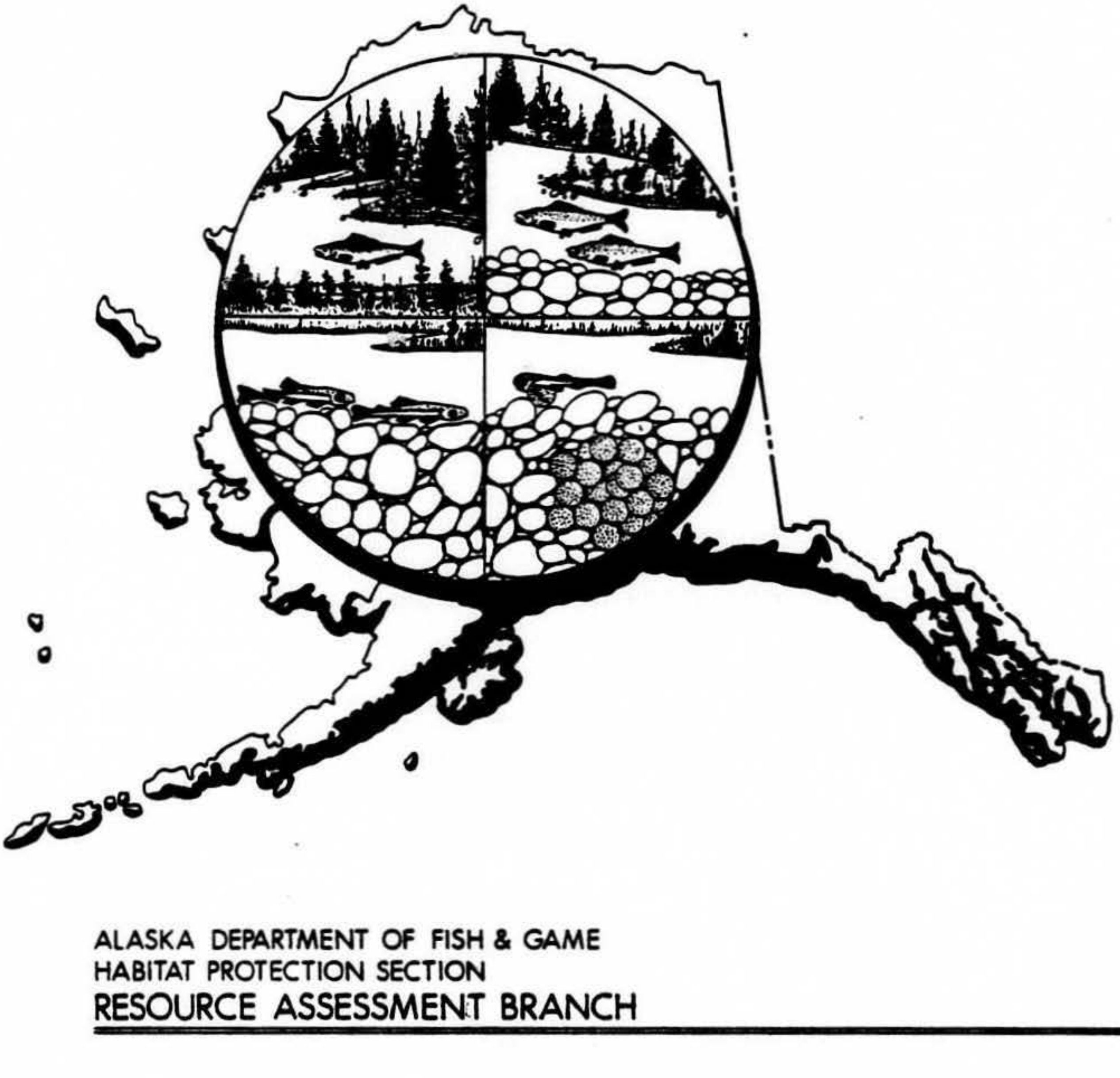
FRESHWATER HABITAT RELATIONSHIPS

ARCTIC GRAYLING - <u>THYMALLUS ARTICUS</u>



ALASKA DEPARTMENT OF FISH & GAME
HABITAT PROTECTION SECTION
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FRESHWATER HABITAT RELATIONSHIPS
ARCTIC GRAYLING (_THYMALLUS ARCTICUS_)

By

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TABLE OF CONTENTS

Arctic Grayling

I. INTRODUCTION

A. Purpose

The purpose of this project is to describe how selected physical and chemical features of lotic habitat within Alaska influence the survival and behavior of the various life stages of Arctic grayling, Thymallus arcticus (Pallas).

Objectives of this project are:

1) To gather data from published and unpublished sources within Alaska, Canada and Montana and from conversations with fishery biologists from the above areas concerning the relationships between lotic aquatic habitat and Arctic grayling survival and behavior.

2) To develop an Alaska data base composed of narrative and tables of observed physical parameters to better understand habitat-Arctic grayling relationships; and

3) To identify areas where data are lacking and to recommend studies to fill gaps in the data.

The following "Life History Summary" and "Specific Habitat Relationships" sections will identify the lotic habitat relationships of the various life history and seasonal behavior stages of the Arctic grayling which include:

upstream spawning migration;
spawning;
post-spawning movements;
incubation;
summer rearing;

migration to overwintering areas; and
winter rearing

B. Distribution

The Arctic grayling is a holarctic species of the genus Thymallus. Within North America it occurs from Hudson Bay west through northern Manitoba, Saskatchewan, Alberta and British Columbia, the Northwest Territories (excluding most islands of the Arctic archipelago), the Yukon and most of Alaska. In Eurasia it is found as far west as the Kara and Ob Rivers and south to Northern Mongolia and North Korea.

Several isolated, relict populations exist in North America. One is located in a fraction of its original range in the extreme headwaters of the Missouri River drainage in Montana (Nelson, 1953). Two other relict populations are found in Canada, one in southeast British Columbia and the other in southwest Alberta (Scott and Crossman, 1973).

An Arctic grayling population in the Great Lakes region was eliminated in the 1930s. Possible causes were log drives during the spawning season, intense angling effort and general habitat degradation (Creaser and Creaser, 1935). Attempts to restock these waters failed. Arctic grayling have been introduced to Colorado, Utah, Idaho and Vermont (Scott and Crossman, 1973). Arctic grayling are distributed over much of Alaska (Figure 1) (McClean and Delaney, 1978). Distribution of Arctic grayling within southeast Alaska is primarily limited to stocked lakes. Occasionally fish drift downstream in large stream systems, such as the Stikine River. These rivers often support substantial populations of grayling in their headwater reaches (McClean and Delaney, 1978).

Insert Figure 1

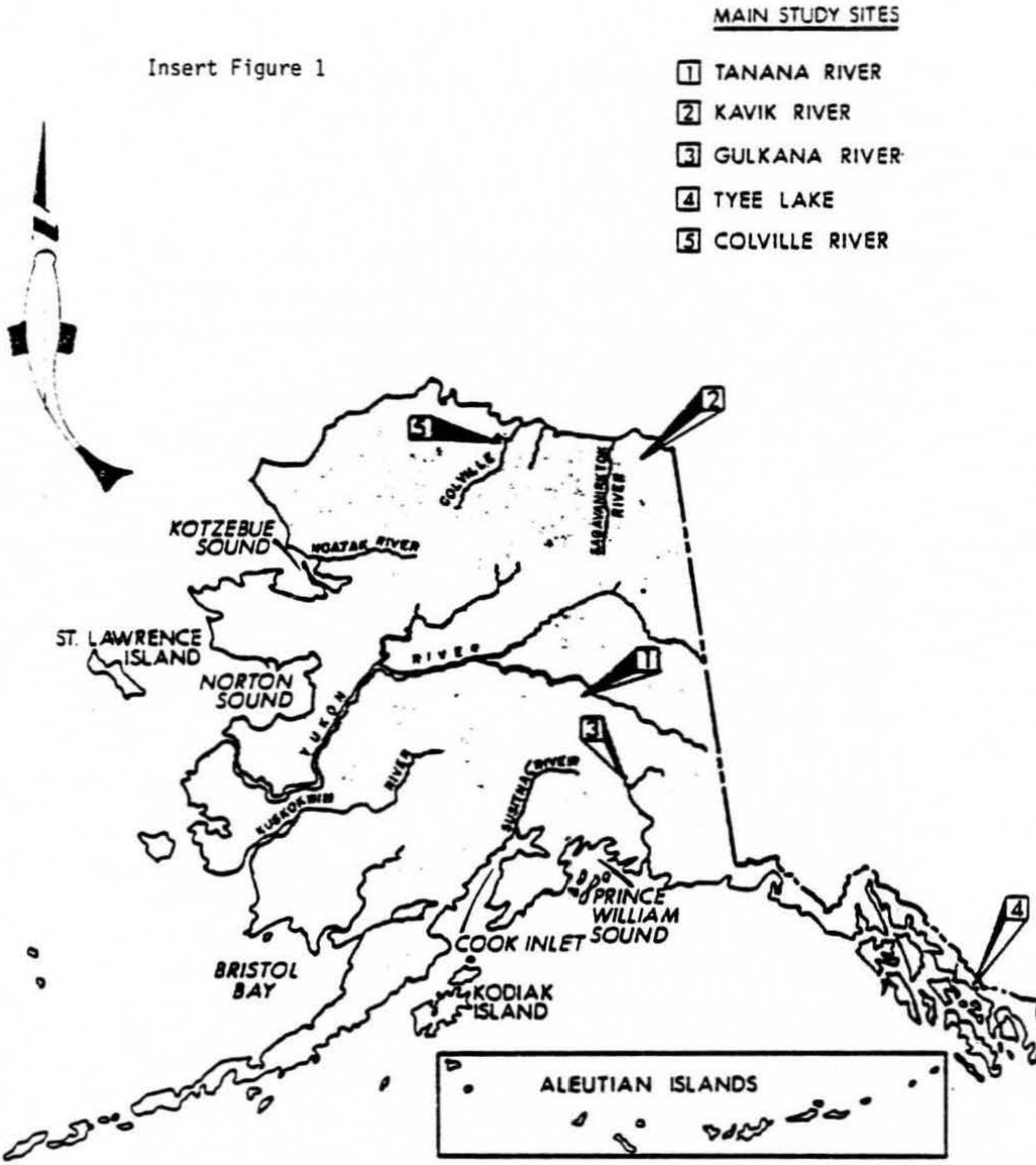

FIGURE 1. DISTRIBUTION OF ARCTIC GRAYLING IN ALASKA (FROM ALASKA DEPARTMENT OF FISH AND GAME, 1978) AND MAIN STUDY SITES.

Numerous clearwater tributaries and lakes within the upper Copper and Susitna River drainages contain Arctic grayling. Grayling are found in the Gulkana and Oshetna Rivers. Arctic grayling are extremely limited within the Prince William Sound area and lower Copper River drainage and somewhat limited within the lower Susitna River drainage. Both of these large rivers are glacial and support relatively small populations. However, a few clearwater tributaries of the lower Copper River and many clearwater tributaries of the lower Susitna River, such as the Talachulitna and Chunilna River, and Lake Creek contain Arctic grayling. Arctic grayling are not found on the west side of Cook Inlet south of Tyonek (McClean and Delaney, 1978).

Numerous lakes within the Kenai Peninsula were stocked and now support reproducing populations of Arctic grayling. These include Crescent, Upper and Lower Paradise, Bench and Twin Lakes (McClean and Delaney, 1978). Selected lakes on Kodiak and Afognak Islands contain Arctic grayling.

Grayling are also found in clear water streams of the Alaska Peninsula and Bristol Bay drainages. Especially large individuals are found in the Ugashik and Becharof Lake and Togiak River drainages (McClean and Delaney, 1978).

Arctic grayling are widely distributed in the remaining Arctic and sub-Arctic areas of Alaska, with the exception of the Yukon-Kuskokwim River delta area (McClean and Delaney, 1978).

C. Life History Summary

Arctic grayling usually migrate to spawning sites just prior to or during spring breakup. Several factors influence the upstream migration of this fish including distance separating overwintering and spawning sites, streamflow and water temperatures. Tack (1971) reported upstream movement of fish within the ice covered Chena River about 2.5 weeks prior to breakup conditions. Tripp and McCart (1974) reported upstream movement of fish in the ice covered Mackenzie River to ice-free tributaries.

Fish passage can be prevented by ice jams, beaver dams or waterfalls. The swimming performances of adult and juvenile Arctic grayling are influenced by fish size, water temperature, current velocity and the size and extent of barriers. Sex and spawning condition also influence the migration of adult fish (MacPhee and Watts, 1976).

The importance of the spawning migration to juvenile fish is not clear. Tack (1980) related this phenomenon to homing. Juvenile fish may become imprinted on visual, olfactory or other conditions and recognize the spawning area upon maturation.

The establishment of male spawning territories may initiate spawning activity (Kruse, 1959; Bishop, 1971; Tack, 1971). Males select territorial sites for various physical conditions where spawning will eventually take place.

Grayling territories vary in size with respect to stream width, water depth, current velocity, channel configuration, spawner density and, possibly, other conditions. Kruse (1959) measured territories of 0.15 by 0.61 m (0.5 by 2.0 ft) in a 1.5 m (5 ft) wide reach of Northwest Creek, an inlet of Grebe Lake, Wyoming. However, in a wider (2.4-3.0 m, 8-10 ft) reach of the same stream, territory dimensions were approximately 1.2 by 1.2 m (4 by 4 ft). Tack (1971) noted that male fish territories in the outlet of Mineral Lake, Alaska were about 2.4 by 2.4 m (8 by 8 ft).

Ripe males establish spawning territories and vigorously defend them from other males. Short head-on thrusts usually repel sub-adults. Adult males are repelled by lateral displays, sometimes followed by direct attacks (Tack, 1971).

Grayling spawn in areas with surface current velocities less than 1.4 m/sec (4.5 ft/sec), varying water depths and relatively small, unimbedded gravels about 2.5 cm (1 in) in diameter.

Fertilization occurs after the females leave their holding areas and pass through male territories. The females are pursued by several males who attempt to court her. The successful male places his dorsal fin over her back, initiating simultaneous body arching and vibrating. The male may drive the posterior third of the female's body into the substrate where eggs and sperm are released.

The fertilized eggs sink to the bottom of the stream and adhere to the substrate. No actual redd is constructed but the eggs may be covered by as much as 5 cm (2 in.) of dislodged substrate. There is no parental care of the eggs. After spawning, the female resumes her former resting position before possibly spawning again. Both sexes may spawn more than once with various partners. They are capable of spawning annually (Brown, 1938; Kruse, 1959; Bishop, 1971; Tack, 1971; Scott and Crossman, 1973). It is not known whether juvenile and adult Arctic grayling return to the same spawning stream.

The duration of Arctic grayling spawning activity may range from four days to two weeks (Warner, 1955; Tack, 1971; McCart, Craig and Bain, 1972; Tripp and McCart, 1974).

Age of maturity is variable and generally is greater in the northern reaches of this fish's range. Grayling have been found to reach sexual maturity at age 2 or 3 in Michigan (Creaser and Creaser, 1935) and in Montana (Kruse, 1959) streams. Most fish in the North Slope (of the Brooks Range, Alaska) and northern

Yukon and the Northwest Territories mature between ages four to nine (Bishop, 1971; McCart, Craig and Bain, 1972; deBruyn and McCart, 1974; Craig and Poulin, 1974). Fish in the lower Kuskowkwim River, Seward Peninsula and Tanana River, Alaska reach maturity at ages five to six (Alt, 1966 and 1978; Wojcik, 1955).

The life span of Arctic grayling is variable; northern populations generally live longer than southern populations. Maximum ages of Arctic grayling from Montana range from seven to eleven years (Brown, 1938; Nelson, 1953). Several fish from selected Beaufort Sea drainages in the Yukon Territories and the Chandalar River drainage in north-central Alaska ranged in age from 15 to 22 years (de Bruyn and McCart, 1974). Maximum ages of fish from various Tanana River, Alaska drainages are about 11 years (Tack, 1973). Regional differences in grayling life spans may result from varying environmental conditions over their range (Craig and Poulin, 1974) or from differences in aging techniques (scale versus otolith).

Female fecundity varies with fish size and stock. Brown (1938) reported egg fecundities ranging from 1,650 among Grebe Lake, Wyoming individuals (length and weight unknown) to over 12,900 eggs among large (0.91 kg (2 lb)) females from Georgetown Lake, Montana. Mean fecundity values among females from Grebe Lake varied from 1,900 eggs in individuals less than 280 mm (11 in) fork length (fl) to 2,800 in fish exceeding 305 mm (12 in) fl. Female fish ranging in fork length (fl) from 331 to 373 mm ($\bar{x}$ = 353 mm) from Weir Creek, a small tributary of the Kavik River, Alaska contained from 4,580 to 14, 730 eggs ($\bar{x}$ = 8,482 eggs) (Craig and Poulin, 1974). Ten females (295 to 395 mm fl) from the upper Chandalar River, Alaska drainage contained 2,330 to 9,150 eggs ($\bar{x}$ = 4,937 eggs) (Craig and Wells, 1974).

Development of Arctic grayling eggs to hatching occurs very rapidly (13-32 days) and is influenced primarily by water temperatures (Henshall, 1907; Ward, 1951; Bishop, 1971; Kratt and Smith, 1971; Tryon, 1974). The hatched fry, or alevins, with attached yolk sac, are about eight mm long (Scott and Crossman, 1973). The yolk sac is completely absorbed in one to two weeks.

Kruse (1959) examined survival of emergent grayling in Grebe Lake, Wyoming. He estimated that fish survival through the fry stage was about six percent in one of several inlet streams. Probable causes of this high mortality were egg dislodgment, predation and low fertilization. Water velocity could also influence egg and alevin survival. No redds were constructed during spawning and fertilized eggs may not have been covered with gravel.

Alevins hatching within the gravels probably have higher survival than those hatching on the exposed substrate (Kratt and Smith, 1977). The gravel provided cover, decreased the chances of dislodgement and lessened swimming stresses in the early stages.

Growth of Arctic grayling varies considerably over its range, but fish from northern regions generally grow more slowly than fish from southern areas (Craig and McCart, 1974b). The largest grayling recorded from Alaska weighed 2.13 kg (4 lb, 11 oz), and was 54.6 cm (21.5 in) long (Ugashik Narrows, Alaska Peninsula, 1975). The Canadian record grayling weighed 2.71 kg (5 lb, 7 oz) and measured 53.3 cm (21 in) (Northwest Territories, 1967).

Growth rates of young of the year (yoy) Arctic grayling can be extremely variable among drainages due to differences in length of open water (growing) seasons, temperatures and food supplies. For example, 49 fish within the outlet of Chick Lake (along the Donnelly River, a tributary of the Mackenzie River, Northwest Territories, Canada) attained a mean fork length (fl) of 49 mm ± 4 mm by 8 July, 1973. In contrast 38 individuals from a small inlet to Chick Lake were only 20 mm ± 4 mm by July (Tripp and

McCart, 1974). The Chick Lake inlet had lower water temperatures and lower benthic invertebrate standing crops than those of the Chick Lake outlet. Elliott (1980) noted substantial differences in growth rates among yoy Arctic grayling among small bog and mountain streams within Alaska. He ascribed those differences to food availability, water temperatures and durations of the growing seasons.

Arctic grayling are opportunistic feeders and consume more and larger prey as they grow. Young of the year fish have been observed feeding prior to total yolk sac absorption (Brown and Buck, 1939; Kruse, 1959). Fish inhabiting lakes may consume Daphnia and chironomid larvae and pupae. Elliott (1980) investigated the summer food habits of fish in selected spring, rapid-runoff and bog streams crossed by the Trans-Alaska Pipeline System (TAPS). Early yoy fish (less than 3.5 mm fl) consumed about three different aquatic and terrestrial invertebrate taxa whereas larger yoy fish (equal to or greater than 3.5 mm fl) consumed up to eight taxa. Immature chironomids were the most frequently eaten taxon.

Larger fish consume drifting immature and mature aquatic invertebrates, mature terrestrial invertebrates and occasionally leaches, fishes, fish eggs, shrews and lemmings (Rawson, 1950; Kruse, 1959; Bishop, 1971; Scott and Crossman, 1973). Mature fish apparently feed infrequently or not at all during the upstream spawning migration.

Arctic grayling may feed during the winter. Fish, captured by gillnet under the ice within pools of the Sagavanirktok and Colville Rivers, Alaska, contained ephemeropteran and plecopteran nymphs (Alt and Furniss, 1976; Bendock, 1980).

Predation on Arctic grayling eggs and alevins by other fishes could significantly reduce fish production. Tack (1971) reported whitefish preying upon Arctic grayling eggs at the outlet of Mineral Lake, Alaska. Rainbow trout (Salmo gairdneri Richardson), Arctic char (Salvelinus alpinus (Linneaus)), round whitefish (Prosopium cylindraceum (Pallus)), northern pike (Esox lucius Linnaeus), longnose suckers (Catostomus catostomus (Forster)), and other fishes may also consume Arctic grayling eggs and alevins (Bishop, 1971; MacPhee and Watts, 1976; Alt, 1977).

Spawned-out adult fish may remain within spawning areas or migrate considerable distances to summer feeding areas within lakes or streams. A spawned-out fish tagged in late June 1972 in a lake outlet entering the Mackenzie River near Norman Wells, Northwest Territories was recovered within a month in the Great Bear River, 159 km (99 mi) distant (Jessop et al., 1974). Tagged adults have been shown to leave Poplar Grove Creek, Alaska, a small bog stream, within several weeks after spawning and move to other areas for feeding (MacPhee and Watts, 1976; Williams and Morgan, 1974).

Movement of juvenile fish out of spawning streams can occur during or slightly after adult fish emigration. Decreased flows and lower food availability influence both adult and juvenile fish movements. Some juvenile fish may remain near spawning areas through the summer.

Studies examining the summer microhabitat selection by juvenile salmonids in various Pacific Northwest streams indicate that larger individuals progressively move to faster and deeper stream reaches for increased cover and food availability (Everest and Chapman, 1972; Lister and Genoe, 1970). Most of the larger juveniles were found in relatively fast water with some cover and areas of low current velocity. Everest and Chapman (1972) speculated that fish hold in areas of low current velocities and feed in areas of faster velocity with higher prey densities.

Fry (yoy) may remain within their natal streams or migrate to other systems where they feed and grow during the relatively short Arctic and sub-Arctic open water season (McCart and Bain, 1972; MacPhee and Watts, 1976). The movement of larger, older fish out of spawning streams may lessen competition among age classes. Rearing fish are segregated by size (age) with yoy fish generally occupying areas of lower current velocities, and more shallow water. Yearling and older fish generally occupy deeper, slightly faster areas (Chislett and Stuart, 1979). Larger fish have been observed in pools upstream of smaller fish; areas which probably contain higher densities of prey (Vascotto, 1971).

Fish appear to return to the same summer rearing areas. Many tagged individuals have been recovered the following year in the same areas (Tack, 1980).

Limited studies monitoring fish movements in small bog and mountain streams have detected a late summer to early fall out migration of juvenile and yoy fish (McCart, Craig and Bain, 1972; MacPhee and Watts, 1972). Downstream movement of juvenile fish generally occurs slightly before migration of yoy fish (Craig, McCart and Bain, 1972). Arctic grayling must migrate to their overwintering grounds before the streams become impassable from low flows or ice buildup. Decreasing water temperatures and flows associated with the onset of winter probably influence the timing of migration to overwintering areas.

The winter distribution of Arctic grayling is more restricted than the summer distribution. Most bog and many small mountain and lake inlet and outlet streams become dewatered or freeze solid during the fall and winter months. Fish overwinter in lakes, open pools, spring and glacial streams and in spring fed mountain streams. Fish have been found in pools of large interior Alaska mountain streams, such as the Chena River. Spring streams in the Tanana River drainage in interior Alaska with seemingly suitable conditions for overwintering fish, do not appear to support overwintering of Arctic grayling (Reed, 1964; Pearse, 1964; Van Hyning, 1978). Spring fed streams along the north slope of the Brooks Range, Alaska, are often the only areas with flowing water and are important fish overwintering areas (Craig and Poulin, 1974).

D. Economic Importance

Arctic grayling are the basis of an important summer recreational fishery. The broad food habits of this fish allow anglers to use a variety of techniques, including fly casting.

Roadside angling is popular during the summer on streams and lakes along the Alaska, Steese, Elliot, Taylor, Glenn, Parks, Richardson and Nome-Taylor highways. Fly-in and float fishing trips are also popular during the summer.

II. SPECIFIC HABITAT REQUIREMENTS.

A. Lake Inlet/Outlets

1. Upstream Migration

a. Water Temperature

Water temperatures associated with the upstream migration of Arctic grayling to spawning areas within inlets and outlets of lakes may range from 0°C (32°F) to about 4°C (39.2°F). Warner (1955) stated that fish began entering a selected inlet of Fielding Lake as soon as there was flowing water. Water temperatures of the inlet during the initial phase of the migration were not given but water temperatures during the last two days of the migration were 0.6°C and 1.1°C (33°F and 35°F).

Many arctic streams may be impassable to Arctic grayling prior to spring breakup because of ice conditions or dewatering. Fish have been observed moving upstream through narrow furrows in anchor ice created by meltwater (Wojcik, 1955). However, maximum numbers of fish usually migrate within these streams at or near peak flow conditions (MacPhee and Watts, 1976; Tack, 1980). Ripe Arctic grayling have been detected moving upriver within ice-covered spawning streams such as Trail Creek, a tributary of the Mackenzie River, Northwest Territories, Canada (Jessop, Chang-Kue, Lilley and Percy, 1974). Arctic grayling may ascend rapid runoff and bog streams, and inlets and outlets of lakes as soon as flow conditions permit passage to spawning sites.

Tack (1972) reported Arctic grayling at the mouth of the Mineral Lake outlet approximately nine days after water temperature of the same outlet reached 1°C (33.8°F). The first large catch of fish at the same location occurred three days later, probably a function of the length of time required to move from their overwintering habitat.

Kruse (1959) noted that Arctic grayling in Grebe Lake, Wyoming, begin spawning migrations into four inlet streams and the outlet stream (the Gibbon River) when water temperatures range from 5.6° to 7.8°C (42°-46°F) and 2.2° to 4.6°C (36°-40°F), respectively. Average daily water temperatures at the conclusion of the spawning migrations in the inlet and outlet streams were 7.2° to 8.3°C (45°-47°F) and 2.2° to 8.9°C (36°-48°F). These temperatures are noticeably higher than those associated with spawning migrations in Fielding and Mineral Lakes.

Tack (1980) found no correlation between momentary temperature reductions below 1.0°C and upstream movement of fish in the Chena River. Diel water temperature patterns may influence upstream fish movement in other streams (Wojcik, 1954, Warner, 1955; MacPhee and Watts, 1976).

b. <u>Current Velocity</u>

Arctic grayling usually begin spawning migrations to inlets and outlets of lakes during breakup conditions. Wojcik (1954) first observed fish in one of several inlet streams of Fielding Lake, Alaska as it began flowing in mid-May, 1954. Warner (1955) observed the first fish in the mouth of the same stream the following year shortly after open water appeared in early June. Tack (1972) reported Arctic grayling entering the outlet of Mineral Lake from the Tok River, via the little Tok River, during high flow conditions. Mature and immature individuals were captured by gillnet as they congregated near the lake's outlet.

2. Spawning

a. Water Temperature

Water temperature appears to significantly influence Arctic grayling spawning. Wojcik (1954) observed fish spawning in an inlet tributary of Fielding Lake in water temperatures of 3.3°C (38°F). Three to four days later, at the termination of spawning activity, water temperatures reached 7.8°C (46°F). Warner (1955) stated that fish spawning began in the same stream the following spring when maximum water temperatures approached 4.4°C (40°F).

Tack (1972) reported male fish establishing spawning territories in the outlet of Mineral Lake when water temperatures approached 4°C (39.2°F). Spawning ceased when water temperatures decreased and remained below 4°C (at 2°-3°C) for two days. Fish resumed spawning when water temperatures reached 4°C (39.2°F) and continued for four additional days as water temperatures ranged from 4° to 10°C (39.2°-50°F).

Grayling were reported spawning in southern tributaries of the Mackenzie River in water temperatures ranging from 8° to 16°C (46.4°-60.8°F) by Jessop, Chang-Kue, Lilley and Percy (1974).

Arctic grayling spawned in four inlet tributaries of Tyee Lake, near Ketchikan, Alaska during May and June of 1980 in water temperatures ranging from 6° to 11°C (42.8°-51.8°F) (Cuccarease, Floyd, Kelly and LaBelle, 1980). Water temperatures of the streams during initial fish spawning were not reported.

Fish spawning occurred in four inlet streams of Grebe Lake, Wyoming in water temperatures ranging from 4.4°C to 10°C (40°-50°F). Water temperatures in the outlet stream during fish spawning ranged from 2.2 °C to 10°C (36°F-50°F) (Kruse, 1959).

Brown (1938) observed several fish spawning in a small, beaver dammed inlet tributary to Agnes Lake, Montana in water temperatures of 10°C (50°F).

b. Current Velocity

Arctic grayling spawn in a wide range of current velocities in inlets and outlets of lakes. Wojcik (1954) reported fish spawning in "slow, shallow backwaters, and not in riffles as had been supposed" in an inlet stream to Fielding Lake. The following spring the fish spawned in surface current velocities of about 1.2 m/sec (3.9 ft/sec) (Warner, 1955). Observations were limited by ice and snow cover during 1954 and 1955.

Surface current velocities in territories of 22 males along the outlet to Mineral Lake, Alaska ranged from 0.34 m/sec to 1.46 m/sec (1.1 ft/sec-4.8 ft/sec) with a mean value of 0.79 m/sec. (2.6 ft/sec) (Tack, 1971).

c. Substrate

Arctic grayling have been reported spawning over gravel substrates of inlets and outlets of lakes within Alaska and Montana. Warner (1955) observed fish spawning over fine (about 1 cm) gravel. Much of the stream was covered by ice and snow, therefore observations were made along an 0.18 km (200 yd) open reach near the mouth of the stream and in smaller open areas upstream. Tack (1971) described the spawning substrate in the outlet of Mineral Lake as being "pea size."

Fish spawning has been observed within riffles and runs of four inlet tributaries to Tyee Lake near Ketchikan, Alaska. Spawning substrate ranged from sand to small cobble. Coarse sand and gravel to about 2.5 cm (1 in) in diameter was commonly used by most fish (Cuccarease, Floyd, Kelly and LaBelle, 1980).

Arctic grayling were observed spawning over a sand-gravel substrate in an inlet stream to Agnes Lake, Montana by Brown (1938). He discussed the limited variety of substrate and other habitat conditions within the stream and the need to better determine the characteristics of optimum Arctic grayling spawning habitat in Montana streams.

Kruse (1959) ranked sand (.3 cm), gravel (.3-7 cm) and rubble (7.6-30.5 cm) in descending order as suitable substrate material for Arctic grayling spawning. Riffles were utilized more often than pools for spawning.

Fish were reported spawning over relatively fine gravel, not exceeding 3.8 cm (1.5 in) in diameter with most material not exceeding 1.25 cm (0.5 in) in diameter, within the outlet of Bench Lake, Alaska (personal communications, Stephen Hammarstrom, 1981). Similar size substrate is used for spawning in the outlet of Crescent Lake, Alaska (personal communication, Ted McHenry, 1981).

d. Water Depth

Arctic grayling spawn in a range of water depths. Selection of spawning sites is more strongly influenced by current velocities and substrate conditions. Fish in an inlet to Fielding Lake spawned in "shallow back waters" (Wojcik, 1954) and in depths of 16 cm (6 in) (Warner, 1955).

Water depths measured in 22 fish territories in the Mineral Lake, Alaska outlet stream ranged from 0.18 to 0.73 m (0.6 to 2.4 ft) with a mean value of 0.30 m (1.0 ft.).

Cuccarese, Floyd, Kelly and LaBelle (1980) observed fish spawning in various inlet streams to Tyee Lake, Alaska in water depths ranging from 0.15 to 0.91 m (0.5-3.0 ft.) in the largest and most intensively utilized stream and from 0.05 to 0.46 m (0.17-1.5 ft) in several smaller, shallower streams with substantially fewer spawners.

e. Light

Grayling spawning occurs during daylight hours and probably stops during the evening (Scott and Crossman, 1973). Few observations of Arctic grayling spawning have been made during the evening (Kruse, 1959).

Netting at the Bench Lake outlet found few Arctic grayling spawning during evening and early morning hours (personal communication, Stephen Hammarstrom, 1981).

3. Post-Spawning Movements

Spawned-out Arctic grayling (fish having completed spawning) commonly vacate spawning sites within lake inlets and outlets and return to lakes or to other areas (Wojcik, 1954; Warner, 1955; Tack, 1980). Fish spawning within the outlet to Mineral Lake leave the stream upon completion of spawning and migrate downstream and then up to the Little Tok River or Trail Creek. Food availability probably influences post-spawning fish movement and distribution (Tack, 1980).

Small lake inlets may become dewatered by mid to late summer. Adult spawned-out fish typically leave these intermittent streams after spawning and enter lakes (Kruse, 1959).

4. Development of Eggs and Alevins

a. Water Temperature

Stream water temperatures influence Arctic grayling development rates within lake inlets and outlets. Kruse (1959) observed that eggs hatched 19 days after fertilization in an inlet stream to Grebe Lake at water temperatures from 3.9° to 9.2°C (39.0°-48.5°F). Fertilized eggs from an inlet to Fielding Lake, Alaska required 18 days to hatch in water temperatures ranging from 6.1° to 9.4°C (43°-49°F) during the spring of 1954 and 1955. Fertilized eggs required only eight days to hatch in water temperatures of 15.5°C (60°F) at an Alaskan hatchery.

Henshall (1907) recommended minimum water temperatures of 5.5°C (42°F) for successful development of Arctic grayling in Montana hatcheries.

Water temperatures characteristically rise during the incubation period; therefore, eggs are not usually exposed to freezing. However, no upper or lower lethal temperature data for Arctic grayling eggs were found in the literature.

5. Summer Rearing

a. Current Velocity

Low flows during incubation could result in desiccation or freezing of developing eggs and alevins. Wojcik (1954) noted significant diel flow fluctuations along an inlet of Fielding Lake, Alaska and discussed the possibility of recently fertilized eggs becoming exposed, desiccated or frozen.

Downstream migration of yoy fish within inlets of lakes is probably a response to more suitable current velocities and an abundance of food items in lakes. Newly emerged yoy fish held positions in "quiet water coves and eddies" during the day along an inlet to

Grebe Lake, Wyoming (Kruse, 1959). At night the yoy fish vacated areas of low current velocities and actively migrated downstream to Grebe Lake.

Fry have also been found in shallow margins of Tyee Lake, Alaska and in small, shallow, pools in the delta area of inlet streams of Tyee Lake. High aquatic invertebrate production in littoral areas provided ample food (Cuccarese, Floyd, Kelly and LaBelle, 1980). Fry have not been observed in mainstem reaches of the inlet streams.

Arctic grayling fry within lake outlets typically occupy areas of low current velocities. Yoy fish have been observed in stream margins with shallow depths and low current velocities (personal communication, Stephen Hammarston and Ted McHenry, 1981).

b. Water Depth

Water depths occupied by yoy fish in lotic and lentic areas may vary considerably. Depths are probably selected for the associated current velocities and food availability. Fry within several inlets to Grebe Lake, Wyoming occupied shallow, slow habitats prior to migrating downstream to Grebe Lake (Kruse, 1959). Fry within Tyee Lake, Alaska occupy shallow littoral reaches ranging in depth from 2 to 46 cm (1-18 in). They also occupy shallow, quiet pools in delta regions of the inlet streams rather than the mainstem reaches (Cuccarease, Floyd, Kelly and LaBelle, 1980). Yoy fish have been observed in shallow margins of the outlets of Bench Lake and Crescent Lake, Alaska (personal communication, Stephen Hammarston and Ted McHenry, 1981).

6. Migration to Overwintering Areas

No information was found in the literature concerning movements of Arctic grayling within lake inlets and outlets to overwintering areas. Fish probably overwinter in lakes that are relatively deep and do not freeze to the bottom.

7. Overwintering

No information was available in the literature concerning overwintering habitat of fish within lakes. The winter ecology of Arctic grayling within lakes is poorly understood (personal communication, Fred Williams, 1981).

B. Bog Streams

1. Upstream Migration

a. Water Temperature

Adult grayling usually migrate upstream before juveniles. Water temperatures are lower at this time. Upstream migration of yearling, older juvenile and adult grayling within Poplar Grove Creek usually commenced when mean water temperatures ranged from 2° to 4°C (36°-39°F) during early to mid-May of 1973, 1974 and 1975. Upstream movement usually ceased when water temperatures approached 12° to 14°C (54-57°F) during late May to early June. Mean water temperatures during peak upstream migration of yearling fish (6°-12°C) were consistently higher than temperatures during adult upstream migration (3°-7°C). Diel variations in water temperatures never exceeded 2°C during May and June.

Mature 'green' (non-ripe) Arctic grayling entered Weir Creek, a tributary of the Kavik River, Alaska when water temperatures were about 5°C. The migration ceased when water temperatures approached 12°C (Craig and Poulin, 1974).

Upstream migration of adults in Weir Creek was similar: mature fish were first observed in water of about 4°C (39°F). Migration ceased when temperatures reached 15°C (60°F) (Craig and Poulin, 1974). Maximum water temperatures at the termination of the juvenile upstream fish migration reached 20°C (67°F).

b. Current Velocity and Discharge

The upstream migration of juvenile and adult Arctic grayling in bog streams usually coincides with high flows resulting from snow melt and surface run-off during spring breakup. The first mature 'green' fish were taken nine days after breakup in Weir Creek, Alaska during early June (Craig and Poulin, 1974). The time between initiation of flow in Weir Creek and arrival of fish was probably due to the distance from overwintering areas to the creek (probably the Shaviovik River, about 85 km distant). Wojcik (1954) captured mature 'green' fish at the mouth of Shaw Creek and Little Salcha Creek in the Tanana River, Alaska in early April 1953 and 1954 while the streams were frozen and impassable to fish. However, as melt water scoured furrows in the ice, the fish began migrating upstream. MacPhee and Watts (1976) trapped adult and juvenile fish in Poplar Grove Creek, a tributary of the Gulkana River, at peak and decreasing stream flows associated with spring breakup.

The upstream fish migration may span several weeks. Streamflow can be substantially reduced by the time the upstream migration of adult and juvenile fish is completed. For example, flows within Poplar Grove Creek, Alaska decreased during the upstream migration of adult and juvenile Arctic grayling during 1973, 1974 and 1975 (MacPhee and Watts, 1976). Adult and juvenile fish generally began moving upstream in mid-May during the initial stages of the open-water season. The relatively high discharge at this time ranged from about 1.3 to 4.0 m^3/sec (46-141 cfs). However, the peak of the juvenile fish migration consistently occurred at lower flows, about five to ten days after the peak of the adult fish migration. Juvenile migration continued for several days after the adult migration. Discharge at the end of the adult and juvenile migrations were generally less than 1.1 m^3/sec (38 cfs). The yearling fish lagged several days behind the older juvenile fish.

Upstream migration of juvenile and adult Arctic grayling in Weir Creek, a tributary of the Kavik River, Alaska, resembled migrations in Poplar Grove Creek (McCart, Craig and Bain, 1974). Adult fish migrated upstream in Weir Creek in 1971 between early and late June, 1971 as discharge decreased from 20 m^3/sec to about 2 m^3/sec. Juvenile fish moved upstream from mid to late June, about two weeks after the peak of the adult fish run.

Juvenile and adult Arctic grayling migrated upstream in Nota Creek, a tributary of the Mackenzie River, Northwest Territories, Canada, during spring breakup in May. During this time dishcarges decreased from

1.67 m^3/sec to 0.38 m^3/sec (58 to 13 cfs) (personal communication, Derrick Tripp, 1981).

Current velocities may influence the timing of juvenile and adult fish passage in bog streams. MacPhee and Watts (1976) demonstrated that large Arctic grayling could negotiate faster water than smaller fish. Decreasing flows may enhance the ability of juvenile fish to pass upstream and could be responsible for the lag between adult and juvenile fish. Other factors, such as increasing water temperatures, probably influence the timing of the upstream migration of juvenile and adult fish (MacPhee and Watts, 1976).

2. Spawning

The influences of current velocity, water depth and substrate on fish spawning in bog streams are not well documented. Flood stage flows and yellow or brown stained water limit observations.

Spawning data correlated to water temperature and flow conditions are available. Selected studies using weirs and seines noted the spawning condition of fish ('green', 'ripe' or 'spawned out'), water temperature, actual or relative flow conditions and direction of fish movement.

a. Water Temperature

Water temperatures of bog streams can be considerably higher than those of lake inlets and outlets during spawning. Minimum water temperatures may approach 4°C, the water temperature which apparently triggers spawning in lake inlets and outlets (Tack, 1980), and may approach or exceed 10°C (50.0°F). Arctic grayling have spawned at the outlet of Tea Lake, Alaska in water temperatures of 7°C (44°F) (McCart, Craig and Bain, 1972). The Tea Lake system drains a flat, marshy area and is a bog stream.

Bishop (1971) reported that water temperatures of about 8° to 10°C (47°-50°F) appeared to stimulate fish spawning in Providence Creek, Northwest Territories.

Maximum water temperatures in Weir Creek during the Arctic grayling spawning period ranged from 4° to 16°C (39°-61°F) (Craig and Poulin, 1974). Maximum water temperatures in Nota Creek when Arctic grayling were "ripe" ranged from 3.5° to 11°C (38°-51°F). Maximum water temperatures at the peak of spawning ranged from 4.5° to 11°C (40°-52°F) (personal communication, Derrick Tripp, 1981).

Water temperatures in Happy Valley Creek during Arctic grayling spawning ranged from 4° to 12°C (39°-53°F) (McCart, Craig and Bain, 1972).

b. Current Velocity and Discharge

Observations of Arctic grayling spawning with respect to current velocities are limited. Several pairs of spawning fish were observed in shallow riffles along Mainline Spring Creek, Alaska (personal communication, George Elliott, 1980).

Flows within bog streams are typically high but usually decrease during the Arctic grayling spawning period. Flows in Happy Valley Creek, Alaska decreased substantially over the 10 day spawning period. Arctic grayling spawned in Weir Creek, Alaska for 10 days as flows decreased. Arctic grayling in Poplar Grove Creek, Alaska spawned in late May to early June as streamflows decreased from peaks of about 1.1 m^3/sec (23.2 cfs) in 1973 and 4.0 m^3/sec (84.8 cfs) in 1971 (MacPhee and Watts, 1976). Bishop (1971) reported fish spawning in Providence Creek, tributary of the Mackenzie River, during breakup conditions.

c. <u>Substrate</u>

Arctic grayling appear to use a wide range of substrate sizes in bog streams for spawning. They spawned over gravel ranging from 2.5 to 3.75 cm (1-1½ in) diameter in Mainline Springs Creek near Atigun Pass, Alaska (personal communication, George Elliott, 1980). Spawning has also occurred in the outlet of Tea Lake, Alaska, near the Trans-Alaska Pipeline, over sand and fine gravel substrate, about 0.6 cm (¼ in.) in diameter (Craig, McCart and Bain, 1972).

Substrate used for spawning in Providence Creek, Northwest Territories, Canada was gravel mixed with sand. Fish did not spawn over pure mud, sand or clay (Bishop, 1971).

Fish spawned in organic detritus in Million Dollar Creek, Alaska, along the Trans-Alaska Pipeline (personal communication, George Elliott, 1980). The substrate in Million Dollar Creek is silt and fine sand overlain by organic muck (Elliot, 1980).

d. Water Depth

Observations of water depths used for spawning in bog streams are limited.

Several pairs of fish spawned in riffles 5 cm (2 in) deep in Mainline Spring Creek, Alaska (personal communication, George Elliott, 1980).

e. Light

Fish apparently spawn only during the day, as observed by Bishop (1971) in Providence Creek.

3. Post-Spawning Movements

Arctic grayling may migrate downstream immediately after spawning. In 1973, post-spawners left Weir Creek, Alaska within two weeks after spawning. Large juvenile Arctic grayling also emigrated within two weeks. Tagged adult fish from Weir Creek, Alaska were captured later in the Kavik River and the Shaviovik River (Craig and Poulin, 1974). Rapidly decreasing streamflows probably influenced fish movements.

Tagged adult post-spawners from Happy Valley Creek displayed similar downstream movement following spawning. No adult fish were found upstream of the weir (McCart, Craig and Bain, 1972).

An outmigration of adult and juvenile Arctic grayling occurred in Poplar Grove Creek during late May and early June after spawning and when streamflows were steadily declining. Emigration of spawned-out adults extended from mid-May through mid-June 1973 as flows steadily declined from 1.4 m^3/sec (49 cfs) to 0.3 m^3/sec (11 cfs). Large juvenile Arctic grayling outmigrated after the adults during mid-June. Not all adult and large juvenile Arctic grayling left Poplar Grove Creek; of the 1,085 adults and 1,973 large juvenile fish found migrating upstream, only 779 and 937 were detected passing downstream. Many of these fish migrate to the Gulkana River drainage (Williams and Morgan, 1974; Williams, 1975 and 1976). Weir data suggest that adults may remain in Poplar Grove Creek until the stream freezes in fall.

Adult grayling ususally leave Nota Creek, a bog stream entering the Mackenzie River, Northwest Territories, Canada, within two weeks after spawning. Some spawned-out adults may return to food-rich Nota Lake for short periods of time. Emigration of large five and six year old juveniles was followed by younger, smaller individuals through early July. By mid-July young of the year Arctic grayling and some yearling and two year olds occupied Nota Creek (personal communication, Derrick Tripp, 1981). Decreased living space and food availability associated with low flows are probably important factors influencing fish movements.

Tack (1980) suggested that the outmigration of juvenile and spawned-out adult fish may allow yoy fish to rear and feed in natal streams without competition. Adult and juvenile fish may rear in other stream systems that are rich in food, such as spring streams.

4. Development of Eggs and Alevins

a. Water Temperature

Extremely limited information is available concerning egg incubation and water temperature relationships in bog streams. Bishop (1971) subjected fertilized eggs to a range of water temperatures. He determined that eggs hatched in approximately 14 days at a mean water temperature of 8.8°C (48°F).

Arctic grayling eggs required 18 to 21 days to hatch in Nota Creek in water temperatures ranging from 5.5° to 13°C (42°-55.5°F) and a mean water temperature of 9.6° to 10.3°C (49°-50.5°F) (personal communication, Derrick Tripp, 1981).

b. Current Velocity and Discharge

Spates could dislodge and destroy eggs and severely reduced flows could lead to desiccation.

Aquatic habitat selected by rearing yoy fish in bog streams may have current velocities of from 0 to 0.15 m/sec. Larger fish generally select faster water. Elliott (1980) measured mean column velocities at holding positions of 'early' yoy ($\leq$ 35 mm fl) and 'late' yoy ($>$ 35 mm fl) fish in selected bog streams during June and August 1980. The mean column current velocities associated with 'early' yoy fish were 0.02, 0.07 and 0.03 m/sec in Million Dollar Creek (n = 198), Pamplin's Potholes (n = 175), and the Tea Lake inlet, Alaska (n = 57), respectively.

Larger 'late' yoy fish were found in slightly faster mean current velocities: 0.08, 0.09, 0.14 and 0.1 m/sec. in Pamplin's Potholes (n = 87), Tea Lake inlet/outlet (n = 71), North Fork Fish Creek (n = 33), Mainline Spring Creek, Alaska (n = 18), respectively.

5. Summer Rearing

a. Current Velocity

Newly emerged yoy fry select protected stream areas where current velocities are extremely low (personal communication, George Elliott, 1980; de Bruyn and McCart, 1974; McCart, Craig and Bain, 1972). Typical emergent fry rearing areas include shallow backwaters and flooded stream margins and side channels.

Juvenile fish (age 1 and older, measuring 50-250 mm fl) have been observed in bog streams with slightly greater current velocities than yoy fish. The average mean current velocities occupied by juvenile fish in the Tea Lake inlet (n = 9) were 0.175 m/sec and in Mainline Springs Creek, Alaska (n = 16), 0.196 m/sec. Limited observations of adult Arctic grayling (250 mm fl) from bog streams showed adult fish holding in mean current velocities of 0.262 m/sec (Elliot, 1980).

b. Substrate

Rearing fish of all ages were associated with a variety of substrates inclusing detritus, silt, sand, and gravels. Arctic grayling showed little movement in small bog streams during July and August following fish spawning and movement to summer rearing areas and before movement of fish to overwintering areas (McCart, Craig and Bain, 1972; Craig and Paulin, 1974; MacPhee and Watts, 1976).

c. Water Depth

Water depths occupied by rearing fish vary considerably. Newly emerged yoy fish have been found in extremely shallow, slow water, flood channels and backwater sloughs (Personal communication, George Elliott; de Bruyn and McCart, 1974; McCart, Craig and Bain, 1972).

Early yoy fish occupied small bog streams with depths from about 0.09 to 0.85 m (0.3-2.8 ft). Late yoy occupied depths (within the same streams) ranging from 0.15 to 1.07 m (0.5-3.8 ft) (Elliott, 1980). Juvenile and adult fish in bog streams along the Trans-Alaska Pipeline System were found in water depths from 0.21 to 1.07 m (0.7-3.8 ft).

6. Migration to Overwintering Areas

Significant downstream movement of fish has been observed in bog streams during late summer, apparently in response to declining water temperatures and flows associated with the onset of winter. Emigration of yoy and juvenile fish may also occur during the summer.

a. Water Temperature

Decreasing water temperatures may influence the downstream movement of Arctic grayling. Significant numbers of yoy and juvenile fish moved downstream in Weir Creek, Alaska during September 1973. Minimum water temperatures during early, mid and late September were about 1°, 4° and 0°C, respectively. Downstream movement of juvenile fish occurred about one week before yoy fish in Weir Creek. No apparent relationship could be demonstrated between downstream movement of juvenile or yoy fish and water temperatures (Craig and Poulin, 1974).

Similar downstream movements of yoy fish occurred in Poplar Grove Creek, Alaska. Of the 65,536 yoy fish observed between July 17 and October 18, 1973, 96% (62,680) were observed in the lower reaches during October (MacPhee and Watts, 1976). In Poplar Grove Creek, downstream migration of yoy fish may be related to stream temperatures.

b. Current Velocity and Discharge

No relationship could be found between the downstream movement of juvenile or yoy fish and stream flows in Weir and Poplar Grove Creeks.

7. Winter Rearing

Winter rearing areas for Arctic grayling are limited in bog streams because they often become dewatered or freeze solid during the winter. Winter rearing areas such as deep lakes, deep pools of mountain streams or spring fed streams, may be quite distant from summer rearing areas. Fish overwintering areas in the Shaviovik River and summer rearing habitat within Weir Creek are about 85 km (53 mi.) distant (Craig and Poulin, 1974).

C. Mountain Streams

1. Upstream Migration

a. Water Temperature

Low water temperatures are prevalent during the upstream migration of adult and juvenile Arctic grayling. Upstream migrants were taken in Vermillion Creek, Northwest Territory, Canada about one week after breakup when water temperatures ranged from 0° to 3°C (32°-37°F) (personal communication, Derrick Tripp, 1981). Tack (1980) also found that water temperatures of at least 1.0°C (34°F) stimulate upstream movement of Arctic grayling in large mountain streams like the Chena River near Fairbanks, Alaska.

b. Current Velocity and Discharge

Upstream migration of adult and juvenile Arctic grayling usually occurs during high flows at spring breakup. A weir placed in Vermillion Creek captured upstream migrating adult and juvenile Arctic grayling for ten days after peak flows in May of 1973 and 1975. The Mackenzie River was covered with ice for up to ten days after breakup occurred in Vermillion Creek during 1973 and 1975 (personal communication, Derrick Tripp, 1981), and observations of fish migration were not made.

Observations made under the ice along the Chena River indicate that Arctic grayling initiate upstream movement prior to breakup (Tack, 1980). The fish were probably moving to upstream reaches of the Chena River or its tributaries. The relative importance of streamflow and water temperature in relation to upstream fish migration is poorly understood.

2. Spawning

a. Water Temperature

Limited data is available concerning the relationship between Arctic grayling spawning and stream water temperatures. Spawning in the Chena River drainage has been observed in water temperatures of 5°C (Reed, 1964; personal communication, Jerome Hallberg). Tack (1980) discussed the possibility of the 4°C isotherm influencing the distribution of spawning fish in large streams like the Chena River.

b. Current Velocity and Discharge

Fish spawn in mountain streams in a wide range of current velocities. They have been observed spawning in an overflow slough in the Chena River, Alaska at relatively low current velocities (Reed, 1964) and in riffles of the East Fork Chena River, Alaska where surface current velocities approach 1.4 m/sec (4.5 ft/sec) (personal communication, Jerome Hallberg, 1981). Bendock (1979) reported spawning in pools of the Colville River, Alaska with negligible current.

Nelson (1954) observed fish spawning activity along Red Rock Creek, Montana in the ends of riffles. Fish spawning occurred in similar low flow areas along the East Fork Chena River, Alaska (personal communication, Jerome Hallberg, 1981).

c. Substrate

Arctic grayling use a variety of substrates for spawning including mud, silt and gravel up to 4 cm (1.5 in) in diameter. Bendock (1979) observed fish spawning on silt overlaying gravel in the mainstem Colville River, Alaska and its tributaries. Spawning substrate used by Arctic grayling in the East Fork Chena River, Alaska consists of fine gravels from 0.75 to 4 cm (0.4-1.5 in) in diameter (personal communication, Jerome Hallberg, 1981). Spawning has also been observed in muddy sloughs along the Chena River (Reed, 1964).

Arctic grayling in Red Rock Creek, Montana spawned in gravel-rubble substrate of unknown size but not in pure silt or sand substrates.

3. Egg and Alevin Development

No information was found in the literature which discussed egg and alevin development in mountain streams.

4. Summer Rearing

a. Water Temperature

Results of standard, 96 hour bioassays (at test water temperatures of 5, 10, 15, 20 and 24.5 or 21.5°C) indicate that Arctic grayling can tolerate a wide range of temperatures. Fish from the Chena River near

Fairbanks, Alaska were used for this study. Results were expressed as median tolerance limit (TL_M), the temperature at which 50 percent of the individuals in a test die (LaPerrier and Carlson, 1973).

Results indicated that young of the year fish are apparently more tolerant of relatively high water temperatures than older fish. The TL_M of yoy fish exceeds 24.5°C, the highest test water temperature.

Individuals of 10 cm fl had TL_M values of 20.0 to 24.0°C and fish of 20 cm fl has TL_M values of 22.5 to 24.5°C. The small fish were acclimated at 4°C and the larger fish at 8°C.

Bioassay results indicate that water temperature differences of 2°C at relatively high water temperatures can cause very different survival rates of Arctic grayling. For example, survival of 20 cm fl fish was 100 percent at 22.5°C (72.5°F) and 0 percent at 24.5°C (75°F).

These bioassay results may not apply to actual stream conditions because fish could avoid warm water temperatures by moving to cooler areas.

b. <u>Current Velocity and Discharge</u>

Recently emerged yoy fry generally occupy areas with low current velocities. The small newly emerged fry (about 20 mm total length at 14 days) have limited swimming abilities. Chislett and Stuart (1979) noted that newly emerged fry clustered in shallow, protected reaches of flood channels, backwater sloughs and sidechannel pools of the Sekunka River, British

Columbia. These fish are found in similar habitats in the East Fork Chena River, Alaska (personal communication, Jerome Hallberg, 1981).

Nelson (1954) noted that recently emerged yoy fish were distributed in "backwaters and protected areas. . ., away from strong currents" within Red Rock Creek, Montana.

Older yoy fish occupy progressively faster waters. 'Early' yoy fish ($\leq$ 35 mm fl) occupied a mean current velocity of about 0.07 m/sec (0.22 ft/sec) (n = 183) in selected headwater areas of the Gulkana River, Alaska in early July. Larger yoy fish (> 35 mm fl) inhabited slightly greater current velocities, 0.16 m/sec (0.52 ft/sec) (n = 157) (Elliot, 1980).

Chislett and Stuart (1979) found yoy fish ($\leq$ 35 mm fl) occupying slow current areas of backwater and side channels in the Sekunka River and Martin Creek, British Columbia during July 1978. Side channels contained flowing water and were less ephemeral than backwater channels. All yoy fish were found in low current velocities.

Most of the backwater habitats dewatered during August low flows and yoy fish (> 35 mm fl) inhabited sidechannel riffle areas and margins of mainstem riffles.

By September and October yoy fish occupied sidechannel riffles and margins of mainstem riffles where current velocities approached 0.8 m/sec. Yoy fish at this time ranged from 50 to 96 mm fl (Chislett and Stuart, 1979).

Summer distributions of yearling and older fish were limited to mainstem and side channel pools in the Sekunka River, British Columbia. Older fish, age 4 to 8+ (oldest aged fish), occupied larger, deeper pools than the younger fish.

The distribution of juvenile and adult Arctic grayling in selected Alaskan mountain streams is similar to the the distribution in the Sekunka River, British Columbia where adult and juvenile fish are generally restricted to pools and sloughs (Alt, 1978; personal communication, Jerome Hallberg, Joe Webb, Terence Bendock, 1981).

Fish will move into shallower, faster riffle areas for more food, such as salmon and whitefish eggs (Bendock, 1979; Alt, 1978).

c. <u>Water Depth</u>

Yoy fish generally occupy shallow lotic habitats with low current velocities. Fry in the Sekunka River, British Columbia selected shallow areas in sidechannels and backchannels (Chislett and Stuart, 1979). Yoy fish have been observed in backwater sloughs and shallow pockets of protected water in the East Fork Chena River, Alaska (personal communication, Steven Grabacki, Jerome Hallberg and Sandra Sonnichsen, 1981).

Older fish generally select deeper pools (Chislett et al.; personal communications, Steven Grabacki, Jerome Hallberg and Sandra Sonnichsen, 1981).

d. Cover

Recently emerged yoy fish seek various forms of instream cover when disturbed. Young (17-45 days old) fry in shallow, siltbottomed backchannels of the Sekunka River moved into deeper water with various types of instream cover. Similar aged yoy fish in sidechannels used substrate interstices and shadows of boulders for cover. Nelson (1954) noted that 14 to 21 day old fish in Red Rock Creek, Montana made little movement when disturbed and appeared to be "relatively helpless."

Older fish commonly use logs, boulders and turbulence for instream cover (personal communication, Jerome Hallberg, 1981).

5. Migration to Overwintering Areas

Little is known about Arctic grayling migration to overwintering areas. Tack (1980) observed a slow downstream movement of Arctic grayling in the Chena River, Alaska and compared it to the faster emigration of fish in North Slope mountain streams where winter conditions occur very early (Yoshihara, 1972). Yoshihara (1972) observed many fish moving downstream in the Lupine River immediately after water temperatures reached freezing. Age distribution of emigrants in the Lupine River is not known.

6. Winter Rearing

The distribution of overwintering Arctic grayling is more limited than the summer distribution. Streamflows are low, much or all of the stream is ice-covered and stream reaches can be frozen solid during the harsh Arctic and sub-Arctic winters. Overwintering areas in mountain streams include pools of intermittent or flowing streams (such as Colville and Chena River, Alaska, respectively) or spring fed streams which remain open during winter months (the lower Shaviovik River, Alaska).

a. Current Velocity

Current velocities in overwintering sites are probably very low. Conventional current velocity meters do not function at air temperatures below freezing. Fish overwinter in intermittent pools of the Colville River where current velocity is negligible. In the Hulahula River overwintering sites had current velocities of 0.15 m/sec (0.5 ft/sec).

b. Water Depth

Fish have been observed under the ice in pools of at least 1.4 m (4.6 ft) depth in the Colville, Chena and East Fork Chena Rivers. Bendock (1980) found fish in intermittent pools deeper than 1.5 m (4.8 ft) in a reach of the Colville River, Alaska. Fish are restricted to pools in the East Fork Chena River and the mainstem Chena River, Alaska (Tack, 1980) during the winter months (Hallberg, personal communication, 1981).

Arctic grayling have been taken by Kaktovik, Alaska villagers in the Hulahula River in late April (Furniss, 1975) and through the ice in the East Fork Chandalar River near Arctic Village, Alaska (McCart, 1974). Maximum water depths were about 0.6 m (2 ft) in open water of the Hulahula River. Water depth of the East

Fork Chandalar River was 1.5 m (5 ft). These sites are thought to be important overwintering areas for Arctic grayling.

Spring fed mountain streams are often the only sites in the North Slope where water remains flowing throughout the winter. These streams are important overwintering sites for Arctic grayling. Alt and Furniss (1976) captured adult Arctic grayling in a spring fed pool in the Franklin Bluffs area of the Sagavanirktok River, Alaska on May 6, 1975. The approximate depth of the pool was about 1.2 m (3.9 ft).

c. Dissolved Oxygen

Bendock (1980) measured dissolved oxygen levels ranging from 0.6 to 4.6 mg/l in Arctic grayling overwintering sites in the Colville River. Dissolved oxygen levels were about 4.8 mg/l in the Sagavanirktok River at the Franklins Bluff site on April 10, 1975 (Alt and Furniss, 1976).

D. Spring Streams

1. Upstream Migration

Limited investigations indicate that Arctic grayling may enter springfed streams after spawning (Reed, 1964; Pearse, 1974; Tack, 1980).

2. Spawning

Arctic grayling apparently do not spawn in springfed streams where low water temperatures may adversely influence egg and alevin development (Van Hyning, 1978).

3. Summer Rearing

Arctic grayling rear in springfed streams. Reed (1964) reported that adult fish enter the Delta Clearwater River in early June and younger juvenile fish enter in late July. Pearse (1974) found similar trends in the Delta Clearwater in 1973; although adults tended to remain in the headwater reaches and immatures remained downstream.

4. Migration to Overwintering Areas

Reed (1964) stated that immature, catchable (by rod and reel) Arctic grayling moved downstream early in 1963 in the Delta Clearwater River. Larger adult fish remained in the river through most of September. Some tagged adult fish were found at the mouth of the Delta Clearwater River in late October.

5. Winter Rearing

Arctic grayling apparently do not rear in interior Alaska springfed streams (Van Hyning, 1978), but have been found in springfed streams in the North Slope (Craig and Poulin, 1974).

III. HABITAT-ARCTIC GRAYLING RELATIONSHIPS

Tables I through VI summarize the reported water temperature levels associated with various life stages and activities of Arctic grayling. Table VII lists the reported current velocities (or discharges) associated with different life history stages and Table VIII, the substrate types used for spawning.

Table I: Observed water temperatures associated with upstream migration of Arctic grayling to lake inlets/outlets.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	0.6° - 1.1°C	Maximum water temperatures during last 2 days of fish migration	Inlet to Fielding Lake, Alaska	Warner (1955)
	1.0°C	First mature fish captured during fish migration	Outlet to Mineral Lake, Alaska	Tack (1972)
	5.6 - 7.8°C	Water temperatures of several inlets to Grebe Lk. during initial fish spawning migration activity 1953, 1954	Four inlets to Grebe Lake, Wyoming	Kruse (1959)
	2.2° - 4.4°C	Water temperatures of outlet (Gibbon R.) to Grebe Lake, Wyoming during initial fish spawning migratiion activity	Gibbon River, outlet to Grebe Lake, Wyoming	Kruse (1959)

Table II: Observed water temperatures associated with upstream migration of Arctic grayling within bog (tundra) streams.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	5° - 12°C	Maximum water temperatures during early to late stage of adult fish spawning migration. Incomplete fish sampling due to high flows, 1973.	Weir Creek, Tributary to Kavik R., Alaska	Craig and Poulin (1974)
	3.9° - 15.6°C	Maximum water temperatures beginning and end of adult fish upstream migration, 1971. Weir placed in stream after fish migration began.	Happy Valley Crk, tributary to Sagavanerktok River, Alaska	McCart, Craig and Bain (1972)
	7.2° - 19.4°C	Maximum water temperatures from start to near termination of juvenile fish upstream migration, 1971.	Happy Valley Crk, Sagavanerktok River, Alaska	McCart, Craig and Bain (1972)
	2° - 4°C	Initial average water temperatures of Poplar Grove Creek during start of adult, sub-adult, juvenile fish upstream migration during May 1973-1975.	Poplar Grove Crk, tributary to Gulkana R., Alaska	MacPhee and Watts (1976)
	12° - 14°C	Average water temperatures at end of adult, sub-adult, juvenile fish migration in June 1973-1975.	Poplar Grove Crk, tributary to Gulkana R., Alaska	MacPhee and Watts (1976)

Table III: Observed water temperatures associated with Arctic grayling spawning in mountain streams.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	5.6°C	Instantaneous water temperature of slough where fish were observed spawning	Slough along Chena River, Alaska	Reed (1964)
	5.0°C	Instantaneous water temperature during fish spawning activity	Riffle, E. Fork Chena River, Alaska	Hallberg (personal communication)
	5.0° - 9.0°C	Instantaneous water temperature during fish spawning activity	Seabee, Rainy, Fossil Crks, tributaries Colville R., Alaska	Bendock (1970)
	5°C	Instantaneous water temperature during fish spawning activity	Nuka River, tributary, Colville River, Alaska	Bendock (1979)
	4°C	Instantaneous water temperature during fish spawning activity	Aniak R, tributary, Kuskokwim River, Alaska	Alt (1977)

Table IV: Observed water temperatures associated with Arctic grayling spawning in lake inlets/outlets.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	3.3°C	Initial fish spawning activity occurred	Inlet to Fielding Lake, Alaska	Wojcik (1954)
	7.8°C	Fish spawning activity was completed at this temperature 3-4 days after commencement of spawning activity.	Inlet to Fielding Lake, Alaska	Wojcik (1954)
	4°C	First spawning activity observed	Outlet to Mineral Lake, Alaska	Tack (1972)
	2° - 3°C	Fish spawning ceased as water temperature dropped below 4°C	Outlet to Mineral Lake, Alaska	Tack (1972)
	4° - 10°C	Fish spawning activity resumed and lasted 4 additional days	Outlet to Mineral Lake, Alaska	Tack (1972)
	6° - 11°C	Fish actively spawning	Several inlets to Tyea Lake, Alaska	Cuccarease, Floyd Kelly, LaBelle (1980)
	4° - 10°C	Fish actively spawning	Four inlets to Grebe Lk, Wyoming	Kruse (1959)
	2.2° - 10°C	Fish actively spawning	Outlet to Grebe Lake, Wyoming Gibbon River	Kruse (1959)
	10°C	Fish actively spawning	Inlet to Agnes Lake, Montana	Brown (1938)

Table V: Observed water temperatures associated with spawning of Arctic grayling within bog streams.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	6.7°C	Direct spawning observation, one temperature reading	Outlet Tyee Lk, Alaska	McCart, Craig and Bain (1972)
	8° - 10°C	Fish spawning activity seemed to be related to these water temperatures.	Providence Crk, tributary to Mackenzie River Northwest Territory	Bishop (1971)
	3.9° - 16°C	Maximum water temperatures based on occurrence of ripe and spawned-out Arctic grayling captured by weir	Weir Creek, Alaska	Craig and Poulin (1974)
	3.5° - 11°C	Maximum water temperatures during Arctic grayling spawning activity based on condition of fish in weir	Nota Creek, Alaska	Tripp (personal communication, 1981)

Table VI: Observed water temperatures associated with Arctic grayling egg and alevin development.

Parameter	Observed Values	Remarks	Location	Reference
Water Temperature	3.9°C - 9.2°C	Eggs hatched in 19 days	Inlet to Grebe Lake, Wyoming	Kruse (1959)
	6.1° - 9.4°C $\bar{x} = 7.7$°C	Eggs hatched in 18 days in 1954 and 1955	Inlet to Fielding Lake, Alaska	Wojcik (1954); Warner (1955)
	15.5°C	Eggs at hatchery facility hatched in 8 days	Somewhere in Alaska	Wojcik (1954)

Table VII: Relationship of current velocity (or discharge) to specific life history stages.

Activity	Current Rate or Flow	Reference
Spawning	slow, shallow backwater	Wojcik, 1954
	1.2 m/s	Warner, 1955
	.34 m/s to 1.46 ($\bar{x}$ =.79)	Tack, 1971
	shallow riffles	Elliott, 1980
	1.1 m^3/sec	MacPhee and Watts, 1976
	4.0 m^3/sec	MacPhee and Watts, 1976
	low flow and riffles of 1.4 m/s	Hallberg, 1981
	negligible	Bendock, 1979
Early Development	.02, .07, .03 m/s	Elliott, 1980
	shallow, protected areas	Chislett and Stuart, 1979
Juvenile Rearing	shallow pools	Cuccarese et al., 1980
	shallow pools	Hammarston, 1981
	.08 to .195 m/s	Elliott, 1980
	.8 m/s	Chislett and Stuart, 1979
Adult Summer Habitat	.26 m/s	Elliott, 1980
Adult Winter Habitat	open areas	Chislett and Stuart, 1979
Upstream Migration	at breakup	MacPhee and Watts, 1976
	1.3 - 4 m^3/s	MacPhee and Watts, 1976
	2 m^3/s $\rightarrow$ 20 m^3/s	McCart et al., 1974
	1.67 m^3/s	Tripp, 1981
	at breakup	Wojcik, 1954
	at breakup	Warner, 1955
	high flow	Tack, 1972

Table VIII: Reported substrate types used for spawning.

Substrate	Reference
Fine gravel (1 cm)	Warner, 1955
"pea-size"	Tack, 1971
sand to small cobble	Cuccarease et al., 1980
sand - gravel	Brown, 1938
sand, gravel, rubble	Kruse, 1959
fine gravel (< 3.8 cm)	Hammarstron, 1981
fine gravel	McHenry, 1981
gravel, 2.5 - 3.75 cm	Elliott, 1980
sand, fine gravel	Craig et al., 1972
sand, gravel	Bishop, 1971
organic detritus	Elliott, 1980
sand, muck	Elliott, 1980
mud, silt, gravel($\leq$ 4 cm)	Bendock, 1979
gravel, .75 - 4 cm	Hallberg, 1981

IV. DEFICIENCIES IN DATA BASE

Factors influencing the migration of adult and juvenile Arctic grayling from overwintering areas to spawning streams is apparently influenced by flow and water temperature conditions. The timing of adult and juvenile fish migrations are not understood; the juvenile fish run lags several days to several weeks behind the adult fish in certain areas.

Information about selection of sites in mountain, lake inlet and outlet, bog and spring streams in relation to current velocity, water depth and substrate is limited. Most of the observations were made in lake inlets and outlets and mountain streams.

Habitat selection by spawning Arctic grayling is influenced by at least three variables - substrate, water depth and current velocity - which collectively determine the habitat quality. For example, Arctic grayling may be excluded from spawning areas by excessive current velocities despite acceptable substrates and water depths. There is limited information on the interaction of various physical parameters.

Factors influencing the survival and development of eggs and alevins are not well understood. Studies indicate that egg dislodgement by other spawning fish and spates may be a major cause of mortality. Minimum water temperatures required for successful egg development are not known; however, water temperatures above 6°C (42°F) have been recommended.

The movement of Arctic grayling to overwintering areas appears to be influenced by flow and water temperatures associated with the onset of winter. This emigration may be of short duration or extend over several weeks. There is very little information about Arctic grayling overwintering areas. Fish overwintering in the North Slope are limited to open water areas or to streams which do not completely freeze. Fish overwintering in interior Alaska and Canada may remain in springfed and glacier streams. It is not known whether young of the year Arctic grayling burrow into interstices within cobble and rubble as water temperatures approach freezing.

The age structure of Arctic grayling populations during the open-water season may be significantly different among various lake inlet and outlet, bog, mountain and spring streams. Some streams appear to function as nursery areas for young of the year and older juvenile fish, and other streams may support only large juvenile and adult fish. Fish may be either sedentary or nomadic during the open-water rearing season. Explanations for fish emigration are speculative but living space and food availability are probably influential. Studies of juvenile and adult Arctic grayling habitats focused on water depth, current velocities and substrate in small bog and mountain streams.

Methods of describing water depth, current velocity and substrate characteristics varied among studies. Some investigators measured current velocity at the site of spawning Arctic grayling; others estimated surface current velocities. Substrate size classification systems also varied; few researchers evaluated substrate imbeddedness at spawning sites.

The effects of water temperatures and current velocities on a grayling's ability to ascend culverts has been studied for juvenile and adult fish. Relatively few tests were conducted with yearling grayling.

V. RECOMMENDATIONS AND FURTHER STUDIES

In depth investigations are needed to determine the relationships between specific chemical and physical features of aquatic habitats and grayling growth and behavior. For example, investigations should be designed and conducted to assess the factors which influence development and survival of Arctic grayling eggs and alevins in bog, lake inlet and outlet, spring and mountain streams. Investigations should consider egg dislodgement, predation, desiccation, and diel drift of emergent fry.

Water temperatures and ice conditions during grayling egg and alevin development may be easier to sample than the lower water temperatures and thicker ice cover characteristic of Pacific salmon and char incubation periods.

Laboratory studies should assess the effects of various durations of low water temperatures on the development and survival of eggs and alevins. Water temperatures at or below threshold levels could cause morphological deformities, slow development rates and high mortality among eggs and alevins. These investigations could explain the apparent avoidance of spring streams by spawning Arctic grayling.

Weirs could be used to sample grayling from bog, mountain, spring and lake inlet and outlet streams to relate residence time and migration to stream flow, water temperature and other physical and chemical stream factors.

Unique tags on upstream migrating adult and juvenile fish would provide specific migration data. Data from consecutive years could be used to determine Arctic grayling homing to specific spawning and rearing streams.

Arctic grayling spawning sites should be studied more extensively in northern latitudes. Characteristics of spawning habitat in terms of water depths, current velocities and substrate conditions should be compared with habitat availability for specific stream systems. Water temperatures and fish spawning activities should be monitored to detect spawning activity cycles.

Internal radio transmitters could be used to monitor grayling movement to and within open-water rearing areas and overwintering sites. Radio telemetry could be used to study fish migration rates and patterns.

Surgical implantation of radio transmitters is probably the best method for spawned-out adult and large juvenile fish. Surgical implantation has less affect on fish equilibrium than esophogeal insertion (Winter, Kvechle, Siniff and Tester, 1978). Rates of healing, condition of internal organs and the occurrence of infection among the fish should be determined for various water temperatures.

Criteria for radio transmitter selection should include size of transmitter and antennae, transmitter various temperatures, and signal receptions at various depths.

The feasibility of marking juvenile Arctic grayling with fluorescent pigment should also be determined. A variety of color combinations could be used to identify specific stream locations and dates of marking. Lack of scale development may prevent pigment retention by yoy Arctic grayling less than 1½ months old.

Comprehensive sampling of fry would determine movement of yoy Arctic grayling. Weirs of small mesh screen could be used to monitor yoy Arctic grayling movements. However smaller mesh size also necessitates more frequent cleaning of the weirs.

Weirs should remain within streams as long as possible prior to freeze-up to monitor Arctic grayling movements and physical and chemical habitat components. Weirs could remain in spring streams which remain ice-free to monitor the presence of fish.

Investigations should be conducted to determine open-water, lotic microhabitat selection by juvenile and adult Arctic grayling using techniques similar to those described by Everest and Chapman (1972). These investigations should describe water depths, current velocities, substrate, proximity to nearest fish and instream cover. Snorkeling, which has been used extensively in the Pacific Northwest and elsewhere, can be used where bank observations of fish are difficult.

Microhabitat investigations could complement fish movement data from weirs and radio telemetry studies. Microhabitat studies could also explain the apparent segregation of various age classes of Arctic grayling in certain rivers such as the Chena River.

Food availability and various physical and chemical habitat influence the summer, open-water distribution of Arctic grayling within streams. Drift and substrate sampling of invertebrates can be used to assess food availability and its relationship to the distribution of Arctic grayling.

Studies of juvenile and adult Arctic grayling overwintering habitat should continue. Gillnets, SCUBA and other techniques could be used to investigate these overwintering habitats.

Fish passage studies should be conducted to assess the ability of juvenile and adult Arctic grayling to ascend culverts and other high current velocity areas. MacPhee and Watts (1976) determined that the ability to ascend culverts was a function of culvert length and spawning condition. Studies of yoy and older juveniles would identify fish movement during the summer rearing season. The possibility that excessive current velocities associated with culverts prevent young grayling from reaching small rearing streams should be investigated.

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