ADF&G Flooded Gravel Mine Studies Since 1986 and an Arctic Grayling Experimental Transplant Into a Small Tundra Drainage

A Synthesis

by

S.M. Roach

Technical Report No. 93-6

Alaska Department of Fish and Game
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ABSTRACT

North Slope flooded gravel mine sites investigated since 1986 contain suitable dissolved oxygen concentrations and sufficient under-ice water during the winter to provide potential overwintering areas for fish. In addition, North Slope flooded gravel mine sites have suitable chemical characteristics, zooplankton abundance, and phytoplankton levels to support fish. Two or more species of fish from adjacent waterways colonized each flooded gravel mine site studied. Five or more species of fish colonized three gravel mine sites modified to enhance fish utilization. Rehabilitation efforts at these sites included providing permanent connections to adjacent waterways, increasing shoreline diversity, and creating additional shallow water. A greater number of freshwater resident species were captured in flooded gravel mine sites associated with the large river drainages of the Kuparuk and Sagavanirktok River than in flooded gravel mine sites associated with small tundra streams. However, ADF&G personnel successfully transplanted Arctic grayling in 1989 to Kuparuk Mine Site B, a unique overwintering site in a small tundra drainage. Investigations indicate that at least 20% (95% CI = 20 to 55%) of the fish transplanted survived at least two years. Growth rate of transplanted fish was comparable to age-2 to age-7 Arctic grayling found in a small tundra stream that drains into the Kavik River. Although, reproductive success was not conclusive, transplanted fish spawned or were in pre-spawn condition in 1991 and five Arctic grayling were captured near Kuparuk Mine Site B that were smaller than any of the fish originally transplanted at the site. Two of these fish were estimated to be age-1 Arctic grayling (fork length = 120 mm and 115 mm) and three estimated to be young-of-the-year Arctic grayling (fork length < 38 mm). The observed lengths of these small Arctic grayling are consistent with the premise that they were the spawning progeny of the transplanted fish.

PART I

FLOODED GRAVEL MINE SITES STUDIED SINCE 1986

Introduction

Both positive and negative potential effects of gravel mining to the habitat on the North Slope is of interest to the Alaska Department of Fish and Game (ADF&G). Gravel mining and large scale development of Alaska's North Slope began after the Prudhoe Bay oil discovery of 1969 and continues today. Gravel is necessary for road construction, road maintenance, drilling pads, and other projects on the North Slope. Construction projects on the North Slope need more gravel compared to similar projects further south because of the presence of permafrost. Thick layers of gravel, besides forming the base for construction, help maintain the thermal regime necessary to prevent permafrost thawing. One large gravel site or a series of sites in one area are not adequate for projects on the North Slope because gravel sites must be located close to construction projects and at regular intervals for road maintenance. Construction in Alaska requires short haul distances because of the high costs of transporting gravel. Economical reasons required gravel haul distances of 16 km or less, for the maintenance of the Trans-Alaska Pipeline.

During early North Slope development, gravel was obtained by shallow scraping of the floodplain gravels. Environmental and hydrological considerations led to state policies that minimized surface disturbances by limiting the number of mine sites and encouraging large deep multi-user mine sites. Potential effects to the environment, from floodplain gravel mining, were identified in the early 1970's (Weeden and Klein 1971; Klein 1973; West 1976). The United States Fish and Wildlife Service (USFWS), consequently, recognized a need to provide information to resource managers that would help minimize negative effects to the environment from floodplain gravel mining. Woodward-Clyde Consultants began a study for the USFWS in 1975, which reported on 25 arctic and sub-arctic gravel mining sites (Woodward-Clyde Consultants 1980). This study culminated in an arctic and sub-arctic gravel extraction guide (Joyce et al. 1980).

During the five-year Woodward-Clyde study, investigations included the evaluation of eight interior Alaska flooded gravel sites for habitat and fauna diversity. This report suggested that these eight flooded gravel mines increased local habitat and fauna diversity. There was a positive relation between flooded pits with the greatest fauna diversity and shoreline vegetation, irregular shoreline development, one or more islands, diversity of water depths, food availability, and connection to a stream or river system (Joyce 1980).

Distributions of fish in the arctic are restricted to deep pools, deep lakes, and spring-fed areas during the winter. On the North Slope most bodies of fresh water, within small tundra drainages, freeze to the bottom during the winter or lack sufficient oxygen for the overwintering of fish, making overwintering habitat a limiting factor for fish diversity and abundance (Bendock and Burr 1985; Schmidt et al. 1989). For example, Craig and Poulin (1975) identified only two overwintering locations for fish within the tundra drainage of the Shaviovik River. Most deep pools are associated with large river drainages such as the Sagavanirktok and Kuparuk River drainages.

Encouraged by the Woodward-Clyde report and considering the paucity of overwintering sites for fish on the North Slope, ADF&G identified North Slope gravel pit reclamation a priority in 1986 and began studies to investigate flooded gravel mines on the North Slope. ADF&G identified Prudhoe Bay - Kuparuk flooded gravel mine management as an opportunity to benefit fish, wildlife, and man. Currently, in the North Slope oilfield, over 320 ha (800 ac) have been mined for gravel. The surface area of these sites range from 1.5 to 46.8 ha (3.7 to 117 ac) and range between 11.8 and 15.2 m (39 to 50 ft) below surface elevation. ADF&G hypothesized that reclaimed deep gravel mines on the North Slope may provide useable fish and wildlife habitat (e.g. rearing and overwintering areas). In addition, flooded deep gravel mines may provide sport fishing opportunities and a source of winter water for domestic and industrial use. This paper provides a synthesis of ADF&G reports on flooded gravel mines on the North Slope since 1986 (Hemming 1988; Hemming et al. 1989; Winters 1990a; Winters 1990b; Hemming 1990; Hemming 1991).

ADF&G investigations of Prudhoe Bay - Kuparuk flooded gravel mines were designed to:

1. determine the presence of fish and other fauna;
2. determine the suitability of these sites for overwintering habitat for fish;
3. compare biological and limnological characteristics among the sites;
4. identify site features that increase aquatic productivity and site utilization by fish and wildlife; and,
5. determine the feasibility of stocking fish in flooded mine sites within small tundra drainages where the opportunity for colonization is low.

Description of Mine Sites

Habitat and Restoration Division of the ADF&G investigated seven flooded gravel mines since 1986. Investigations included gravel mine sites in drainages between the Ugnuravik and Sagavanirktok (Sag) River on the North Slope of Alaska. There was one gravel mining site each in the Ugnuravik, East Creek, Kuparuk, and Putuligayuk (Put) drainages, and three sites in the Sag drainage (Table 1).

Flooded gravel mine sites are dynamic systems, continually changing because of spring flooding, thawing of adjacent ice fields, erosion from water and wind, and other natural events. Rehabilitation efforts by man are also a source of change for flooded gravel sites. Nature or man has altered several or all the sites studied since original flooding. In addition to flooding the sites, the oil industry completed enhancement projects for Sag Site C, Kuparuk Mine Site B, Kuparuk Dead Arm Reservoir 5, and Kuparuk Mine Site D. Natural events notably altered Sag Site C after enhancement efforts.

After gravel mine sites fill with water, a permanent or temporary connection to a stream, river, or lake is necessary for the colonization of fish. Permanent connections provide pathways for open water movement and temporary

Table 1. North Slope flooded gravel mine sites investigated by Habitat Division of the Alaska Department of Fish and Game since 1986.

		Year Studied				
Drainage	Site	1986	1987	1988	1989	1990
Sag[a]						
	Sag Site C	*	*	*	*	*
	Ott's Oxbow Site				*	*
	Goose Green Gulch				*	*
Kuparuk[a]						
	Kuparuk Deadarm 5 & 6	*	*	*		
Ugnuravik[b]						
	Kuparuk D Pit	*	*	*	*	
East Creek[b]						
	Kuparuk B Pit	*	*	*	*	*
Put[b]						
	Put 27 Mine Site				*	*

[a] Large river drainage.

[b] Small tundra river drainage.

connections provide pathways for movement during high water events. All the mine sites investigated were either permanently or temporarily connected to natural water bodies for colonization. Flooded gravel mine sites in large river drainages should have higher fish abundance and more species diversity than small tundra drainages because the source of colonization is greater in larger systems.

Mine Sites in Large River Drainages:

The Kuparuk and Sag drainages are large systems with deep pools and spring-fed areas, which enables the support of several species of freshwater and anadromous fish throughout the winter (Bendock 1977; Bendock 1982; Bendock and Burr 1984). There were four gravel mine sites studied in these two large river drainages; three in the Sag drainage (ARCO Sag Site C, Ott's Oxbow Site, and Goose Green Gulch) and one in the Kuparuk drainage (Kuparuk Deadarm Gravel Site).

ARCO Sag Site C. ARCO Sag Site C is near the west channel of the Sag River in the floodplain of the Sag River Delta. The Sag River oil pipeline crossing borders the north side of Sag Site C and the Sag River causeway borders the south side. The Sag River flooded this site when the western perimeter berm was breached in June of 1986 resulting in a 15.5 ha (38.2 ac) lake. High water created an outlet channel during breakup in 1987, which provided a seasonal connection to the Sag River. Depth profiles of this rectangular flooded mine site, before rehabilitation efforts, indicated steep sides, flat basin floors, and depths greater than 10 m (Hemming 1988).

In the fall of 1987 ARCO Alaska, Inc. established littoral areas in Sag Site C. ARCO personnel established 2.0 ha (4.9 ac) of shallow water habitat by removing 183 m of the gravel berm and removing gravel 0.6 to 1.2 m below water surface elevation. In June of 1989 flood waters from the Sag River washed the causeway road out, depositing the gravel on top of about 5 ha (12.3 ac) of the ice in Sag Site C. Additional erosion resulted in the redistribution of gravel in the newly created shallows, reducing the littoral habitat to 0.3 ha (0.7 ac). However, 0.2 ha (0.5 ac) of shallow water developed when the outlet channel expanded because of erosion. In addition, the tundra subsided along the east side of the site and surface flow changed near the northeast corner of the site, which resulted in a new inlet into Sag Site C from the tundra in August of 1989 (Hemming 1990). In 1990, erosion and sediment deposits from spring flooding almost completely filled the littoral area established by ARCO. In addition, water flow through the inlet was discontinuous and water discharge through the outlet was minimal (Hemming 1991). However, in the fall of 1992, ARCO Alaska installed culverts on a high water channel bordering the east side of the site.

Ott's Oxbow Site. Ott's Oxbow Site is in the floodplain of the Sag River. The ARCO airstrip and Prudhoe Bay Operations Center borders the west side of this gravel mine site. Ott's Oxbow is a 6.9 ha (17.0 ac) backwater area of the Sag River, which formed in the mid-1970's from shallow parallel scraping of gravel from the river. A gravel road partly isolates this shallow (not exceeding 2 m) backwater area from the main channel of the Sag River. The depth of gravel removal was irregular, which resulted in several small islands and spits within the mine site (Hemming 1990).

Goose Green Gulch. The Goose Green Gulch Site is in the floodplain of the Sag River. The Dalton Highway borders the west side of this gravel mine site and the Sag River borders the east side. Gravel removal, from six aliquots within the site, created shallow interconnected wetland habitat. An outlet channel, at the north end of the site, connects the shallow ponds of Goose Green Gulch to the Sag River. In 1977, Goose Green Gulch was fertilized and grass planted. Between 1978 and 1980 the site was planted with willow. This flooded gravel mine site has an extensive shoreline development of spits, embayments, and islands. The depths of these ponds range from 0.2 m to 1.2 m. During the 1990 spring flood, erosion, sedimentation, and scouring caused extensive changes to Goose Green Gulch. Flooding expanded the width of the outlet channel from 5 m to 15 m and deposited sand and silt at the southern end of the complex, which reduced the depth of the ponds. Other disturbances included scour holes and removal of vegetation. During the summer of 1990, the Sag River flowed continuously through the Goose Green Gulch mine site (Winters 1990).

Kuparuk Deadarm Gravel Site. The Kuparuk Deadarm Gravel Site is on the east side of the Kuparuk River floodplain. This site was a former high-water channel of the Kuparuk River. The Deadarm Site is a string of six connected gravel mining pits. In 1986, Kuparuk River water backed up into the former high-water channel creating lakes totaling 58.3 ha (143.6 ac). Depth profiles, before rehabilitation efforts, of Kuparuk Deadarm Gravel Reservoirs 4 and 5 indicated steep sides, flat basin floors, and depths greater than 10 m. There is little shoreline development at these two sites. Depth profiles of Reservoir 6, however, indicated extensive areas with depths less than 2 m. In addition, there is more shoreline development, small islands, and spits at Reservoir 6 (Hemming 1988).

In the winter of 1988 and 1989 BP Exploration established littoral habitat as part of an expansion of the Kuparuk Deadarm Gravel Site by removing gravel adjacent to Reservoir 5. This excavation to about 2.5 m below the water surface level of the reservoir, added 6.2 ha (15.3 ac) to the complex. There is an overburden dike between the reservoir and the expansion. There is a deep channel through the dike that connects the expansion and the reservoir. In addition, high water connects the two bodies of water south of the overburden dike during spring flooding (Hemming 1990).

Mine Sites in Small Tundra Drainages:

The lack of water deep enough to provide overwintering habitat limits fish abundance and species diversity in the Ugnuravik, East Creek, and Put drainages (Dew 1981). ADF&G studied three gravel mine sites in these tundra drainages; Kuparuk Mine Site D, Kuparuk Mine Site B, and Put 27 Mine Site.

Kuparuk Mine Site D. Kuparuk Mine Site D is adjacent to Charlie Creek. Charlie Creek is a western tributary of the Ugnuravik River, which flows into the Beaufort Sea. In early June 1984, excavation of a diversion channel between Kuparuk Mine Site D and Charlie Creek resulted in a 15.6 ha (38.7 ac) lake. However, there was significant erosion in the diversion channel and in Charlie Creek itself. In 1984 and 1985, the entire flow of Charlie Creek diverted to the mine site. In 1986, the water level of the pit reached the stream water surface level, reestablishing stream flow downstream of the mine site. Depth profiles of this rectangular flooded mine site, before rehabilitation efforts, indicated steep sides, flat basin floors, and depths greater than 10 m (Hemming 1988).

Rehabilitation efforts completed in early May 1990 for Kuparuk Mine Site D included construction of several inlet and outlet channels, removal of overburden berms from the south and west side of the mine site, improvements to the access road culvert, and excavation of two perched ponds on top of the overburden pile (Hemming 1991). Material removed from the overburden berms was placed on top of the ice to provide organic and fine grained material to the basin after the ice thawed. A decrease in the surface water elevation at this site has limited the effectiveness of this rehabilitation project.

Kuparuk Mine Site B (Aanaaliq Lakes). Kuparuk Mine Site B is next to East Creek, which drains directly into the Beaufort Sea. The Kuparuk Oil Pipeline and Spine Road borders Mine Site B on the north. This gravel mine site has two pits, which when flooded in 1978 resulted in lakes totaling 3.7 ha (9.1 ac). Channels independently connect both Kuparuk Mine Site B lakes to East Creek. Depth profiles of this rectangular flooded mine site, before rehabilitation efforts, indicated steep sides, flat basin floors, and depths less than 10 m (Hemming 1988).

In May 1989 ARCO Alaska, Inc. established an inlet channel and permanently connected the two lakes. ARCO Alaska personnel excavated a 18 m x 24 m section between East Creek and the southern lake to a depth of 1.8 m to create an inlet channel. Two additional excavations of 14 m x 24 m between the two lakes connected the lakes and formed an island. In 1989, ADF&G conducted an experimental introduction of Arctic grayling from the Sag River into Kuparuk Mine Site B to determine if a reproducing population could be established over time (Winters 1990b).

Lower Put River Mine Site and Put 27. Lower Put River Site is 3.2 km from Prudhoe Bay within the Put River. This gravel mine site is within the estuarine influence of Prudhoe Bay. In addition, there is a deep mined gravel site (Put 27 Mine Site) next to this river site, separated by a 115 m buffer strip and a flood control berm. The Lower Put River Site is a 9.5 ha (23.4 ac) pool, which resulted from gravel extraction during the early 1970's (Hemming 1990). In April 1990, BP Exploration excavated a channel between the Put River and Put 27 Mine Site, which flooded in late-May 1990 creating a 14.2 ha (35 ac) lake. This mine site is different from the other mine sites because BP Exploration conducted rehabilitation efforts recommended by ADF&G before flooding, the channel was excavated with a slope of 3:1 to a depth of 1.8 m and the excavated material was deposited within the mine site to provide organic debris and fine grained sediment.

Biological and Limnological Sampling

Methods:

This section provides a brief summary of the methods used by ADF&G personnel to investigate the biological and limnological characteristics of seven North Slope flooded gravel mine sites. Readers may obtain more in depth information on methods from Hemming (1988), Hemming et al. (1989), Winters (1990a), Hemming (1990), and Hemming (1991).

Fish Surveys. ADF&G personnel captured fish from four flooded gravel mine sites within large river drainages (Sag Site C, Ott's Oxbow, Goose Green Gulch, and Kuparuk Deadarm) and from three flooded gravel mine sites within small tundra drainages (Kuparuk Site D, Kuparuk Site B, and Put 27 Mine Site). Fish were captured with variable mesh gill nets (sinking and floating), wire minnow traps, and fyke traps to survey relative abundance and species diversity. Fish were generally captured during the open-water period from June through September. Under-ice sampling, however, was conducted in April 1987 in Sag C, Kuparuk D, and Kuparuk B gravel mine sites (Hemming 1988). Investigators used fyke traps to capture fish in all sites investigated except Kuparuk Mine Site D and gill nets in all sites except the Ott's Oxbow and Goose Green Gulch Mine Sites. In addition, minnow traps were used in Sag Site C, Kuparuk Mine Site D, and Kuparuk Mine Site B. Fishing time was recorded for each unit of gear to obtain catch-per-unit of effort and total effort for each site. Total hours of effort varied among flooded mine sites; 1332 hours in Sag Site C, 96 hours in Goose Green Gulch, 118 hours in Ott's Oxbow, 300 hours in Kuparuk Mine Site B, 218 hours in Put 27, and 567 hours in Kuparuk Mine Site D.

Zooplankton Surveys. ADF&G personnel surveyed two flooded gravel mine sites within large river drainages (Sag Site C and Kuparuk Deadarm) and two flooded gravel mine sites within small tundra drainages (Kuparuk Mine Site D and Kuparuk Mine Site B) to determine the presence and relative abundance of zooplankton (Hemming 1988; Hemming et al. 1989). ADF&G personnel removed and preserved stomachs from fish that died from sampling. Stomachs were separated by species and contents were examined for prey organisms. In addition, zooplankton were gathered with a Wisconsin-type tow net. In 1987, the net was pulled horizontally, but in 1988 the net was pulled vertically through the water column, slowly from the bottom of the lake to the surface (Hemming 1988; Hemming et al. 1989). Individual prey organisms were identified to the highest possible taxonomic level and numbers of each were counted or estimated.

Phytoplankton Surveys. ADF&G personnel evaluated phytoplankton standing crop in two flooded gravel mine sites within large river drainages (Sag Site C and Kuparuk Deadarm) and two flooded gravel mine sites within small tundra drainages (Kuparuk Mine Site D and Kuparuk Mine Site B) from chlorophyll-a sampling (Hemming 1988; Hemming et al. 1989). In 1987, 1-liter water samples were gathered from each mine site in an area thought to be typical of all mine sites (Hemming 1988). In 1988, samples were taken at various depths (Hemming et al. 1989). A trichromatic method, corrected for turbidity, was used to determine amounts of chlorophyll-a, -b, and -c.

Chemical Evaluations. ADF&G personnel determined temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, conductivity, alkalinity, and hardness from water samples collected with a vanDorn sample bottle from three flooded gravel mine sites within large river drainages (Sag Site C, Goose Green Gulch, and Kuparuk Deadarm) and from three flooded gravel mine sites within small tundra drainages (Kuparuk Site D, Kuparuk Site B, and Put 27 Mine Site). Water samples were taken during both open-water and ice-covered periods. In 1986, samples were taken at the surface or just below the ice at 3 m depth intervals (Hemming 1988). In 1987, samples were taken at various depths through the water column (Hemming et al. 1989).

Results:

Fish Surveys. ADF&G personnel captured 11 species of fish in the flooded gravel mine sites: four freshwater resident species (Arctic grayling *Thymallus arcticus*, round whitefish *Prosopium cylindraceum*, slimy sculpin *Cottus cognatus*, and burbot *Lota lota*); six anadromous species (Ninespine stickleback *Pungitius pungitius*, broad whitefish *Coregonus nasus*, Dolly Varden *Salvelinus malma*, Arctic cisco *Coregonus autumnalis*, least cisco *Coregonus sardinella*, and rainbow smelt *Osmerus mordax*); and one marine resident species (fourhorn sculpin *Myoxocephalus quadricornis*) (Hemming 1988; Hemming et al. 1989; Winters 1990a; Hemming 1990; Hemming 1991). Ninespine stickleback were captured in all sites investigated. Ninespine stickleback, Arctic grayling, and burbot were captured in all sites associated with large river drainages. Ninespine stickleback and least cisco were captured in all sites associated with small tundra drainages. Burbot and slimy sculpin were captured only in sites associated with large rivers. Fourhorn sculpin and rainbow smelt were captured only in sites associated with small tundra drainages near the coast within sites influenced by estruarine conditions (Table 2).

Table 2. Number of flooded gravel mine sites that ADF&G personnel captured fish by species and type of drainage; all sites (N=7), sites within large river drainages (n=4), and sites within small tundra drainages (n=3).

	Number of Flooded Gravel Mine Sites		
Species	All Sites	Sites Within Large River Drainages	Sites Within Small Tundra Drainage
Arctic cisco	2	1	1
Arctic grayling	5	4	1
Broad whitefish	4	2	2
Burbot	4	4	0
Dolly Varden	3	2	1
Fourhorn sculpin	1	0	1
Least cisco	4	1	3
Ninespine stickleback	7	4	3
Rainbow smelt	1	0	1
Round whitefish	4	3	1
Slimy sculpin	3	3	0

Two or more species of fish colonized each gravel site after flooding (Table 3) and five or more species colonized three gravel mine sites that were modified to enhance fish utilization (Table 4). Sag Site C showed the greatest increase in number of species after habitat modifications (Figure 1). A greater number of freshwater resident species were captured in flooded gravel mine sites associated with the large river drainages of the Kuparuk and Sag River than were captured in flooded gravel mine sites associated with small tundra streams (Figure 2). When considering all species (marine, anadromous, and freshwater resident), the greatest number of species were captured in Put 27 Mine Site, a gravel mine site with a strong estuarine influence within a small tundra drainage, which was developed using guidelines recommended by ADF&G for habitat enhancement before initial flooding. Fewer species, however, were captured in the two other sites within a small tundra drainage compared to sites within large drainages (Figure 3).

Zooplankton Surveys. ADF&G personnel identified zooplankton from seven taxonomic orders in four flooded gravel mines: four from class Insecta (Trichoptera, Diptera, Coleoptera, and Hymenoptera); two from class Crustacea (Copepoda and Cladocera); and one from class Mollusca (Gastropoda) (Hemming 1988; Hemming et al. 1989). Copepoda families Diaptomidae and Cyclopodae were identified in all four sites and Temoridae in all sites except Kuparuk D Mine Site. Trichoptera were identified in Sag Mine Site C and Kuparuk Mine Site B. Diptera, Coleoptera, and Hymenoptera were identified only in Sag Site C, a site associated with a large river drainage. Gastropoda were identified only in Kuparuk Mine Site B, a site associated with a small tundra drainage (Table 5).

Hemming (1988) subjectively rated the relative density of zooplankton abundance in Kuparuk Deadarm Mine Site as moderate to high, in Kuparuk Mine Site B as moderate, in Sag Mine Site C as low, and in Kuparuk Mine Site D as low. Hemming et al. (1989), likewise, reported low numbers of small zooplankton (Cladocera < 0.75 mm; Copepoda < 0.50 mm) and large zooplankton (Cladocera > 0.75 mm; Copepoda > 0.50 mm) in Sag Mine Site C compared to the other three sites. Estimated densities of large Copepoda and Cladocera ranged from zero organisms per liter found in May in each site to 4.9 organisms per

Table 3. Fish species captured in North Slope flooded gravel mines after initial flooding.

Site	Species
Sag Site C[a]	Arctic grayling Dolly Varden Broad whitefish Round whitefish
Ott's Oxbow[a]	Arctic grayling Broad whitefish Burbot Ninespine stickleback Round whitefish
Goose Green Gulch[a]	Arctic grayling Round whitefish Slimy sculpin Burbot Dolly Varden
Kuparuk Deadarm[a]	Arctic cisco Arctic grayling Ninespine stickleback
Kuparuk Site D[b]	Least cisco Ninespine stickleback
Kuparuk Site B[b]	Ninespine stickleback Broad whitefish
Put 27[b]	Round whitefish Dolly Varden Ninespine stickleback Arctic cisco Broad whitefish Least cisco Rainbow smelt Fourhorn sculpin Arctic grayling

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.

Table 4. Fish species captured in North Slope flooded gravel mines after initial flooding and after habitat enhancement.

Site	Species	
	After Initial Flooding	After Enhancement
Sag Site C[a]	Arctic grayling Dolly Varden Broad whitefish Round whitefish	Arctic grayling Dolly Varden Broad whitefish Round whitefish Least cisco Burbot Slimy sculpin Ninespine stickleback
Kuparuk Deadarm[a]	Arctic cisco Arctic grayling Ninespine stickleback	Arctic cisco Arctic grayling Ninespine stickleback Burbot Slimy sculpin
Kuparuk Site B[b]	Ninespine stickleback Broad whitefish	Ninespine stickleback Broad whitefish Round whitefish Least cisco Dolly Varden

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.

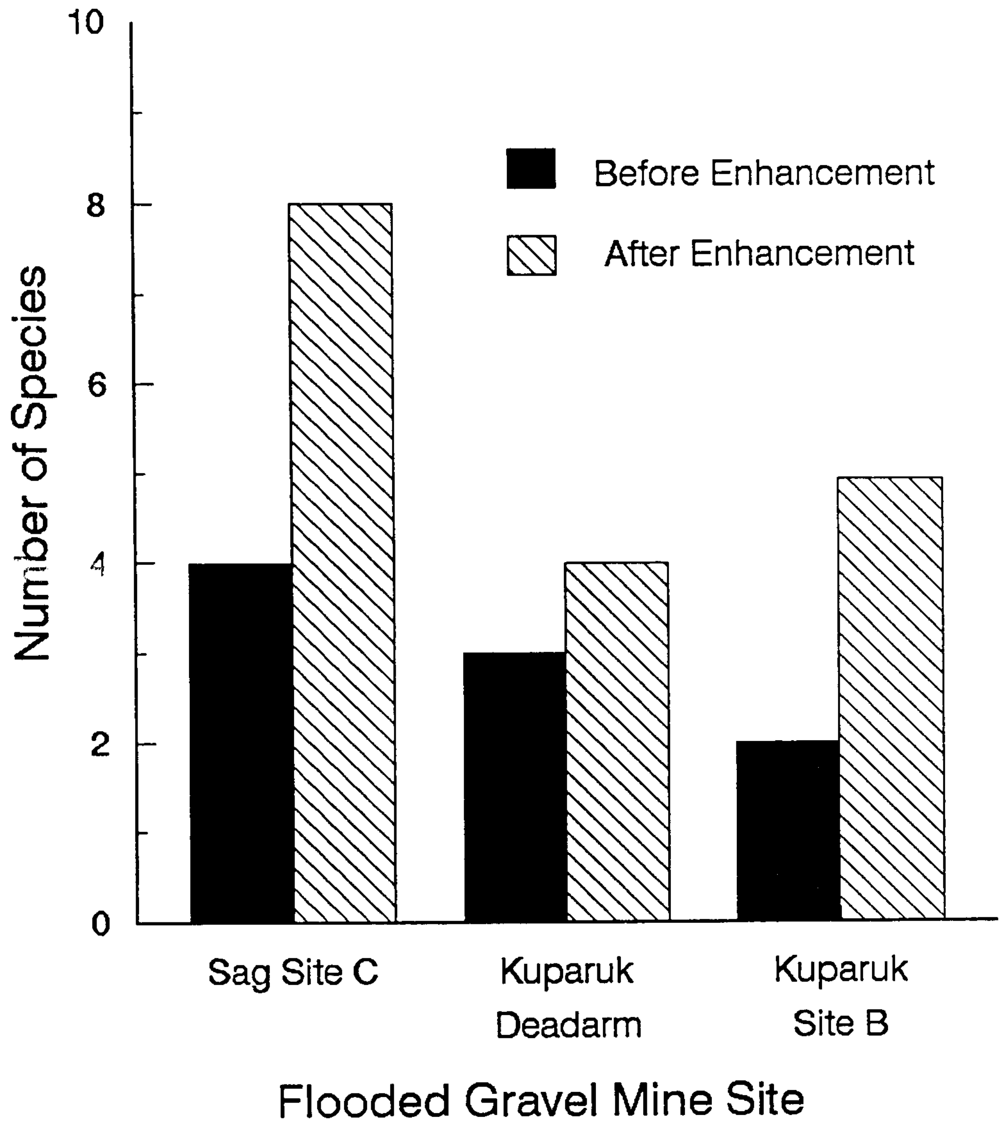

Figure 1. Number of species captured in North Slope flooded gravel mines, before and after habitat enhancement.

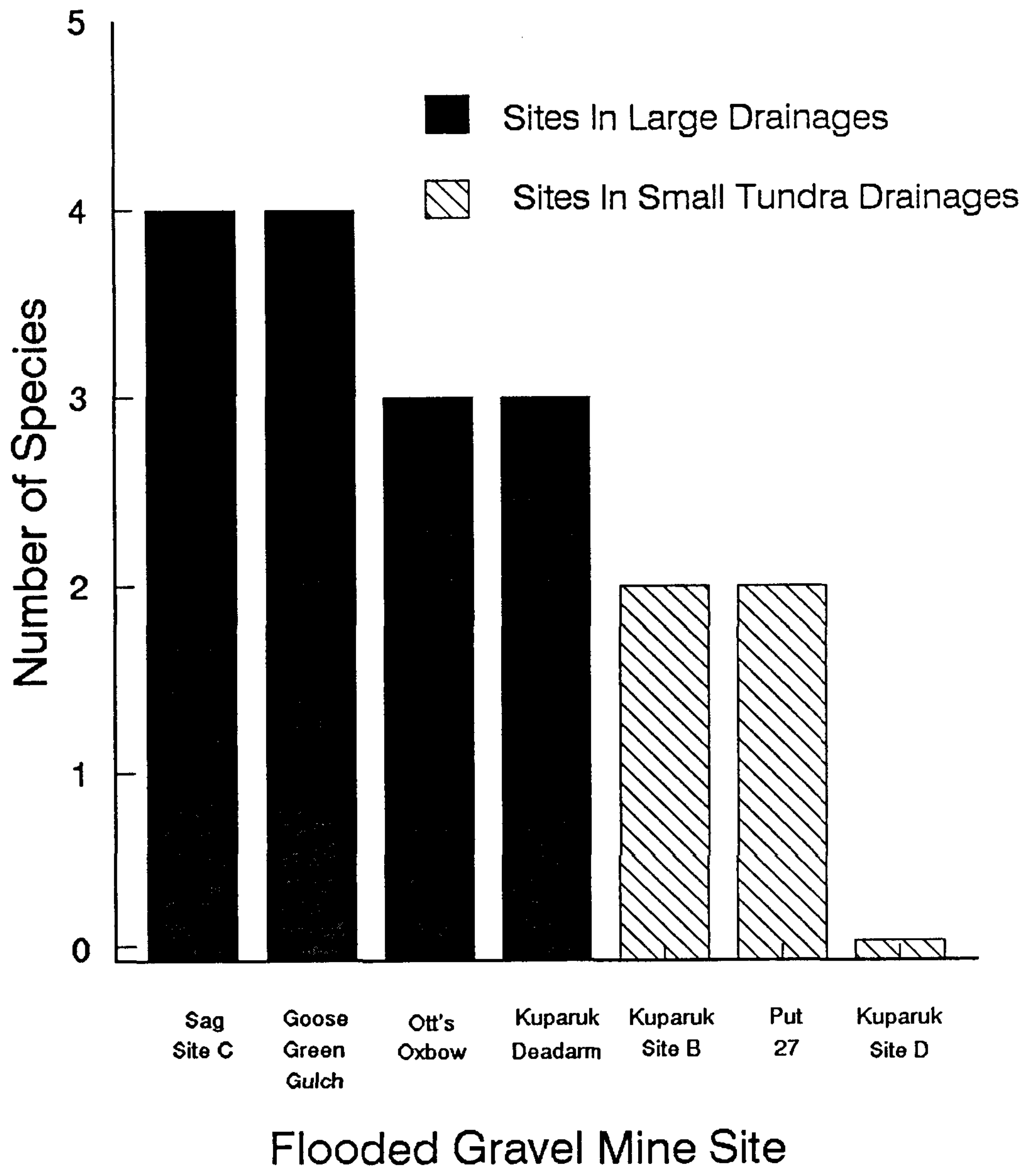

Figure 2. Number of freshwater resident species captured in North Slope flooded gravel mines from large river and small tundra drainages.

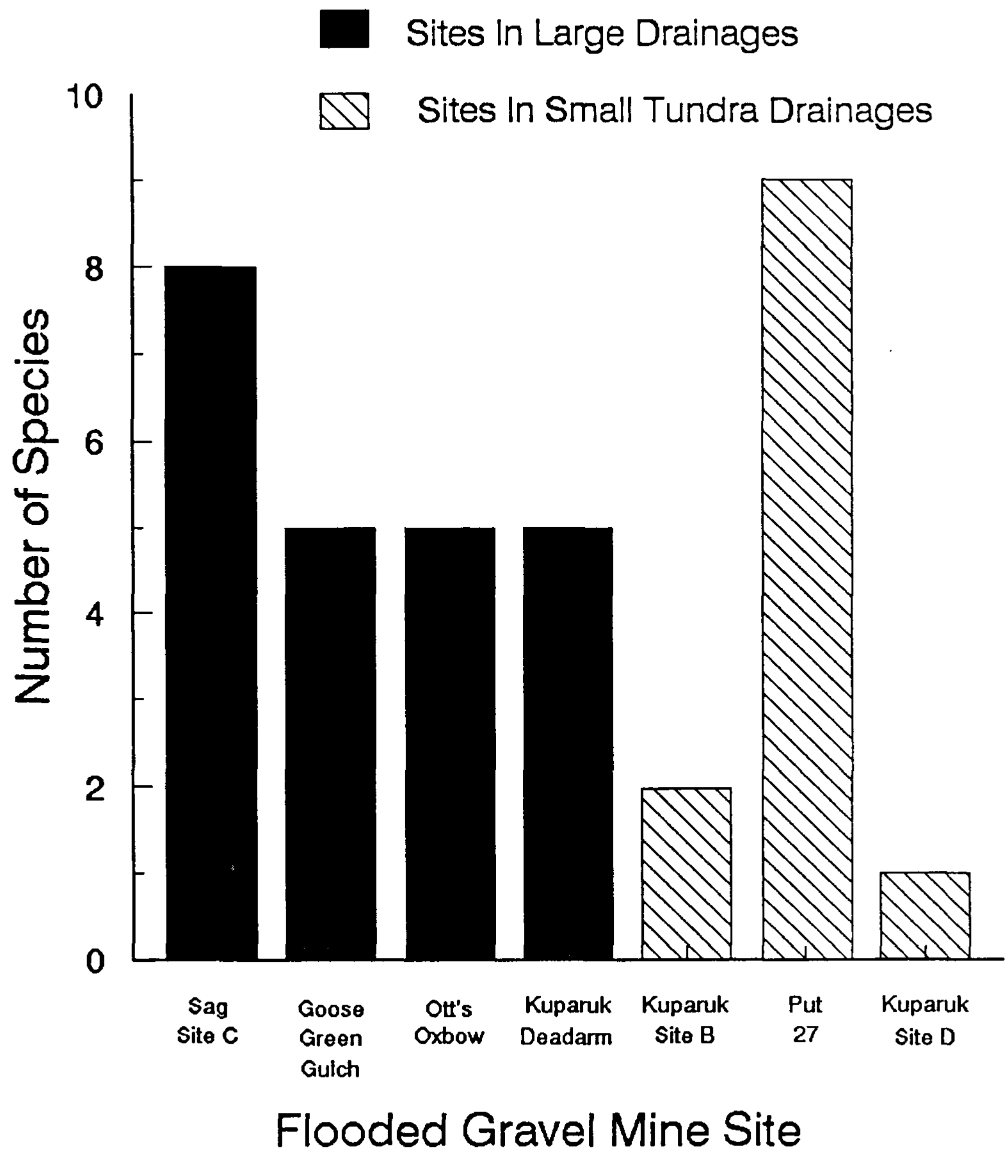

Figure 3. Number of species captured in North Slope flooded gravel mines from large river and small tundra drainages.

Table 5. Zooplankton collected from flooded gravel mine sites by taxonomic group (Class, Order, and Family).

	Taxonomic Group		
Site	Class	Order	Family
Sag Site C[a]	Crustacea	Copepoda	Cyclopodae
			Diaptomidae
			Temoridae
	Insecta	Coleoptera	not identified
		Diptera	Chironomidae
			Tabanidae
			Tipulidae
		Hymenoptera	not identified
		Trichoptera	not identified
Kuparuk Deadarm[a]	Crustacea	Cladocera	Daphnidae
		Copepoda	Cyclopodae
			Diaptomidae
			Temoridae
Kuparuk Site D[b]	Crustacea	Cladocera	Daphnidae
		Copepoda	Cyclopodae
			Diaptomidae
Kuparuk Site B[b]	Crustacea	Cladocera	Daphnidae
		Copepoda	Cyclopodae
			Diaptomidae
			Temoridae
	Insecta	Trichoptera	not identified
	Mollusca	Gastropoda	not identified

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.

liter in Kuparuk Deadarm Mine Site in August. Large Cladocera or large Copepoda were not found in any of the sites in May. Estimated densities of small Copepoda and Cladocera ranged from zero organisms found in May in Sag Site C to 50 to 75 organisms per litter in Kuparuk Mine Site D in August (Table 6).

Phytoplankton Surveys. Hemming (1988) determined average chlorophyll-a surface concentrations ranged from 1.28 to 5.51 μg/L in four North Slope flooded gravel mine sites in August 1987 (Table 7). Hemming et al. (1989) determined average chlorophyll-a concentrations at various depths ranged from 0.98 to 2.10 μg/L in the four flooded mine sites in May, July, and August 1988. During May 1988, concentrations of chlorophyll-a ranged from 0.72 μg/L in Sag Mine Site C to 3.35 μg/L in Kuparuk Mine Site D. During July 1988, concentrations of chlorophyll-a ranged from 1.22 μg/L in Kuparuk Deadarm Mine Site to 2.76 μg/L in Sag Mine Site C. During August 1988, concentrations of chlorophyll-a ranged from 0.79 μg/L in Kuparuk Deadarm Mine Site to 2.75 μg/L in Kuparuk Mine Site B (Table 7). Additionally, Hemming et al. (1989) determined average chlorophyll-b concentrations in the four flooded mine sites in May, July, and August 1988 ranged from 0.14 μg/L in Sag Mine Site C to 0.20 μg/L in Kuparuk Mine Site D and average chlorophyll-c concentrations ranged from 0.67 μg/L in Kuparuk Deadarm Mine Site to 1.03 μg/L in Kuparuk Mine Site B (Table 8).

Chemical Evaluations. Hemming (1988) and Hemming et al. (1989) reported water temperature profiles of North Slope flooded gravel mines isothermal during April-May and August. Kuparuk Deadarm Mine Site, Kuparuk Mine Site D, and Kuparuk Mine Site B, however, were not isothermal in July. Average water temperatures during April-May ranged from 0.1 °C in Kuparuk Deadarm Mine Site to 3.4 °C in Put 27 Mine Site, average water temperatures during July ranged from 3.6 °C in Sag Site C to 11.0 °C in Goose Green Gulch, and average water temperatures during August ranged from 7.0 °C in Put 27 Mine Site to 8.5 °C in Kuparuk Site D. Average DO during April-May ranged from 9.0 mg/L in Kuparuk Site B to 13.6 mg/L in Kuparuk Deadarm Mine Site, average DO during July ranged from 9.3 mg/L in Goose Green Gulch to 13.5 mg/L in Sag Site C, and average DO during August ranged from 10.5 mg/L in Put 27 Mine

Table 6. Estimated density of small zooplankton (Cladocera < 0.75 mm; Copepoda < 0.50 mm) and large zooplankton (Cladocera > 0.75 mm; Copepoda > 0.50 mm) in four North Slope gravel mine sites (adopted from Hemming et al. 1989).

	Number / L					
	Small Zooplankton			Large Zooplankton		
Site	May	July	Aug	May	July	Aug
Sag Site C[a]	0	< 1	< 1	0	< 1	< 1
Kuparuk Deadarm[a]	2-10	26-50	11-25	0	3.5	4.9
Kuparuk Site D[b]	< 1	11-25	50-75	0	< 1	< 1
Kuparuk Site B[b]	< 1	2-10	26-50	0	< 1	2.1

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.

Table 7. Average concentrations of chlorophyll-a in five[c] North Slope flooded gravel mine sites by year and month (adopted from Hemming et al. 1989). (Samples from each site ranged from two to six).

	Chlorophyll-a (μg/L)				
	1987	1988			
Site	Aug	May	July	Aug	Avg
Sag Site C[a]	1.70	0.72	2.76	1.79	1.70
Kuparuk Deadarm[a]	1.28	0.95	1.22	0.79	0.98
Kuparuk Site D[b]	5.51	3.35	1.65	1.72	2.10
Kuparuk Site B[b]	1.59	0.85	1.54	2.75	1.89

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.
[c] Average concentration of chlorophyll-a in Goose Green Gulch in July 1990 was 0.27 (μg/L).

Table 8. Average concentrations and ratios to chlorophyll-a of chlorophyll-b and chlorophyll-c in four North Slope flooded gravel mine sites from data collected in May, July, and August 1988 (adopted from Hemming et al. 1989).

	Chlorophyll-b (μg/L)		Chlorophyll-c (μg/L)	
Site	Concentration	Ratio	Concentration	Ratio
Sag Site C[a]	0.14	0.13	0.83	0.62
Kuparuk Deadarm[a]	0.15	0.16	0.67	0.71
Kuparuk Site D[b]	0.20	0.07	0.85	0.41
Kuparuk Site B[b]	0.15	0.11	1.03	0.59

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.

Site to 11.3 mg/L in Kuparuk Site D (Table 9).

Average pH ranged from 6.7 in Goose Green Gulch during July to 8.3 in Put 27 Mine Site during August. Average conductivity ranged from 102 μS/cm in Sag Site C during January-February to 894 μS/cm in Put 27 Mine Site during April-May. Average alkalinity ranged from 56 mg/L in Kuparuk Site B during August to 260 mg/L in Put 27 during April-May. Average hardness ranged from 64 mg/L in Kuparuk Site B during August to 194 mg/L in Put 27 Mine Site during April-May (Table 9).

Discussion:

ADF&G studies indicate that fish species found in adjacent waterways will colonize North Slope flooded gravel mine sites. However, connecting pathways, permanent or temporary, are necessary for colonization. Given the pathway, the number of species of fish utilizing flooded gravel mine sites are directly related to the number of species occurring in the adjacent waterways (i.e., colonization is limited to the number of available species). The number of those species moving into flooded gravel mine sites, furthermore, are related to the amount of time since initial flooding and the success of rehabilitation efforts to provide overwintering or rearing habitat.

The ADF&G found that two or more species of fish colonized each North Slope flooded gravel mine site investigated. This represents a minimum number of fish species. It is likely that with increased effort, or sampling at different times of the year, more species would be discovered. ADF&G studies indicated that flooded gravel mine sites within the large river drainages of the Sag and Kuparuk Rivers are more likely colonized by freshwater fish species than the flooded gravel mine sites found within small tundra drainages. Hemming (1988) suggested that the lack of overwintering habitat within the small tundra drainages, and in particular, the inability of obligatory freshwater fish to traverse saline waters to escape the poor winter conditions may help to explain the absence of these fish in these systems. However, it is believed that Arctic grayling could be self sustaining in these small tundra streams if overwintering areas were available within these

Table 9. Average water temperature (temp), dissolved oxygen (DO), acidity (pH), conductivity (cond), alkalinity (alk), and hardness (hard) values for North Slope flooded gravel mines by month[e] and site.

Month	Site	Temp °C	DO mg/L	pH	Cond µS/cm	Alk[c] mg/L	Hard[c] mg/L
January-February							
	Sag Site C[a]	0.9	10.8	7.5	102	90	88
April-May							
	Sag Site C[a]	1.0	12.6	7.7	105	86	99
	Goose Green Gulch[a]	-	-	-	-	-	-
	Kuparuk Deadarm[a]	0.1	13.6	-	-	-	-
	Kuparuk Site D[b]	1.2	10.9	7.4	438	112	172
	Kuparuk Site B[b]	0.8	9.0	7.2	325	144	167
	Put 27[b]	3.4	13.4	7.7	894	260	194
July							
	Sag Site C[a]	3.6	13.5	-	-	-	-
	Goose Green Gulch[a]	11.0	9.3	6.7	-	75	101
	Kuparuk Deadarm[a]	10.6[d]	11.8	-	-	-	-
	Kuparuk Site D[b]	5.1[d]	12.6	-	-	-	-
	Kuparuk Site B[b]	8.1[d]	11.1	-	-	-	-
	Put 27[b]	-	-	-	-	-	-
August							
	Sag Site C[a]	7.7	10.7	7.9	155	77	84
	Goose Green Gulch[a]	-	-	-	-	-	-
	Kuparuk Deadarm[a]	-	-	-	-	-	-
	Kuparuk Site D[b]	8.5	11.3	7.8	408	80	144
	Kuparuk Site B[b]	8.0	10.9	7.4	175	56	64
	Put 27[b]	7.0	10.5	8.3	776	117	178

[a] Gravel mine site within a large river drainage.
[b] Gravel mine site within a small tundra river drainage.
[c] Expressed as $CaCO_3$.
[d] Temperatures were not isothermal.
[e] Sag Site C sampled August 1986; January, February, April, July, and August 1987; and, May, July, and August 1988. Goose Green Gulch sampled July 1990. Kuparuk Deadarm sampled May, July, and August 1988. Kuparuk Site D sampled August 1986; April, July, and August 1987; May, July, and August 1988. Kuparuk Site B sampled August 1986; April and July 1987; May, July, and August 1988; and May 1990. Put 27 Mine Site sampled May and August 1990.

systems. For example, Arctic grayling are self sustaining in Weir Creek, a small tundra stream that flows into the Kavik River drainage (Craig and Poulin 1975). Deep water in the Kavik River provides overwintering habitat for these fish. However, very little deep water is available to Arctic grayling in small tundra systems that flow directly into the Beaufort Sea. Flooded gravel mine sites provide unique deep water habitat that may be used for overwintering, but it would be necessary to initially transplant Arctic grayling or other desired species at these sites.

The investigators found ninespine stickleback present in all flooded gravel mine sites investigated and especially in the flooded gravel mine sites within small tundra drainages with few other species. This suggests that ninespine stickleback are adapted to intermittent water flow and low oxygen conditions during the winter found in adjacent tundra waterways. Hemming (1988) attributes this to greater tolerance to low oxygen, small size, and high reproductive rate of ninespine stickleback. The effect of ninespine stickleback on Arctic grayling is not known. However, Skaugstad (1989) suggested that trophic competition between threespine stickleback *Gasterosteus aculeatus* and Arctic grayling resulted in poor growth of Arctic grayling fingerlings and no apparent survival of sac fry in Farmer and Sliver Lakes in the interior of Alaska. For this reason, it may be necessary to transplant Arctic grayling that are larger than the ninespine stickleback present in these flooded gravel mine sites in order to establish an Arctic grayling population. Investigators found both Arctic grayling and ninespine stickleback in Sag Site C, Ott's Oxbow, Goose Green Gulch, and Kuparuk Deadarm mine sites. This indicates, that once established, Arctic grayling populations can exist in the same system with ninespine stickleback.

All North Slope flooded gravel mine sites investigated contain sufficient under-ice water during the winter to provide overwintering areas for fish. When compared to the shallowness of natural lakes and ponds on the North Slope, the flooded gravel mine sites have the potential to greatly increase the amount of overwintering habitat for fish on the North Slope. However, depth is only one characteristic to consider for overwintering habitat. These flooded gravel mine sites must also provide forage and escape cover for fish that utilize these man-made lakes during the winter. A gradual transition from shallow water to deep water, irregular shoreline development, and the strategic placement of islands would ensure that these needs are met by providing increased shoreline vegetation that would extend into the under-ice water.

The greatest abundance and species richness of zooplankton were found in the shallow areas of Kuparuk Deadarm Mine Site and Kuparuk Mine Site B. This lends further support to the notion that littoral zones are important to flooded gravel mine sites for providing zooplankton prey organisms for fish. However, stomach analysis of fish captured at other sites, also indicated the presence of prey organisms, but these organisms were mainly terrestrial insects. Littoral zones would likely increase the food-base within these sites. In addition, over time, as vegetation becomes more established in flooded gravel mine sites, the food-base will likely increase. *Artophilia fulva* may also be transplanted in shallow zones of these flooded mine sites to help in establishing littoral vegetation. Zooplankton, similar to fish, may disperse into the flooded mine sites provided there are pathways for movement.

Chlorophyll-a values found in the North Slope flooded gravel mine sites are similar to values found in lakes and ponds near Yellowknife, Northwest Territories that support fish populations (Ostrofsky and Rigler 1987). Other water bodies with similar chlorophyll-a values and populations of fish are Charr Lake (high of 1.2 μg/L and average of 0.8 μg/L), Harding Lake (high of 4 μg/L in May and average of 2 μg/L during the summer months), and Toolik Lake (1.3 μg/L) (Kalff and Welch 1974; LaPerriere 1988; Hobbie et al. 1986).

The North Slope flooded gravel mine sites investigated have suitable chemical characteristics and dissolved oxygen levels to support fish. Hemming (1988) reported that the dissolved oxygen concentration in Sag Site C were at least three times higher than that in known overwintering areas for fish in the Sag River drainage. Likewise, Bendock (1980) reported dissolved oxygen concentrations, in several overwintering areas in the Colville River, one-third less than the dissolved oxygen concentrations found in the flooded gravel mine sites studied.

PART II

ARCTIC GRAYLING TRANSPLANT INTO A SMALL TUNDRA DRAINAGE

Introduction

Considering the information gathered from fish, zooplankton, phytoplankton, and chemical surveys of North Slope flooded gravel mine sites, ADF&G expect that gravel mine sites within small tundra drainages may provide unique and suitable rearing and overwintering habitat for fish not generally found in these systems. ADF&G, in 1989, determined the Kuparuk Mine Site B was suitable for experimentally introducing Arctic grayling. This mine site is found within a small tundra drainage with little or no opportunity for colonization by Arctic grayling. Freshwater fish are prevented from entering or leaving this small tundra system because of the marine saltwater barrier of the Beaufort Sea. Before 1989, only the anadromous ninespine stickleback, broad whitefish, and least cisco were documented using this flooded gravel mine site. In addition, Dolly Varden were documented using this site in 1991.

Kuparuk Mine Site B is next to East Creek, which drains directly into the Beaufort Sea. The Kuparuk Oil Pipeline and Spine Road borders Mine Site B on the north. This gravel mine site has two pits, which when flooded in 1978 resulted in lakes totaling 3.7 ha (9.1 ac). In May 1989 ARCO Alaska, Inc. established an inlet channel and permanently connected the two lakes. ARCO Alaska personnel excavated a 18 m x 24 m section between East Creek and the southern lake to a depth of 1.8 m to create an inlet channel. Two additional excavations of 14 m x 24 m between the two lakes connected the lakes and formed an island (Hemming 1990).

In 1989, ADF&G conducted an experimental introduction of Arctic grayling from the Sag River into Kuparuk Mine Site B to determine if Arctic grayling could be introduced, survive, and establish a reproducing population over time. Hemming (1988) determined that this flooded gravel mine site holds sufficient quantities of suitably oxygenated under-ice water for overwintering fish. Winters (1990b) suggested that the permanent connection between Kuparuk Mine

Site B and East Creek provides a pathway between the mine site and the stream for fish movement that may provide access to rearing and spawning areas, as a source of additional nutrients to the mine site that may enhance productivity, and as a source of warmer water that may promote rapid ice melt during the spring and warm the mine site during the summer.

Methods

This section provides a brief summary of the methods used by ADF&G personnel to capture and transplant Arctic grayling from the Sag River drainage to Kuparuk Mine Site B. Readers may obtain more in depth information on methods from Winters (1990b), and Hemming (1991).

In June 1989, ADF&G personnel captured Arctic grayling from seven locations within the Sag River drainage using fyke traps, seines, and hook and line. Arctic grayling were captured along the Sag River between Mark Creek and Oksrukuyik Creek. Each fish was measured to the nearest millimeter (fork length) and scales removed for age analysis. Numbered yellow floy tags were attached at the base of the dorsal fin of each fish for individual identification. ADF&G personnel released 210 Arctic grayling at the northeast section of Kuparuk Mine Site D in June 1989 (Winters 1990b).

ADF&G personnel sampled Kuparuk Mine Site B in late August 1989 with fyke traps and October 1989 by angling to determine if transplanted Arctic grayling remained in the site. Sampling also took place in June 1990 with fyke traps and angling, and in August and September 1990 with fyke traps to evaluate survival, growth, and reproductive success of the transplanted Arctic grayling. The 1990 sampling event included sampling sites within East Creek upstream and downstream of the mine site, within the inlet channel to the mine site, and within the mine site. Each fish captured was examined for the presence of a floy tag or a tag scar and fork length measured (Winters 1990b).

ADF&G personnel conducted a mark-recapture experiment at Kuparuk Mine Site B in 1991 to estimate Arctic grayling abundance in Kuparuk Mine Site B. Arctic grayling captured in June and July were marked with internal anchor floy tags and adipose fin clipped. The recapture event took place in August to allow sufficient mixing. Investigators used an adjusted Peterson calculation to estimate the Arctic grayling abundance at the Kuparuk Mine Site B (Ricker 1975).

Results

Fork length of the Arctic grayling transplanted into Kuparuk Mine Site B ranged from 176 to 399 mm with a mean of 283 mm and standard deviation of 52 mm. The age of the Arctic grayling transplanted ranged from three to eleven years. Visual observation indicated that all transplanted Arctic grayling were healthy at the time of release. One Arctic grayling was observed moving into East Creek and several were observed feeding within minutes of release (Winters 1990b).

In 1989, investigators captured five Arctic grayling within the Kuparuk Mine Site B; two in fyke traps during August and three on hook and line during October. One fish captured in August was recaptured in October. Four of these fish were examined for the presence of a floy tag and length measured. All four fish were identified as transplanted fish; three by floy tag and one by tag scar. These fish exhibited average daily growth from the time of initial length measurements to recapture of 0.23 to 0.34 mm (Winters 1990b).

In 1990, investigators captured a total of 44 Arctic grayling within Kuparuk Mine Site B, within the inlet channel, or within East Creek. Thirty-six fish (eight of the 44 fish were captured more than once) were examined for floy tags and fork length measured. Thirty-one of these fish were identified as transplanted fish; 16 by floy tag and 15 by tag scar. These fish exhibited average annual growth rates of 25 to 92 mm with a mean of 58.6 mm. During June, investigators captured 22 Arctic grayling with fyke traps; three within the inlet channel, 13 upstream of the mine site, six downstream of the mine site. In addition, 18 Arctic grayling were captured on hook and line; three upstream of the mine site and fifteen within the mine site. During August, investigators captured four Arctic grayling within the inlet channel with fyke traps. Although fyke traps were set and angling took place, Arctic grayling were not captured within the stream during the August event. During September, investigators did not capture any Arctic grayling. Three fyke traps were set; one within the inlet channel, one at the north end of the mining site, and one upstream of the lake. The effectiveness of these nets was questionable and after 1-day of soaking had to be pulled because of freezing in place (Hemming 1991).

In 1991, investigators captured a total of 79 Arctic grayling within Kuparuk Mine Site B, within the inlet channel, or within East Creek. Forty-three fish (36 of the 79 fish were captured more than once) were examined for floy tags and fork length measured. Identified fish exhibited average annual growth rates of 9 to 68 mm with a mean of 42.3 mm. During June, investigators captured 21 Arctic grayling with fyke traps; nine upstream of the mine site, one downstream of the mine site, and 11 within the mine site. During July, investigators captured 25 Arctic grayling with fyke traps; four within the inlet channel, two downstream of the mine site, and 19 within the mine site. In addition, nine Arctic grayling within the mine site and two within East Creek were captured on hook and line. During August, investigators captured 22 Arctic grayling with fyke traps; 19 within the inlet channel and 3 downstream of the mine site. Five Arctic grayling captured in 1991 were smaller than any of the fish transplanted at Kuparuk Mine Site B in 1989. Two of these were estimated to be age-1 Arctic grayling (fork length = 120 mm and 115 mm) and three estimated to be young-of-the-year (fork length < 38 mm).

In 1991, investigators estimated the abundance of Arctic grayling in and near Kuparuk Mine Site B to be 56 fish (95% CI = 43 to 116 fish) in June and July. Thirty-seven Arctic grayling were marked in June and July and 18 were captured (12 with marks) in August. Investigators estimated that 27% (95% CI = 20 to 55%) of the original 210 Arctic grayling survived two years, based on the mark-recapture experiment.

Discussion

ADF&G personnel successfully transplanted Arctic grayling in a North Slope tundra drainage with few or no overwintering areas except for a rehabilitated flooded gravel mine site. Visual observation indicated that all transplanted Arctic grayling were healthy at the time of release. One Arctic grayling was observed moving into East Creek and several were observed feeding within minutes of release (Winters 1990b). At least 20% or possibly as high as 55% (95% CI) of the Arctic grayling transplanted at Kuparuk Mine Site B from the Sag River drainage survived two years.

Growth information indicated that these fish increased in length at a rate comparable to age-2 to age-7 Arctic grayling in Weir Creek, a small North Slope tundra stream that drains into the Kavik River (Craig and Poulin 1975). Craig and Poulin (1975) characterized the growth rate of Weir Creek Arctic grayling as being among the highest for Arctic populations. As expected, fish at a smaller size at the time of the transplant showed the greatest increase in length (Figure 4).

Although, reproductive success was not conclusive, transplanted fish spawned or were in pre-spawn condition in 1991 and five Arctic grayling were captured near Kuparuk Mine Site B that were smaller than any of the fish originally transplanted at the site. Two of these fish were estimated to be age-1 Arctic grayling (fork length = 120 mm and 115 mm) and three estimated to be young-of-the-year Arctic grayling (fork length < 38 mm). The observed lengths of these small Arctic grayling are consistent with the premise that they were the spawning progeny of the transplanted fish.

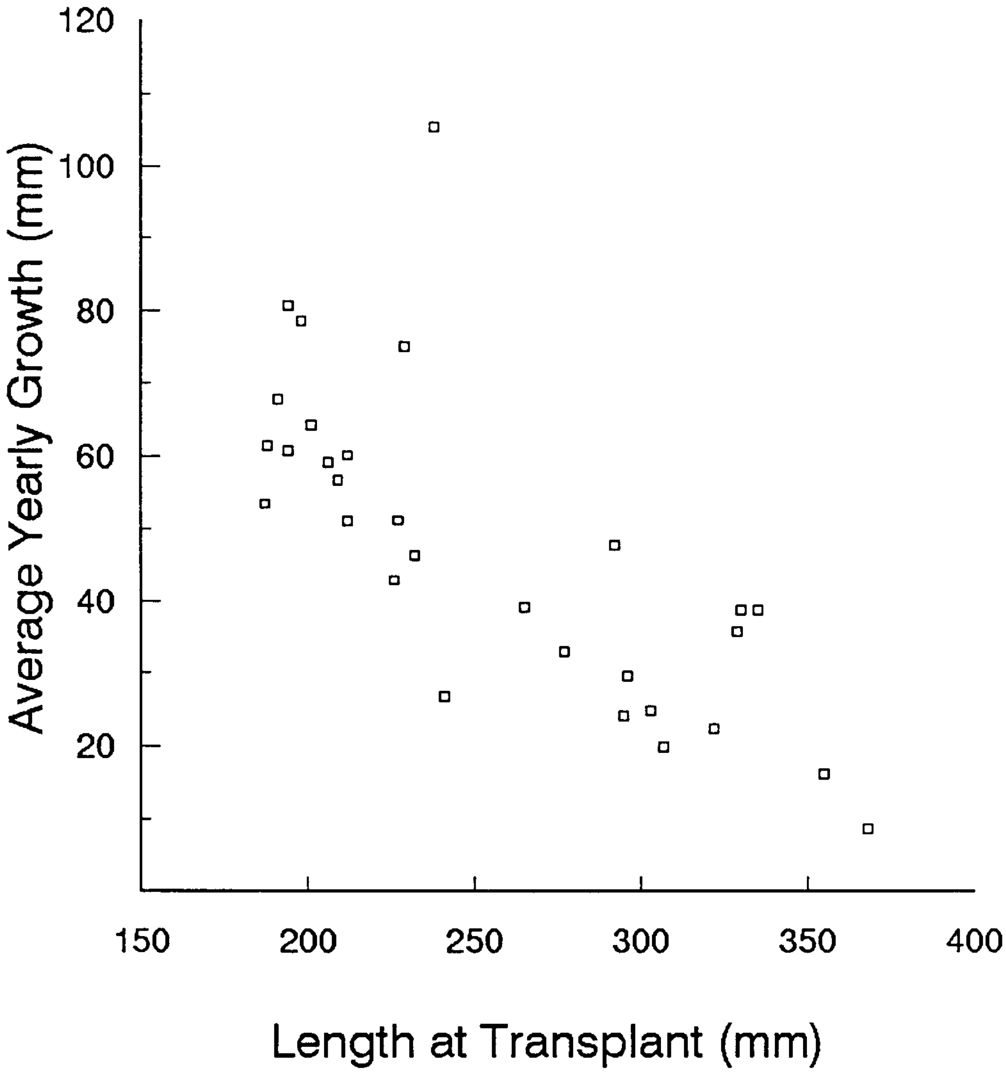

Figure 4. Average yearly growth rate to length at time of transplanting of Arctic grayling in Kuparuk Mine Site B transplanted in 1989 and recaptured in 1990 and 1991.

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