
James W. "Jim" Mullan, 73, of East Wenatchee, died Monday, Feb. 28, 2000.
He had lived in East Wenatchee for 22 years and had worked as a biologist with the U.S. Fish and Wildlife Service for many years.
Survivors include two daughters, Georgianna Keller of Federal Way and Frances Mullan of Torrance, Calif.; and two sisters, Shirley DonFro of Leominster, Mass., and Beverly Unsworth of Reno, Nev.
A memorial gathering for family and friends will be 3 to 5 p.m. Saturday at Canyon Creek Club House, 225 N.E. 19th St., East Wenatchee.
Arrangements are assisted by Telford's Chapel of the Valley, East Wenatchee.

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[redacted]

- Audubon!

- Jack Dean chair

Dr. Robert Behnke
3429 East Prospect Road
Ft. Collins, CO 80525

- be Grace
- Penn
- Trout autumn

Ala PW
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Susitna R
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21 – tom.

Cooper L 'dwarf'
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dwarf

norther DV
southm.
northern
Dolly Varden
anadromous
Chukots

Iceland Thingvallavatn
4 morphs

- preserve specimens but keep them (my coll.)

- Mollon Bean L.

- Jennifer - ... genetics ... how k.f ... & local ... but Bear ... real) (100 ... guide ...

- sent

- misc. (100 ...

- Jack Pirelle.
Nick Hughes U Ak Fairb.
son Ted Hughes
Sylvia Plath

ORGANIZING THE DIVERSITY OF THE ARCTIC CHARR COMPLEX

Robert J. Behnke
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ABSTRACT

The subgenus Salvelinus is divided into the Dolly Varden complex and the Arctic charr complex. S. leucomaenis, S. confluentis, and S. albus are assigned to the Dolly Varden complex. The Arctic charr, S. alpinus, is viewed to be composed of three major groups with origins associated with Europe, Siberia, and the Arctic Ocean in the Chukoskt Sea-Bering Sea region. Except for sympatry between S. malma and S. alpinus, examples of sympatric charr populations almost always involve populations derived from within the geographical area of occurrence and they are very closely related to each other. The origins of most sympatric charr are attributed to divergences during and since the last glacier epoch. Recommendations are given on the preservation and utilization of the diversity present in charrs.

INTRODUCTION

Questions might be asked concerning the rationale of why I should write another paper on *Salvelinus* systematics in view of the fact that I so recently gave opinions in a systematic review of the genus (Behnke 1980) published in a large volume of works devoted to charr (Balon 1980). An examination of the works of the various authors in this volume on charrs reveals a range of opinions quite divergent from my position on the evolutionary relationships and classification of the genus. Immediately following my paper, Savvaitova (1980a) discusses how her opinions on charr systematics differ from mine.

Paging through the charr volume, a paper by Leggett (1980) discusses the reproductive behavior of the Dolly Varden charr, *S. malma*, of Kootenay Lake, British Columbia; but, according to the work of Cavender (1980) in the same volume, the Kootenay Lake charr is the "bull trout," *S. confluentus*. Cavender (op. cit.) recognized *S. imbrius* and *S. pluvius* of Japan as valid species whereas in my paper I considered *imbrius* as a synonym or subspecies of *S. leucomaenis* and *pluvius* as a subspecies of *S. malma*. Savvaitova (1980b) repeated her stout belief that the Dolly Varden charr, *S. malma*, should be treated as a synonym of Arctic charr, *S. alpinus*, but she discussed "alpinoid," "high arctic," and "malmoid" types of charr. Most authors in the charr volume followed the classification given in McPhail and Lindsey (1970) which regarded the common charr in North American waters westward from the Mackenzie River (tributaries to the Beaufort Sea), as *S. alpinus*, whereas Morrow (1980) and I (Behnke 1980) pointed out that this group of charr is identical to *S. malma* of the type locality (Kamchatka). Johnson (1980) presented an excellent and comprehensive review on S. alpinus but had to admit that he could only arbitrarily draw taxonomic boundaries for the species because of the problems in separating S. alpinus from S. malma. There is also considerable controversy regarding the spelling; char vs. charr. There is something about the beautiful fish known as char or charr that excites the imagination and emotions.

Thus, on the basis of the divergent opinions found in the most recent and comprehensive compendium on the genus, it is now appropriate that I again try to organize the diversity into a taxonomic scheme and attempt to better define the limits of the subgenus Salvelinus, the Arctic charr species complex, and the Arctic charr, S. alpinus. Recent literature, color slides, and specimens of the Kamchatkan "stone charr," all kindly sent to me by I. A. Chereshnev, have contributed to my latest "revision." I also borrow heavily from my studies on a group of salmonid fishes, the Pacific basin trouts of the subgenus Parasalmo, which are similar in respect to the degree of evolutionary divergence within a comparable era of geological time, relatedness between species, evolution of diverse behavioral and ecological forms, great morphological diversity, and taxonomic problems.

THE SUBGENUS Salvelinus

The first step toward a more precise definition of "Arctic charr" is to divide the genus into smaller phylogenetic units. In my last two papers on charr, I recognizec three subgenera; one for the North American lake charr, S. namaycush, one for the North American brook charr, S. fontinalis, and one for all other members of the genus, but pointed out that the correct position of the Far Eastern "kundscha" charr, _S. leucomaenis_, is in doubt (Behnke 1972, 1980). _S. leucomaenis_ has some similarities to _S. namaycush_, but these may be the result of convergent evolution as a predaceous species. Until convincing evidence is forthcoming regarding the phylogenetic branching sequence in the genus leading to _S. leucomaenis_, I will provisionally include the kundscha charr in the subgenus _Salvelinus_.

Thus, based on zoogeographic evidence correlated with degrees of divergence, it appears that an early (Pliocene?) branch of the genus becaue established in North America, eventually giving rise to the two, widely distributed living species, _S. namaycush_, and _S. fontinalis_. The former species specialized as a large lacustrine predator whereas the latter species, in the general absence of other salmonine fishes, evolved a more generalized way of life, utilizing a wide range of environments, more typical of the trouts in the genus _Salmo_. Conveniently ignoring _S. leucomaenis_, the evolutionary divergence in the rest of the genus resulted in two major groups or species complexes--the Arctic charr group and the Dolly Varden group. This split may have occurred during an early Pleistocene glacier period when the common ancestral charr was divided into northern (precursor of the Arctic charr) and southern (precursor of the Dolly Varden group) groups in the Pacific and Arctic ocean drainages.

In view of the contentious nature of my recognition of Arctic charr and Dolly Varden charr not only as separate species but as separate species groups or complexes, the evidence supporting my position must be presented.

Reality of Arctic Charr and Dolly Varden Species Groups

DeLacy and Morton (1943) presented the first conclusive evidence that Dolly Varden charr and Arctic charr are valid species by finding representative populations of the two species occurring sympatrically in Karluk Lake, Alaska where they exhibited sharp differences in life history and taxonomic characters. McPhail (1961) found other Alaskan lakes where the two species were sympatric with no evidence of hybridization and he further strengthened the case for full species recognition between Dolly Varden and Arctic charr. The problem was that all of these examples involved the southern form of North American Dolly Varden which formerly was generally assumed to characterize the taxon S. malma.

Consideration of the taxonomic data on Dolly Varden throughout its range reveals a major divergence occurs between northern and southern Dolly Varden that likely was initiated by isolation during a glacier period subsequent to the separation of Dolly Varden and Arctic charr. A relative homogeneous northern Dolly Varden occurs in both Asia and North America. In the Far East, in the northern Okhotsk Sea drainages, Kamchatka, and northward around the Chukotsk Peninsula, the Dolly Varden is typically characterized by 21 to 23 gill rakers, 66 to 68 vertebrae, and 25 to 30 pyloric caeca. This same form of Dolly Varden (which should be recognized as S. malma malma, because Kamchatka is the type locality for the name malma) occurs in North America, from the Alaska Peninsula (north side) to the Mackenzie River. McPhail (1961) and McPhail and Lindsey (1970) were not aware of the similarities between the Alaskan and Far Eastern northern forms of Dolly Varden and they considered the northern North American form of Dolly Varden as the western Arctic form of S. alpinus.

South of the Alaska Peninsula to Oregon, the southern form of North American Dolly Varden occurs and it is differentiated from the northern form by fewer gill rakers and vertebrae (typically 17-18 and 62-64, respectively). In the Far East, the most differentiated southern form of Dolly Varden is found in Honshu Island, Japan and in the Kuril Islands. This extreme form has only 58 to 60 vertebrae, 20 to 25 pyloric caeca, and 16 to 18 gill rakers. This form is commonly recognized as *S. pluvius* in Japan, but I have pointed out that if the Kuril Islands Dolly Varden is the same taxon then the name should be *S. malma curilus*. The taxonomic characters of Dolly Varden in Hokkaido and Sakhalin (19-23 gill rakers and 61-63 vertebrae) indicates introgression has occurred between the northern and southern forms in the Far East. There is no evidence of intermediacy between the northern and southern forms of Dolly Varden in North America. All of the above forms that I have identified as Dolly Varden are differentiated from all North Pacific forms of Arctic charr by their general phenotypic appearance (smaller size spots on the body, a more blunt snout) and fewer gill rakers and fewer pyloric caeca. There is no evidence of sympatric occurrence between northern and southern forms of Dolly Varden. The diversity within the species can be arranged into three broadly distributed subspecies--*S. malma malma*, the northern form in both Asia and North America, *S. m. curilus*, the southern Asiatic form of Honshu and the Kuril Islands, with probable intergradation between the two subspecies in Hokkaido, Sakhalin and Korea, and the southern North American form, which I have tentatively recognized as *S. malma lordi* (Behnke 1980).

The validity of full species recognition of *S. malma* depends on its degree of reproductive isolation where it has come into contact with members of the Arctic charr complex. If Dolly Varden occur sympatrically with Arctic charr over a broad area in Asia and North America, with sympatric populations maintaining their integrity with reproductive isolation, then biologists with a reasonable understanding of evolution and systematics should agree with me that S. malma is indeed a "real" species of relatively long (perhaps early Pleistocene) separation from any member of the Arctic charr complex. That is, they are not, as Savvaitova (1980) believed, simply local populations of Arctic charr that happen to be so similar because of convergent evolution since the last glacier period.

In my recent paper (Behnke 1980) I reviewed the records of sympatric occurrence of both the southern and northern forms of North American Dolly Varden with Arctic charr in several lakes in Alaska. Typically, in Alaska, the Dolly Varden is anadromous, overwintering in the lakes and spawning in tributaries (or resident in tributaries) to the lake whereas the Arctic charr is strictly lacustrine (and the more piscivorous species). The most common coexistence is with the form of Arctic charr called the Bristol Bay-Gulf of Alaska form of S. alpinus by McPhail (1961), but sympatry also occurs between the northern Dolly Varden and the "eastern Arctic" form of S. alpinus in some lakes east of the Mackenzie River mouth. Thus, in North America, there is sympatric occurrence over a broad geographical area between populations of Dolly Varden and Arctic charr and two subspecies of Dolly Varden (northern and southern) and two subspecies of Arctic charr (Bristol Bay-Gulf of Alaska and eastern Arctic) are involved. There is no real evidence of intermediacy or hybridization between Dolly Varden and Arctic charr.

In Asia, there is widespread sympatry between the northern Dolly Varden and Arctic charr. The Asiatic Arctic charr of the Chukotsk Peninsula and Kamchatka is identical to the Gulf of Alaska-Bristol Bay form of Arctic charr of Alaska. It is characterized by large spots, typically 23-26 gill rakers, 40-55 pyloric caeca, and 66-68 vertebrae. Two names have been given for this charr from the Chukotsk area--*S. andraishevi* and *S. taranetzi*.

In Kamchatka, the Arctic charr occurs as lacustrine relict populations in Lake Dalnye and Lake Nachinskoye where it is sympatric with populations of Dolly Varden. In lakes and rivers draining the Chukotsk Peninsula, Arctic charr and Dolly Varden are sympatric, often with both species being anadromous (Chereshnev 1978a, 1978b, 1979). A paper by Volobuyev, et al. (1979) attempted to cast doubt on Chereshnev's conclusions that the Arctic charr and Dolly Varden are two distinct species. The authors examined a series of charr specimens from the Kukekkuyum River, in southern Chukoskt (previously studied by Chereshnev), and attempted to emphasize that intermediate (hybrid) specimens between the large-spotted Arctic charr and small-spotted Dolly Varden occurred in their sample. They did this by emphasizing the overlap in the ranges of numbers of gill rakers and pyloric ceaca that occur between the two species and attributing the overlap to hybridization. If given proper editorial review such a paper should not have been published. Overlap in taxonomic characters between two closely related species is certainly not evidence for hybridization. The appropriate method for the treatment of data from the Kukekkuyum River charr specimens to test the assumption for or against reproductive isolation would be to use a form of multivariate analysis such as a principal components analysis of taxonomic characters from specimens identified as large-spotted specimens and small-spotted specimens. If this were done, I believe 100% separation (or very close to it) would have been obtained between the Arctic charr and Dolly Varden specimens--and complete (or virtually complete) reproductive isolation between them would be the only logical conclusion. Thus, the conclusions drawn by the authors that the two types of Chukoskt charr may be only seasonal races of a single species and should not be recognized as different species (Volobuyev, et al. 1979) borders on the ridiculous, especially in view of the evidence of such widespread sympatric occurrence of Dolly Varden and Arctic charr in Asia and North America.

A problem I must point out, however, concerns the relationships of the north Pacific form of Arctic charr (S. anadraishevi or S. taranetzi). Is it a subspecies of S. alpinus? Where would its branching point be positioned in the phylogeny of Salvelinus? Its large spots are somewhat similar to S. leucomaenis. Is this type of spotting an example of convergent evolution? This form of charr needs much more information on its genetic relationships. Until demonstrated otherwise, however, the large-spotted charr, "S. andriashevi," of the north Pacific drainages of Asia and North America can be considered as part of the S. alpinus "complex."

In relation to phylogenetic affinities to the Dolly Varden or to the Arctic charr complexes, two other Pacific drainage species must be considered--the stone charr, S. albus, of Kamchatka, and the bull trout, S. confluentus, of North America. I discussed the stone charr in my 1980 paper but I did not realize that the description of Salvelinus albus by Glubokovsky (1977) for a charr from the Kamchatkan River basin actually was a description of the stone charr. There is some confusion surrounding the stone charr as I discussed in my 1980 paper. Viktorovsky (1975) discussed various forms of charr from Lake Kronotskoye, Kamachatka, using common names--the white (bely) charr, the longheaded (dlinnogolovy) charr, and the nose or snout (nosaty) charr. Glubokovsky (1977) in naming the "white" charr, S. albus, from the Kamchatka River, mentioned it is identical to the white charr of Lake Kronotskoye. Viktorovsky (1978) revised the Lake Kronotskoye charr. He decided the white charr is actually the typical S. malma, the nose charr was described as a new subspecies of malma, S. m. schmidti, and the longheaded charr was described as a new species, Salvelinus kronocius. From the descriptions given by Glubokovsky and Viktorovsky and from previous data on the stone charr supplemented by two specimens of S. albus sent to me by I. A. Chereshnev, there is no doubt that S. albus and S. kronocius both represent the stone charr of Kamchatka. Thus S. kronocius is a synonym of S. albus. Unfortunately, the confusion with the "white"charr of L. Kronotskoye led to the inappropriate name S. albus; the stone charr could be called the black charr; the coloration in freshwater specimens is decidedly dark.

As mentioned in my previous paper, I believe the closest relationship of the stone charr is with the North American bull trout, S. confluentus. There are some real differences in meristic characters (about what would be expected from two branches of a monophyletic origin that has been separated for more than 100,000 years), but there are basic similarities in the shape of the head and jaws and overall appearance. I believe the bull trout and stone charr represent an early divergence in the Dolly Varden complex.

Associated with the Pacific basin origin of the Dolly Varden complex, I suggest that the relationships of *S. leucomaenis* are also with the Dolly Varden complex. The low values of meristic characters and the karyotype of *S. leucomaenis* (2N = 84-86, identical to *S. malma curilus*) (Viktorovsky 1978) also indicate the closest affinities of *leucomaenis* are to the Dolly Varden complex.

The Arctic Charr Complex

By the process of elimination at the subgeneric and 'complex' levels of discrimination, all the rest of the diversity in the genus can be attributed to the Arctic charr complex. That is, the phylogenetic branching points leading to all of the living forms in the Arctic charr complex should connect to a common ancestor after the separation between the Dolly Varden and Arctic charr complexes.

The key to defining the limits of the species *S. alpinus* concerns the charr of the type locality area ("Swedish Lappland" as given by Linnaeus). Thus, all forms included as *S. alpinus* or in the Arctic charr complex should be more closely related (more recent phylogenetic separation) to Scandinavian *S. alpinus* than they would be to *S. malma* of Kamchatka.

The typical Scandinavian form of *S. alpinus* has about 63-64 vertebrae, 30-50 pyloric caeca and 21-28 gill rakers. This form is distributed in the Kola and Karelian region of the USSR, Finland, northern Sweden, Norway, Great Britain and Ireland. A closely related group, *S. a. salvelinus*, occurs in the Alpine lakes of central Europe. Typically, the central European "normalsaibling" or "wildfangsaibling" has slightly more gill rakers (typically 25-30).

There is an interesting group of Arctic charr that is likely monophyletic in origin but now has a broad and disjunct distribution. These charr have the highest numbers of gillrakers in the genus, from 25 to 35; they are also characterized by about 65 to 70 vertebrae and about 40 to 50 pyloric caeca. They may obtain a weight of 12 kg or more and are typically piscivorous. This type of charr is concentrated in the Taimyr Peninsula region of Siberia and in the Arctic Ocean drainages of North America east of the Mackenzie River (eastern Arctic form of *S. alpinus*). In these regions they occur as anadromous and resident lacustrine populations (resident lacustrine stocks are much more common in Siberia where *S. namaycush* is absent). They occur as disjunct relict populations far inland in Siberia in lakes of the Yenesei, Lena, and Kolyma river basins and in the Baical region (*S. erythrinus*). Headwater transfer from the Kolyma drainage has established this form of charr in lakes of the Okhota River basin, tributary to the Okhotsk Sea (*S. neiva*). They also occur as resident lacustrine populations in lakes west of the Mackenzie basin where they are sympatric with anadromous *S. malma*. I also believe this same form of charr occurs in Lake Coomarsahrn, Ireland (*S. fimbriatus*). The distribution of the Arctic cisco, *Coregonus autumnalis*, exhibits many similarities with this particular group of charr. The Arctic cisco also occurs as relict lacustrine populations in Ireland where it is known as the pollan (Ferguson et al. 1978).

The Taimyr Peninsula is of special interest in regards to sympatry between populations of Arctic charr. I have previously discussed a charr from L. Taimyr (Behnke 1972, 1980) named *S. taimyricus* that has a distinctive morphology. Savvaitova et al. (1980) recorded *S. taimyricus* from Lake Keta and described four sympatric *Salvelinus* populations from

Lake Lama. All have meristic characters similar to the generalized anadromous Taimyr charr and most probably all represent minor divergences within this particular "major" divergence in the Arctic charr complex. The life history and ecological differences between the various Taimyr charrs are pronounced. There are anadromous and lacustrine forms and the various lacustrine forms differ in feeding specialization, depth distribution, growth rate and maximum life span.

For a classification of S. alpinus best denoting evolutionary relationships among the major divergences making up the species, I could suggest that all of these charr (Taimyr region, eastern Arctic North America, interior Siberia lakes, and Lake Coomarsaharn) be considered as one subspecies (S. alpinus erythrinus). The great ecological diversity encompassed in such classification (or any taxonomic arrangement of S. alpinus conforming to the international rules of zoological nomenclature), readily reveals the severe limitations of our binomial or trinomial system of nomenclature to accurately describe and classify the enormous diversity manifested in the Arctic charr complex. For proper management of this diversity, the various ecological forms, particularly in sympatry, should be regarded as if they were different species.

One other form of S. alpinus that probably deserves subspecific recognition is the group of disjunct lacustrine relicts of northern New England and southern Quebec known as Sunapee, blueback, and red "trout," S. alpinus oquassa. This group of charr appear to be an early derivative of the evolutionary line leading to the northern European S. a. alpinus. They differ mainly in having fewer gillrakers (18 to 24 vs. 21 to 28). Their distribution appears to be largely the result of exclusion or extermination by S. namaycush. Native populations occurred only where namaycush was absent and they soon disappeared in those lakes where namaycush was introduced.

From a preliminary synthesis of all information, I provisionally recognize three major centers of evolution in the Arctic charr complex (or S. alpinus in the broad sense). A European origin of the north European S. alpinus alpinus. The central European S. a. salvelinus and the eastern North American S. a. oquassa, are probably most closely associated with this group. A Siberian origin for the vast and diverse group that, for purely practical taxonomic purposes, can be recognized as S. a. erythrinus with a multitude of derivative forms such as taimyricus, neiva, drjagini, etc.

The peculiar form of charr with very large spots occurring in Asiatic and North American drainages to the Chukotsk and Bering seas where it is widely synpatric with S. malma, probably evolved in that area. The extremely large spots of this form of Arctic charr may be an example of character displacement that reinforces reproductive isolation with S. malma. This form can provisionally be recognized as S. a. andriashevi, but this taxon should be redescribed because both Dolly Varden charr and Arctic charr occur in Lake Estikhet, the type locality of the taxon. Berg's (1948) description of andriashevi is probably based on a specimen of Dolly Varden.

From what I have been able to determine, examples of sympatry in the Arctic charr complex, are always between members of the same evolutionary group, and are the result of recent divergences initiated during or since the last glacier period. That is, the three major divergences that, for practical purposes of communication, I have classified as S. a. alpinus,

S. a. erythinus, and S. a. andriashevi, do not occur in sympatry with each other. The sympatric populations in Lake Windemere, England, and in many Scandinavian and Karelian lakes are more closely related to other members of the broad and inclusive S. a. alpinus than they are to any member of the S. a. erythrinus or S. a. andriashevi evolutionary lines. This also appears to be true for the numerous sympatric populations in lakes of Taimyr--they are all probably derived from within the S. a. erythrinus evolutionary lineage after divergence from the S. a. alpinus branch. From a practical point of view and in relation to principles of animal taxonomy, it seems absurd to classify all four of the sympatric populations in Lake Lama as a single subspecies. The most useful taxonomic arrangement of the subgenus Salvelinus (for other than evolutionary or systematic purposes) most likely will considerably stray from a strictly cladistic interpretation.

The tiefseesaibling, S. profundus, is a striking exception to the rule that sympatric populations (except for malma and alpinus) have their origins in relatively recent geological time. The degree of differentiation of the tiefseesaibling is extreme in the genus. The uniform, dull coloration, the broad and overhanging snout, the peculiar structure of the gillrakers, the low numbers of gill rakers, vertebrae and pyloric caeca (20-25, 61-63, and about 25-35, respectively) sets off S. profundus from any other known form in the genus. I have examined specimens of tiefseesaibling only from the Bodensee but it has been reported from the following Alpine lakes of Central Europe: Neuchatel, Walchensee, Ammersee, Tegernsee, Achensee, Plansee, Attersee, and Traunsee (Berg 1932, Nerseheimer 1937). Brenner (1980) described the tiefssesaibling from the Attersee. Brenner concluded that tiefseesaibling are not a distinct taxon but are only "local forms created in response to different environmental and feeding conditions." Such a statement is pure nonsense to anyone familiar with the range of variability in charr specimens throughout the distribution of the genus. If it were true that sympatric populations of tiefseesaibling evolved independently in each lake inhabited by Salvelinus where suitable conditions were present, then there would be tiefseesaibling throughout the Holarctic region and not only in central European lakes. The rich whitefish (subgenus Coregonus) fauna of the European Alpine lakes, has probably severely restricted the distribution and abundance of tiefseesaibling by competitive exclusion. This would suggest to me that the evolution of the tiefseesaibling occurred before Coregonus invaded the Alpine lakes or it occurred in a contiguous area where Coregonus was absent. In any event, the tiefseesaibling is morphologically very different from any other form of charr. I include it in the Arctic charr complex only on zoogeographical grounds.

DISCUSSION

I believe the charrs in the subgenus Salvelinus like the trouts of the subgenus Parasalmo have undergone rapid morphological and ecological divergence. That is, the morphological or regulatory part of the genome has speciated much more rapidly than the structural or metabolic part of the genome. If this is true then it can be expected that information obtained from the structural genes, typically from electrophoretic studies of proteins, will not be in full accord with the evidence of morphological divergence. As far as is known, all forms in the genus are interfertile when hybridized. This would indicate rather recent origins of all living forms from a common ancestor in relatively recent geological times (perhaps upper Pliocene). To date, comprehensive comparative electrophoretic studies have not been made on diverse forms of charr. A comprehensive study should include data from 25 to 35 gene loci to arrive at comparable genetic relatedness indices such as genetic identity scores. When such research has been done, I suspect that genetic identity scores between the most divergent forms in the genus will be high--on the order of 90 or higher. Unless electrophoretic studies can establish substantial evidence for a discussion of primitive (plesiomorphic) and derived (apmorphic) protein, and not merely allelic frequency differences, then their contributions to Salvelinus systematics will be more-or-less limited to some generalizations on degrees of relatedness but lacking in authoritative cladistic information.

Comprehensive electrophoretic studies should be useful, however, to test my hypothesis concerning the evolutionary reality of the Dolly Varden and Arctic charr complexes and their respective components and to examine the relative affinities of S. leucomaenis and S. profundus.

In the western North American trouts of the subgenus Parasalmo, electrophoretic taxonomic studies on the cutthroat trout (Salmo clarki) and rainbow trout (Salmo gairdneri) have probably been more intensive than that of any other fish species. However, there is a lack of evidence on primitive and derived genes in these species and no real cladistic interpretation is possible. An overall summation of the electrophoretic data indicates four equally related groups--rainbow trout and three subspecies of cutthroat trout, but the genetic identities are tightly clustered, suggesting all could be considered as subspecies of a single species. The genetic basis governing the striking morphologidal distinctions of the California golden trout (S. aguabonita), can not be detected by electrophoresis. Two subspecies of cutthroat trout that have pronounced differences in spotting pattern and ecologies, and are in part sympatric in the upper Snake River drainage, Wyoming, exhibit no electrophoretic differences in the products of 26 gene loci (Loudenslager and Kitchin 1979). Electrophoretic studies of western North American trouts demonstrate close genetic identities, and a distinct lack of concordance in the evolutionary rates of change between the regulatory genome governing morphology and ecological specialization and the structural genome sampled by electrophoresis. I expect the same situation will be found in Salvelinus.

The data on Salvelinus karyotypes indicate the general trend of Robertsonian fusion--going from higher chromosome numbers in primitive form to lower numbers in derived forms. The karyotype of S. leucomaenis is given as 2N=84-86 with 100 arms. This same karyotype is found in S. malma curilus. S. malma malma is listed as 78-80 with 96 arms, and the Far Eastern form intermediate in morphological characters (S. m. krascheninnikovi) also has an intermediate karyotype with a diploid number of 82-84 and 98 arms according to Viktorovsky (1978). S. fontinalis and S. namaycush have diploid numbers of 84 with 100 arms. S. alpinus (Sweden) has 80 chromosomes with 100 arms. The stone charr of Kamchatka and the bull trout of North American evidently posses a common karyotype of 2N=78 with 100 arms (Viktorovsky op. cit. and T. Cavender personal communication).

I would not necessarily interpret a smooth progression in karyotype speciation from this data. That is, I don't believe the list of karyotypes can be used as strong evidence that *S. leucomaenis* and all subspecies of *S. malma* were already evolved before *S. malma malma* gave rise to the Arctic charr complex.

In the closely related species and subspecies of western North American trouts, diploid chromosome numbers range from 56 (106 arms) in *S. gilae* and *S. apache* to 68-70 (104 arms) in *S. clarkii clarkii*, but there has been considerable rearrangement of karyotypes in several evolutionary lines. The three major subspecies groups of cutthroat trout follow a Robertsonian fusion pattern of decreasing numbers: 2N=68-70 in *S. c. clarki*, 2N=66 in *S. c. lewisi*, and 2N=64 in *S. c. bouvieri*. In the rainbow trout evolutionary line, the diploid number associated with the most primitive morphological characters and the most primitive distribution pattern is 58. In various populations of the more advanced coastal rainbow trout, modal diploid numbers are 58, 60, 62, and 64. Evidently the evolutionary trend has been that of converting metacentric chromosomes into acrocentric chromosomes with an increase in the diploid number. The most divergent species of *Parasalmo* is the Mexican golden trout, *S. chrysogaster* which has a diploid number of 60. Thus, within a closely related group of trouts of probable relatively recent (perhaps late Pleicene - early Pleistocene) origin from a common ancestor, there is great variation in the karyotypes and the chromosome numbers of 60 and 64 must have been arrived at independently in different evolutionary lines.

Extrapolating the karyotype information from *Parasalmo* to *Salvelinus* suggests that after all of the diverse geographical forms of charr have been karyotyped, the comparative data may not be a decisive factor for determining the position of phylogenetic branching points in Salvelinus.

Mednikov, et al. (1980) published an interesting attempt to resolve taxonomic problems in Salvelinus by the use of DNA hybridization. I pointed out (Behnke 1980) that DNA hybridization data cannot be trusted because of the noise of experimental error when dealing with groups such as the Arctic charr complex and the Dolly Varden complex. Their evolutionary separation has not had sufficient time to accumulate the amount of genetic differentiation needed to overcome the noise of experimental error.

Thus, despite modern methodology, I doubt that a taxonomic arrangement of charrs will ever be constructed that will be universally accepted and endorsed. This is particularly true because of the conflict between the goals of a phylogenetic (in the strict cladistic sense) classification and the goals of a practical classification useful for fisheries management in relation to degrees of morphological and ecological divergence and sympatric occurrence.

A final point of emphasis concerns the management, preservation, and utilization of the great range of diversity found in diverse groups of charrs. In comparison to other salmonid fishes, most of the distribution of charrs occurs in areas of the world with low human population density and, as yet, relatively lightly impacted by man. In contrast, I estimate that the cutthroat trout species in western North America has lost about 98% of its original distribution (with concommitant loss of genetic diversity) in interior waters during the past 100 years. There can be great ecological and life history differences between local populations of the same subspecies that may be of major significance for management purposes (Hickman and Behnke 1979, Behnke 1981). A long range goal should be to maintain the geographical and ecological diversity still present in *Salvelinus*, in order that the base of the natural resource (its genetic diversity) be available for utilization.

The natural distribution of the Arctic charr complex, with the exceptions of the European Alpine lakes and some lakes in the interior of Siberia, is largely restricted to within about 100 km of the Arctic coast and associated islands. The Arctic charr is an effective agent to channel the food resources in waters of very low primary productivity into a highly desirable product. There is a great potential to introduce various forms of Arctic charr into suitable new waters and greatly increase the fishery values of these waters. In 1978, I examined specimens of an unknown charr, sent to me from a lake in the Rocky Mountains of Idaho. I identified the specimens as *S. alpinus oquassa*. Later, it was discovered that charr from Sunapee Lake, New Hampshire, were stocked into a few Idaho lakes in 1925 (the native charr in Sunapee Lake later becaue extinct after *S. namaycush* was introduced). The Sunapee charr is now known to persist in two lakes in Idaho. These lakes are ultra oligotrophic but the Sunapee charr attain weights of 2 and 3 kg whereas *S. fontinalis* in these same lakes seldom exceed 100 g. In numerous such lakes in the Rocky Mountains of North America, without suitable spawning inlets to maintain trouts of the genus *Salmo*, *S. fontinalis* is often the only fish species but they typically are represented by stunted populations of little fishery value. There must be thousands of similar lacustrine situations in the world where the introduction of members of the Arctic charr complex would greatly improve the fisheries by maximizing salmonid biomass production with their specializations to make efficient use of the pelagic and benthis zones, and produce large size specimens because of their range of food utilization and long life span. Innovative ways to maximize growth and production could be tried such as hybrid combinations and attempts to create sympatric stocks with introductions from diverse parental sources. Consideration of the diversity of the potential niches of the diverse forms of Arctic charr and how the potential niches would be contracted into realized niches in interaction with other species (or other sympatric populations of Arctic charr) offers a wealth of opportunities for theoretical and practical application of fisheries management concepts. I believe the Arctic charr is a fish that will become more widely appreciated, despite its confused taxonomy.

LITERATURE CITED

Balon, E.K., editor. 1980. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands: 928pp.

Behnke, R.J. 1972. The systmatics of salmonid fishes of recently glaciated lakes. J. Fish. Res. Bd. Can. 29:639-671.

Behnke, R.J. 1980. A systematic review of the genus Salvelinus. Pages 441-480 in E.K. Balon, editor. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands.

Behnke, R.J. 1981 (in press). Systematic and zoogeographical interpretation of Great Basin trouts. In R.J. Naiman and D.L. Soltz, editors. Fishes in North American deserts. John Wiley Pub. Co.

Berg, L.S. 1932. Übersicht der verbreitung der susswasserfische Europas. Zoogeographica 50:107-208.

Berg, L.S. 1948. Freshwater fishes of the U.S.S.R. and adjacent countries. Zool. Inst., Acad. Sci. USSR 1(27) Vol. 1:466pp (English Translation 1962).

Brenner, T. 1980. The Arctic charr, Salvelinus alpinus salvelinus, in the prealpine Attersee, Austria. Pages 765-772 in E.K. Balon, editor. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands.

Cavender, T.M. 1980. Systematics of Salvelinus from the North Pacific Basin. Pages 295-322 in E.K. Balon, editor. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands.

Chereshnev, I.A. 1978a. The systematics of charrs, genus Salvelinus, of the Bering Sea region of the Chukotsk Peninsula. Biol. Morya 1:36-46 (in Russian).

Chereshnev, I.A. 1978b. The systematics of charrs, genus Salvelinus, of the Amguema River (Chukotsk). Pages 276-289 in V. Ya. Levanidov, editor. Systematics and biology of freshwater organisms of northeast Asia. Acad. Sci. USSR Far East Sci. Center, Vladyvostok (in Russian).

Chereshnev, I.A. 1979. Systematics of anadromous charr (genus Salvelinus) from the Ionivyeem River basin (Chukotsk Peninsula). Pages 114-125 in V. Ya. Levanidov, editor. Systmatics and ecology of fishes of the continental waters of the Far East. Acad. Sci. USSR Far East Sci. Center, Vladyvostok (in Russian).

De Lacy, A.C. and W.M. Morton. 1943. Taxonomy and habits of the charrs, Salvelinus malma and Salvelinus alpinus of the Karluk drainage system. Trans. Am. Fish. Soc. 72:79-91.

Ferguson, A., K-J.M. Himberg, and G. Svärdson. 1978. Systematics of the Irish pollan (Coregonus pollan): an electrophoretic comparison with other Holarctic Coregoninae. J. Fish. Biol. 12:221-233.

Glubokovsky, M.K. 1977. Taxonomic relationships of charr of the genus Salvelinus of the Kamchatka River basin. Biol. Morya 3:24-35.

Hickman, T.J. and R.J. Behnke. 1979. Probable discovery of the original Pyramid Lake cutthroat trout. Prog. Fish Cult. 41:135-137.

Johnson, L. 1980. The Arctic charr, Salvelinus alpinus. Pages 15-98 in E.K. Balon, editor. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands.

Leggett, J.W. 1980. Reproductive ecology and behavior of Dolly Varden charr in British Columbia. Pages 721-738 in E.K. Balon, editor. Charrs, salmonid fishes of the genus Salvelinus. W. Junk, The Hague, Netherlands.

Loudenslager, E.J. and R.M. Kitchin. 1979. Genetic similarity of two forms of cutthroat trout, Salmo clarki, in Wyoming. Copeia (4):673-678.

McPhail, J.D. 1961. Study of the Salvelinus alpinus complex in North America. J. Fish. Res. Bd. Can. 18:793-816.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwest Canada and Alaska. Fish. Res. Bd. Can. Bull. 173:381pp.

Mednikov, B.M., V.A. Maksimov, and K.A. Savvaitova. 1980. Genetic divergence of Eurasian charrs. Pages 357-364 _in_ E.K. Balon, editor. Charrs, salmonid fishes of the genus _Salvelinus_. W. Junk, The Hague, Netherlands.

Morrow, J.E. 1980. Analysis of the Dolly Varden charr, _Salvelinus malma_, of northwestern North America and northeastern Siberia. Pages 323-338 _in_ E.K. Balon, editor. Charrs, salmonid fishes of the genus _Salvelinus_. W. Junk, The Hague, Netherlands.

Neresheimer, E. 1937. Die Lachsartigen (Salmonidae). Handb. Binnenfischerei Mitteleuropas 3:219-370.

Savvaitova, K.A. 1980a. Comments to the systematic review of the genus _Salvelinus_. Pages 480-481 _in_ E.K. Balon, editor. Charrs, salmonid fishes of the genus _Salvelinus_. W. Junk, The Hague, Netherlands.

Savvaitova, K.A. 1980b. Taxonomy and biogeography of charrs in the Palearctic. Pages 281-294 _in_ E.K. Balon, editor. Charrs, salmonid fishes of the genus _Salvelinus_. W. Junk, The Hague, Netherlands.

Savvaitova, K.A., V.A. Maksimov, and E.L. Nesterov. 1980. Systematics and ecology of charrs of Taimyr Peninsula. Voprosy Ikhtiologii 20:195-210 (in Russian).

Viktorovsky, R.M. 1975. Karyotypes of the endemic charrs of Lake Kronotskoye. Tsitologiya 17:464-466 (in Russian).

Viktorovsky, R.M. 1978. Mechanisms of speciation in the charrs of Lake Kronotskoye. Acad. Scil USSR Far East Sci. Center, Vladyvostok: 110pp (in Russian).

Volobuyev, V.V., E.D. Vasilyeva, and K.A. Savvaitova. 1979. Systematic status of the anadromous Chukotsk charr of the genus _Salvelinus_. Voprosy Ikhtiologii 19:408-418 (in Russian).

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Genetic Similarity among Endemic Arctic Char (*Salvelinus alpinus*) and Implications for Their Management

IRV KORNFIELD, KENNETH F. BELAND, JOHN R. MORING, AND FREDERICK W. KIRCHEIS

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Government of Canada Fisheries and Oceans
Gouvernement du Canada Pêches et Océans

Department of Fishery and Wildlife Biology

Colorado State University
Fort Collins, Colorado
80523

3 November 1981

Dr. Irving Kornfield
Department of Zoology
University of Maine
Orono, ME 04469

Dear Irv:

Hopefully, you are preparing for a trip to Lake Lanao (although I heard that the civil unrest in the area may preclude or greatly delay foreign visitation). In any event, I believe my recollection of a Miocene age from the plateau on which the lake is situated is from Frey's 1969 paper (cited in your bibliography), or it may have been from discussions I had with Villawock of Hamburg University several years ago when he visited me on his way to Lanao. You should also be aware that the work by Charles Woods on Lanao fishes is worthless. Evidently, Woods simply made up stories in his mind without factual basis.

As I wrote to your department chairman, I greatly admire your biochemical-genetic work on fishes. I consider your work among the best because you select highly significant issues to resolve. As with virtually all people publishing on similar subject matter, however, you are hindered by an overemphasis on nongenetic environmental influence on morphological-meristic characters (the underlying implications I perceive from this is that all classification from the time of Linnaeus is without validity because of possible nongenetic influence on taxonomic characters). You must assess the degree of expertise that each author has with any particular group of fish. An experienced ichthylogist who has worked intensively for many years on a particular group of fish knows what characters are most important to denote phylogenies (ability to perceive primitive and advanced states), what characters are stable and which are labile and more under environmental influence. It is highly unlikely that such a person would be deceived into a false classification because of nongenetic influence on characters (or differences due to sex, age, and growth rate), although such mistakes may be common during the early stages of a long study (and in such situations biochemical-genetic evidence may be most useful to correct erroneous interpretations).

Specifically, in your Arctic char paper, I see the same problems and limitations for arriving at a valid basis of degrees of relatedness, detecting phylogenies, and applying the information to classification comparable to utilizing electrophoresis on western North American trouts. When many loci are analyzed and allelic frequency differencies are found with genetic identity scores of more than .90, and these alleles can not be considered as primitive or derived states - the overall phenotypic similarities of proteins is not a valid basis for classification, or even of degrees of genetic relatedness.

Table 6 gives genetic similarity scores of about .93 to .99 among various New England S. alpinus populations, and about .99 between the New England populations and a sample from the Northwest Territories, representing a highly divergent form of char. The NW Territories char averages 6 to 7 more gillrakers and about 4 more vertebrae and these differences are certainly not explained by environmental differences. Essentially all populations of a species respond to similar environmental cues for spawning. Temperatures for spawning and egg incubation are comparable throughout the range of a species. If consistant differences in meristic characters are associated with different geographical areas in S. alpinus, it can be confidently assumed that these differences have a genetic basis and are an expression of phyletic branching in the species. I examined a series of Sunapee char from Sawtooth Lake, Idaho (stocked from Sunapee Lake in 1925). The thermal regime of Sawtooth Lake is comparable to a lake in the Northwest Territories, yet the meristic characters of the specimens are the same as Kendall reported for the char of Sunapee Lake.

Table 3 of your paper (allelic frequencies) suggests to me that intensive electrophoretic studies on a group of fish might lead an investigator to sort out characters and become selective as to their relative value for detecting phyletic divergence. For example, I note that most of the "divergence" among New England samples is due to esterase-4 (a labile character subject to convergent change probably from temperature selection, and of little value for detecting monophyletic branching points). However, 50% of the Northwest Territory char have the LDH-6 92 allele, an allele not found at all in your other char samples, and 80% have the PGI-3 105 allele, also not found at all in other char examined. Having my word for it that the Northwest Territories char represent a divergent branch of S. alpinus, I would emphasize these loci in future work on Salvelinus systematics.

I am hoping to encourage your further interest in this most challenging group, because the leading spokesman for electrophoretic analysis of Salvelinus has been Dr. Nyman of Drottingholm. Nyman is personally a fine person but he is hooked on esterase frequencies to detect "species" of char.

I am preparing another paper on Salvelinus systematics and I'll send a copy when completed.

I've written to Lev Fishelson requesting specimens of Lake Tiberias Mirogrex for comparison with my Arabian specimens — many thanks for this reference.

Sincerely,

Robert Behnke

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2 copies

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② Rozfield

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Sincerely,

December 23, 1983

Genetiska institutionen, Stockholms universitet
Box 6801, 113 86 STOCKHOLM
Tel. 08 - 34 08 60 (växel)

Dear Bob,

Thanks for the manuscript. I enclose a reprint of a paper that you may not have seen.

Sincerely,

Nils

Nils Ryman

J. Fish Biol. (1983) **23**, 75–94

Protein loci in the Arctic charr, *Salvelinus alpinus* L.: electrophoretic expression and genetic variability patterns

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(*Accepted 24 September 1982*)

In the search for electrophoretically detectable protein loci in the Arctic charr, *Salvelinus alpinus* L., tissue samples of eye, liver, and muscle from a total of 934 specimens collected at 10 Swedish localities were analysed. General protein staining and specific staining for 33 enzymes revealed 52 detectable loci; 37 of which were considered usable in population surveys. Variability was observed at four loci coding for esterase (*est-2*), the liver-specific form of lactate dehydrogenase (*ldh-3*), and the skeletal muscle form of malate dehydrogenase (*mdh-4, 5*); genetic variation at loci coding for *ldh-3* and *mdh-4, 5* has not previously been described in the Arctic charr. Relating our results to the multiple locus studies presented in the literature including Arctic charr from Ireland and North America reveals polymorphism at approximately one-third of the loci studied in the Arctic charr, and the fraction of variable loci does not appear lower in this species than in other salmonids. There were highly significant allele frequency differences between samples. Nevertheless, there was a high degree of genetic similarity among all the populations sampled indicating that they were derived from a relatively recent common ancestor. The results are discussed in relation to the current controversy concerning the number of major evolutionary lines in Scandinavian Arctic charr.

I. INTRODUCTION

The Arctic charr, *Salvelinus alpinus*, has a holarctic distribution and exists in both freshwater resident and anadromous forms. The systematics are confusing and the species has been suggested to constitute a species complex (Behnke, 1980). A major controversy is the possible existence of different sibling species representing discrete evolutionary lines. The presence of reproductively isolated sympatric populations with different morphological and ecological characteristics has been indicated throughout the geographic range of the Arctic charr (Johnson, 1980).

This tendency to evolve ecologically specialized populations with some degree of reproductive isolation between them seems to be characteristic of salmonid species. The existence of genetically distinct populations has been documented in population genetics studies on several salmonid species including the Arctic charr (Nyman, 1972; Child, 1977; Allendorf & Utter, 1979; Ryman *et al.*, 1979; Ferguson & Mason, 1981; Ryman, 1981; Ståhl, 1981; Kornfield *et al.*, 1981; and references therein). Thus, a large fraction of the total genetic variation in salmonid species is distributed between local populations of limited size.

This circumstance makes salmonids inclined to lose genetic variation due to the extinction of genetically unique populations. It is clear that a considerable loss of genetic variability in most Scandinavian salmonid species has taken place during the last century as a consequence of habitat destruction by pollutants and

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hydroelectrical power plant constructions (Ros, 1981; Ryman, 1981). A major goal in fishery management must be to conserve genetic diversity in salmonid species for future exploitation of this biological resource. Relevant descriptions of the population structure of these species are a prerequisite for the successful fulfilment of this important task.

Nyman (1972) analysed the population structure of Scandinavian Arctic charr on the basis of the allele frequency distribution at a single esterase locus and related the genetic information to growth rates and ecological data. He postulated that at least three sibling species invaded Scandinavia after the last period of glaciation. According to Nyman (1972) the three sibling species evolved allopatrically since preglacial time, now being characterized by body size differences and by high, low, or intermediate frequency, respectively, of an allele at the esterase locus. Currently, these sibling species should occur sympatrically in some lakes, whereas incomplete isolation mechanisms resulted in introgression and loss of the species characteristics in other lakes.

This interpretation has been questioned by Behnke (1980) who argued, on the basis of morphological data (Behnke, 1972) and from Nyman's own data, that each pair of sympatric populations is more closely related to each other than to any other population outside the lake. Behnke concludes that a single ancestor colonized Scandinavia after the last glaciation period; repetitive colonization together with allopatric divergence in the meantime should explain the occurrence of sympatric populations.

The concept of a single ancestor is further supported by the data of Ferguson (1981) who found perfect electrophoretic identity for a large number of proteins among Irish charr populations exhibiting the whole range of allele frequencies at the esterase locus studied by Nyman. A third hypothesis, based on observations of ecological and morphological data, has been put forward by Savvaitova (1980) advocating that current sympatric populations of Arctic charr have evolved sympatrically from a single colonizing ancestor. There is an obvious lack of more extensive genetic data to clarify this problem.

Electrophoresis combined with specific enzyme stainings is a simple method to genetically analyse large numbers of specimens. Population genetic analyses based on electrophoretic data for a large number of structural loci provide information on the amount and pattern of genetic variability and may clarify genetic relationships within the species. Thus, electrophoretic analyses may be a useful tool to delineate the complex population structure of the Arctic charr.

Although there are several previous electrophoretic studies on the Arctic charr (Table I), no detailed description has been documented for the majority of proteins analysed. In addition to those studies (Table I), Saunders & McKenzie (1971) compared the electrophoretic patterns of eye lens and muscle proteins, liver LDH, and liver esterases and concluded that several of these systems may be useful as population markers. The purpose of the present study was to apply electrophoretic techniques by means of standard buffers and stains for routine screening of a large number of protein loci in the Arctic charr. The results complement and extend those data presented by Ryman & Ståhl (1981). We give a detailed description of the electrophoretic banding patterns and our genetic interpretations. The results are discussed in relation to the different views on the Arctic charr systematics.

Q-band chromosomal polymorphisms in arctic char (*Salvelinus alpinus*)

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Received August 12, 1988
Accepted October 17, 1988

PLEYTE, K. A., and PHILLIPS, R. B. 1989. Q-band chromosomal polymorphisms in arctic char (*Salvelinus alpinus*). Genome, **32**: 129–133.

Stock-specific variation in the number and location of quinacrine-staining chromosomal bands was found in North American and European stocks of arctic char (*Salvelinus alpinus*). The mean number of bands per genome varied from 5.8 ± 5.3 in the Northwest Territories stock to 15.4 ± 2.1 in the Scottish stock. These bands appear to represent a subset of heterochromatin since they stain darkly with the C-band technique. Since the four stocks examined were each distinguishable on the basis of their Q-band patterns, these chromosome markers should be useful in genetic comparisons between different arctic char stocks and populations.

Key words: Q banding, chromosomes, polymorphisms, arctic char, *Salvelinus alpinus*.

PLEYTE, K. A., et PHILLIPS, R. B. 1989. Q-band chromosomal polymorphisms in arctic char (*Salvelinus alpinus*). Genome, **32** : 129–133.

Des variations spécifiques ont été trouvées dans des stocks d'omble de l'arctique (*Salvelinus alpinus*), en Europe et en Amérique du Nord, quant au nombre et à la localisation des bandes chromosomiques qui se colorent au quinacrine. Le nombre moyen de bandes par génome a varié de 5,8 ± 5,3 dans les stocks des Territoires du Nord-Ouest à 15,4 ± 2,1 dans ceux de l'Écosse. Ces bandes semblent représenter un sous-groupe d'hétérochromatine, puisqu'elles deviennent très foncées avec la technique de coloration des bandes C. Les quatre stocks soumis à l'examen ont pu être distingués les uns des autres par les patterns des bandes Q. Ces chromosomes marqueurs devraient donc s'avérer utiles pour fins de comparaison entre différents stocks et différentes populations d'omble de l'arctique.

Mots clés : bandes Q, chromosomes, polymorphismes, omble de l'arctique, *Salvelinus alpinus*.

[Traduit par la revue]

Introduction

The fluorochrome quinacrine, which produces distinctive banding patterns on the chromosomes of higher vertebrates, stains subsets of the constitutive heterochromatin (C-banded material) in the chromosomes of amphibians and fishes (Schmid 1980; Phillips and Hartley 1988). Heterochromatin polymorphisms have proved useful for stock identification in a number of organisms (John and Miklos 1979) and have been found in populations of salmonid fishes (Hartley 1987).

Geographic variation for the number of C bands has been found in the Iwana (*Salvelinus leucomanis*) (Ueda and Ojima 1983*a*). Polymorphism for the number and size of Q bands has been found in lake trout (*Salvelinus namaycush*) (Phillips and Zajicek 1982) and chinook salmon (*Oncorhynchus tshawytscha*) (Phillips et al. 1985) where these markers have been found to be inherited in Mendelian fashion (Phillips et al. 1985; Phillips and Ihssen 1986*a*).

Previous studies comparing Q-banding patterns of chromosomes from embryos, fingerlings, and adult salmonids have shown no differences among the various age groups (Phillips and Zajicek 1982; Phillips and Ihssen 1986*b*; Phillips and Hartley 1988). Polymorphisms in number and size of Q bands have been shown to be heritable in lake trout (Phillips and Ihssen 1986*b*).

In this paper we describe the extensive intraspecies variation in the number and chromosomal position of Q bands in two North American and two European stocks of arctic char (*Salvelinus alpinus*) and discuss its significance.

Materials and methods

Eggs and sperm were obtained from four different stocks of *S. alpinus*: from the Kent Peninsula, Northwest Territories, Canada; from the Fraser River, Labrador; from Storavatn, Norway; and from Loch Rannoch, Scotland. Embryos from the first three stocks were obtained from mass matings of gametes from fish collected from the wild and being maintained at the Rockwood Hatchery in Manitoba, Canada. Both embryos and adult fish were sampled from Loch Rannoch, Scotland, with no significant difference in results between the two age groups.

Chromosome preparations were made from embryos after vitelline vein formation was apparent but before the appearance of eye pigmentation. Preparations from blood of adult fish were made using methods described previously (Phillips and Zajicek 1982; Phillips and Hartley 1988; Hartley and Horne 1985).

Slides were stained in a 0.5% solution of Atebrin (BDH Chemicals Ltd., Poole, England) for Q banding, and were stained for C banding by the method of Sumner (1972). Slides were viewed with a Zeiss Universal microscope on bright field for C banding and with a B12 excitation filter and 47 or 50 barrier filter for Q banding. Photos were made using Kodak Technical Pan film with standard development.

At least six cells were examined per fish. For each cell examined the number and location of any bands were noted. In most cases it was difficult to distinguish metacentric from submetacentric chromosomes and therefore the term metacentric includes both metacentric and submetacentric chromosomes.

Results

Both the North American and European stocks were found to have a chromosome number of 78 with 20 metacentric or

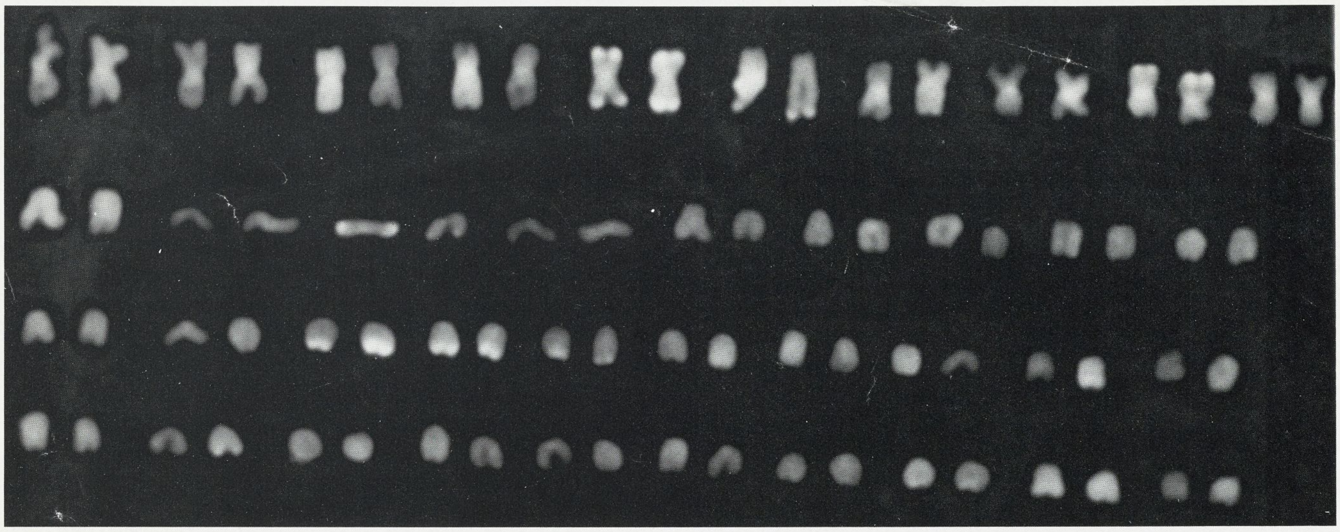

FIG. 1. Q-banded karyotype of arctic char from Loch Rannoch, Scotland (pelagic form).

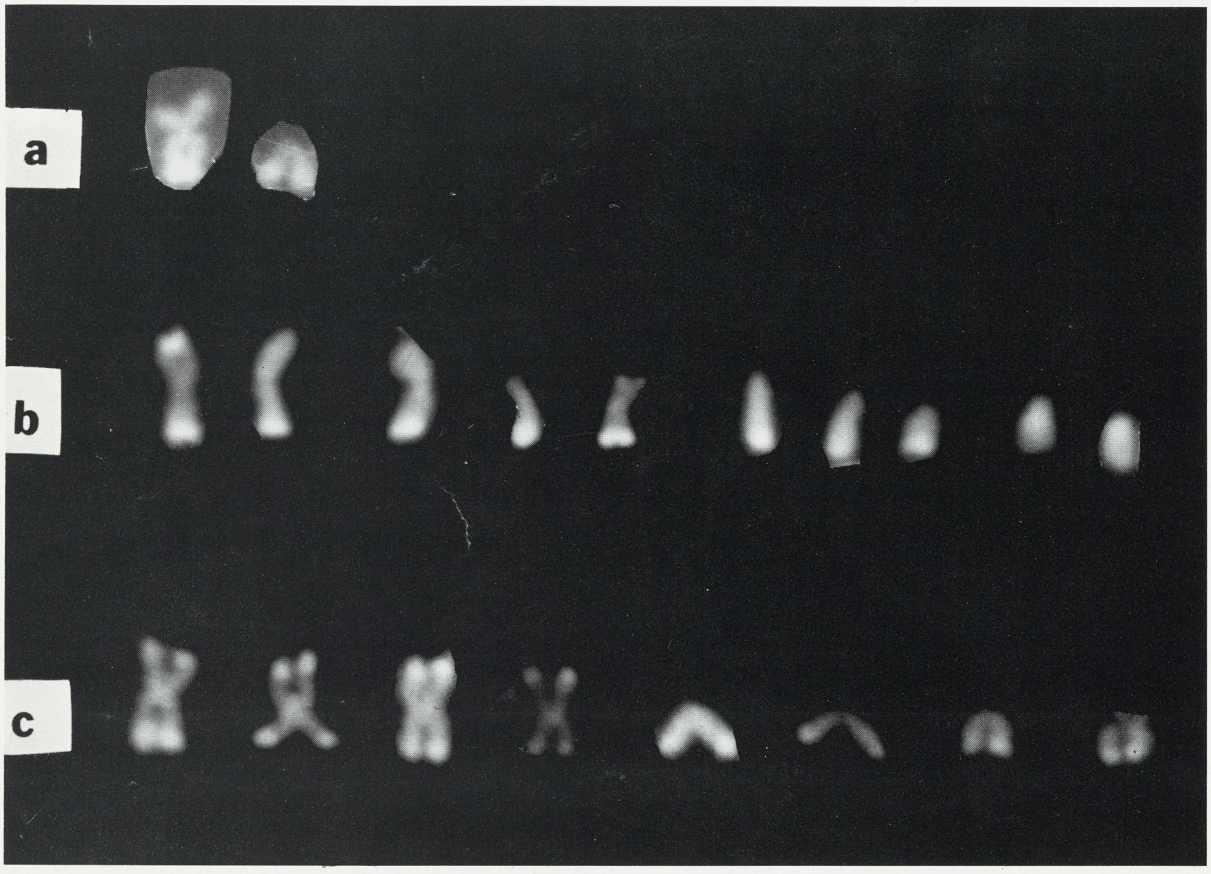

FIG. 2. Partial karyotypes, showing chromosomes with quinacrine bands, from individuals of (*a*) Northwest Territories, (*b*) Labrador, and (*c*) Scottish stocks of arctic char.

submetacentric chromosomes and 58 acrocentric chromosomes (Fig. 1). No differences in chromosome morphology between stocks was evident. This is in contrast to previous reports of a chromosome number of 80 in European (Scandinavian) stocks (Nygren et al. 1971; Gjedrem et al. 1977) but agrees with Cavender's interpretation of those results (Cavender 1981).

The total number of Q bands varied between different individuals but appeared constant for a given individual. Since it was often difficult to identify chromosome pairs unambiguously, the Q-band sites were classified into four groups according to the type of chromosome and chromosomal location. Q bands were found on telomeres of metacentric chromosomes, telomeres of acrocentrics, and short arms of acrocentrics (Fig. 2).

The mean total number of bands varied from 5.8 ± 5.3 in

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Genetic differentiation among local populations and morphotypes of Arctic charr, *Salvelinus alpinus*

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The systematics of coexisting morphotypes of Arctic charr, *Salvelinus alpinus*, has been a matter of dispute ever since the days of Linnaeus. Widespread allelic variation at an esterase locus has led some investigators to propose that the morphotypes reflect a complex of at least three sibling species. We tested this hypothesis by examining 42 electrophoretically detectable loci in natural and transplanted charr populations from 15 localities in S Norway. The absolute values of Nei's genetic distance between morphotypes and populations are small (typically in the order of 0.001), and morphotype changes may occur without accompanying changes in frequencies of esterase alleles. Differentiation among localities explains far more of the total gene diversity than differences between morphotypes in the four cases of naturally occurring sympatric morphotypes examined. The data are consistent with an intraspecific population structuring based on locality, and the multiple species hypothesis is rejected.

KEY WORDS:—Biochemical systematics – genetic variation – ecological polymorphism – speciation – Salmonidae.

CONTENTS

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Comparative Karyology and Karyotype Evolution of Chars*

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Key words: Comparative karyology, karyotype evolution, chars

Chars of the genus *Salvelinus* are one of the most complex and interesting groups of salmonid fishes. Their great morphological and ecological plasticity is the reason why, despite intensive investigation, there is no consensus on the number of species and their phylogeny. At present, there are three points of view regarding the systematics of chars. Two of them are diametrically opposed: proponents of one view recognize only a few valid species plus the extremely polymorphic *S. alpinus* complex (see Savvaitova, 1989); proponents of the second view identify at least 15 species of chars, granting species status to most local endemics and some widely distributed, recently described species (Chereshnev et al., 1989; Glubokovsky and Frolov, 1994). An intermediate position is held by some American workers (see Behnke, 1989).

In recent years, genetic methods, including investigation of karyotypes, have been used to resolve some problems of char systematics and phylogeny. Many species and forms of chars from the Arctic and Pacific regions have been karyotyped. It has been demonstrated that some features of char karyotypes can be used as taxonomic and phylogenetic markers. Several phylogenies have been proposed for chars based on karyotypes (Viktorovsky, 1975a, 1978; Cavender and Kimura, 1989; Phillips et al., 1989a). But these phylogenies are based on a limited amount of material. Viktorovsky's study (1975a) used whole chromosome staining, and the other two examined only North American species and *S. leucomaenis*. Since the publication of the last two reviews, I have investigated the karyotypes of a number of endemic and widely distributed species of Asian chars, from Chukotka, Sakhalin, and Primor'ye (Maritime Province), and I here attempt to generalize the data.

Methods

I use my data on karyotypes of chars from Kamchatka, Chukotka, Primor'ye, and Sakhalin (Frolov, 1991, 1992, 1993, 1994; Frolov and Miller, 1992, 1994; unpublished data). All karyo-

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