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MIGRATIONS AND DISTRIBUTIONS OF ARCTIC GRAYLING, *Thymallus arcticus* (Pallas), IN INTERIOR AND ARCTIC ALASKA

by

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ABSTRACT

The seasonal migrations and resultant distributions of Arctic grayling, *Thymallus arcticus* (Pallas), are described for five basic river types in the Interior and Arctic in Alaska. An attempt is made to generalize and identify causative factors as well as to point out major gaps in information.

Deep lakes and large rapid runoff rivers serve as overwintering habitat in the Tanana River drainage. Further north, spring areas in rapid runoff (mountain) streams and isolated deep pools in the larger rapid runoff rivers provide the only overwintering habitat other than deep lakes.

The spring migration consists of both a prespawning migration to the spawning areas and a postspawning migration to feeding areas; both involve juvenile as well as adult grayling. The prespawning migration is probably stimulated by the first rise of water temperature to 1°C in the spring. Homing to specific spawning streams and spawning locations within large unsilted rapid runoff rivers is evident. Homing to feeding streams and feeding locations within large unsilted rapid runoff rivers is also indicated. The observed tendency for juvenile grayling to follow adults to spawning and feeding areas provides a mechanism for imprinting this complex migration pattern.

Spawning is limited to the main stem and major tributaries of large unsilted rapid runoff rivers, bog (tundra) streams, outlets of shallow lakes, and inlets of deep lakes. The hypothesis is advanced that these locations are used for spawning because they are the first areas in their systems to warm in the spring. Achievement of an optimum spawning density appears to supercede selection of the warmest part of the system in establishment of

spawning distribution in large unsilted rapid runoff rivers. Homing to a river section, plus territorial competition among males, is proposed as the mechanism producing the density distribution at spawning times.

Summer feeding distribution changes during the life cycle. Fry spend the first summer near their hatch site. Age I, II, and III grayling occupy lower portions of large unsilted rapid runoff rivers and associated tributaries. They also utilize spring-fed streams and some lakes. Yearling grayling also remain in bog-fed streams all summer. Subadults (Ages IV, V, and some VI) occupy the midsections of large unsilted rapid runoff rivers. They also utilize spring-fed streams and some lakes. Adult grayling also utilize spring-fed streams, some lakes, and unsilted rapid runoff streams where they occupy the headwater tributaries to the exclusion of smaller grayling.

All age classes of grayling are involved in the fall migration. The migration begins and proceeds well in advance of ice formation that could limit movement. The migration is downstream, except for fish moving into lakes from their outlets or fish moving upstream to spring areas.

RECOMMENDATIONS

1. The extent of overwintering in rivers of management importance should be studied. Rivers such as the Salcha, Goodpaster, Chatanika, and upper Tok in the Tanana River Drainage possibly harbor overwintering grayling. Spring netting at the mouths and upstream sites may be the best way to approach this problem, as under-ice netting is difficult, time consuming, and often unproductive. Overwintering sites should be related to habitat type and water quality to arrive at general requirements.

2. Bog streams in the Tanana River drainage should be studied to determine if all fit the presently indicated pattern of being spawning and nursery streams only. Weir studies may be practical in some of these streams, which would save a great deal of extensive sampling.

3. The phenomenon of homing in grayling needs study. Present work indicates homing to overwintering areas, spawning areas, and juvenile and adult feeding areas. The relationship between bog streams and spring-fed streams may provide a good starting point for such studies.

4. The use of small tributary streams and headwater streams in large unsilted rapid runoff systems needs study. Small streams may be especially important rearing waters for juvenile grayling, but this may vary along the course of a large, clear river.

5. Upper limits of water temperature at which grayling begin to exhibit avoidance behavior should be elaborated.

6. The rivers and portions of rivers used for spawning need delineation. Concurrently the conditions that make these waters favorable for spawning can be elaborated.

7. Studies should be made to determine whether grayling choose lake inlets in larger, deep lake systems and lake outlets in small shallow lake systems for spawning. The underlying theory is that grayling spawn in that part of the system warming to 3.9°C earliest in the year.

8. It should be determined whether or not the feeding stocks seen in spring-fed streams represent a unified stock; replaced by their own progeny returning from one or more natal streams.

9. It should be determined why grayling leave the spring-fed streams of the Tanana River drainage for the winter.

BACKGROUND

The Arctic grayling, is a member of the family Thymallidae (McPhail and Lindsey, 1970) and is the only species of four in the genus Thymallus that occurs in North America (Scott and Crossman, 1973). The genus is found in most watersheds from the Kara and Ob rivers in Russia, east to the west side of Hudson Bay in Canada, and south into northern Saskatchewan, Alberta, and Manitoba. Arctic grayling are also present in the upper Missouri River above Great Falls, Montana, but ranges have been altered through extinction, hatchery plantings, and introductions from Canada (McPhail and Lindsey, 1970). This paper is based upon studies of Arctic grayling in interior and arctic Alaska, where they are widely distributed in every major drainage.

Grayling spawn in May or early June, usually over gravel bottoms in riffle areas of streams. Spawning begins when the water temperature reaches 3.9°C and usually lasts about one week (Tack, 1972). Male grayling establish and vigorously defend territories on the spawning riffle, while females enter the riffle only to spawn and then return to deep holes (Fabricius and Gustafson, 1955; Tack, 1972). Redds are not constructed; eggs are deposited as the posterior third of the female is forced into the gravel by the male during spawning. Eggs are adhesive prior to water hardening. The fry hatch in 2 to 4 weeks (Warner, 1955; Bishop, 1971) and after a short stay in the gravel move to shallow backwaters along the stream bank to feed.

Growth is highly variable during the first summer, resulting in fork lengths varying from 35 mm (1.4 in) (McCart et al., 1972) to 120 mm (4.7 in) in the fall. Most grayling in interior and arctic Alaska are mature at 300 mm (11.8 in) fork length and 7 years of age. Few grayling in this area live more than 12 years, or exceed 430 mm (16.9 in) fork length, or 1 kg (2.2 lb) in weight. Grayling are referred to as young-of-the-year or fry when less than 1 year old; as yearlings during their second year of life (Age Class I); as juveniles during their third and fourth years of life (Age Classes II and III); as subadults during their fifth and sixth years of life (Age Classes IV and V) and as adults once they have matured. Once mature, grayling spawn every year.

One of the most obvious adaptions the Arctic grayling has made to facilitate its highly successful invasion of far north rivers is the ability to move to areas that best suit seasonal needs. It has been generally believed for many years that grayling feed during summer in numerous rivers and streams that freeze solid or dry up during the winter, and often overwinter in rivers unsuitable for summer feeding. Numerous studies during the last 25 years have described the movements of grayling in particular streams during particular seasons, but no comprehensive interpretation of grayling migration exists; this report attempts such an interpretation.

OBJECTIVES

1. To analyze and interpret grayling migration and movement information collected and reported on for a number of years under Study R-I.

2. To identify research needed for further delineating grayling migration and movements to better manage the grayling fishery.

TECHNIQUES USED

Since this paper is based entirely on data reported elsewhere, no attempt will be made to detail collection methods or analysis techniques here. The names of fish species mentioned in this report appear in Table 1.

FINDINGS

Study Area

Much of the work on which this paper is based was carried out in the Tanana River drainage (Fig. 1), but frequent reference is made to studies conducted in other Alaskan rivers flowing north from the Brooks Range to the Arctic Ocean (the North Slope) (Fig. 2). Locations discussed in the text are named in the two figures. Of prime importance in relating the numerous observations of grayling migration and distribution is a functional stream type classification. Wojcik (1955) proposed a classification of stream types for the Tanana River drainage that has proven useful and will be used here as follows: (1) rapid runoff streams, silted and unsilted; (2) spring-fed streams; (3) bog-fed streams; and (4) glacier-fed streams.

Rapid Runoff Streams:

Rapid runoff streams arise in hills or mountains fed primarily by runoff from rain, snow or glacial melt. Groundwater provides a fraction of the summer flow, but all of the winter flow in those rapid runoff streams that have winter flow. Small groundwater flows may freeze a short distance downstream from the source causing large build-ups of <u>aufeis</u> during the winter. Some fish spend the winter in the short stretches of open water below these springs. If the flow of groundwater is large, ice forms only on the surface and the river will maintain a constant flow all winter.

In summer, runoff water predominates and both discharge and temperature vary widely (3-2,100m^3/s and 0°C to 19°C for the Chena River near Fairbanks). The periods of high discharge cause considerable bank erosion

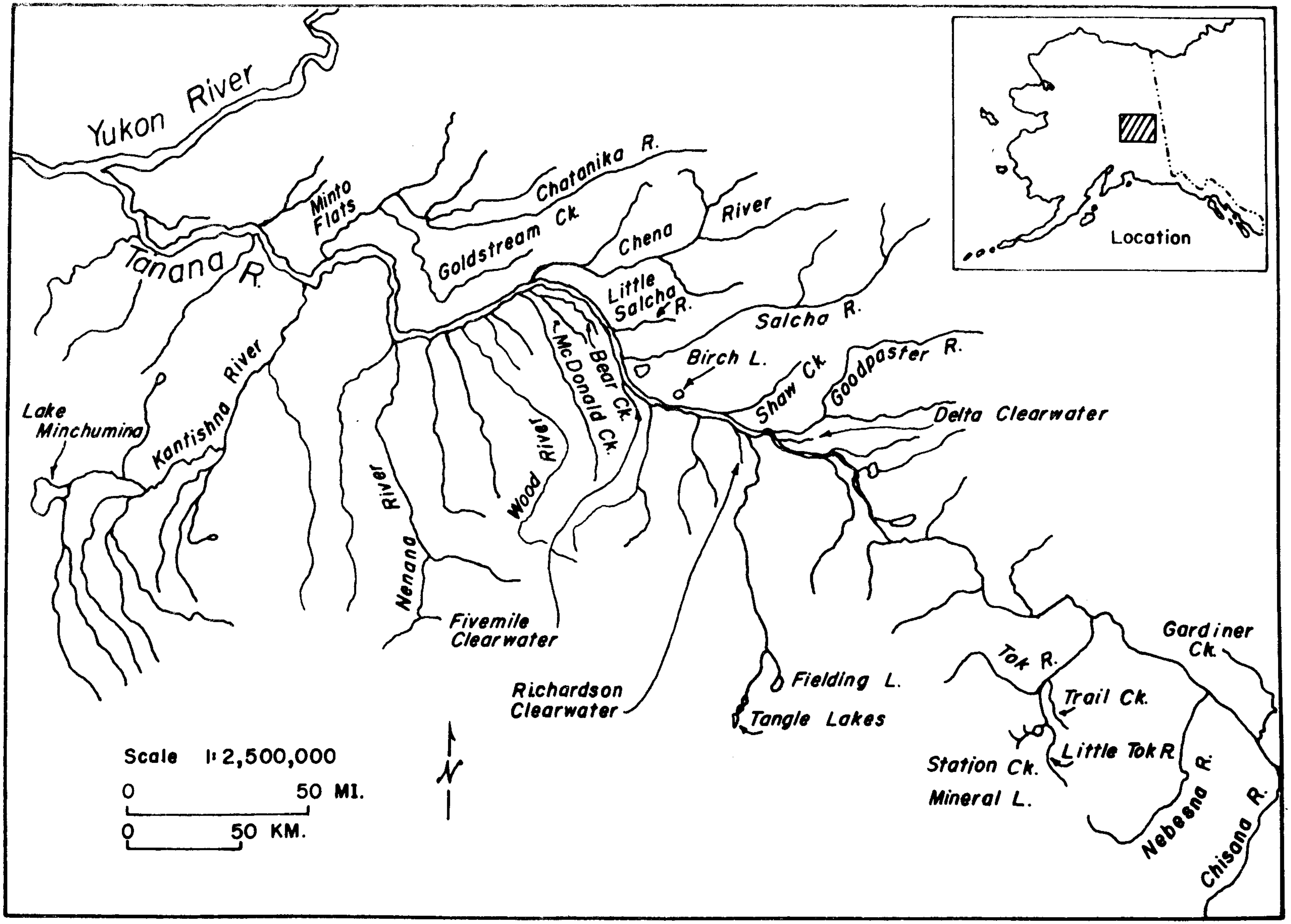

Figure 1. The Tanana River drainage.

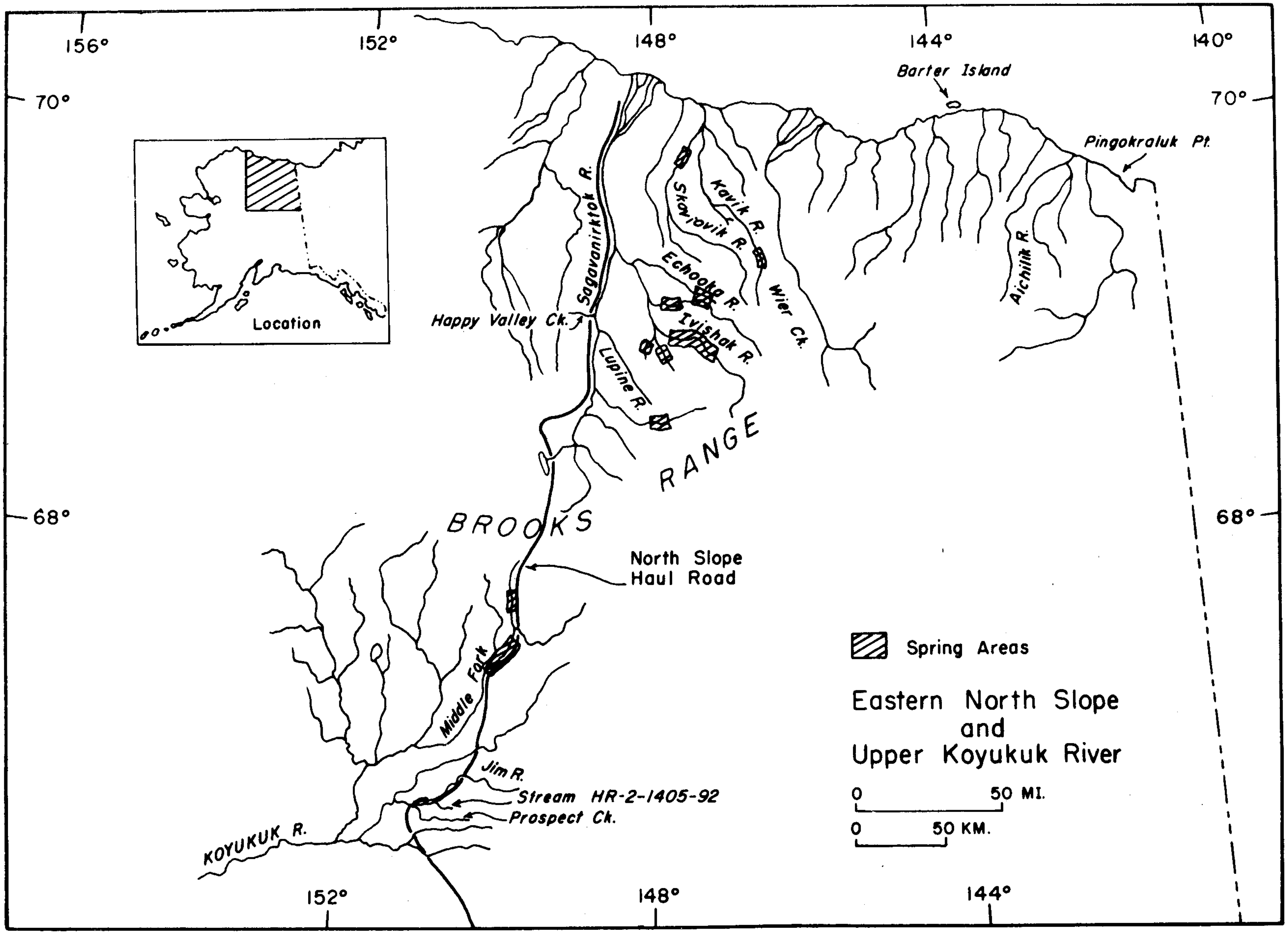

Figure 2. Eastern North Slope and upper Koyukuk River.

and channel alteration. The basic water chemistry (Table 2) varies according to geographic area, reflecting the character of mineral types in the area.

Rapid runoff streams are of two types: silted and unsilted. The unsilted type provides most of the summer grayling habitat in interior Alaska. These streams are clear except during periods of high discharge after rains, or during spring runoff, when they carry silt and are stained brown. Included among unsilted rapid runoff rivers are the Chatanika, Chena, Salcha, and Goodpaster rivers in the Tanana River drainage, and the Jim River, Prospect Creek, the Middle Fork Koyukuk, and many of its tributaries, all in the Koyukuk River drainage. Silted rapid runoff rivers are clear during winter but, during summer, carry a heavy load of gray silt originating from glaciers at their headwaters. This stream type, of which the Tanana River is a good example, is usually large and is often used by grayling for overwintering and to some extent for migration during the early summer, but is generally avoided by grayling during most of the silted period. Other silted rapid runoff rivers include the Chisana, Nabesna, Tok, Wood, and Kantishna rivers of the Tanana River drainage and the major Yukon, Kuskokwim, Copper, and Susitna rivers.

Spring-fed Streams:

Spring-fed streams in the Tanana River drainage arise in flat country and derive most of their water from springs. Discharge is relatively constant compared to rapid runoff streams, resulting in stable, well vegetated banks. Winter water temperatures usually remain slightly above freezing for several miles from the springs, resulting in little or no ice formation. In long spring-fed streams some ice formation occurs in the lower sections. Summer water temperatures remain low, compared to other stream types, and the water is very clear year-round. Spring-fed Tanana River tributaries tend to be basic and of high alkalinity. Spring-fed tributaries of the Tanana River include the Delta Clearwater, Richardson Clearwater, and Fivemile Clearwater rivers.

Bog-fed Streams:

Bog-fed streams drain flat swampy country similar to that drained by spring-fed streams, but most water is from surface runoff. They usually freeze solid during the winter, often flood during spring runoff, and experience high flows following rains, though not as high as in rapid runoff streams. Summer water temperatures are warm due to the slow flow rate and limited shade in swampy headwaters. They are usually small, of relatively uniform depth, and have a characteristic brown stain. Some of the bog-fed streams in the Tanana River drainage are Little Salcha river and Shaw, Gardiner, Desper, Scottie, and Goldstream creeks.

Glacier-fed Streams:

Glacier-fed streams are those that carry a load of glacial silt during their entire period of flow, which is only during open water months. They originate from glaciers and discharge into rapid runoff rivers, causing the latter to become silted. These streams support little or no fish life and will not be considered further here.

McCart et al. (1972) classified the North Slope streams in the vicinity of the Trans-Alaska Pipeline Corridor into three groups, on the basis of their origins as follows: mountain streams, foothill streams and spring streams. The spring streams are similar to those of the Interior but are generally very short, joining mountain streams within a few kilometers. The mountain streams are similar to unsilted rapid runoff streams.

Overwintering Distribution

Grayling are limited in their winter distribution by some obvious conditions such as ice encroachment, or cessation of flow in small streams, or by the reduction of dissolved oxygen under ice cover, notably in small shallow lakes. In other cases grayling inexplicably leave waters that appear suitable for overwintering. For many years the only known overwintering areas in the Tanana River drainage were the Tanana River itself, Tangle Lakes, Lake Minchumina and Fielding Lake. It was assumed that all fish in those Tanana River tributaries without lakes, overwintered in the Tanana River itself which, like other silted rapid runoff rivers, cleared in the fall following freeze-up.

Large Unsilted Rapid Runoff Rivers:

During the spring of 1974 and winter of 1974-1975 gill nets were fished under the ice of the Chena River at five sites from the mouth to 157 km (102 mi) upstream. Grayling were found throughout the 157 km (102 mi) main stem all winter. No out-migration was detected at the mouth during the fall and winter nor was there a spring in-migration to the Chena River mouth.

This evidence showed that, not only do grayling overwinter in the Chena River, but exclusively so, thus establishing the grayling population of the Chena River as relatively distinct from those in adjacent Tanana River tributaries. Furthermore, it might reasonably be expected that grayling overwinter in other large unsilted rapid runoff rivers in the Tanana River drainage and elsewhere. The Salcha River, parallel to and south of the Chena River, probably overwinters grayling, as it is slightly larger than the Chena River and possesses many deep pools. On the other hand, at least some of the grayling that summer in the Goodpaster River, located southeast of the Salcha River, spend the winter in the Tanana River, as indicated by tag recoveries. The Goodpaster River is slightly smaller than the Chena River. The Chatanika River, also smaller than the Chena River, was studied in some detail by Schallock (1966). He noted a decline in numbers of grayling in the upper sections of the river through the fall and recovered only two grayling by detonation of dynamite under 137 m (425 ft) length of ice during late winter. Schallock concluded that most Chatanika River grayling overwinter in the lower Chatanika River below the Elliott Highway, but presented no positive evidence for this conclusion. Later work by Roguski (1967) and Cheney (1972) shows that it is unlikely that the lower 40 to 50 km (25 to 32 mi) of the Chatanika River that flows through the Minto Flats is suitable for overwintering fish because of anoxic conditions. Thus, if grayling overwinter in the Chatanika River it would be in the 100 km (65 mi) section between the Elliot Highway and Minto Flats. It is known (Townsend and Kepler, 1974) that some grayling pass upstream through Minto Flats during the spring, but it is not known whether a significant number of grayling are involved.

Spring-Fed Streams:

There is abundant evidence that grayling migrate out of the spring-fed (clearwater) streams during the fall or winter and do not return until spring. These fish presumably overwinter in large rivers such as the Tanana. Streams for which this pattern has been determined include the Delta Clearwater (Reed, 1964), Richardson Clearwater (Pearse, 1974), and Fivemile Clearwater rivers (Bendock, 1974 and pers. comm.). Most grayling left Five Mile Clearwater River by late August in 1979 (Hallberg, per. comm.).

In contrast to the situation just described is the situation found in rivers flowing north to the Arctic Ocean from the Brooks Range. Here spring areas and deep holes provide the only overwintering habitat available and they are used by grayling as well as other freshwater fish species (Yoshihara, 1972; Craig and Poulin, 1975; Bendock, 1977). Grayling are also known to overwinter in spring areas in two places south of the Brooks Range. Netsch (1975) found grayling overwintering in a spring area in the Dietrich River, a tributary to the Middle Fork Koyukuk River. Wojcik (1955) recorded the well known concentrations of grayling at a spring area in the upper reaches of Beaver Creek, tributary to the Yukon River.

The reason grayling leave the clearwater streams of the Tanana River drainage is not known. These streams appear to be good habitat all winter with high oxygen levels, water temperatures slightly above freezing, abundant larval insects, and flows essentially the same as in the summer. Furthermore, silver salmon fry normally spend 2 years in these streams before out-migration. Slimy sculpin also remain in the clearwater streams all winter (Pearse, 1974; Bendock, 1974).

Large Silted Rapid Runoff Streams:

The waters of large silted rapid runoff rivers become clear in the winter and provide much of the overwintering habitat for grayling in interior Alaska. The Yukon, Kuskokwim, and Tanana rivers receive the grayling from numerous tributaries too small to provide overwintering habitat. Though little formal study has been done on grayling in these large rivers during winter, there seems little doubt that they are present. Grayling can be caught throughout the winter in the Tanana River at Big Delta where springs keep several miles of river partially ice free.

Bog-Fed Streams:

Most bog-fed streams freeze solid, or dry up, during the winter, requiring their summer populations to out-migrate. Tanana River drainage examples include the Little Salcha River, and Moose, Shaw, Desper, and Gardiner creeks. Bog-fed streams in other Interior drainages and the similar foothill streams of North Slope drainages also freeze extensively in the winter and provide no overwintering habitat. Some large bog-fed streams retain free, well oxygenated water all winter, but no indication of fish presence in these streams is available.

Prespawning Migration

During the prespawning migration adult grayling move from overwintering locations to spawning areas. In most cases this involves leaving a lake, large silted rapid runoff river, spring area, or deep hole and moving into a bog stream or unsilted rapid runoff stream. Only in the case of large unsilted rapid runoff rivers do grayling spawn in the same stream in which they overwinter; and even in these rivers there is a marked upstream migration to parts of the system not used for overwintering. The prespawning run begins as early as mid-April in some low altitude Interior streams and as late as early June in high altitudes. The progression of spring may cause as much as 3 weeks variation in timing from year to year.

The stimulus triggering the onset of movement away from the overwintering area probably involves a general environmental stimulus, such as day length, as well as more specific stimuli, such as water temperature or discharge. A readiness to migrate is shown by increased activity and congregating at stream mouths, but insufficient data are available to attempt correlations with environmental stimuli. In 1972 increased activity, primarily involving subadults, began 11 days before the intense prespawning migration and 18 days before breakup in the Chena River (Tack, 1973). Congregating at the mouth of Shaw Creek begins as much as 2 weeks before ice conditions permit migration. In the Chena River in 1972 (Tack, 1973) and also at an inlet to Fielding Lake in 1955 (Warner, 1955) the prespawning migration of adults began when the maximum water temperature first reached 1°C (33.8°F).

Although 1°C (33.8°F) is indicated here as the temperature stimulating onset of migration, the actual critical temperature may be lower. However, substantial numbers of fish do not move until the water temperature rises above 1°C (33.8°F). Interestingly, there is a drop in temperature after the run begins, a drop that normally occurs at breakup in large rapid runoff rivers, but it does not appreciably slow the run (Fig. 3).

The prespawning migration lasts from 2 to 6 weeks depending upon length of migration and rate of seasonal progression. Warner (1955) reports that the migration into a 3.2 km (2 mi) long tributary of Fielding Lake lasted 23 days (May 15-June 6) in 1954 and 14 days (June 5-19) in 1955. The run into 8 km (5.2 mi) long Poplar Grove Creek lasted 14 days in both 1973 and 1974 (McPhee and Watts, 1976) and 19 days in 1977 (Tack and Fisher, 1977).

The prespawning migration in long unsilted rapid runoff rivers is of longer duration and is more complex than just described for lake inlets and bog-fed streams. For example, in the Chena River where overwintering occurs throughout the lower 157 km (102 mi), spring observation reveals a strong upstream prespawning migration throughout most of the main stem and large tributaries; yet spawning occurs throughout the main stem from 10 km to about 240 km (155 mi). Spawning also occurs as much as 4 weeks later in the headwaters than near the mouth. The complex question of how the observed spawning distribution results is far from answered. A few thoughts will be mentioned here to aid in future study.

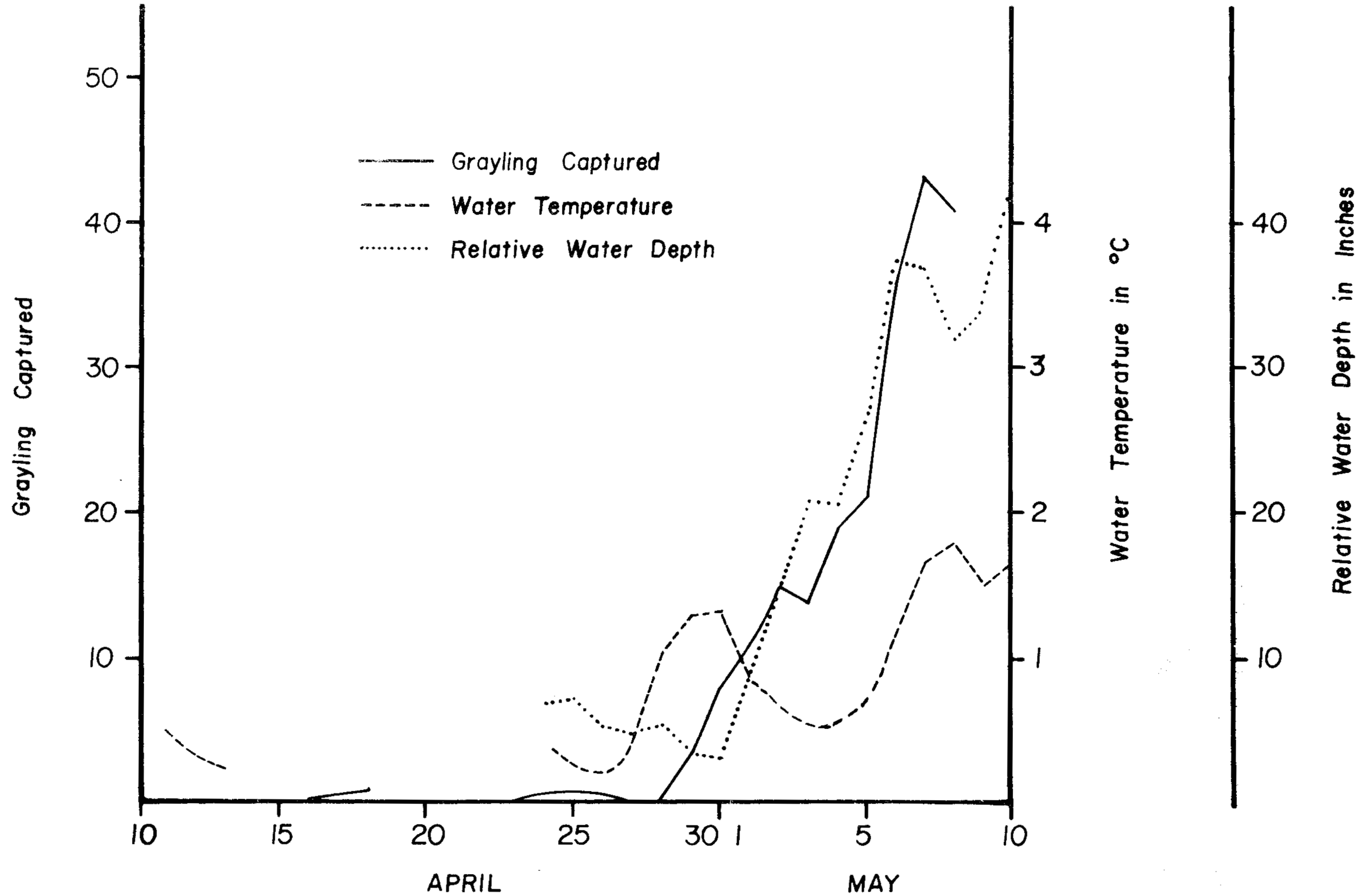

Figure 3. Relationship of relative water depth and water temperature to onset of grayling migration, Goodpaster River, 1973.

Table 1. List of common names, scientific names and abbreviations.

Common Name	Scientific Name and Author	Abbreviation
Arctic grayling	*Thymallus arcticus* (Pallas)	GR
Humpback whitefish	*Coregonus pidschian* (Gmelin)	HWF
Least cisco	*Coregonus sardinella* Valenciennes	LCI
Sheefish	*Stenodus leucichthys* (Guldenstadt)	SF
Coho salmon	*Oncorhynchus kisutch* (Walbaum)	SS
Slimy sculpin	*Cottus cognatus* Richardson	SSC

The extent, both spatially and temporally, of the prespawning run in long rapid runoff rivers may be controlled by the rate at which the water warms. The water temperature reaches daily maximums above 1°C (33.8°C) for a number of days before breakup, drops to near 0° during breakup and then rises toward 3.9°C (39°F), the temperature at which grayling begin to spawn (Tack, 1972). The temperature reaches 3.9°C (39°F) about 4 weeks later in the headwaters than near the mouth. At this time of year the days are long and the sun angle is high. A few days of intense sunlight and warm air temperatures can warm lower reaches of even a flooding river to 3.9°C (39°F). On the other hand, cool, cloudy weather following breakup may extend the prespawning period 3 weeks or more. If 3.9°C (39°F) functions as a threshhold temperature at which grayling begin to spawn, regardless of where they are, and, if all adult grayling migrate at about the same rate, then both the distance and time spent migrating and therefore the resulting spawning distribution could be determined by the spring water temperature regimen. Grayling that spawn in the lower reaches of these rivers have little or no prespawning migration and spawn several weeks before members of the same population that migrate many miles upstream over a period of several weeks.

However, evidence from studies in a small bog-fed stream (McPhee and Watts, 1976) shows that grayling will continue to migrate at temperatures well above 3.9°C (39°F). The run studied by McPhee and Watts moved through what appeared to be suitable spawning habitat at suitable spawning temperatures and therefore may have been homing to a destination. This may also be the case in rapid runoff rivers as spawners seem to establish a rather uniform distribution throughout long rivers such as the Chena and Goodpaster.

The peak of the prespawning run occurs after breakup in the large unsilted rapid runoff rivers and after bottom ice melts out of small ice-bound streams. Though movement often starts under the ice in large streams and through leads in the ice of bog streams, the run intensifies markedly during the increased flow accompanying breakup. Most of the prespawning migration is accomplished when the rivers and streams are at or near flood stage.

Migrating upstream during the spring freshet might initially appear wasteful of energy but, in fact, probably represents near optimum migration conditions for grayling. At high discharge, the water level rises, causing flow outside its normal well defined channel with pools and riffles, and flows next to trees or sod lined banks that are highly uneven in the natural state. Large eddies and slow flow are created along the banks, providing an avenue for migration nonexistent at low flows. The increased turbidity of the water at high flows may also be advantageous in providing protection from predators.

During the prespawning migration at Poplar Grove Creek a diurnal pattern of activity was apparent (McPhee and Watts, 1976; Tack and Fisher, 1977). All migrating grayling, juveniles as well as adults, began moving at about 1300 hours each day, peaked at about 1700 hours, and ceased moving at about 2300 hours. This pattern lasted throughout the migration. McPhee and Watts concluded that this pattern enabled the fish to migrate when water temperature was near maximum for the day, thereby taking advantage of demonstrated increased swimming ability at higher water temperatures. Tack and Fisher (1977) showed that the activity period has become internalized as part of a circadian rhythm, because it occurs whether water temperature rises or falls during the afternoon.

Wojcik (1955) observed grayling entering the Little Salcha River and Shaw Creek, both bog streams, and noted that once these runs started, fish moved only during the evening and at night. Later in the run fish moved into and up the streams during the entire 24 hour day. He associated this change with the disappearance of bottom ice, speculating that the bright reflection of light from the ice discouraged the fish from passing over it. Warner (1955) noted the same pattern of increased activity during the twilight hours from 2000 hours to 0400 hours which he says was especially true before the peak of the run. Why the latter two streams differ from Poplar Grove Creek is unknown and needs further clarification.

Spawning Distribution

Grayling spawn in unsilted rapid runoff streams, bog (tundra or foothill) streams, lake inlets and outlets, but not to any extent in spring-fed streams or silted rapid runoff streams. Known spawning locations in the Tanana River drainage have all been in gravel bottom riffle areas. A study of conditions on the spawning riffles in the outlet of Mineral Lake, 40 km (26 mi) southwest of Tok, (Tack 1973) revealed a balanced composition of sand and gravel with a very small amount of silt. Water velocities ranged from less than 0.25 m/s to 1 m/s (0.82 to 3.28 fps). Similar conditions were reported for grayling spawning in the Red Rock Creek system in Montana (Nelson, 1954).

Apparently grayling spawn under other conditions as well. In a small bog stream known as One-O-One Creek, tributary to the Middle Fork Koyukuk River, grayling were observed spawning among the sedges over an organic bottom in a nearly stagnant bog at the head of the Creek (Lou Pamplin, U. S. Fish and Wildlife Service, pers. comm.). Grayling fry were collected from this stream by the author in August of the same year. Some spawning may occur in lakes near the mouths of inlet streams (Warner, 1955) but this is probably not common.

Observations by the author of numerous spawning areas lead to the theory that grayling seek the portions of their resident systems that warm earliest in the spring and remain warmest during the incubation period. This theory will be elaborated upon in the following discussion of spawning distribution in the major stream types.

Unsilted Rapid Runoff Rivers:

In the large unsilted rapid runoff rivers of the Tanana drainage, grayling spawning tends to be distributed throughout the main stem and large tributaries. Spawning is seldom observed directly in these rivers as the turbid water of the spring freshet is usually still at bank level when water temperatures reach 3.9°C (39°F) and spawning begins. However, sampling with boat mounted electrofishing equipment in the Chena and Goodpaster Rivers shows the presence of spawning adults on riffle areas throughout the main stem of these rivers. In addition gill net sampling and fry distribution observations have confirmed the occurrence of spawning in most major tributaries of these rivers, but indicate that small tributaries are not used. Schallock (1966) also found little or no evidence of spawning in the numerous small tributaries of the upper Chatanika River. Spawning appears to be rather evenly distributed throughout the sections of these rivers that are used for spawning, as no large concentrations of adults were found in either the Chena or Goodpaster rivers. The males establish and defend territories throughout riffle areas in the lower Chena and Goodpaster rivers, but tend to use only the upper and lower ends of riffles in the fast headwater sections.

The use of the main stem and lower sections of large tributaries of large unsilted rapid runoff rivers for spawning in preference to small tributaries is probably due to the spring temperature regimen in these rivers and the tendency of grayling to spawn in the warmest portion of the system. The main stem and lower ends of large tributaries warm first and remain warm throughout the summer, whereas most of the small tributaries in these systems receive melt water late into the spring and continue to be cooler throughout the summer.

The spawning distribution does, however, extend a considerable distance up the larger tributaries; to the extent that spawning begins 2 to 5 weeks later than in the lower main stem due to the delayed warming of the water. This extension of the spawning distribution into the cooler headwaters of the major tributaries appears inconsistent with the hypothesized relationship between spawning distribution and temperature. Although temperature is probably the primary factor determining grayling spawning distribution, there is apparently an optimum dispersion of spawners which affects the distribution. Above a certain density, crowding may become more important in determining distribution than temperature. If this is true, the observed upstream expansion of spawning area would effectively increase the number of grayling that could successfully spawn in a river system.

Assuming that there is an optimal temperature regimen for spawning, but that the existence of an optimal density as well necessitates dispersion of some spawners into thermally less suitable areas, there must be a mechanism by which this dispersion occurs. Three possibilities are suggested: 1) through direct competition among territorial males, the more dominant (larger) fish command the most favorable (warmest) spawning habitat, displacing the less dominant (smaller) males upstream into cooler water, 2) spawning grayling exhibit a homing instinct, returning to the section of river where they were hatched, or 3) since adult grayling migrate upstream at varying individual rates, they will be overtaken at different points along the river by the upstream progression of the 3.9°C (39°F) isotherm which may act as a threshold temperature triggering spawning at that location. Little evidence is available in support of any of these mechanisms, but the first seems unlikely because no stratification of spawner size has been observed in the large runoff rivers. Apparently the third hypothesis is not adequate either, since cool weather in the spring would result in the spawning population being displaced further upstream--conversely most spawning would occur in the lower reaches during a warm spring. Neither of these situations has been observed. The homing hypothesis appears most likely, as there is no conflicting evidence and homing is strongly indicated in other aspects of grayling migration.

Bog Streams:

Most bog streams of interior Alaska are utilized for spawning by Arctic grayling. Even many bog streams that become dry during late summer will be used for spawning. The bog (tundra or foothill) streams draining the North Slope of the Brooks Range are important spawning streams in that area. However, for all their importance as spawning streams, little is known of spawning distribution within them.

Bog streams known to be used by grayling for spawning in the Tanana River drainage include the Little Salcha River, Shaw, Gardiner, and Scottie Creeks. Streams in other areas include Poplar Grove Creek in the Copper River drainage (McPhee and Watts, 1976), Happy Valley Creek in the Sagavanirktok drainage (McCart et al., 1972), Weir Creek in the Kavik River drainage (Craig and Poulin, 1975), Mary Angel Creek, and One-O-One Creek (Hallberg, 1975), and stream HR2-1405+92 (Netsch, 1975) in the Middle Fork Koyukuk River drainage.

The use of bog or tundra streams for spawning is probably a result of their favorable temperature regimens. Because they are small, slow flowing, and usually exposed, the water warms rapidly. Craig and Poulin (1975), recorded a rise in temperature of Weir Creek from 3.9°C (39°F) on June 11, when spawning began, to 16.7°C (62°F) on June 16, near the end of spawning. The rapid rise in water temperature to a relatively high level causes rapid egg development and early hatching, thus providing the longest possible feeding period for fry before winter. Grayling hatch in 11 (Brown, 1938) to 23 days (Tryon, 1940) requiring from 216.5 degree days (Bishop, 1971) to 256.7 degree days (Ward, 1951). The high temperatures found in small bog-fed streams are tolerated by juvenile grayling as well as fry, but subadults and adults tend to avoid water temperatures above 16°C (60°F) (Wojcik, 1955; Schallock, 1966), which is probably the reason they leave tundra and bog streams following spawning.

Lake Inlets and Outlets:

A special situation exists with regard to grayling spawning distribution in lake inlets and outlets. Though spawning distribution in relation to lake systems has been only slightly studied, a pattern consistent with the hypothesized selection of the warmest part of the system for spawning seems to emerge. Observations of lake systems in the Tanana River drainage indicate that grayling spawn either in inlet streams or in the outlet of a given lake, but not in both.

Selection of the consistently warmest water in the system seems to be the only explanation for grayling concentrating in the 1.5 km (1 mi) long outlet of Mineral Lake. Grayling that spawn in this area winter somewhere downstream, possibly in the Tanana River itself. They summer in Station Creek, the primary inlet to Mineral Lake, and in the upper Little Tok River, both small rapid runoff streams (Fig. 1). During the spring, waters from Station Creek and numerous spring areas in Mineral Lake are warmed as they move through the shallow lake, resulting in the outlet stream warming sooner than surrounding streams and also reaching higher maximum temperatures.

Consistent with the hypothesis that grayling spawn in the warmest part of a system, one would expect spawning to occur in outlets of only those lakes small and shallow enough to open early in the spring, allowing the outlet to warm more rapidly than the inlet streams. Conversely, the slowness of ice melt in deep lakes would tend to retard warming in the outlets, resulting in the inlet streams warming earlier and being more favorable spawning sites.

This pattern is true for the shallow Mineral Lake outlet. Apparently it also holds for the deep Tangle and Fielding lakes, where spawning is known to occur in several rapid runoff and bog-stream type inlets. It is known that no spawning occurs in the outlet of Fielding Lake. The relatively inaccessible outlet of Tangle Lakes has not been surveyed at spawning time.

Situations where grayling spawn in lake outlets are of special interest as study sites because they often have clear water at spawning time due to the settling action of the lakes.

Postspawning Migration

Unsilted Rapid Runoff Rivers:

In large unsilted rapid runoff rivers such as the Chena and Goodpaster, the adult postspawning run is primarily upstream into headwater tributaries where they spend the summer feeding. The run begins shortly after spawning, which is 2 to 3 weeks earlier near the river mouths than in the headwaters, and the run is completed by all adults in early July. Fish that spawn near the mouths of these rivers must migrate considerable distances, but since they start earlier than fish spawning further upstream, they arrive in the headwaters about the same time spawning is being completed there. During netting in the headwaters of the Chena River in 1972, the first spent grayling began entering small headwater tributaries on the same day that the 3.9°C (39°F) isotherm reached those areas and the grayling already there began spawning. The spent grayling were apparently arriving from spawning locations further downstream.

The movements of subadults during the postspawning period in the large rapid runoff rivers appear to be affected by interaction with adults. Sampling during June, shortly after the spawning was completed in the upper Goodpaster River (100-185 km [65-120 mi]), showed the presence of significant numbers of subadults (Tack, 1974). In July there were far fewer subadults and in August there were almost none. Competition for food or space was probably the factor which caused the subadults to leave. Vascotto (1970) showed that such competition occurs, but he did not observe displacement to the extent seen in the Goodpaster River.

It is not clear whether these subadults that followed the adults into the upper Goodpaster River returned downstream or were displaced into small headwater tributaries. The headwater tributaries have not been surveyed except in one instance when the upper 24 km (15 mi) of the South Fork of the Goodpaster River were surveyed in July 1973. Here it was found that in the extreme headwaters, where the stream was less than 0.5 m (1.6 ft) wide and tumbled nearly vertically from one small pool to the next, subadults, Ages III, IV and V were present. Where the stream became 1.0 to 1.5 m (3.2

to 5 ft) wide and no longer fell between pools, only adults were found. It appears that at least some subadults are displaced or move by choice to the small tributaries or small tips of streams.

Juvenile grayling in Age Classes I and II are usually present in the pre and postspawning migration in large rapid runoff rivers but lag several days behind the adults in the lower river and do not reach the extreme headwaters.

Bog-Fed Streams:

Postspawning migrations by grayling in bog-fed streams and their arctic correlates, tundra streams, generally involve the adults and larger subadults leaving the stream. Most adult and subadult grayling 240 mm or longer left Poplar Grove Creek, before July 1, 1973 (McPhee and Watts, 1976). Spawning was probably completed by June 1, 1973 in Poplar Grove Creek, indicating that the postspawning migration proceeds at a slower pace than the prespawning migration. The same pattern was seen in a small tundra stream, Weir Creek, in the Kavik River drainage where nearly all adults and subadults emigrated soon after spawning (Craig and Poulin, 1975). Here the adults were gone by July 3, about 2 weeks after completion of spawning, while subadults left 2-3 weeks after the adults. McCart et al. (1972) noted the same pattern in Happy Valley Creek, a tundra stream in the Sagavanirktok River drainage. Netsch (1975) found some adults and large subadults remaining in the lower 0.5 km (0.3 mi) of a small tundra stream tributary to the Jim River on the South Slope of the Brooks Range, but most adults left shortly after spawning.

After emigrating from the bog-fed spawning streams, the adults and Subadults either remain in the parent lake or river or move into a spring-fed or rapid runoff tributary. Grayling that leave Poplar Grove Creek during the postspawning run remain in the parent Gulkana River, as several tag returns from fish tagged in Poplar Grove Creek have come from the Gulkana River upstream from Poplar Grove Creek (Williams and Morgan, 1974; Williams, 1975 and 1976). Adults and subadults that emigrated from Weir Creek are believed to have remained in the parent Kavik or Shaviovik rivers (Craig and Poulin, 1975). One of 81 grayling tagged in Happy Valley Creek during spawning was captured at a weir near the mouth of the Lupine River, a rapid runoff (mountain) type tributary to the Sagavanirktok River 8 km (5.2 mi) upstream from the mouth of Happy Valley Creek. One other was recaptured in the Sagavanirktok River near the mouth of Happy Valley Creek (Yoshihara, 1972). Emigration from bog streams tributary to the Tanana River, most of which are larger than those discussed above, is not well studied. Bendock (pers. comm.) found only a few adult and subadult grayling during a survey of the lower 20 km (13 mi) of the 28 km (18.2 mi) long Little Salcha River and believes the adults may be the same ones that appear in Fivemile Clearwater River in early June. Tag recoveries show that grayling move from Shaw Creek to both the Delta Clearwater and Richardson Clearwater rivers (Roguski and Schallock, 1967), but the sexual condition and number of migrating fish are not known.

Spring-Fed Streams:

Spring-fed streams are used, but little for spawning by grayling, thus adult grayling are rarely in these streams until after spawning. Reed (1964), on the basis of angler interviews, described the adult run into the Delta Clearwater River as occurring between May 1 and 20. He further states, on the basis of tagging information, and sampling throughout the river that no immature grayling were present until mid-June when a "mass movement of immatures" entered the river. Pearse (1974), using electro-fishing equipment, observed adult grayling entering the Delta Clearwater River from mid-May to early June; extending somewhat the documented period of adult in-migration. However, in contrast to Reed's observations on the timing of in-migration of immatures, Pearse found immatures entering the river in April in sufficient numbers to support a small sport fishery. It is possible that Reed missed the April in-migration of immatures and did not detect their presence. Pearse, on the other hand, has no information regarding in-migration, or lack of it, after the adult in-migration. It seems likely that immatures enter both before and after adults every year, but the possibility exists that the in-migration timing of immature grayling is totally unrelated to that of adults and may occur entirely before, entirely after, or coincident with the adult migration.

Bendock (Alaska Department of Fish and Game file report) determined that spent adult grayling entered Fivemile Clearwater during early June, 1975. There were no immature grayling in the stream during the early June sampling. The stream was sampled again in mid-July and immature grayling were present in good numbers. Other spring-fed streams in the Tanana River drainage are known to harbor many adult grayling during the summer, but no information is available regarding immature grayling.

The question arises as to where the grayling spawn that enter the clear-water (spring-fed) streams to feed. Do they represent a pure spawning stock or are they a mixture of fish from several spawning areas? Tagging studies in the Delta Clearwater and Goodpaster Rivers, and to a lesser extent in the Richardson Clearwater River and Shaw Creek during the early 1960's, indicated a strong tendency for the same grayling to be in the same spring-fed stream from one year to the next during the summer feeding period (Schallock and Roguski, 1967). Of the grayling tagged in the two clearwater rivers, 99.2% and 96.4% of over 1,000 recoveries made between 1960 and 1966 that allowed at least one year between tagging and recovery were in the same river as initially tagged. These fish were certainly homing consistently to their spring-fed summer feeding streams. The tagging program was not extensive enough to determine if all the adult grayling that faithfully return to a particular feeding stream also spawn in a common stream, but a small amount of data suggests that spawning affinities differ from the observed feeding associations. Fourteen percent of 320 recoveries of grayling tagged in the Goodpaster River were made in the Delta Clearwater River and 12% were made in the Richardson Clearwater River. Most of these fish were immature, so little was learned of the movements of adult grayling unless one supposes that immatures follow the same migration pattern as their parents. If this were the case, the tag recoveries indicate that at least some adult grayling from both the Delta and Richardson Clearwater Rivers spawn in the Goodpaster River. A similar situation was found with Shaw Creek. Here, only 12 recoveries were made of grayling tagged in Shaw Creek. Five were taken in each of the Clearwater rivers. The consistent homing by adults to their summer feeding stream leads one to expect that they may home equally consistently to their spawning stream, in this case, Shaw Creek, the Goodpaster River, or possibly some small creek in the area.

A mechanism for imprinting juvenile grayling to this complex pattern may possibly be present in the observed habit of juvenile grayling accompanying adults on spawning migrations.

For this mechanism to function faithfully, a means of yearling grayling recognizing the adults of their feeding stock must have been established prior to the eggs being laid; a highly unlikely situation. A more likely situation is that there is a tendency among immature grayling to follow adults and in doing so become imprinted to the places they go through olfactory recognition of the place. In this latter case there would be no specific relationship between the immature and adult grayling in a feeding stock. This less rigid system would accommodate occurrences such as that observed in the Delta Clearwater River where many immatures return to the system before the adults. Of course, there should be no yearlings among these early returning immatures except the very few that may have been hatched in the Delta Clearwater River itself.

Lake Inlets and Outlets:

The postspawning migration in lake-stream systems depends on the size, depth, and probably the type of lake. Grayling that spawn in small inlets of the large Fielding Lake migrate back downstream to the lake during the 2 to 3 weeks following spawning (Warner, 1955) and stay in the large lake or outlet all summer. Grayling that spawn in the outlets of small lakes usually migrate to other streams in the system to feed. Most grayling that spawn in the small outlet of Mineral Lake, a bog lake, migrate upstream through the lake and into Station Creek, the main rapid runoff type inlet; however, some migrate a short distance downstream, then up the Little Tok River or Trail Creek. The fish that moved through Mineral Lake began entering the inlet (Station Creek) about 1 week after they first entered the lake on May 13, 1972.

From June 8 through 15, adult and subadult grayling moved up Station Creek in substantial numbers. The postspawning movement of Age I and II grayling was not monitored but they were present in Mineral Lake outlet during spawning, having arrived about the time spawning began. These grayling all return downstream through Mineral Lake in the fall and winter somewhere below Mineral Lake; possibly as far away as the Tanana River.

Summer Distribution

Large Unsilted Rapid Runoff Rivers:

The summer distribution of grayling is fairly stable, though short lived. Most adult and subadult grayling have reached their summer feeding areas by the first of July and the main fall downstream movement begins in Interior and Arctic streams about September 1.

The summer distribution of grayling in the Goodpaster River is typical of the large unsilted rapid runoff rivers in the Tanana River drainage. Adult grayling were the predominant Age Class for 65 km (42.2 mi) upstream from Central Creek (64 km [42.2 mi]) on the North Fork and probably nearly to the source of the North Fork, another 35 km (23 mi) upstream (Fig. 4). Virtually no subadult grayling were taken with hook and line or small mesh gill nets between 82 km (53 mi) and 132 km (66 mi) on the North Fork. Subadults were dominant between 0 km (0 mi) and 45 km (29 mi) of the North Fork while juveniles prevailed in the 53 km (34 mi) long main stem.

In the South Fork Goodpaster River, adults dominated the upper 70 km (45 mi) of the 102 km (66 mi) long fork except for the uppermost 5 km (3.2 mi), where only subadults were found. The exclusive presence of juveniles in the upper 5 km (3.2 mi) of the South Fork suggested that they had moved there to escape competition with the larger grayling. It would, then, seem a likely theory that the numerous tiny tributary streams in the headwaters of large rapid runoff rivers (usually less than 1 m (3.28 ft) wide and only a few centimeters deep) would be important for juvenile rearing. The indicated importance of small tributary streams for juvenile rearing should be a stimulus to obtaining the survey information needed to prove or disprove the theory.

Another feature of the summer distribution of grayling in large rapid runoff rivers is the tendency for the same individuals to be in the same general area of the river in successive years. When grayling were tagged in 17 sections throughout the Goodpaster River in 1973 and sought during a 2 week recovery trip in 1974 (Tack, 1975), 56% of 54 tagged recoveries came from the same river section in which they had been tagged the previous year (Table 2). Though the Goodpaster River sections varied in length from 4.8 km in the lower 12 sections to 20 km in sections 14, 15, 16 and 17, and 40 km in section 13, which could have resulted in a bias showing more movement among the shorter sections of the lower river, grayling in the lower river appear to be in the same section more often than fish in the longer upper sections.

As previously mentioned, the winter distribution of the Goodpaster River grayling is not known, but it is probable that most fish leave the North Fork to avoid heavy icing. A strong prespawning migration into the North and South forks has been documented (Tack, 1974), indicating that many, if not all, grayling leave the upper forks during the winter. This being the case, the high incidence of individuals returning to the same study section in successive years certainly represents a homing tendency.

Further careful study will be required to reconcile the observed summer distribution of juveniles almost exclusively in the lower river sections, adults in the upper sections, and subadults occupying the middle sections and some small headwater tributaries with the tendency for individuals to return or to stay in the same section from one summer to the next.

One possible theory that should be tested might be called incremental maturity group homing. According to this theory juvenile grayling home to the same feeding area in the lower sections of large rapid runoff rivers through about their fourth year of life (Age Class III). Upon returning from overwintering grounds as Age Class IV fish, they continue further

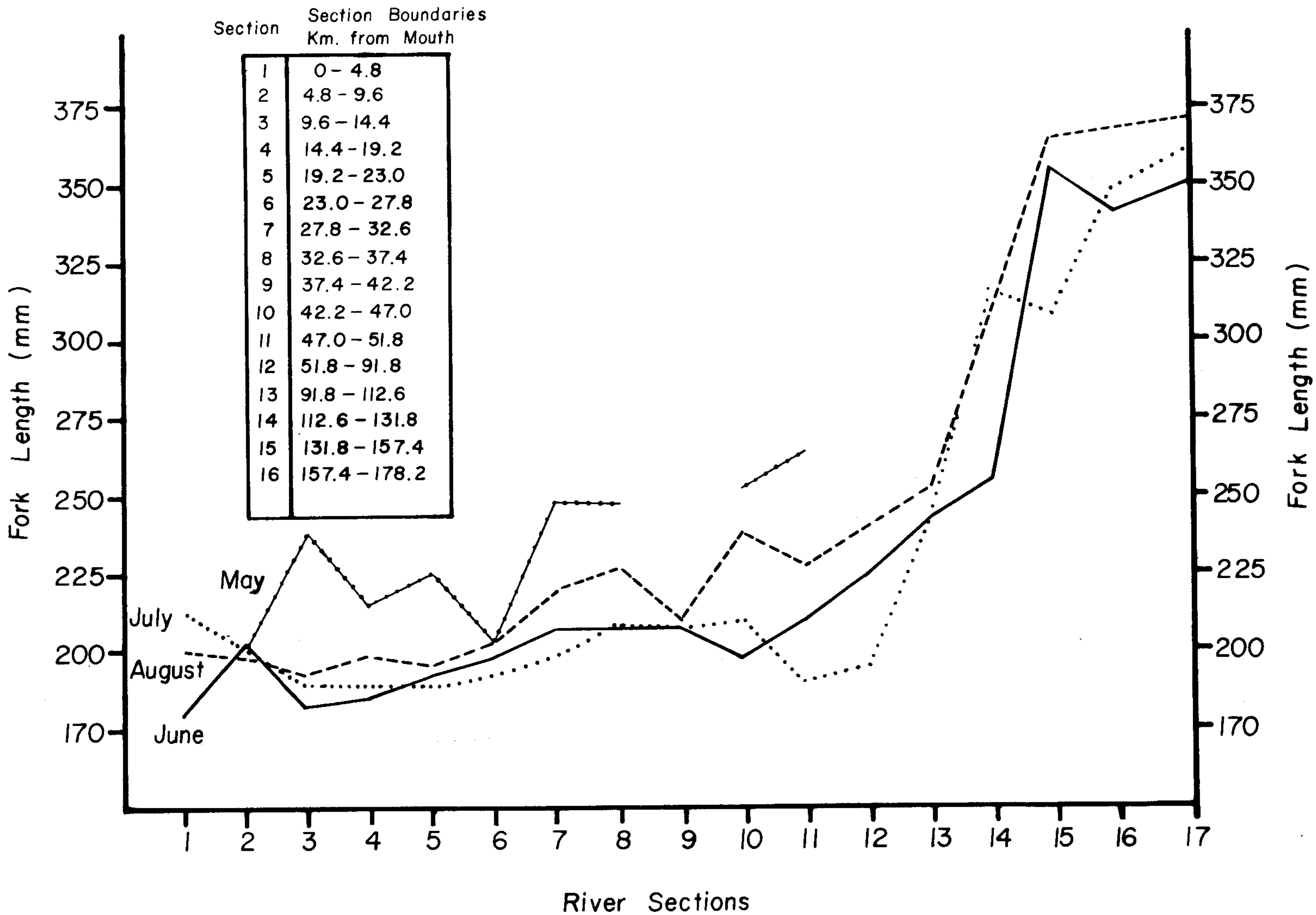

Figure 4. Mean fork length of Arctic grayling by river section by month in the Goodpaster River, 1973.

Table 2. Movement between Goodpaster River sections by 54 Arctic grayling tagged in 1973 and recaptured during recovery trip in late summer 1974. Entries in parentheses indicate no movement.

Section In Which Tagged	Section of Recapture 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1																	
2		(6)				1											
3		1	(1)			2					1						
4				(2)		1											
5					(5)	1							1				
6		1		1	1	(1)											
7						1	(3)										
8									2							1	
9									(1)				1				
10										(2)							
11						1							1				
12																	
13								1					(4)				
14																1	
15															(2)	3	
16																(3)	
17																	

No Movement ------------------>
n=30=55%

Downstream Movement ---->
n=8=15%

<---- Upstream Movement
n=16=30%

upstream following the adult spawners. Through competition they are kept from the upper sections and establish feeding areas in the middle sections of the river. They home to this feeding area until they become sexually mature, whereupon they establish feeding grounds in the upper sections of the river and return to them year after year. The theory basically asserts that grayling have a homing tendency, or habit, which causes them to remain in a particular river area until a change in sexual maturity stimulates them to move further upstream. Since maturity changes manifest themselves in the spring, section changes by maturing fish occur prior to establishment of the summer feeding distribution and thus appear as incremental upstream advances.

Bog Streams:

Detailed study of summer distribution of grayling in bog-fed streams is lacking. Only recently have bog streams been indicated as spawning and yearling rearing streams (McPhee and Watts, 1976; Bendock, pers. comm.). Further study will probably reveal that most of these streams are important spawning and rearing streams. The similar foothill streams are apparently used in this manner in the Sagavanirktok River drainage (McCart et al., 1972) and the tundra stream studied by Craig and Poulin (1975) was almost exclusively a spawning and nursery stream.

Spring-Fed Streams:

The summer distribution of grayling in the Delta Clearwater River was described by Reed (1964), who noted that adult grayling migrate directly to the headwater tributaries by early June and remain there until mid June where they spread downstream and occupy the entire river. Reed concluded that following the in-migration of immature grayling in late June, size groups were well mixed throughout the river. In 1973, when Pearse (1974) studied seasonal distribution in the Delta Clearwater, he found a similar movement to the upper reaches of the river following in-migration and a downstream spreading during June and July, but there remained throughout the summer, a concentration of adults in the upper sections and immatures in the lower sections of the river.

Fall Migration

The fall migration is a downstream movement except for grayling known to migrate upstream from lake outlets into lakes and on the North Slope of the Brooks Range where there are instances of grayling migrating upstream to spring areas to overwinter (Craig and Poulin 1975). The fall migration is probably the least understood facet of the Arctic grayling seasonal cycle, especially in rapid runoff streams, because of the severe environmental conditions at the time. Forming ice, and drifting leaves usually combine to keep sampling equipment out of the water. Virtually nothing is known of the downstream migration of fry in the large rapid runoff rivers, and details of what determines the onset of the run and the rate of migration are unknown in these rivers. Grayling do feed during the fall migration, at least until freeze-up, and are readily taken by anglers at this time.

Large Unsilted Rapid Runoff Rivers:

In the Chena River, where grayling overwinter in the main stem, the downstream migration from headwater tributaries is spread over the months from September through December. Anglers start catching more fish and larger fish in early September in the upper main stem of the Chena River, but grayling are still distributed throughout the headwater tributaries at this time. Grayling were caught under the ice at the lower end of the North Fork of the Chena River through early November, 1971, when the nets were removed. In 1969 the cold and snow of winter were late in coming and grayling 250-300 mm (10 to 12 in) were seen under clear ice in the North Fork as late as December 8, 1969. On February 4, 1970 at this site ice was no longer transparent. Upon drilling through the ice, only 2 in of water remained and the fish had probably departed (Roguski and Tack, 1970).

Schallock (1966) considered the downstream migration to begin in mid-July in the Chatanika River, based on the fact that none of the 1,241 grayling tagged after July 2, were recovered upstream of the power house raceway where they were tagged, whereas many of a similar number tagged before July 2, were retaken upstream. He also recovered five grayling, of 139 tagged on the same day in mid-July at the tailrace, from 6 to 13 km (4 to 8 mi) downstream. Downstream movement, however, was minimal until mid-September through early October when he said "grayling vanished" from large sections of the river with only a few fish remaining in large holes. Also during the last half of September grayling moved out of tributary streams both in the headwaters and further downstream. In November Schallock found no grayling in the Chatanika River above the powerhouse.

Schallock found evidence of downstream movement of young-of-the-year and yearling grayling in early August when fyke traps began taking 10 to 20 of these fish each 48 hours from two small tributaries. Prior to this time they had taken only one or two fish in a 48 hour period. Vascotto (1970) disputes Schallock's conclusion that young-of-the-year are migrating at this time as he found large numbers in the Chatanika River as late as August 25. Vascotto explains that young-of-the-year move from shallow backwaters to deep pools in early August.

The rather slow progression of the fall migration in the large rapid runoff rivers of the Interior gives little clue to the causative factors governing timing of the migration. However, on the North Slope where the seasons often progress rapidly, Yoshihara (1972) found emigration of grayling from the Lupine River, a small unsilted rapid runoff stream, closely related to the first occurrence of 0.0°C (32°F) minimum water temperature in the fall. Emigration rate rose from about 10 grayling per day to over 100 per day following the first 0.0°C (32°F) water temperature. Most Lupine River grayling emigrated during the following 2 weeks even though minimum water temperature did not again reach 0.0°C (32°F) for 5 days. In the bog and tundra streams, as well as in the spring-fed streams and small rapid runoff streams, grayling depart for overwintering areas well in advance of significant ice formation. Water temperatures may prove to be the triggering stimulus for all grayling as it was for those in the Lupine River.

Miscellaneous Movements

Movements to Avoid High Water Temperatures:

Mass movements of grayling to avoid naturally occurring high water temperature have been observed in a large unsilted rapid runoff river and in a lake system. Schallock (1966) observed grayling migrating upstream and into small tributaries of the Chatanika River from the main river during a period of record low flow and high water temperatures (18°C [64°F]) in early August 1960. The tributary streams averaged 5°C (9°F) cooler than the main river. In other years he found no upstream movement after mid July. Wojcik (1955) observed grayling congregated in an inlet to a small lake in the Tangle Lakes system when the surface water temperature of the lake was 17°C (63°F). When some of these fish were seined and held a short time for tagging, they suffered higher than normal mortality; evidence of their being under stress. Again on July 5, 1953, Wojcik observed grayling congregated at a small inlet of a pond near Tangle Lakes.

The surface temperature of the pond was 20°C (68°F). Wojcik noted that grayling moved to inlets rather than the deeper, cooler water in the lakes, as he took none in deep set gill nets during these warm water periods.

Short Term Feeding Movements:

During sampling in late June and the first week of July along the coastline adjacent to the Arctic National Wildlife Range in 1970, (Roguski and Komarek, 1971), Arctic grayling were taken around river mouths and behind barrier reefs from Pingokraluk Point west to the mouth of the Aichilik River. The spring runoff from numerous rivers entering this area occupied the coast behind the nearly continuous barrier islands, keeping the salinity at or below 1 ppt. The grayling captured were primarily adults, but subadults as small as 220 mm (8.75 in) fork length were taken. All fish had been feeding heavily on marine isopods and other crustaceans. No grayling were caught in coastal waters after early July, nor were any grayling found in salinities exceeding 1 ppt. This spring feeding foray into coastal waters may occur in other areas where barrier islands or coastal fast ice contain fresh water along the coast for a short period in the spring. Bendock and Doxey (pers. comm.) made incidental catches of grayling in the Prudhoe Bay area in salinities as high as 14 ppt but, found no evidence of a general migration into estuaries by grayling.

Feeding concentrations of grayling have been noted in association with the spawning of other species. In late September, 1968, a large number of grayling (873) moved upstream through a weir across the Chatanika River near the Elliot Highway Bridge. This upstream movement was in contrast to the downstream migration that had been passing the weir since August 10, and coincided with a large upstream spawning migration of least cisco, humpback whitefish, and sheefish. The grayling were still present among the spawning whitefish, probably feeding on eggs, when freeze-up ended observation in mid-October (Roguski and Winslow, 1969). Grayling are also known to congregate on salmon spawning grounds (Bendock, 1974).

Movements Resulting from Intraspecific Competition:

Vascotto (1970) describes the competition for feeding positions in a pool among various size grayling, noting that the larger fish command the best feeding location at the head of the pool. My findings that adult grayling occupy the upper ends of large unsilted rapid runoff rivers during late summer to the exclusion of juveniles may represent an extension of Vascotto's findings. As was mentioned earlier, juvenile grayling that were present in the upper Goodpaster River in June were displaced later in the summer. Much remains to be learned about the effect of intraspecific competition on grayling distribution.

CONCLUSIONS

The annual cycle of adult grayling migrations and distributions is generalized in Figure 5. Immature grayling tend to follow the same pattern except that they do not spawn. Young-of-the-year feed in the natal area then migrate directly to wintering areas. Overwintering occurs in lakes and large rapid runoff rivers in the Tanana River drainage. Further north, spring areas in rapid runoff (mountain) streams and isolated deep pools in the largest rapid runoff rivers provide the only overwintering habitat other than a few lakes.

The spring migration is in two parts, a prespawning run to spawning areas and a postspawning run to feeding areas. Both involve juvenile as well as adult grayling. The prespawning run is probably stimulated by the first rise of water temperature to 1°C (33.8°F) in the spring. Homing to specific spawning streams and spawning locations within large unsilted rapid runoff rivers is evident. Homing to feeding streams and feeding locations within large unsilted rapid runoff rivers is also indicated. The observed tendency for juvenile grayling to follow adults to spawning and feeding areas provides a mechanism for imprinting this complex migration pattern.

Spawning occurs throughout the main stem and lower ends of major tributaries in large unsilted rapid runoff rivers. Bog-fed streams of the Interior are favored for spawning and the similar tundra or foothill streams provide most of the spawning habitat on the North Slope. It is hypothesized that the locations just mentioned plus the inlets of large deep lakes and the outlets of shallow lakes are favored spawning locations because they are the first areas in their systems to warm in the spring and remain the warmest areas during the incubation period and usually all summer. Achievement of an optimum spawning density appears to supercede selection of the warmest part of the system in establishment of spawning distribution, especially in large unsilted rapid runoff rivers. Homing to a section of river plus territorial competition among males is proposed as the mechanism producing the density distribution at spawning time.

Summer feeding distribution changes during the life cycle. Fry spend the first summer near their hatch site. Age Class I, II and III grayling occupy lower portions of large unsilted rapid runoff rivers and associated tributaries. They also utilize spring-fed streams, mountain streams of the Arctic, and some lakes. Yearlings may also remain in bog-fed streams all summer. Subadults (Ages IV and V and some VI) occupy the midsections of

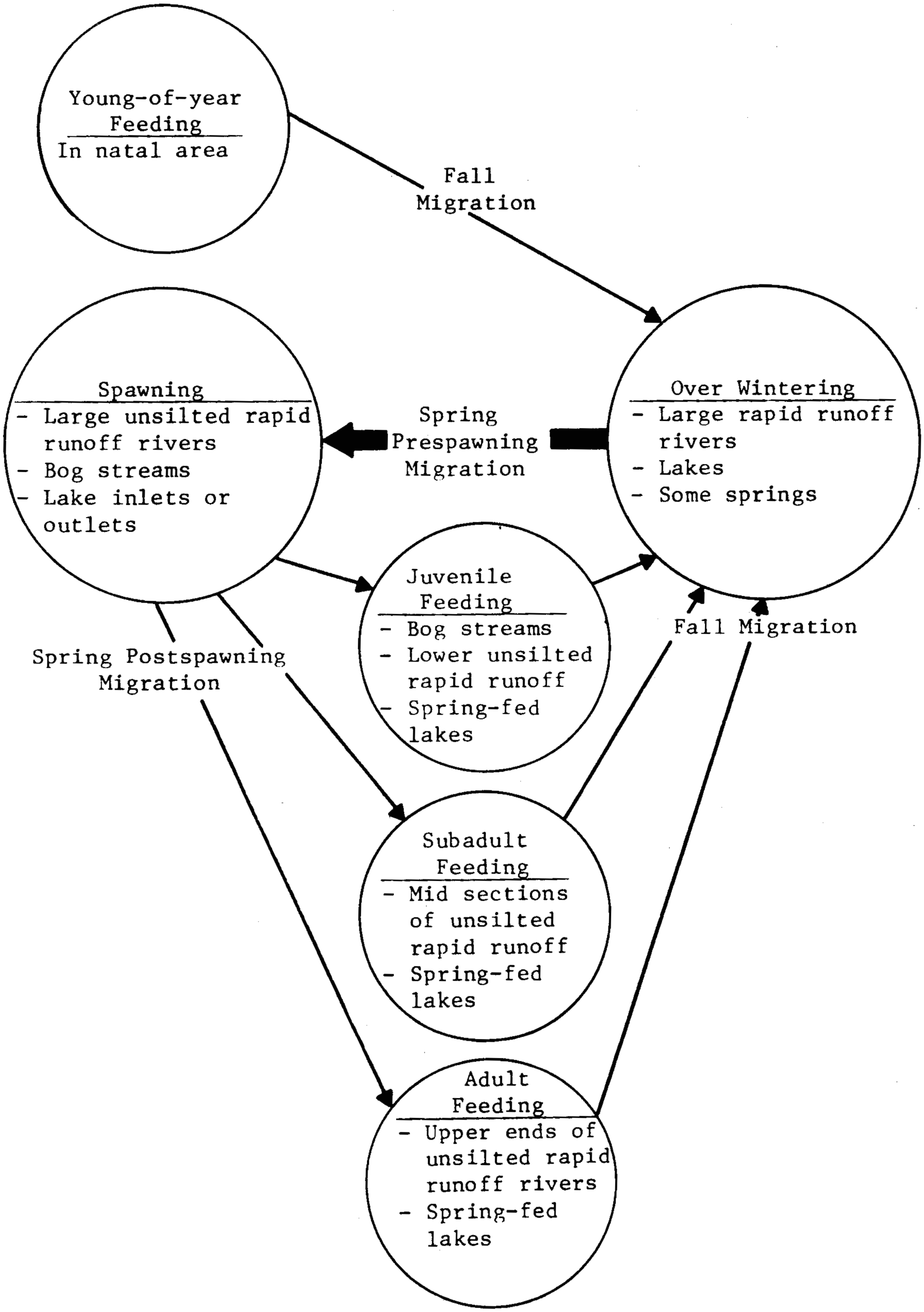

Figure 5. Migrations and distribution of Arctic grayling, *Thymallus arcticus*, in Interior Alaska.

large unsilted rapid runoff rivers. They also utilize spring-fed streams and some lakes. Adult grayling, again, feed in the same types of rivers, but in unsilted rapid runoff streams, they dominate the upper reaches of the streams to the exclusion of smaller grayling.

The fall migration includes all age groups. It begins and proceeds well ahead of ice formation that could hinder movement. The migration is downstream except for fish moving into lakes from their outlets or fish moving upstream to spring areas as they do in some Arctic streams.

LITERATURE CITED

Bendock, T. N. 1974. First interim report of the Sport Fish technical evaluation study. Special Report No. 6. Alaska Dept. of Fish and Game, Fairbanks. 19 p plus appendix.

__________. 1977. Beaufort Sea estuarine fishery study. Final Report for Outer Continental Shelf Contract 03-5-022-69. Alaska Dept. of Fish and Game, 1300 College Road, Fairbanks, Alaska 99701.

Bishop, F. G. 1971. Observations on spawning habits and fecundity of the Arctic grayling. The Progressive Fish Culturist. 33(1): 12-19.

Cheney, W. L. 1972. Life history investigations of northern pike in the Tanana River drainage. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1971-1972, Project F94, 13(R-III): 20 p.

Craig, P. C., and V. A. Poulin. 1975. Movements and growth of Arctic grayling (*Thymallus articus*) and juvenile Arctic char (*Salvelinus alpinus*) in a small arctic stream, Alaska. J. Fish Res. Board Can. 32: 689-697.

Fabricius, E., and K. J. Gustafson. 1955. Observations on the spawning behavior of the grayling *Thymallus thymallus* (L). Institute of Freshwater Research, Drottingholm, Report 36, p 75-103.

Hallberg, J. 1975. Second interim report of the Sport Fish technical evaluation study. Special Report No. 7. Alaska Dept. of Fish and Game. Fairbanks. 9 p plus appendix.

MacPhee, C., and F. J. Watts. 1976. Swimming performance of Arctic grayling in highway culverts. Final Report to U.S. Fish and Wildlife Service Anchorage, Alaska, Contract 14-16-001-5207. 41 p.

McCart, P., P. Craig, and H. Bain. 1972. Report on fisheries investigation in the Sagavanirktok River and neighboring drainages. Report to Alyeska Pipeline Service Company, Bellevue, Washington. 170 p.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Bull. Fish. Res. Board Can. 173: 381 p.

Nelson, P. H. 1954. Life history and management of the American grayling (*Thymallus signifer tricolor*) in Montana. J. Wild. Manage. 18: 324-342.

Netsch, N. 1975. Fishery resources of waters along the route of the Trans-Alaska pipeline between Yukon River and Atigun Pass in North Central Alaska. U. S. Fish and Wildlife Service Resource Publication 124.

Pearse, G. A. 1974. A study of a typical spring fed stream of Interior Alaska. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1973-1974, Project F-9-6, 15(G-III): 49 p.

Reed, R. J. 1964. Life history and migration patterns of Arctic grayling, *Thymallus arcticus*, (Pallas), in the Tanana River Drainage of Alaska. Alaska Department of Fish and Game. Research Report No. 2. 30 p.

Roguski, E. A. 1967. Inventory and cataloging of the sport fish and sport fish waters in the interior of Alaska. Alaska Dept. of Fish and Game, Fed. Aid in Fish Restoration, Annual Report of Progress, 1966-1967, Project F-S-R-8, 8:231-246.

Roguski, E. A., and P. C. Winslow. 1969. Investigations of the Tanana River and Tangle Lakes grayling fisheries: Migratory and population study. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1968-1969, Project F-9-1, 10(16B): 19 p.

__________ and E. Komarek, Jr. 1971. Monitoring and evaluation of Arctic waters with emphasis on the North Slope Drainages: Arctic Wildlife Range study. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1970-1971, Project F-9-3, 12(G-III):22 p.

__________ and S. L. Tack. 1970. Investigations of the Tanana River and Tangle Lakes grayling fisheries: migratory and population study. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1969-1970, Project F-9-2, 11(16B): 17 p.

Schallock, E. W., 1966. Grayling life history related to a hydroelectric development of the Chatanika River in Interior Alaska. M.Sc. Thesis University of Alaska. 113 p.

__________ and E. A. Roguski. 1967. Investigations of the Tanana River and Tangle Lakes fisheries: Migratory and population study. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress 1966-1967, Project F-5-R-8, 8(16-B): 89 p.

Scott, W. B., and E. J. Crossman 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184: 96 p.

Tack, S. L. 1972. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1971-1972, Project F-9-4, 13(R-I): 36 p.

Tack, S. L. 1973. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game, Fed. Aid in Fish Restoration, Annual Report of progress, 1972-1973, Project F-9-5, 14(R-I): 34 p.

__________. 1974. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game, Fed. Aid in Fish Restoration, Annual Report of progress, 1973-1974, Project F-9-6, 15(R-I): 52 p.

__________. 1975. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game, Fed. Aid in Fish Restoration, Annual Report of progress, 1974-1975, Project F-9-7, 16(R-I): 35 p.

__________ and J. G. Fisher. 1977. Performance of Arctic grayling in a twenty foot section of Model "A" Alaska Steeppass Fish Ladder. Final Report on Contract No. DAC-W85-77-C-0018, Army Corps of Engineers, Alaska Division, Anchorage, Alaska 19 p.

Townsend, A. H. and P. P. Kepler. 1974. Population studies of Northern pike and whitefish in the Minto Flats complex with emphasis on the Chatanika River. Alaska Department of Fish and Game. Fed. Aid in Fish Restoration, Annual Report of Progress, 1973-1974, Project F-9-6, 15(G-II): 20 p.

Tryon, C. A. 1974. The Montana grayling. Progressive Fish Culturist 9(3):136-142.

Vascotto, G. l. 1970. Summer ecology and behavior of the grayling of McManns Creek, Alaska. M.Sc. Thesis. Univ. of Alaska, College, Alaska. ix+132 p.

Ward, J. C. 1951. The breeding biology of the Arctic grayling in the southern Athabaska Drainage. M.Sc. Thesis. Univ. of Alberta, Edmonton. 71 p.

Warner, G. W. 1955. Spawning habits of grayling in interior Alaska. U.S. Fish and Wildlife Serv., Fed. Aid in Fish Restoration, Quarterly Progress Report. Project F-1-R-5, Work Plan E, Job. No. 1, 10 p.

Williams, F. T. and C. Morgan. 1974. Inventory and cataloging of sport fish and sport fish waters of the Copper River and Prince William Sound Drainages, and the Upper Susitna River Drainage. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1973-1974, Project F-9-6, 15(G-I-F): 24 p.

Williams, F. T. 1975. Inventory and cataloging of sport fish and sport fish waters of the Copper River and Prince William Sound Drainages and the Upper Susitna River Drainage. Alaska Dept. of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress, 1974-1975, Project F-9-7, 16(G-I-F): 23 p.

Williams, F. T. 1976. Inventory and cataloging of sport fish and sport fish waters of the Copper River and Prince William Sound Drainage, and the upper Susitna River Drainage. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1975-1976, Project F-9-8, 17(G-I-F): 22 p.

Wojcik, F. J. 1955. Life history and management of the grayling in Interior Alaska. M.Sc. Thesis. Univ of Alaska, College, Alaska . 54 p.

Yoshihara, H. T. 1972. Monitoring and evaluation of Arctic waters with emphasis on the North Slope drainages. Alaska Dept. of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, Project F-9-4, 13(G-III-A): 1-49.

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