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Migration Patterns of Freshwater and Anadromous Inconnu, *Stenodus leucichthys*, Within the Mackenzie River System

by

Kimberly Lynn Howland ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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ABSTRACT

Inconnu, *Stenodus leucichthys*, are migratory whitefish important to subsistence and commercial fisheries in the western Arctic. Although both freshwater and anadromous migratory forms are thought to exist in the Mackenzie River system, little detailed information has been available to substantiate this hypothesis. To determine their migratory patterns within this river system, I synthesized the scattered historical information and conducted an intensive field study involving long-term seasonal gillnetting and radio telemetry on two representative rivers, the Arctic Red and Slave. The combined information from the historical survey and field study revealed substantial differences in the timing and extent of spawning migrations in these two rivers. Strontium analysis of otoliths confirmed the existence of the two migratory forms; inconnu from the Slave River remain in freshwater throughout their lives, whereas inconnu in the lower Mackenzie annually migrate between the sea and freshwater after spending 1-6 years in freshwater.

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1. INTRODUCTION

Migration is considered to be an adaptive mechanism allowing animals to exploit food or other resources that may occur only seasonally, or that are found in habitats not suited to other parts of their life cycle (e.g., egg incubation, rearing of young, overwintering) (Aidley 1981). It is uncommon for the best feeding and reproductive habitats of an animal to coincide with one another. This is especially so for fish occurring in northern environments, which are characterized by harsh conditions and substantial seasonal changes in productivity (Northcote 1978). In such environments, ideal breeding habitat (*i.e.*, few predators, suitable abiotic conditions) is usually unproductive, food availability is seasonal and good feeding habitats are not necessarily suitable for overwintering or breeding (Northcote 1978). Consequently, a variety of fish species found in temperate and especially northern latitudes are migratory. Many exhibit anadromy; *i.e.*, they migrate seaward as juveniles to feed and, upon reaching maturity, return to suitable freshwater habitat to spawn. A number of these species, however, also have populations that complete their entire life cycle in freshwater. Such variation in life history has been observed for the chars, *Salvelinus* spp. (Hutchings and Morris 1985; McCart 1980), Atlantic salmon and brown trout, *Salmo* spp. (Power 1969; Jonsson 1985), Pacific salmon, *Onchorynchus* spp. (Randall *et al.* 1987; Foote *et al.* 1989) and sticklebacks, *Gasterosteus* spp. (Snyder and Dingle 1989).

The inconnu, *Stenodus leucichthys* (Güldenstadt), the focal species for this study, is a highly migratory whitefish (coregonine) commonly found in large northern rivers and associated lakes of northwestern North America and northern Eurasia (McPhail and Lindsey 1970). Within North America they are distributed throughout many parts of the Yukon River system in Alaska and northwestern Canada, the Mackenzie River system to Great Slave Lake, the Slave and Liard Rivers and north in coastal drainages from Alaska to the Anderson River, Northwest Territories (Figure 1) (Scott and Crossman 1973). The inconnu is an important resource in the western Arctic of North America, where it contributes significantly to both subsistence and commercial fisheries. Inconnu are fall spawners; in Alaska, where they have been studied extensively, they typically begin to move upstream in late spring/early summer, and spawn in late September (Alt 1977). Inconnu are repeat spawners (iteroparous),

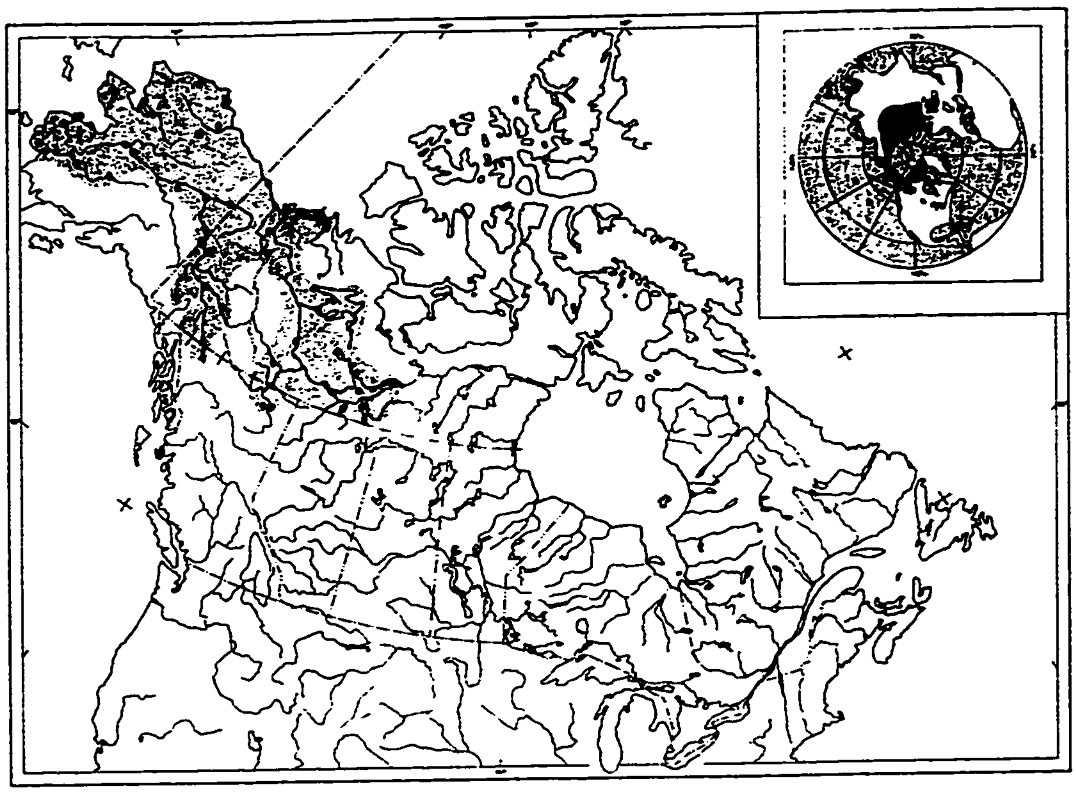


Figure 1. World and North American distribution of inconnu, Stenodus leucichthys (from Scott and Crossman 1973)

and are believed to spawn anywhere from every two to every four years (Scott and Crossman 1973).

Migration studies suggest that inconnu, like many other salmonids, exhibit a high degree of population variation. Inconnu in Siberia, for example, are reported to form both anadromous and freshwater races (Berg 1948). Another population of inconnu, thought to have originated from andromous inconnu in the basin of the Arctic Ocean, inhabits the inland Caspian Sea (Nikol'skii 1954). Freshwater and anadromous populations are also known to exist in the Yukon River system, Alaska (Alt 1977, 1988); both types are migratory, but the former move only within lake/tributary systems and not to the sea (Alt 1977, 1988).

It has been suggested that inconnu in the MacKenzie River system, N.W.T. are represented by two such life history forms (McPhail and Lindsey 1970; Scott and Crossman 1973): those occurring in the lower Mackenzie River north of Norman Wells are thought to feed and overwinter in coastal areas but spawn in freshwater, resulting in lengthy spawning migrations, whereas inconnu in the Great Slave Lake area are assumed to be year-round residents of freshwater and undergo much shorter spawning migrations. Although the basis for these ideas was never mentioned by the authors, I suspect that it was mainly local knowlege.

Very little detailed information is available to substantiate this hypothesis. Most of the existing information on inconnu migration and life history in the Mackenzie River system was generated during the 1970's from general surveys initiated as a result of proposed construction of the Mackenzie Valley oil pipeline. This information is scattered throughout government documents, consultants reports and other unpublished sources (e.g., Shotton 1971; Hatfield *et al.* 1972a, b; Jessop *et al.* 1973,1974; Stein *et al.* 1973; Jessop and Lilley 1975). Because of the extensive (versus intensive) nature of these surveys, details on the timing and location of spawning, rearing areas for young, and overwintering and feeding areas of adult inconnu remain largely unknown.

As a consequence of their highly migratory nature and requirements for silt-free water and clean gravel for spawning (Alt 1988), inconnu may be particularly vulnerable to environmental disturbances and over-fishing. Fish species that tend to concentrate in rivers or streams during their spawning migrations are easily targeted for harvest at a single location (McDowall 1988) and, to magnify the problem, a single population can be fished at multiple locations along its migratory route. Furthermore, environmental disturbances that block spawning routes, alter spawning habitat or reduce water quality (particularly on the spawning grounds) can be especially detrimental for migratory species of fish. This has been well demonstrated in the cases of both Pacific and Atlantic salmon (Netboy 1980; Levings *et al.* 1987; Mills 1989). Thus, the identification and protection of major spawning areas and migratory routes of inconnu are essential to its preservation. The present study was undertaken to i) determine the timing and extent of inconnu spawning migrations within two representative rivers in the Mackenzie River system, ii) identify the time of spawning, and the spawning, overwintering and feeding areas within these rivers, and iii) establish whether or not both anadromous and freshwater forms of inconnu occur in the Mackenzie River system.

Two different approaches were used to determine the migratory patterns and identify spawning, overwintering and feeding areas of inconnu in the Mackenzie River system. I first synthesized the existing scattered information and then conducted a focussed, intensive field study involving radio telemetry and long term seasonal gillnetting of inconnu. I restricted this study to inconnu populations from two rivers (Arctic Red River and Slave River), representing each of the two suspected migratory forms of inconnu. The Arctic Red River has been suggested as a spawning area for anadromous inconnu based on the capture of high numbers of current-year spawners at the mouth of the river during a summer survey (Hatfield *et al.* 1972a). Although spot surveys have been previously conducted at the mouth of the Arctic Red River, no long-term seasonal sampling of inconnu has ever been done within this river. The Slave River is a known spawning river for freshwater-resident inconnu (Tripp *et al.* 1981; McLeod *et al.* 1985), but the precise timing and extent of inconnu migrations into Great Slave Lake following spawning remain unknown.

A relatively new fisheries technique, otolith microchemistry analysis, was used to distinguish anadromous and freshwater inconnu from the Mackenzie River system. This technique identifies trace elements within the otoliths of fish and is now being used by researchers to trace the environmental histories of fish (e.g., Radtke 1989; Kalish 1990; Secor 1992; Rieman *et al.* 1994; Thresher *et al.* 1994; Halden *et al.* 1996). The otoliths of teleost fish, located within the labyrinth of the inner ear, are composed of a combination of calcium carbonate in the form of aragonite crystals, and the protein otolin (Carlstrom 1963; Degens *et al.* 1969). They are thought to form through the deposition of layers of these compounds from the endolymphatic fluid surrounding the otolith (Mugiya 1964). Trace elements from the surrounding environment, such as strontium (Sr) and zinc may also be incorporated into the otoliths as they grow (Kalish 1989), thus providing a potential record of the environmental history of an individual fish. Analysis of the variation in Sr levels in otoliths has proven particularly useful in determining the migratory tendencies of fishes (Halden *et al.* 1995, 1996; Kalish 1990; Rieman *et al.* 1994). The Sr concentration of water is known to increase in proportion to its salinity (Ingram and Sloan 1992); pure sea water contains an average of 8.0 ppm Sr, while freshwater has an average of only 0.6 ppm Sr (Rosenthal *et al.* 1970). Thus, it has been assumed that the Sr content of the otoliths accurately reflects the salinities encountered by a fish throughout its lifetime (Secor 1992). A recent verification study has supported this assumption (Secor *et al.* 1995). For the present study, I analysed the distribution of strontium within the otoliths of inconnu from two populations in the Mackenzie River system (Arctic Red River, Slave River) to investigate whether these fish had ever entered a high Sr environment (*i.e.*, migrated to sea) or had stayed in a lower Sr environment (freshwater) throughout their life history.

2. STUDY AREA

The Mackenzie River system, extending from 54 to 69°N latitude, runs 4,321 km from headwaters in northern British Columbia, Alberta and Saskatchewan, which drain into Great Slave, to the Mackenzie River proper (and its tributaries), which traverses the western Northwest Territories to the Beaufort Sea (Hatfield *et al.* 1972a; Rosenberg and Barton 1986). It has a drainage area of over 1.5 million km^2 and an average total annual discharge of 333 km^3, making it the largest river system in Canada, and the fourth largest river to flow into the Arctic Ocean (Brunskill 1986). Inconnu are distributed from the lower reaches of tributaries draining into Great Slave Lake, north to the lower Mackenzie River and adjoining rivers such as the Arctic Red and Peel. This study was conducted in two separate areas within the Mackenzie River system, the lower Mackenzie/Arctic Red River region, and the Great Slave Lake/Slave River region.

2.1 The Lower Mackenzie and Arctic Red River

The Mackenzie River runs a distance of 1,650 km from its head at the west end of Great Slave Lake to the Beaufort Sea coast (Rosenberg 1988) (Figure 2). The Mackenzie River is wide (1.5-3 km), swift and turbid downstream of Fort Simpson, where its largest tributary, the Liard River, enters (Hatfield *et al.* 1972a). The discharge, which averages 10,000 m^3s^{-1} (Rosenberg and Barton 1986), tends to increase slightly as the Mackenzie follows its course towards the Beaufort Sea and receives outflow from additional tributaries. The appearance and water chemistry of the Mackenzie River, however, change little until it enters the Mackenzie Delta, which is composed of an immense network of lakes and channels covering an area of 12,170 km^2 (Hatfield *et al.* 1972a; Brunskill 1986). Once the Mackenzie River enters the Beaufort Sea, its freshwater plume is deflected to the northeast, creating a narrow zone of freshened water along the coast of the Tuktoyaktuk Peninsula that persists throughout the year because of the Mackenzie's continuous discharge (Reist and Bond 1988). West of the Mackenzie, however, most coastal rivers freeze to the bottom in winter resulting in almost no freshwater discharge and highly saline coastal waters, rendering these areas unsuitable overwintering grounds for coregonines. When flows resume in summer, a narrow brackish-water zone develops along the west coast of the Beafort Sea to Point Barrow, Alaska (Craig 1984). Because of the high abundance of various whitefish species in the estuarine and nearshore coastal areas during the summer months, these zones, east and west of the delta, are thought to serve as productive summer feeding grounds and as travel corridors for anadromous coregonids (Reist and Bond 1988). However, these zones of freshened water are frequently disrupted by storm events; this unpredictability likely results in such habitats being avoided by fish species that are not able to withstand even short periods in full-strength sea water (J. Reist, Department of Fisheries and Oceans (DFO), Winnipeg; pers. comm.)

Arctic Red River, one of several large tributaries that originate in the Western Cordillera (Brunskill 1986), enters the Mackenzie River approximately 25 km south of the Mackenzie Delta (Figure 3). The upper reaches of Arctic Red River, some 150 km upstream from the mouth, appear to contain ideal inconnu spawning habitat; the water

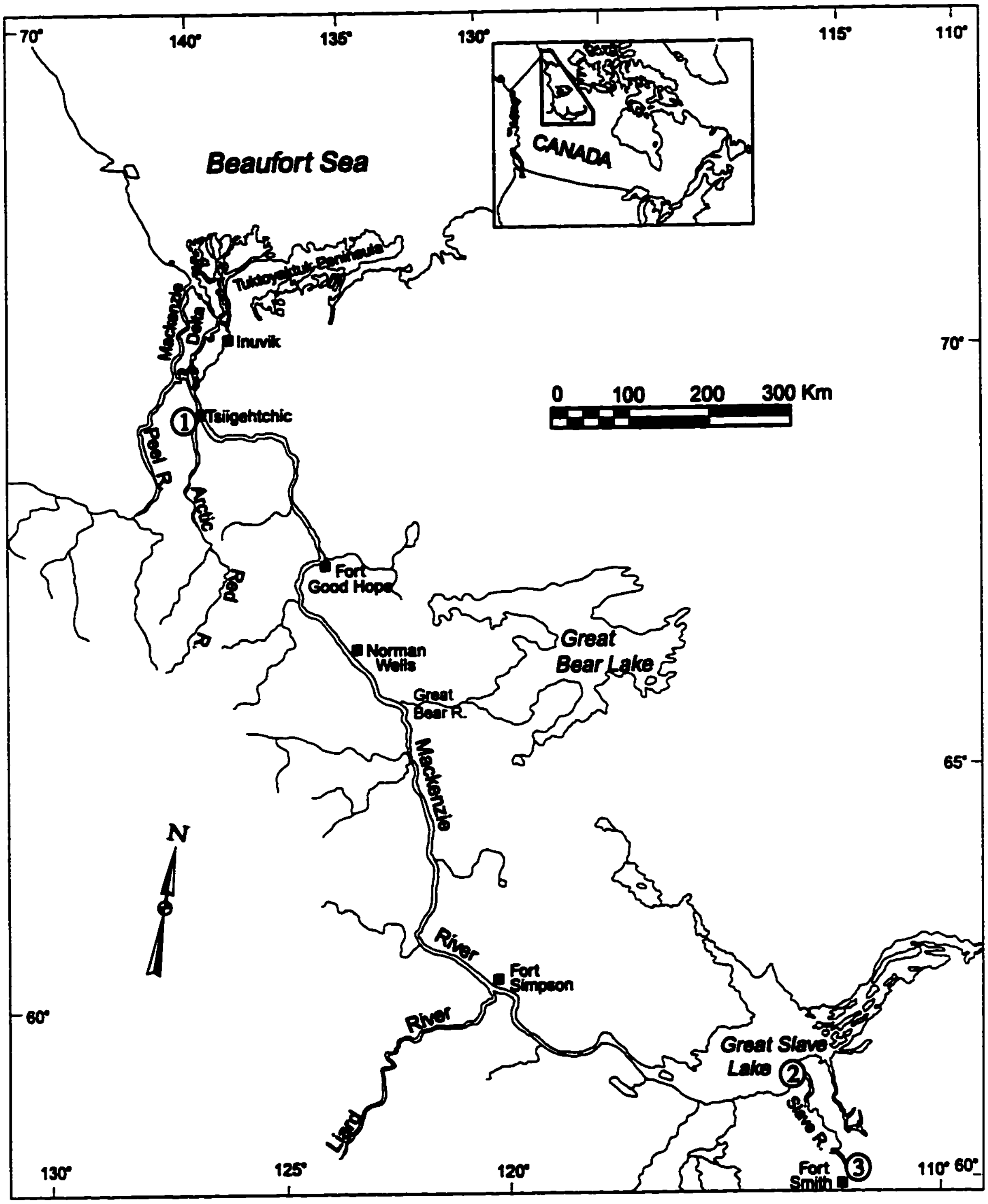


Figure 2. Study area showing main study sites (1 = Arctic Red River, 2 = Slave Delta, 3 = Slave River-Fort Smith area).

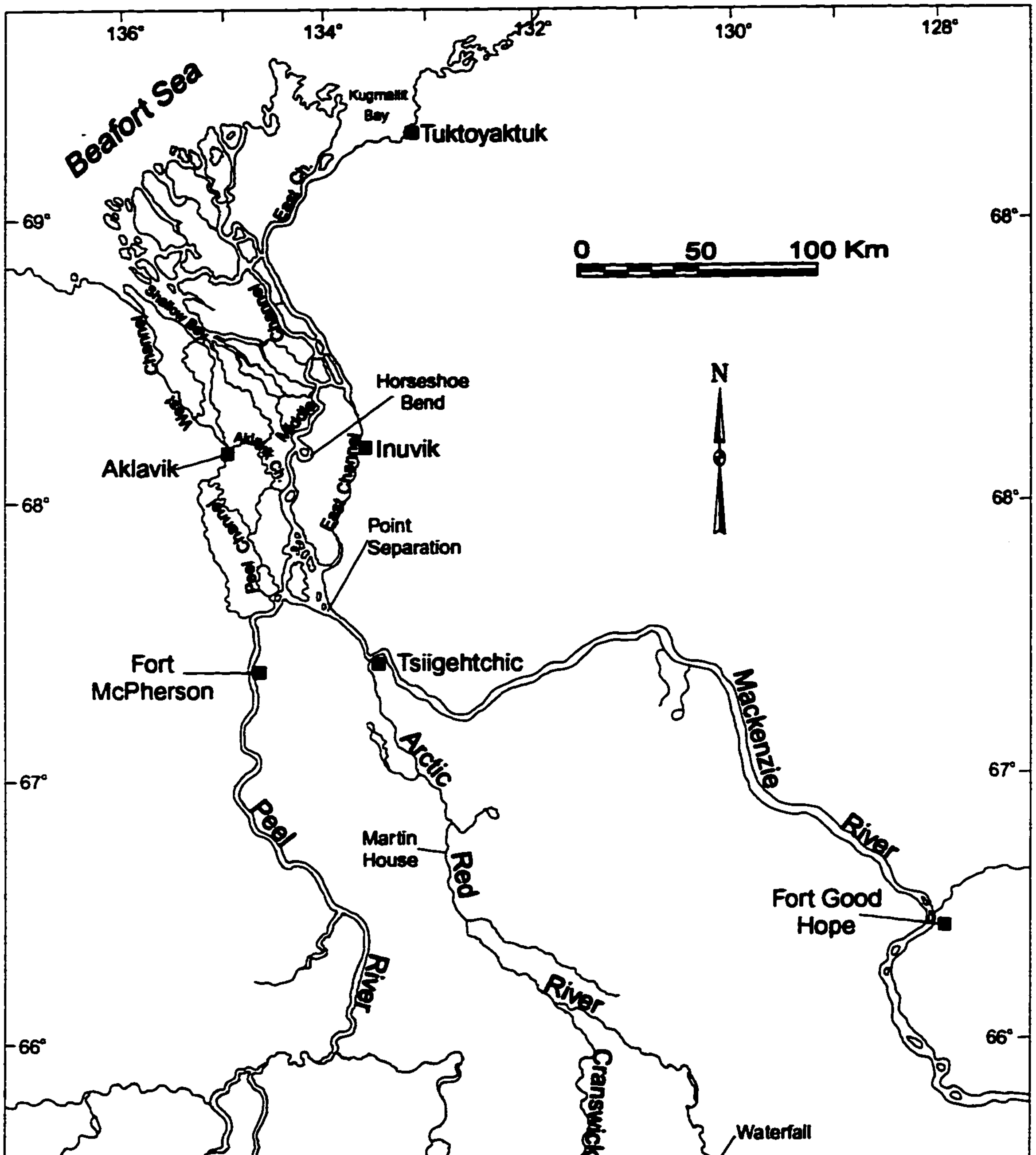


Figure 3. The lower Mackenzie River study area showing rivers, channels and other place names referred to in the text.

is clear and swift, flowing over course gravel substrate and with numerous rapids. A three meter waterfall (likely impassable for most fish) is reported to be located 332 km from the mouth (R. Cruikshank, land use planner, Gwich'in Tribal Council, Inuvik; G. Niditchie, local fisherman, Tsiigehtchic; pers. comm.). As the river nears the Mackenzie it widens, flows more slowly, and becomes turbid and silty. The channel width ranges from 200 (upstream) to 500 (at mouth) meters across with depths of up to 10 meters. Ice-out generally occurs in the last week of May and, on average, freeze-up takes place in the second week of October; however, the exact dates can vary from year to year by up to a month (Table 1). During 1992 and 1993 average discharge was 151.5 m^3s^{-1} (Environment Canada 1992, 1993) and surface water temperatures ranged from 0.5 °C in winter to a maximum of approximately 20°C in mid-late July (see Figure 21, p. 47).

The fish community in the Arctic Red River is relatively simple; only 10 species were regularly caught during this study, half of which were migratory coregonids (arctic cisco, *Coregonus autumnalis*, least cisco, *Coregonus sardinella*, lake whitefish, *Coregonus clupeaformis*, broad whitefish, *Coregonus nasus*, and inconnu); the remaining species included burbot, *Lota lota*, flathead chub, *Hybopsis gracilus*, longnose sucker, *Catostomus catostomus*, northern pike, *Esox lucius*, and walleye, *Stizostedion vitreum*. A substantial domestic fishery is located in the settlement of Tsiigehtchic, situated at the mouth of the Arctic Red River. Domestic fisheries also exist in other communities along the lower Mackenzie River, such as Aklavik, Inuvik, and Fort Good Hope. A modest number of fish are taken during summer months, but most fishing is done between September and December when the main whitefish runs occur. Fish are dried and smoked for human consumption, but are also taken in fairly large numbers to feed sled dog teams that are still kept by many families.

2.2 Great Slave Lake and Slave River

Great Slave Lake is the fifth largest lake in North America with a total surface area of 27,195 km^2 and a drainage area of 958,300 km^2 (Rawson 1950) (Figure 2). It has three major basins, north, west and east. The north and east basins are both deep, cold and oligotrophic. In contrast, the west basin, into which the Slave River flows, is relatively shallow (mean depth 41 m), turbid and nutrient rich (Rawson 1950). The west basin usually remains ice-covered from mid-December to mid-June, but warms more

Table 1. Ice-on/ice-off dates (Julian calendar) for the Slave and Arctic Red Rivers, 1965-1995 (data obtained from Water Survey of Canada).

Slave River at Fort Fitzgerald (St. SR07NB001)			Arctic Red River at Martin House (St. AR10LA002)		
Year	Date of Ice-off	Date of Ice-on	Year	Date of Ice-off	Date of Ice-on
1965	130	326	1965	.	.
1966	134	314	1966	.	.
1967	137	308	1967	.	.
1968	132	306	1968	.	.
1969	125	312	1969	127	293
1970	130	310	1970	137	288
1971	125	305	1971	136	281
1972	132	303	1972	156	276
1973	127	310	1973	.	.
1974	128	318	1974	152	273
1975	128	308	1975	141	274
1976	120	314	1976	137	286
1977	123	313	1977	140	285
1978	134	314	1978	152	278
1979	141	318	1979	138	294
1980	116	315	1980	146	290
1981	131	302	1981	139	279
1982	138	308	1982	153	282
1983	133	316	1983	153	284
1984	122	300	1984	139	277
1985	131	307	1985	154	283
1986	134	299	1986	151	275
1987	131	304	1987	147	294
1988	128	290	1988	140	285
1989	123	319	1989	150	288
1990	127	300	1990	151	281
1991	128	296	1991	131	285
1992	124	313	1992	148	262
1993	121	306	1993	137	293
1994	125	310	1994	.	.
1995	134	302	1995	.	.
Average =	129 (May 9)	309 (Nov. 5)	Average =	144 (May 24)	283 (Oct. 10)
Average length of open water period 180 d			Average length of open water period 139 d		

quickly than the other two basins, and can reach a maximum surface temperature of 19 °C in the summer (Brunskill 1986).

The Slave River is the largest of several rivers along the south shore of Great Slave Lake (Figure 4). The Slave River, like the lower Mackenzie and Arctic Red River, is wide and turbid by the time it enters Great Slave Lake. The main channel is 1 km across, with depths ranging from less than a meter to 25 meters (personal observations). The 22 km stretch ending at Fort Smith, N.W.T. (300 km upstream of the delta at Great Slave Lake) has many rapids and deep pools; the 40 m drop (M. Jones, Water Survey of Canada, Yellowknife; pers. comm.), represents a barrier to inconnu movement as indicated by their absence in the upper Slave River (Boag and Westworth 1993). Downstream of Fort Smith the Slave River is relatively featureless. The Slave delta, however, is a maze of variable-sized channels and islands with heavily vegetated banks. Ice-out on the Slave River usually occurs in the second week of May, and freeze-up takes place in the first week of November, about three weeks later than on the Arctic Red River (Table 1). During 1994 and 1995 the yearly average discharge of the Slave River was 2638 - 3400 m^3s^{-1} (Environment Canada 1994, 1995) and surface water temperatures reached a maximum of 22°C in late July (see Figure 21, p. 47). The fish community in the Slave River is more diverse than that of the Arctic Red River, with up to 25 species having been recorded in the lower Slave River (Tripp *et al.* 1981; Mcleod *et al.* 1985; Little 1996). Subsistance fishing, for human consumption and dog food, takes place in the communities of Fort Smith and Fort Resolution (situated near the Slave River Delta), as well as in various other small communities on Great Slave Lake. In addition, a commercial fishery has been operating on Great Slave Lake since 1945. Although lake whitefish is the main species taken by the fishery, inconnu are also targeted because of their considerably higher value on the commercial market (G. Low, DFO, Hay River; pers. comm.)

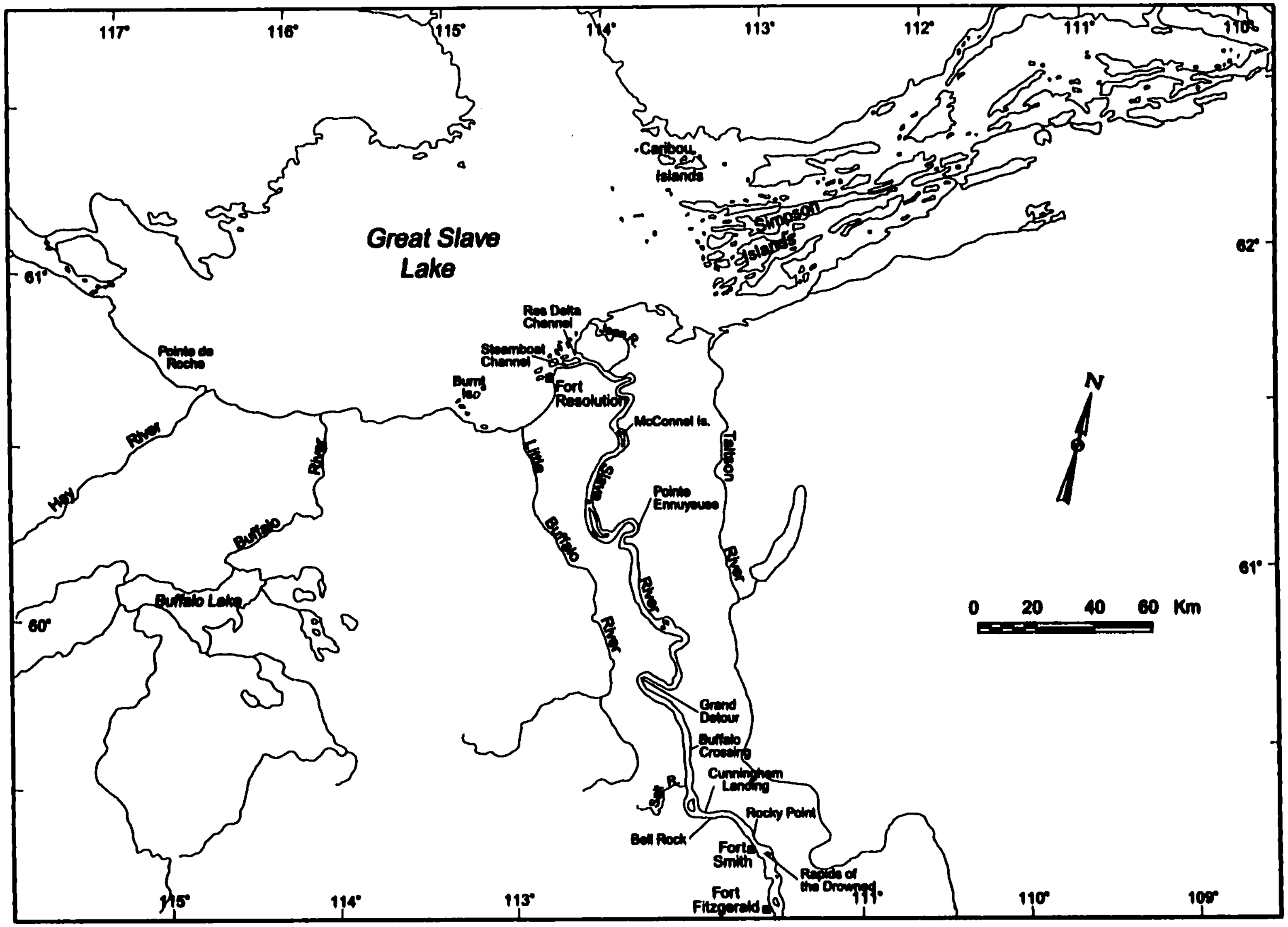


Figure 4. The Slave River/Great Slave Lake study area showing rivers, islands and and other place names used in the text.

3. SYNTHESIS OF HISTORICAL DATA

The following synthesis was completed to identify the movement patterns and potential spawning, overwintering and feeding areas of inconnu in the Mackenzie River system. This information was used to complement the field component of this study, which is presented later.

3.1 Seasonal distribution of different life history stages

From numerous, but largely unpublished, reports (Larkin 1945, cited in Fuller 1955; Hatfield *et al.* 1972a; Jessop *et al.* 1973; Stein *et al.* 1973; McCart *et al.* 1974; Griffiths *et al.* 1975; Jessop and Lilley 1975; Mann 1975; De Graaf and Machniak 1977; Tripp et al. 1981; Bond 1982; Hopky and Ratynski 1983; Lawrence *et al.* 1984; McLeod et. al. 1985; Bond and Erickson 1989; Chiperzak *et al.* 1991; Day and Low 1993; G. Low and C. Day, DFO, Hay River and Winnipeg; pers. comm.), I compiled information on locations in the Mackenzie River system where inconnu have been captured during winter (October 16-May 24) and summer (May 25-October 15); several of these studies also identified the life stages of inconnu (fry, immature, mature non-spawner, mature spawner, mature fish of unknown status) captured at those locations. From this compilation (Figure 5), patterns of seasonal distribution emerged.

Most inconnu captured in coastal and outer delta areas during the summer months were either immature individuals, or mature fish not capable of spawning in the year of capture, suggesting that these areas are most likely used for feeding. In contrast, most inconnu captured further upstream (*i.e.*, the inner delta, and the Peel, Arctic Red and mainstem Mackenzie Rivers) during the summer were mature, although their spawning status at the time of capture had not been determined. It seems likely these fish were spawners moving upstream, given the absence of current year spawners elsewhere in the lower Mackenzie delta during the summer months. Few fry have ever been captured in the lower Mackenzie River area. A few inconnu fry were captured during the summer in freshwater tributaries upstream of the delta (McCart *et al.* 1974; Stein *et al.* 1973); the only other record of inconnu fry in the study area consisted of 12 individuals captured along the Beaufort Sea coast at Phillips Bay (Bond and Erickson 1989).

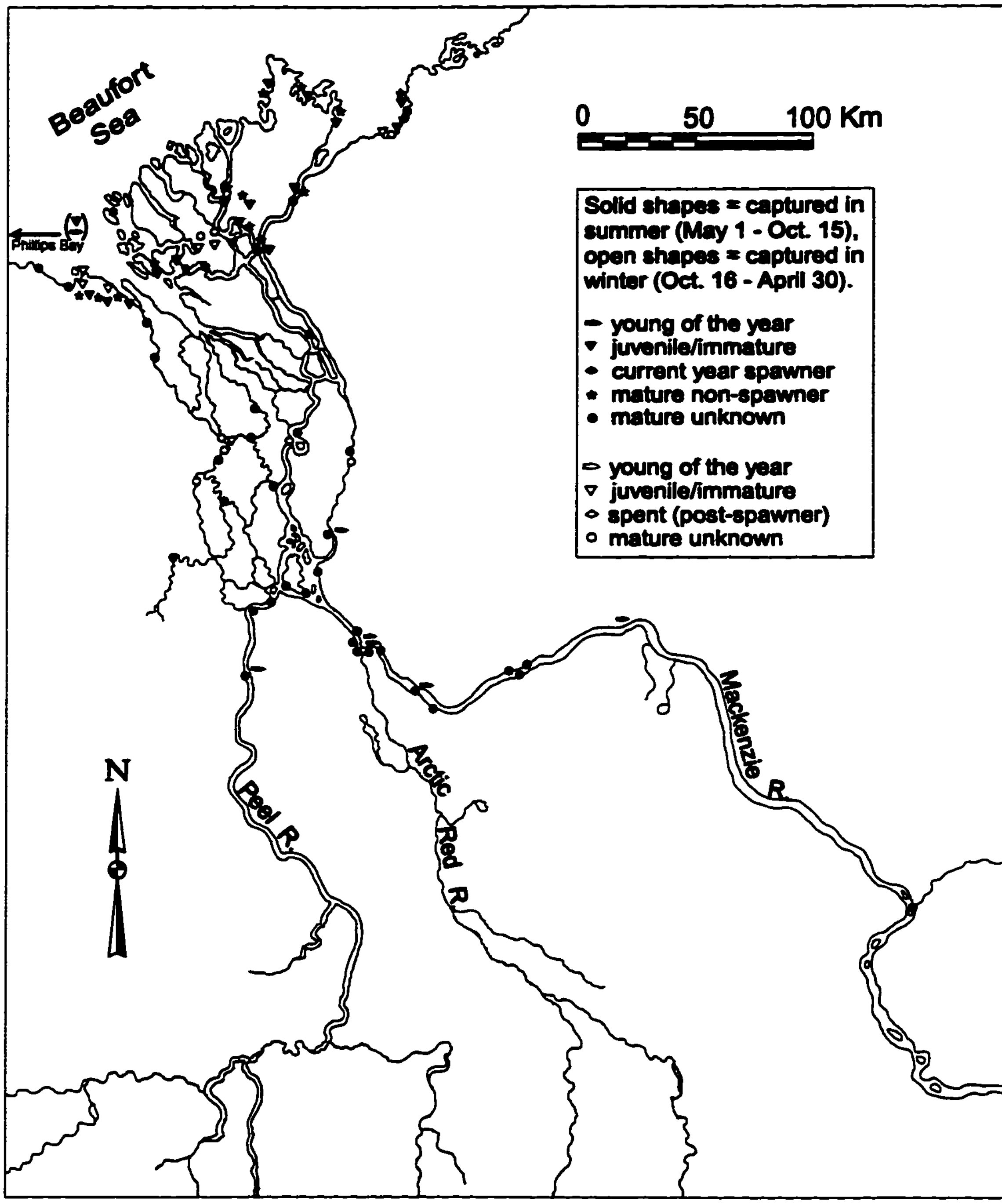


Figure 5. Seasonal distribution of different inconnu life history stages in the lower Mackenzie River. Based on Hatfield et al. 1972a; Jessop et al. 1973; Stein et al. 1973; Griffiths et al. 1975; McCart et al. 1974; Jessop and Lilley 1975; Mann 1975; De Graaf and Machniak 1977; Bond 1982; Hopky and Ratynski 1983; Lawrence et al. 1984; Bond and Erickson 1989; Chiperzak et al. 1991. See figures 2 and 3 for additional place names.

Very little winter sampling has been conducted in the lower Mackenzie; thus, knowledge of the overwintering areas used by inconnu is limited. The available information suggests that both mature and immature inconnu overwinter in deeper parts of the outer delta as well as in the main channels of the inner delta. No fry have ever been captured during the winter months. Since no winter sampling has been done upstream of the delta, it is unknown if inconnu also overwinter in rivers such as the Peel and Arctic Red.

A limited amount of life history data has been published on inconnu in the Great Slave Lake area. The existing information, collected mainly in early June, shows that at this time of year, a mixture of life history stages (immature, current year spawner, mature non-spawner) may be found in Great Slave Lake near the mouths of rivers, suggesting these are probably important summer feeding areas for inconnu (Figure 6). Similarly, Fuller (1955) found a mixture of different life history stages when he randomly sampled 342 inconnu taken by the Great Slave Lake commercial fishery in early July. Later in the summer (August to October) current year spawners were found in the Slave and Buffalo Rivers. Fuller (1955) noted that commercial catches of inconnu also tended to drop at this time of year, while those of other species did not, suggesting that in late summer a portion of the population may move out of the lake and into the rivers.

Although little winter sampling has been done on Great Slave Lake and its tributaries, the capture of spent inconnu near the mouths of the Buffalo and Slave Rivers during late fall/early winter suggests that mature inconnu probably move back to Great Slave Lake to overwinter once spawning is completed. It is unkown if juvenile inconnu overwinter in Great Slave Lake or if inconnu use tributaries such as the Slave and Buffalo Rivers for overwintering.

3.2 Migration timing and distance

Using scattered reports and unpublished data (Stein *et al.* 1973; Jessop and Lilley 1975; McLeod *et al.* 1985; Day and Low 1993; J. Babaluk, unpublished data), I compiled information on locations in the Mackenzie River system where inconnu have been either floy-tagged or radio-tagged, and where those tagged fish were subsequently recaptured. Some interesting patterns emerged from the compilation.

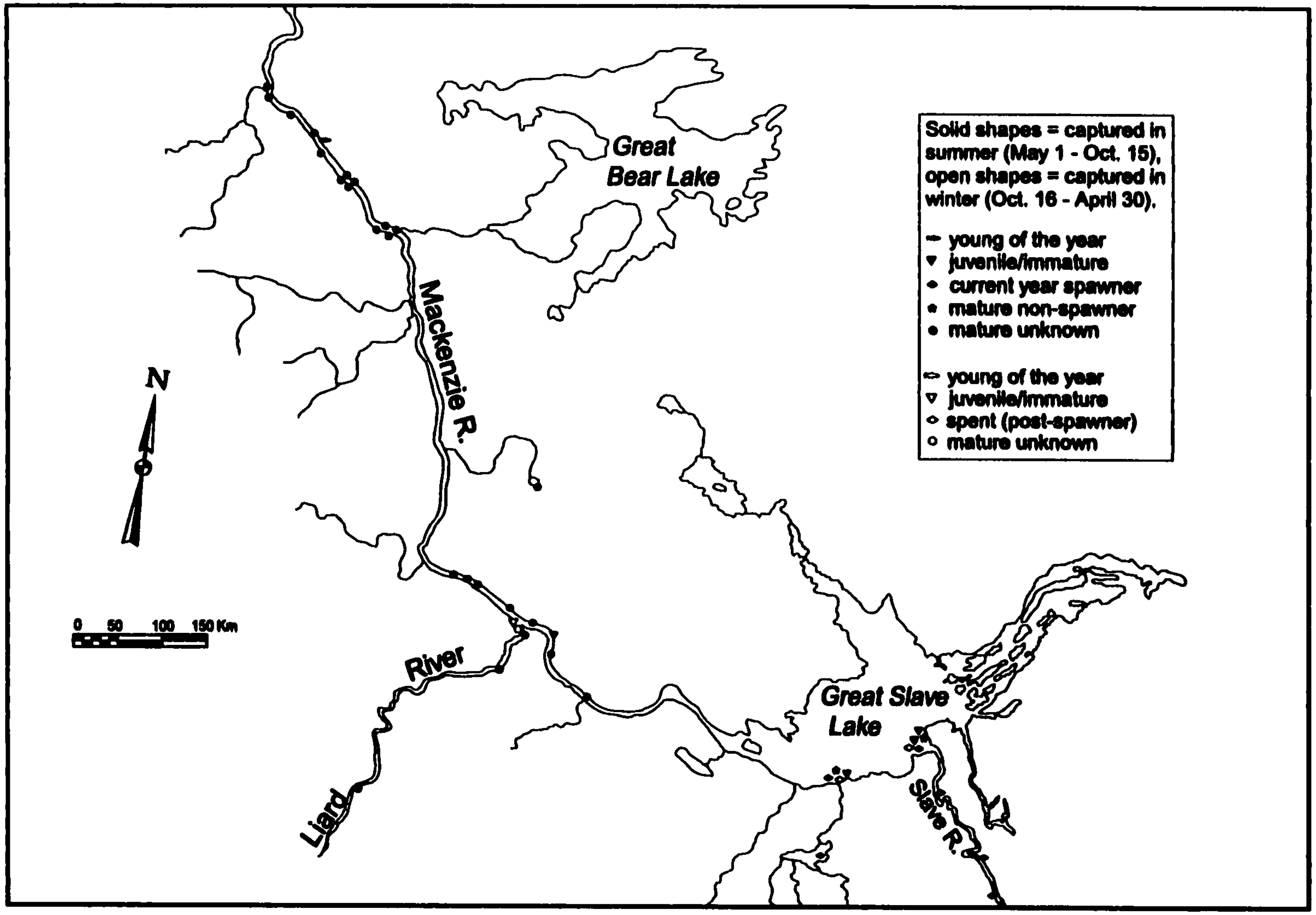


Figure 6. Seasonal distribution of different inconnu life history stages in the upper Mackenzie River and Great Slave Lake area. Based on Larkin 1945, cited in Fuller 1955; Hatfield et al. 1972a; Jessop et al. 1973; Stein et al. 1973; Jessop and Lilley 1975; Tripp et al. 1981; McLeod et al. 1985; Day and Low 1993; G. Low and C. Day, DFO Hay River and Winnipeg, pers. comm. See figures 2 and 4 for additional place names.

These historical data clearly show that there is little, if any, mixing between inconnu in the lower Mackenzie and Great Slave Lake (Figure 7), supporting the idea that at least two life history forms of inconnu exist within the Mackenzie River system. Although there are no known barriers to movement, inconnu tagged in the lower Mackenzie River and its delta have, with one exception, never been recaptured upstream of Norman Wells (one inconnu tagged just upstream of the Mackenzie Delta was recaptured 1,104 km upstream, near Fort Simpson, a year later). Of inconnu tagged in Great Slave Lake and the Slave River, the majority have been recaptured in the lake itself or in tributaries that flow into the south shore, and none have ever been recaptured in the Mackenzie River.

There also appears to be a third group of inconnu in the upper Mackenzie River (Fort Simpson area) that have fairly localized movement. Although two inconnu migrated long distances upstream into this area (from Great Bear River and the lower Mackenzie, 503 km and 1,104 km away, respectively), the farthest away that inconnu tagged in the area have ever been recaptured is 312 km. Stein *et al.* (1973) suggested that inconnu in the Fort Simpson area represent a non-anadromous population, possibly part of the Great Slave Lake population. I also think these inconnu are non-anadromous, given their restricted movement and the fact that large numbers of immature fish have been found in the area (Stein *et al.* 1973; Jessop and Lilley 1975). However, they may be distinct from those occuring in Great Slave Lake. Although not extensive, existing tag return and radiotracking data indicate that inconnu from these two areas do not mix. Inconnu in the upper Mackenzie River may thus represent a local "riverine" life history type similar to that described in the Yukon River system, Alaska (Alt 1988).

It is also interesting to note that inconnu tagged in the lower Mackenzie River and Delta areas migrated much longer distances than inconnu tagged within the Great Slave Lake area. Assuming that the former group feed/overwinter in the Mackenzie estuary and along the coast of the Beaufort Sea (Figure 5), tag recaptures then indicate that these fish migrate from 600 to 900 km, and on occassion up to 1500 km, between these areas and suspected spawning sites (upper Arctic Red, Peel, and mainstem Mackenzie Rivers; Hatfield *et al.* 1972a; Stein *et al.* 1973). In contrast, radio-tracking and tag recaptures of inconnu in the Great Slave Lake area indicate that they

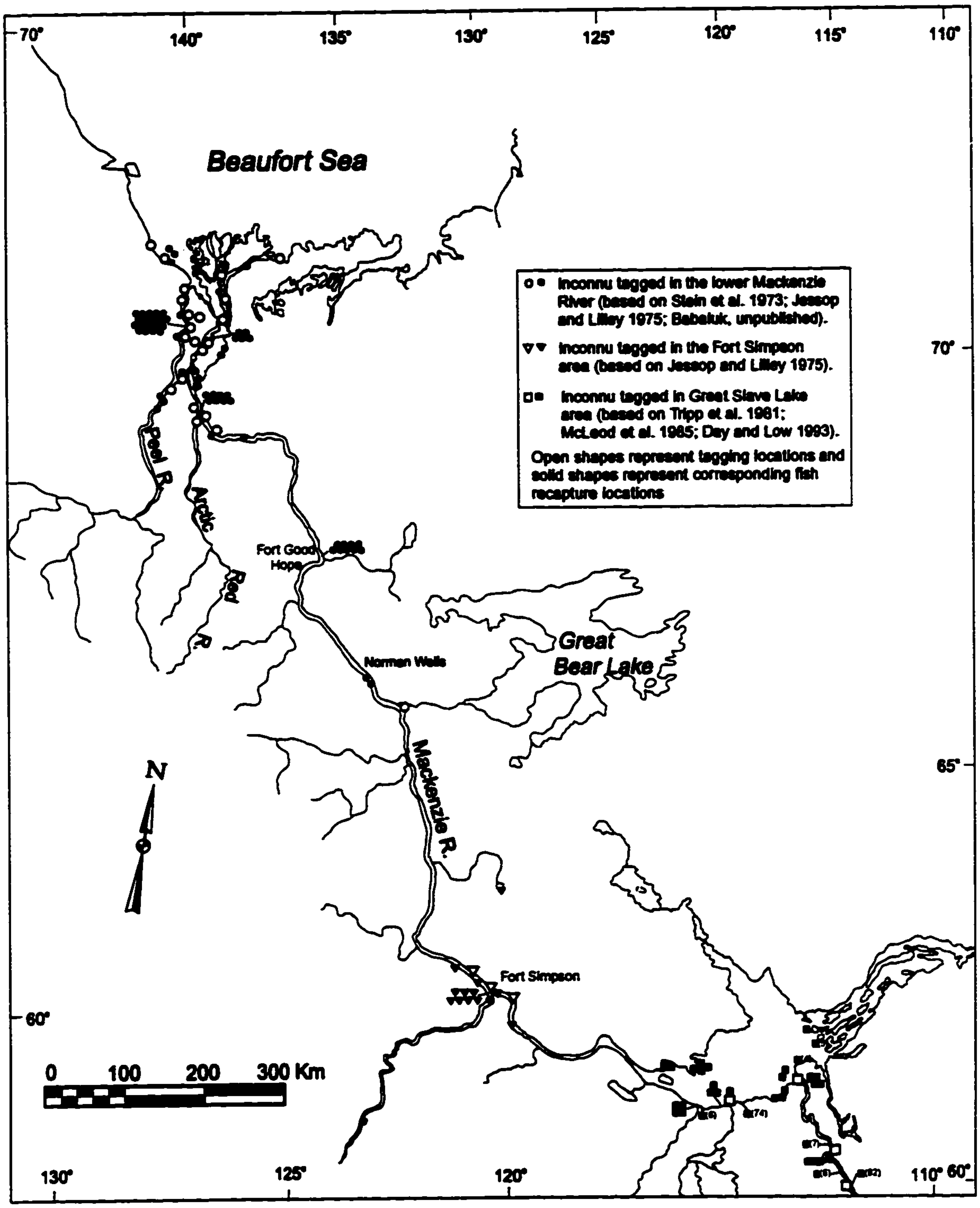


Figure 7. Tag and recapture locations of inconnu floy tagged in the Mackenzie River system. See figures 2-4 for additional place names.

move less extensively and, given that spawning rivers are all blocked by falls or rapids a relatively short distance upstream, spawning migrations are probably between 40 km (Taltson River; Fuller 1955) and 300 km (Slave River; McLeod *et al.* 1985).

3.3 Spawning stock structure

It is believed that coregonines, like other salmonids, exibit spawning site fidelity, and thus may have multiple genetically distinct groups within an area. To investigate this, I identified the original capture site of each recaptured inconnu in the historical tag return data to detect patterns of movement that might indicate stock separation. Indeed, there are fairly consistent differences in the movements of individuals that were tagged on different sides of the Mackenzie Delta. The majority of inconnu tagged in the West Channel, Peel Channel, and along the West side of the Outer Delta were recaptured in the Peel River and Aklavik area, or were recaptured close to their points of release (Figure 8a), often 1-2 years later, suggesting that inconnu return to the same overwintering/ feeding areas in years following spawning. Conversely, inconnu tagged in the Middle and East channels, and on the east side of the outer delta, were captured at the confluence of the Arctic Red and Mackenzie Rivers, upstream in the mainstem Mackenzie, or at various locations on the east side of the delta (Figure 8b). Inconnu tagged in the Arctic Red area of the Mackenzie River were all recaptured upstream in the mainstem Mackenzie, mainly at Fort Good Hope and Norman Wells (Figure 8b). There were only 3 out of 55 cases where individuals tagged on one side of the delta strayed to the opposite side of the system.

Based on this information, it seems likely that at least two anadromous stocks are present, one that enters the Peel River and one entering the Arctic Red River and mainstem Mackenzie. The latter group of migrants may split at the confluence of the Arctic Red and Mackenzie Rivers, with some individuals entering the Arctic Red and others continuing up the Mackenzie; inconnu are thought to spawn in the Arctic Red River (Hatfield *et al.* 1972a; Stein *et al.* 1973). Furthermore, inconnu migrating up the mainstem Mackenzie River may consist of several stocks that spawn in different areas. We cannot be sure of this, however, until more is known about where migrants in the mainstem Mackenzie spawn.

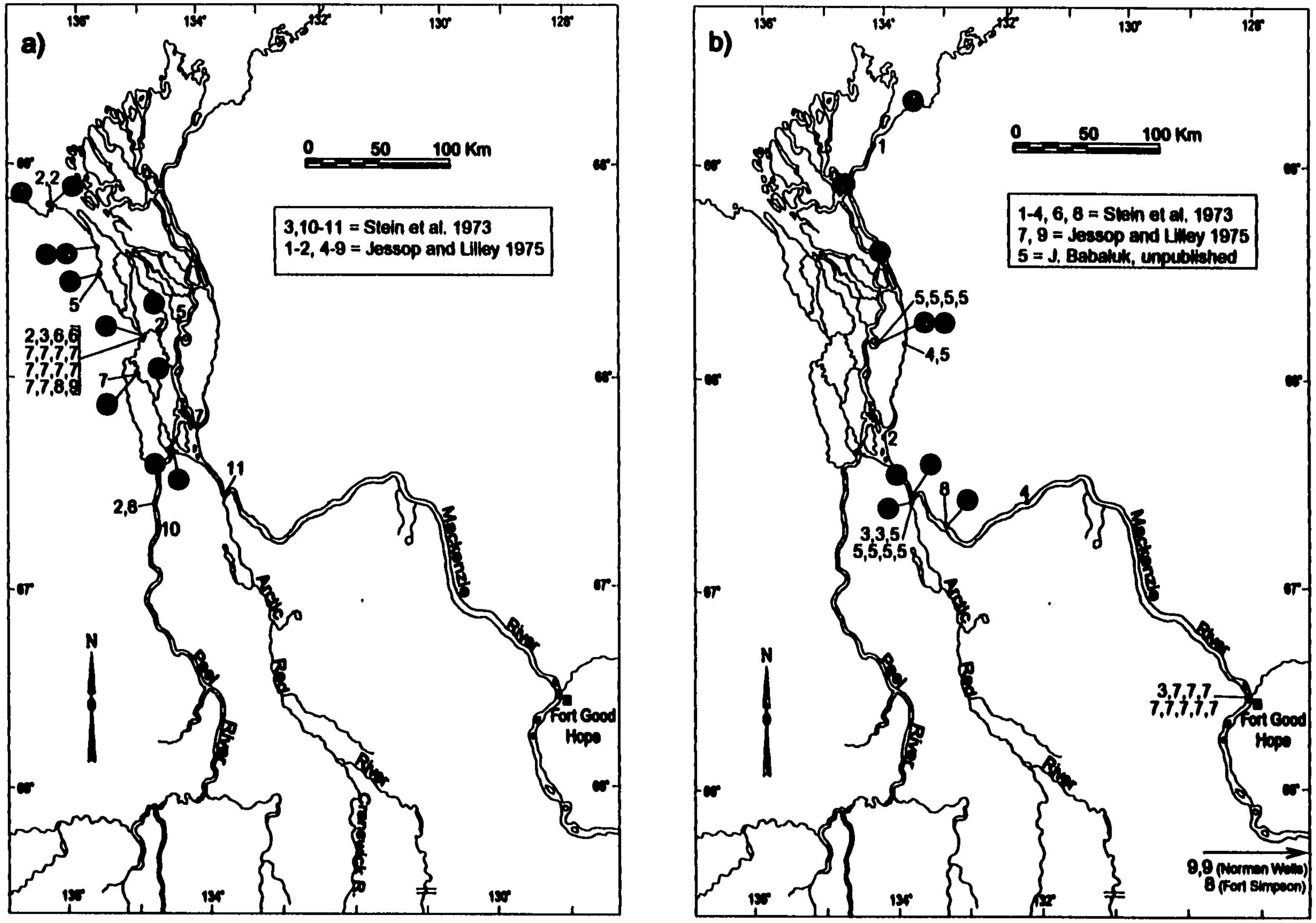


Figure 8. Tag and recapture locations of inconnu floy tagged: a) on the west and, b) on the east side of the Mackenzie Delta. Circled numbers represent different tagging locations. Uncircled numbers represent corresponding recaptures.

Tag return data in Great Slave Lake are not as extensive as those for the Lower Mackenzie, so it is difficult to make inferences about stock structure. Most floy tagging on the lake was done at the mouth of the Buffalo River (Day and Low 1993). Other work in the area included radio-tagging (McLeod et al. 1985) and limited floy-tagging done in the Slave River during the early 1980's (McLeod et al. 1985; Tripp et al. 1981). Inconnu tagged at the mouth of Buffalo River were recaptured throughout the lake (Figure 9), where they are thought to feed and overwinter (Fuller 1955) and upstream in Buffalo River (at Buffalo Lake), but none were ever recaptured in other rivers entering Great Slave Lake. However, this may have been due to a lack of fishing effort (by domestic fishermen) within other rivers. Similarly, commercial fishing only takes place on Great Slave Lake itself, so there may be a bias towards recaptures throughout the lake. Fish that were radio-tagged in the Slave River were tracked successfully only within the Slave River and none were recaptured at a later date. Similarly, all but a few floy-tagged inconnu were recaptured within the Slave River (exceptions were recaptured in Great Slave Lake). Given that inconnu spawn in several rivers tributary to Great Slave Lake, it is probable that mutiple spawning socks are present. The existing tag return data are, however, not able to show this. Genetic analysis or more extensive tagging of inconnu in the different spawning rivers needs to be done to resolve this question.

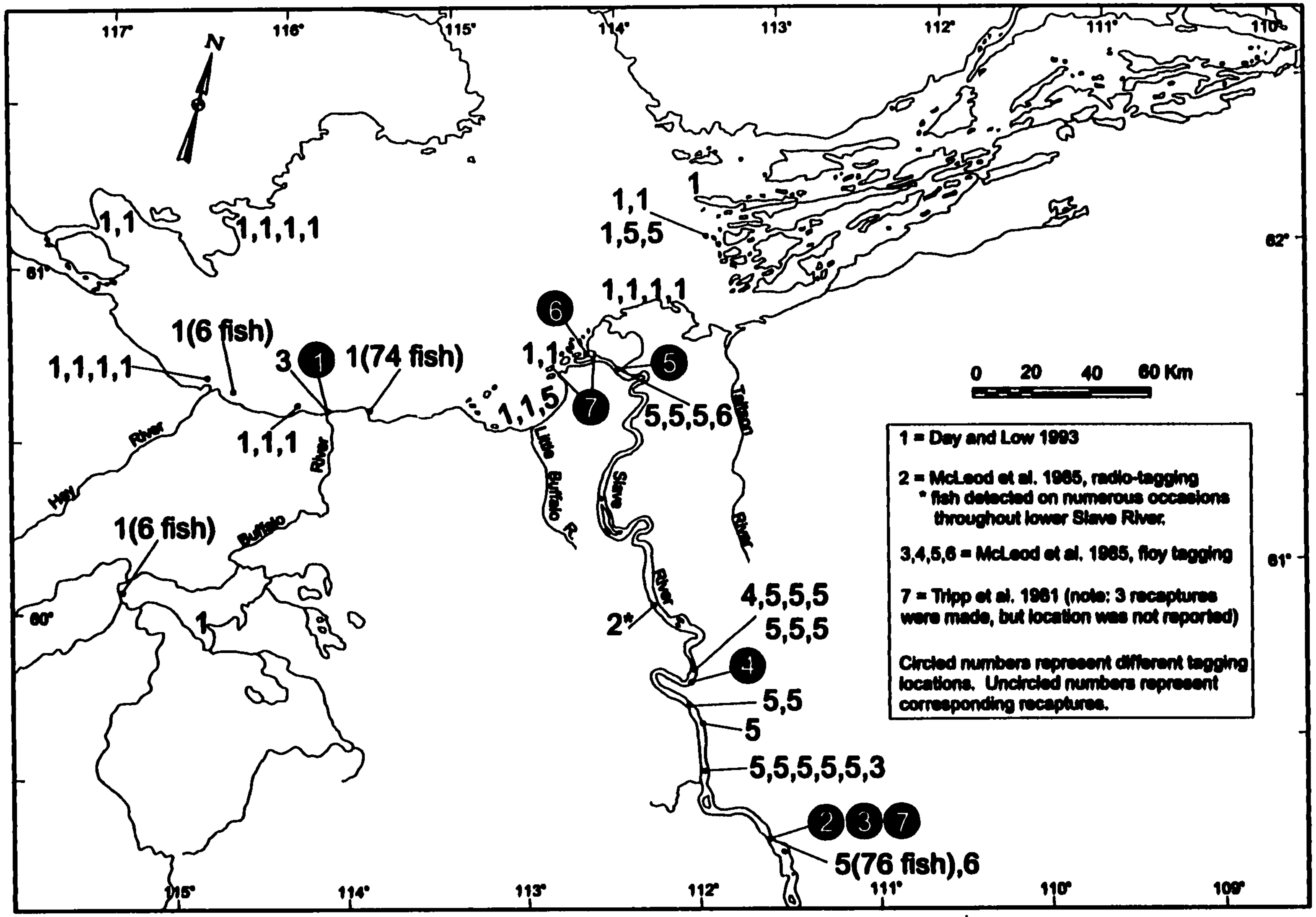


Figure 9. Tag and recapture locations of inconnu tagged in the Slave River and Great Slave Lake. See figure 4 for additional place names.

4. MATERIALS AND METHODS:

For the field component of this study, migratory patterns of inconnu populations from the Lower Mackenzie and Great Slave Lake areas were established in 1992-93 and 1994-95, respectively, through the use of radio telemetry and from catch-per-unit-effort (CPUE) data from gillnets monitored throughout the migratory season (approximately June to November). Telemetry allowed me to track movements of individual fish, whereas data from gillnetting indicated the temporal extent and peak of migration.

4.1 Long-term gillnetting

The seasonal abundance and timing of movements of inconnu in the Arctic Red and Slave Rivers were monitored using multi-mesh (38 mm, 51 mm, 63.5 mm, 76 mm, 89 mm, 101.5 mm) and 139 mm stretch mesh floating gillnets. Occasionally other types of gillnets were used: 101.5 mm, 114.5 mm, 127 mm and 133.5 mm stretch mesh. Nets were 23-55 m long and 1.8-3.7 m deep. As well, a 20-m beach seine was occasionally used during the open water period, close to shore, to check for the presence of young-of-the-year inconnu. Gillnets were set throughout the summer and under the ice in fall and winter in back-eddies or protected areas within the rivers. Based on communication with local fisherman I expected that the majority of fish moving through the Arctic Red and Slave Rivers in summer and fall would be spawners; the large mesh gillnets (139 mm) were used to target spawning fish, whereas the multi-mesh gillnets were set to check for the presence of smaller, younger fish. Gillnets were set daily (weather permitting) and the duration of each set was recorded. Physical factors that might potentially influence fish movements, including water temperature, weather conditions, and the surrounding habitat, were recorded each time a net was pulled. Discharge data for the Arctic Red and Slave Rivers were obtained from the Water Survey of Canada Stations at Martin House (Station 10LA002) and Fort Fitzgerald (Station 07NB001), respectively.

At Arctic Red River gillnets were set in two areas, close to (≤ 5 km upstream) and away from (> 5 km upstream) the mouth of Arctic Red (Appendix A). The confluence of the Arctic Red and Mackenzie Rivers is thought to be an important feeding area for fish migrating through the Mackenzie River and may, during the summer in particular, harbour a mixture of inconnu en route to different spawning areas (personal communication, from local fishermen). Because different spawning populations could differ in their migration timing, I initially analysed summer catches (July 10-September 25) of inconnu from the Arctic Red proper and the mouth of the Arctic Red River separately. Based on examination of stomachs, pre-spawning inconnu captured during july and august were still feeding in the river, whereas the majority of post-spawning inconnu captured near the confluence of the Arctic Red River after September 25 did not appear to have been feeding. I was therefore confident that these inconnu were post-spawners from the Arctic Red River, on their way downstream, as opposed to being transients from another population feeding in the area.

Catch data for the Slave River were mainly collected approximately 300 km upstream of Great Slave Lake, but occasional sampling was also conducted in the Slave River Delta. Because of the long distance between these two areas I analysed catch data for each location separately. Maps with the locations of gillnetting stations for the Slave River/Delta are presented in Tallman *et al.* (1996).

I sampled a portion of the inconnu captured in gillnets for biological information, such as forklength, body weight, gonad weight, sex, maturity and aging structures. I assessed sex and maturity by examining the gonads and assigning a code based on their appearance (Appendix B). Only data on sex, maturity and gonadosomatic index [gonad weight/(body weight-gonad weight)] will be presented here.

To quantify seasonal changes in relative abundance of inconnu, I calculated CPUE, with effort standardized to a 23 X 1.8 m net. CPUE was calculated for each set by dividing the standardized catch for that set by the soak time (in hours). Because I used nets that differed in mesh size, I also standardized catches to the most common mesh size, 139 mm, using mesh size correction factors that were calculated in the following manner: for a given week at a given location, the catch rate (standardized CPUE) for nets of each mesh size was divided by the catch rate for 139 mm mesh nets. Correction factors were calculated only within weeks where more than one net of a given mesh type was set and where average weekly CPUE was > 0.01 fish/hour. From these week- and location-specific calculations an overall mean correction factor was determined for each mesh size (Appendix C); mild and extreme outliers were identified using box plots, and removed prior to calculating overall mean correction factors. Because juveniles were rarely captured (and never in the Slave River), I excluded them from the CPUE analyses presented here.

4.2 Radio telemetry

Radio telemetry was used to monitor migratory movements of individual inconnu and to identify possible spawning, overwintering and feeding sites. I applied radio transmitters to 12 inconnu during the upstream spawning run in Arctic Red River during early August of 1993. During 1994, 25 inconnu from the Slave River were fitted with radio transmitters; 16 fish, thought to be aggregating pre-spawners, were tagged at Ft. Smith Landing (Rapids of the Drowned) and at Buffalo Crossing between August 20-31; nine more inconnu were tagged at Fort Smith Landing as spawners on October 12-13 (see Figures 19 and 20, p. 42 and 44, for specific tagging locations).

Individual fish were captured using 139 mm stretch mesh gill nets; fish were removed as soon as they became snagged to cause as little tissue damage and trauma as possible. Only undamaged and active fish were tagged. Prior to tagging, fish were lightly anaesthetized using a 25 ppm benzocaine solution to ensure continuous gill movement. Radio transmitters (model # 1035, Advanced Telemetry Sytems, Isanti, Minnesota) were attached externally using the sub-dorsal fin mount method (Winter *et al.* 1978). Transmitters used in 1993 had a 6-month life, whereas those used in 1994 had a life of 9 months. A surgical needle was used to thread the two teflon-coated wires (that extend from the transmitter) through the supporting tissue under the dorsal fin. The transmitter was then pulled snug, and two soft plastic washers were slid over the wires and against the body of the fish. Overhand knots or wire crimps were used to prevent the wires from slipping through the washers. A whip antenna trailed along the fish's body. All tagging was done with the fish immmersed in a tub of river water. After being tagged, and until they recovered (usually about 15 minutes), inconnu were held underwater beside the boat in the direction of travel while the boat was being driven at slow speed into the flow of the river.

Initial tracking in the Arctic Red River was done on a weekly basis using a hand held reciever; however, once fish had moved out of range (September 4), they were tracked during three aerial surveys between September 16 and November 16, 1993. Inconnu in the Slave River were tracked by air, on a weekly basis, from October 6 through December 9, 1994 (by this date all inconnu appeared to have moved out of the river). Additional surveys of the Slave River were conducted on January 9, January 27, January 31 and February 15, 1995 to confirm that inconnu had moved out of range into Great Slave Lake.

Aerial tracking was done from a Cessna 185 plane equipped with either dual Larson NMO-40 whip antennas, or loop antennas attached to the wing struts. The aircraft flew at an average altitude of 1500 m. The areas surveyed by the tracking plane are shown in figures 10 (Arctic Red River) and 11 (Slave River). A Smith-Root Inc. SR-40 search receiver was used; this receiver was capable of monitoring up to 20 radio transmitter signals at a time. A reward of $25.00 was offered to domestic fisherman for returning radio-tagged fish and reporting important information, such as the date and location where the fish was captured. The distances travelled by tagged fish were estimated from 1:250,000 maps using EASYDIJ digitizing software.

4.3 Otolith microchemistry analysis

The saggitae, largest of the three pairs of otoliths located within the inner ear (Degens *et al.* 1969), were collected from inconnu that had been captured by gillnet in the Arctic Red and Slave Rivers between 1992 and 1994. Otoliths were cleaned and stored dry in coin envelopes. One otolith was used to age the fish using the break and burn technique (Chilton and Beamish 1982); Sr analysis was conducted on the other otolith. Otolith Sr levels were determined for 5 males and 5 females from each of the two rivers. Otoliths were chosen based on two criteria : ease with which the annuli could be read and the inclusion of a range of ages and maturities for each sex (Table 2). Otoliths used for Sr analysis were embedded in epoxy resin, sectioned in transverse plane using a Buehler Isomet slow speed saw, and then mounted in a 3mm thick, 25.4 mm diameter epoxy resin disk probe mount. The surface of the disc and otoliths were ground, using a Buehler Polimet I grinder with a 20 um (600 grade) diamond grit wheel,

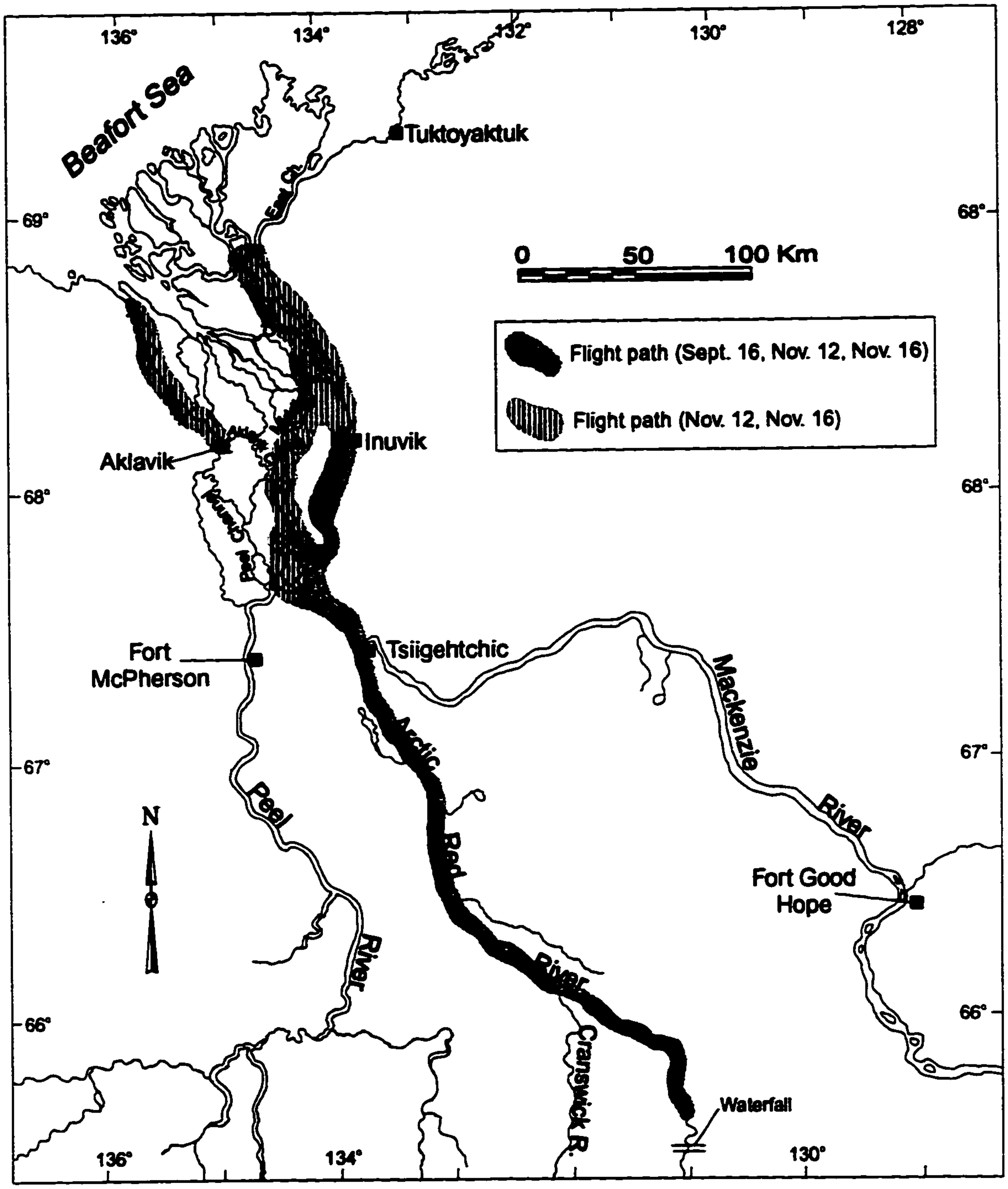


Figure 10. Flight path of radio-tracking plane in the Arctic Red River and Mackenzie Delta.

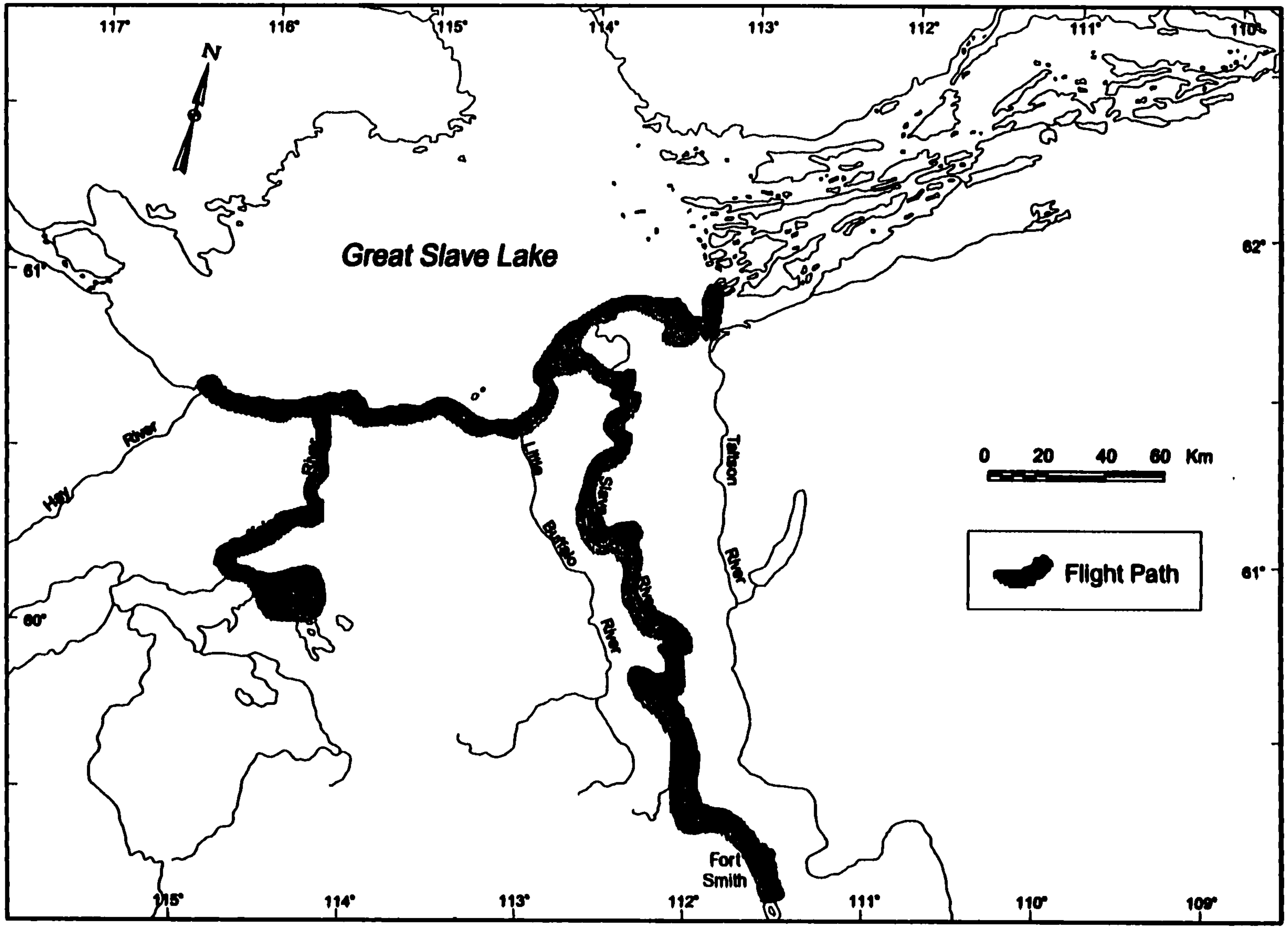


Figure 11. Flight path of tracking plane in the Slave River/Great Slave Lake area. .

Table 2. Age, otolith readability, and other information about the inconnu from which otoliths were taken for strontium analysis.

Sample No.	Sex	Maturity at Time of Capture	Age (years)	*Otolith Readability	Collection River	Collection Year
1	Male	current year spawner	11	1	Slave	1994
2	Male	current year spawner	12	1	Slave	1993
3	Male	current year spawner	9	1	Slave	1994
4	Male	current year spawner	8	1	Slave	1994
5	Male	current year spawner	7	1	Slave	1994
6	Female	current year spawner	9	1	Slave	1994
7	Female	current year spawner	9	1	Slave	1994
8	Female	current year spawner	10	1	Slave	1994
9	Female	current year spawner	13	2	Slave	1994
10	Female	ripe	24	2	Slave	1994
11	Male	current year spawner	16	1	Arctic Red	1994
12	Male	spent	18	1	Arctic Red	1992
13	Male	spent	20	1	Arctic Red	1993
14	Male	spent	14	1	Arctic Red	1993
15	Male	spent	27	1	Arctic Red	1992
16	Female	current year spawner	19	1	Arctic Red	1993
17	Female	spent	19	1	Arctic Red	1992
18	Female	current year spawner	19	1	Arctic Red	1994
19	Female	spent	20	1	Arctic Red	1993
20	Female	current year spawner	31	1	Arctic Red	1993

* Scale used to describe otolith readability: 1= very good readability, total confidence in age estimate; 2 = good readabilty, high confidence in age estimate; 3 = poor readability, age estimate may be off by 1-2 years; 4=unreadable, no age estimate can be made.

microscope) to be free of any scratches that could cause artifacts in the microprobe analysis. The surface was ultrasonically cleaned, dried and coated with 100-200 Å. carbon.

Several techniques are available for elemental analysis of otoliths, with electron probe microanalysis (EPMA) being the most common (e.g., Radtke 1989; Kalish 1990; Secor 1992; Rieman *et al.* 1994; Thresher *et al.* 1994). Although the EPMA has good spatial resolution, making it a useful instrument for determining patterns of element distribution within the otolith, it has high detection limits and sample ablation often occurs, reducing the accuracy of analyses (Gunn *et al.* 1992). Techniques such as atomic absorption spectroscopy (e.g., Hoff and Fuiman 1995) and atomic emmission spectrometry (e.g., Gauldie *et. al.* 1986) offer accuracy, but require complete destruction of otoliths (*Willard et al.* 1988), thus precluding examination of element distribution within the otolith. The proton microprobe, although not yet commonly used for otolith microanalyses, has the spatial resolution of the electron microprobe, while offering much higher sensitivity (Teesdale *et al.* 1993; Campbell *et al.* 1995) and has been successfully used by other researchers to determine the environmental histories of fish (e.g., Gauldie *et al.* 1986; Sie and Thresher 1993; Halden *et al.* 1995, 1996). For these reasons, I used the proton microprobe method.

Strontium levels of otoliths were analysed using the scanning proton microprobe (SPM) in the Department of Physics, University of Guelph. The SPM uses an electrostatic accelerator to deliver a focussed beam of protons to the specimen of interest, causing the release of X-rays (Figure 12). The X-rays of all elements above detection limits are recorded using a silicon/lithium detector. The wavelength (energy) and intensity (number of counts) of these X-rays reflect the identities and concentrations of the elements contained within the specimen (Figure 13) (Campbell *et al.* 1995). Because X-rays of Sr are in the higher energy region of the X-ray spectrum (14-16 KeV), 0.125 um mylar and 106 um aluminum filters were used to filter out lower energy X-rays. The software package GUPIX (Maxwell *et al.* 1989) was used to analyze X-ray spectra. The proton beam entered each otolith at a 45 degree angle to the surface and otoliths were oriented such that the growth zones were horizontal, while the longitudinal growth axis was vertical to the beam. The 90% depth yield (D_{90}) for Sr, the depth above which 90% of the observed K X-rays originate is 20-25 um

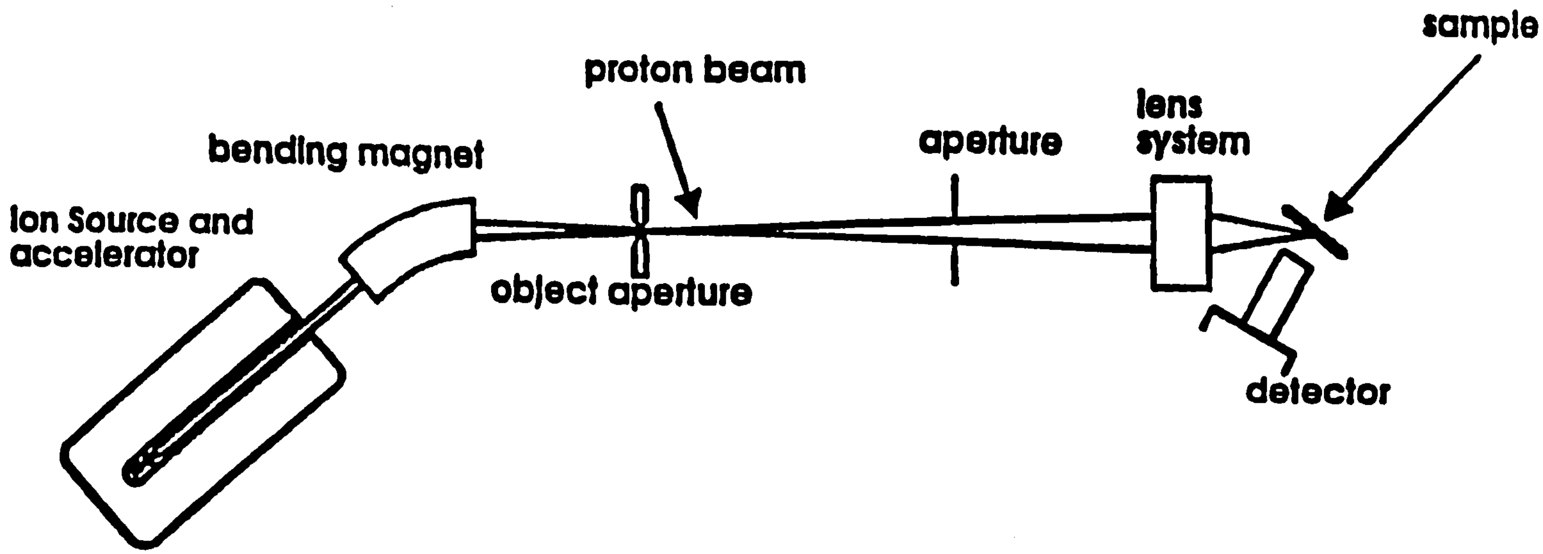


Figure 12. Schematic showing general features and arrangement of a proton microprobe (from Campbell *et al.* 1995).

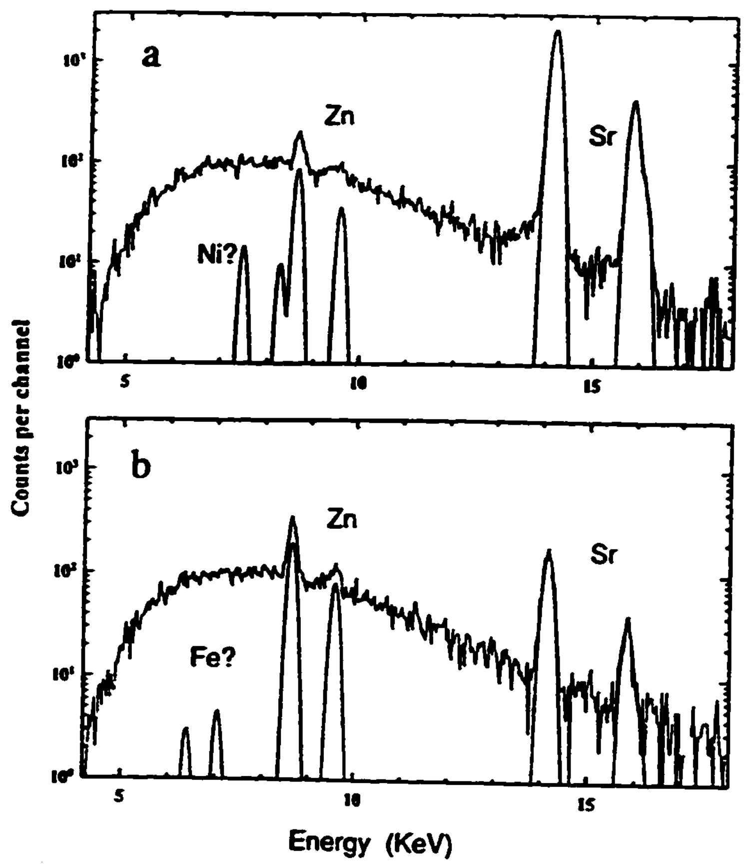


Figure 13. Typical X-ray spectra obtained from the otolith. Spectrum a) is representative of a high Sr region of the otolith and b) of a low Sr region. The two separate Sr peaks correspond to Sr Kα and Sr Kβ X-rays, respectively (from Halden *et al.* 1995).

(W.J. Teesdale, Department of Physics, University of Guelph; pers. comm.). Other details regarding operating procedures, spectrum fitting and standardization for the SPM system at Gueph are outlined in Czamanske *et al.* (1993) and Campbell *et al.* (1995).

Two types of analyses were conducted for this study: I) For all otoliths, one-dimensional vertical line-scans were used to determine Sr levels at 4 um intervals along the longitudinal growth axis from the nucleus to the otolith edge. Strontium profiles were produced by rastering the proton beam over each specimen 50 times; approximately 10-15 minutes/otolith; ii) Three point analyses were conducted on the nuclei of 8 otoliths. Each point analysis is repeated numerous times in a given spot to allow accurate quantitative analysis of the Sr concentration in that part of the otolith. For the line scans, a 5 um (high) X 12 um (wide) proton beam was used, which had a strength of 3 MeV and current of 8.5 nA. A 5 X 5 um proton beam was used for the point analyses.

Video images of the otoliths, made prior to the microprobe analyses, were used as reference maps for the line scans and spot analyses (e.g., Figure 14). Following microprobe analyses, otoliths were reground to remove the thin reflective carbon coating and new video images were taken. The paths of line scans and the locations of spot analyses were clearly visible. To relate patterns of Sr levels from microprobe analyses to periods within the lifetime of each fish, locations of annuli along each line scan were determined from these images using the program Optimus 5.2.

X-ray intensities from line scans were converted to Sr concentration (ppm) in the following manner: for each otolith on which point analyses were conducted, average concentration and X-ray intensity for the core area were calculated from the three analysed points, and from the first 100 um of the line scan, respectively. Using these values, the ratio of X-ray intensity to Sr concentration was determined for each otolith (Appendix D). The mean of these ratios was then used to convert X-ray intensities of line scans to Sr concentration.

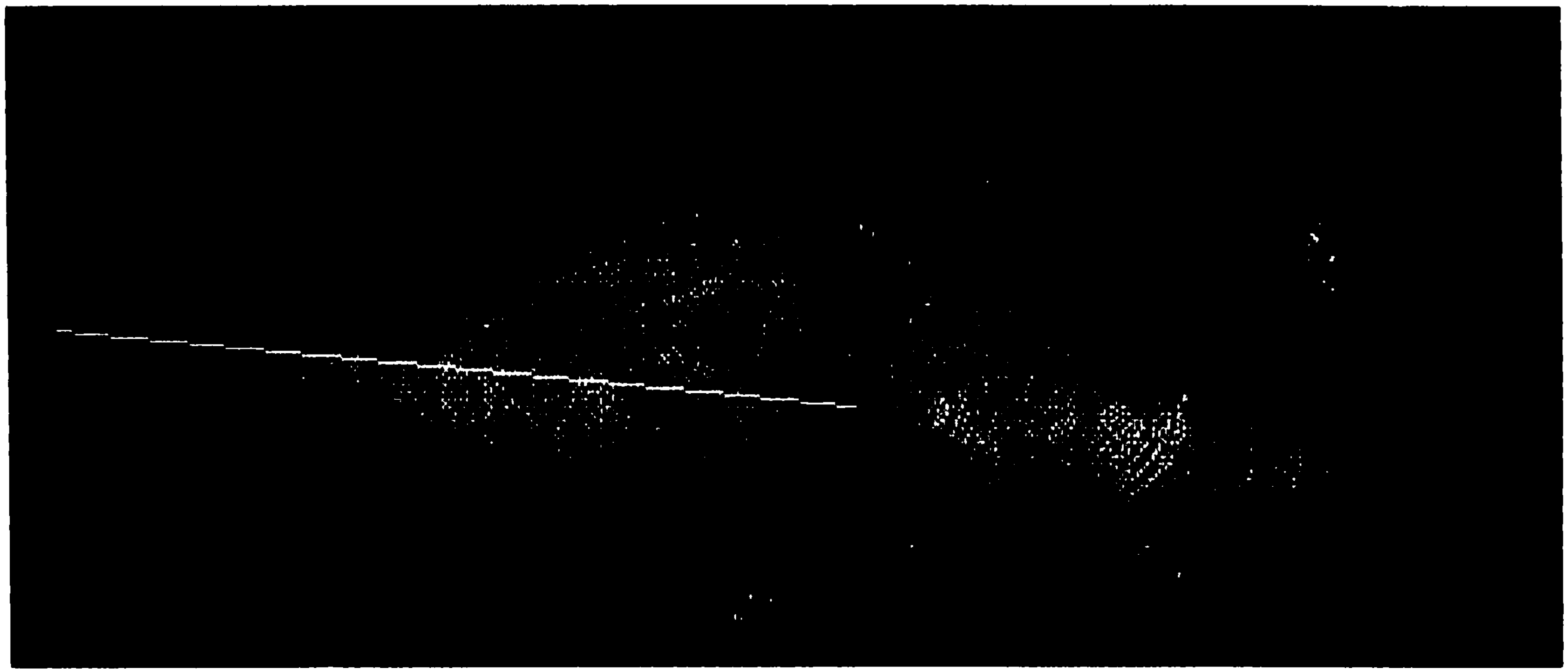


Figure 14. Video image of an otolith (in Cross section) showing the transect along which the line-scan was conducted.

5. RESULTS

5.1 Migration timing based on seasonal changes in relative abundance

5.1.1 Arctic Red River

Visual inspection of the seasonal catch-per-unit-effort (CPUE) plots from the two sampling area did not reveal any major differences in migration timing between inconnu from the mouth area and the upstream area of Arctic Red River (Figure 15). As well, there was no difference between the average forklengths of inconnu from upstream ($n = 260$) and near the mouth ($n = 66$) of Arctic Red River (t-test, $t = -0.445$, $p = 0.656$), further suggesting that inconnu from the two sections of the river were not from different spawning populations. Based on these results, I combined data for inconnu captured at the mouth of Arctic Red River and the upstream area for the remainder of the analyses.

Although the relative abundances of inconnu in the Arctic Red River differed between years (the fall peak was higher in 1992 and the summer peak was higher in 1993), the timing of inconnu migration through the Arctic Red River was similar during both years of the study (1992 and 1993). Sexually mature inconnu first began to appear in gillnets in early July (Figure 16a,b). There was continual movement of inconnu through to mid-August, with the average weekly CPUE reaching maximums in the second week of August. The summer migration of inconnu through the Arctic Red River coincided with a rapid increase in female gonadosomatic index (GSI) (Figure 16c,d), indicating that these fish were coming into spawning condition. The seasonal pattern of change in GSI was similar for males. Based on size and appearance of the gonads, nearly all mature inconnu sampled between July 10 and September 25 were pre-spawners ($n = 178$ pre-spawning males, $n = 75$ pre-spawning females, $n = 1$ resting female); most mature inconnu sampled after September 25 appeared to be spent, indicating they were post-spawners ($n = 165$ post-spawning males, $n = 69$ post-spawning females, $n = 13$ partially spawned males, $n = 1$ partially spawned female).

From mid-August to late September very few inconnu were captured at our sampling sites. Catch-per-unit-effort remained low until early October when large numbers of spent inconnu began to reappear. The majority of post-spawners moved

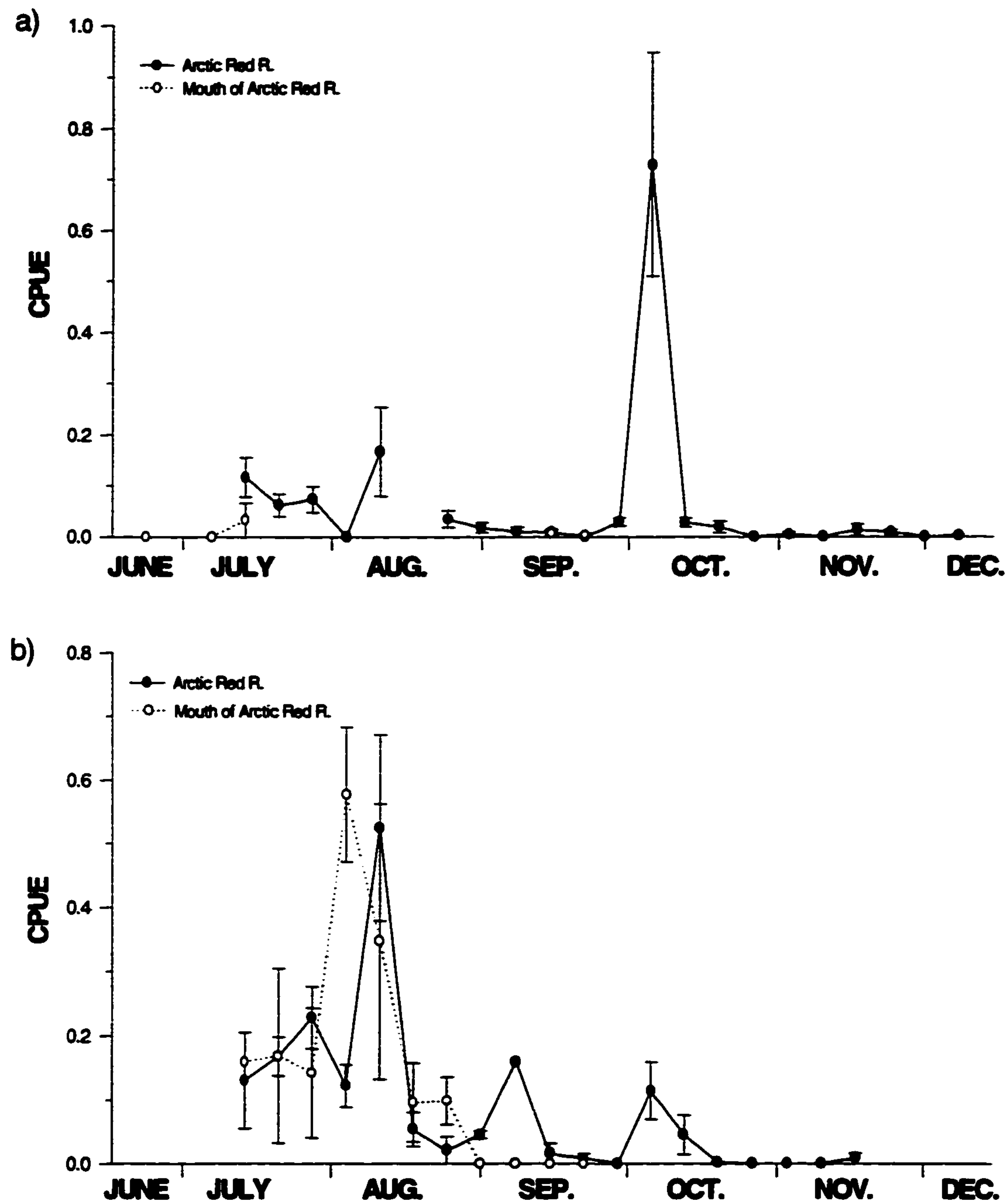


Figure 15. Average weekly catch-per-unit-effort (CPUE) of inconnu captured in the Arctic Red River (solid circles) and the mouth of the Arctic Red River (open circles) during a) 1992 and b) 1993. Vertical bars represent one standard error. Combined sample sizes for Arctic Red River and the Mouth of Arctic Red River are in appendices E1 and E2.

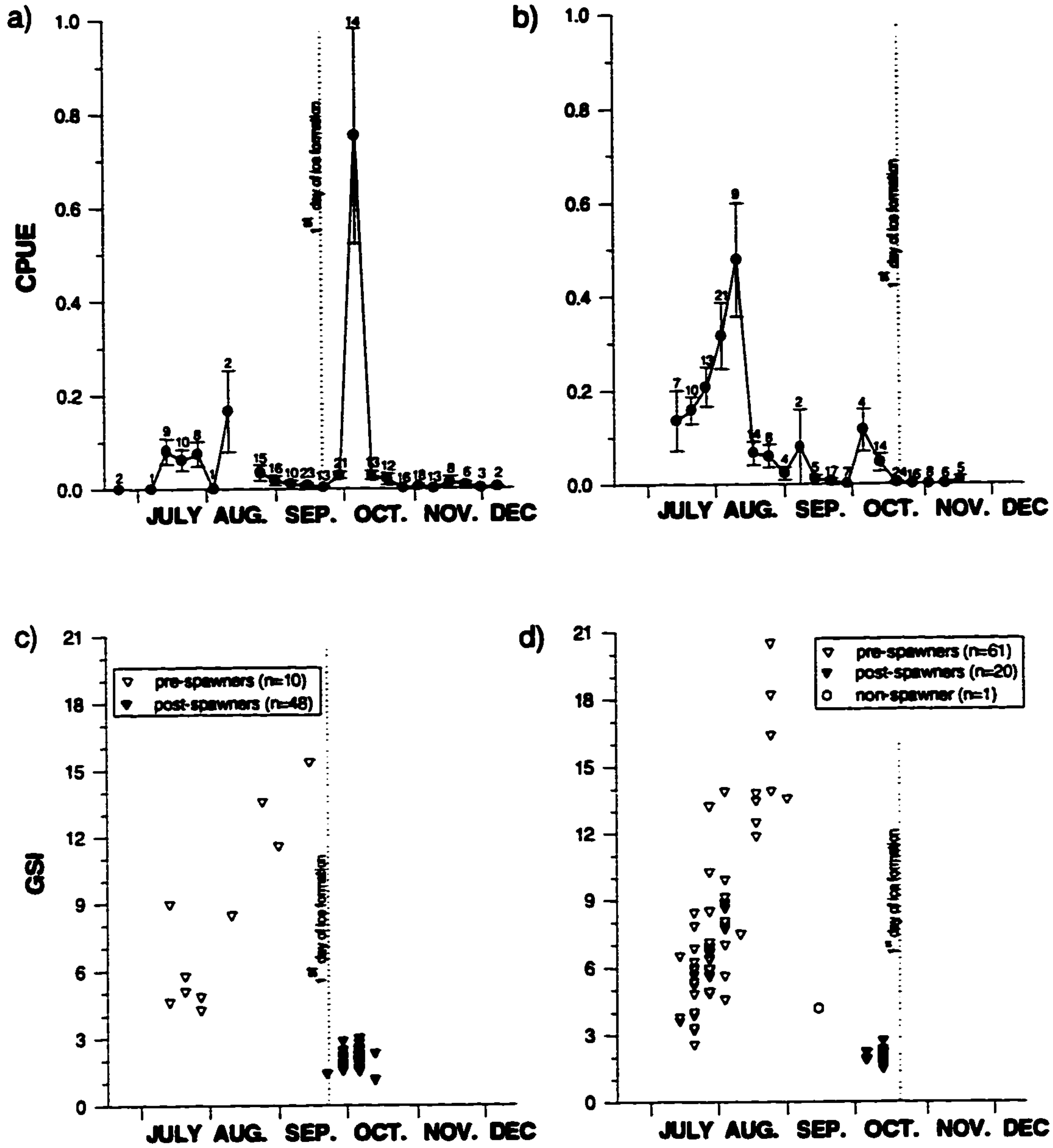


Figure 16. Seasonal changes in average weekly CPUE and female gonadosomatic index [gonad weight/(body weight-gonad weight)} of inconnu captured in the Arctic Red River during 1992 and 1993.
a) average weekly CPUE 1992
b) average weekly CPUE 1993
c) female GSI 1992
d) female GSI 1993
First day of ice formation is indicated by a vertical dashed line. Vertical bars on CPUE plots represent one standard error. Numbers represent number of nets used to determine average CPUE within a given week. For c) and d) open triangles, solid triangles and open circles represent pre-spawners, post-spawners and non-spawning fish respectively.

out of the Arctic Red River between September 28 and October 15 in 1992, and between October 5 - 14 in 1993.

5.1.2 Slave River

As in the Arctic Red River, the timing of migration into the Slave River by pre-spawning inconnu was similar during both years of study (1994 and 1995) (Figure 17a,b). Relative abundance, however, tended to be higher in 1995. Given that inconnu are thought to spawn in alternate years (Scott and Crossman 1973), this could be a result of the spawning population being composed of year classes of different strength in alternate years.

Sexually mature inconnu were occasionally caught in the Slave Delta in late June and July (5 fish in 1994, 2 fish in 1995), but didn't appear regularly in gillnets until the second week of August (Figure 17a,b). Catch-per-unit-effort in the delta peaked in the last week of August and then decreased by mid-September during 1994. Sampling in 1995 was limited to a single week in August, so determining when the peak in migration occurred was not possible.

Inconnu first appeared in the upper part of the Slave River (Buffalo Crossing to Fort Smith) in the second week of August and continued to move into this part of the river until late October (Figure 17a,b). Catch-per-unit-effort peaked in early September and again in mid-October. By the third week of October (17-23), the last week of netting, CPUE had dropped off substantially. Over the course of the migration period in the Slave River there was a steady increase in female GSI (Figure 17c,d), indicating that these fish were coming into spawning condition. Examination of gonads and the range of GSI values confirmed that all inconnu sampled during the study were pre-spawners (n = 331 pre-spawning males, n = 193 pre-spawning females).

5.1.3 Males versus females

In both the Arctic Red (1992,1993) and the Slave River (1994), CPUE for females was generally about half of that for males (Figure 18). Gillnetting throughout the migratory season gave seasonal average sex ratios (males:females) of 2.27:1

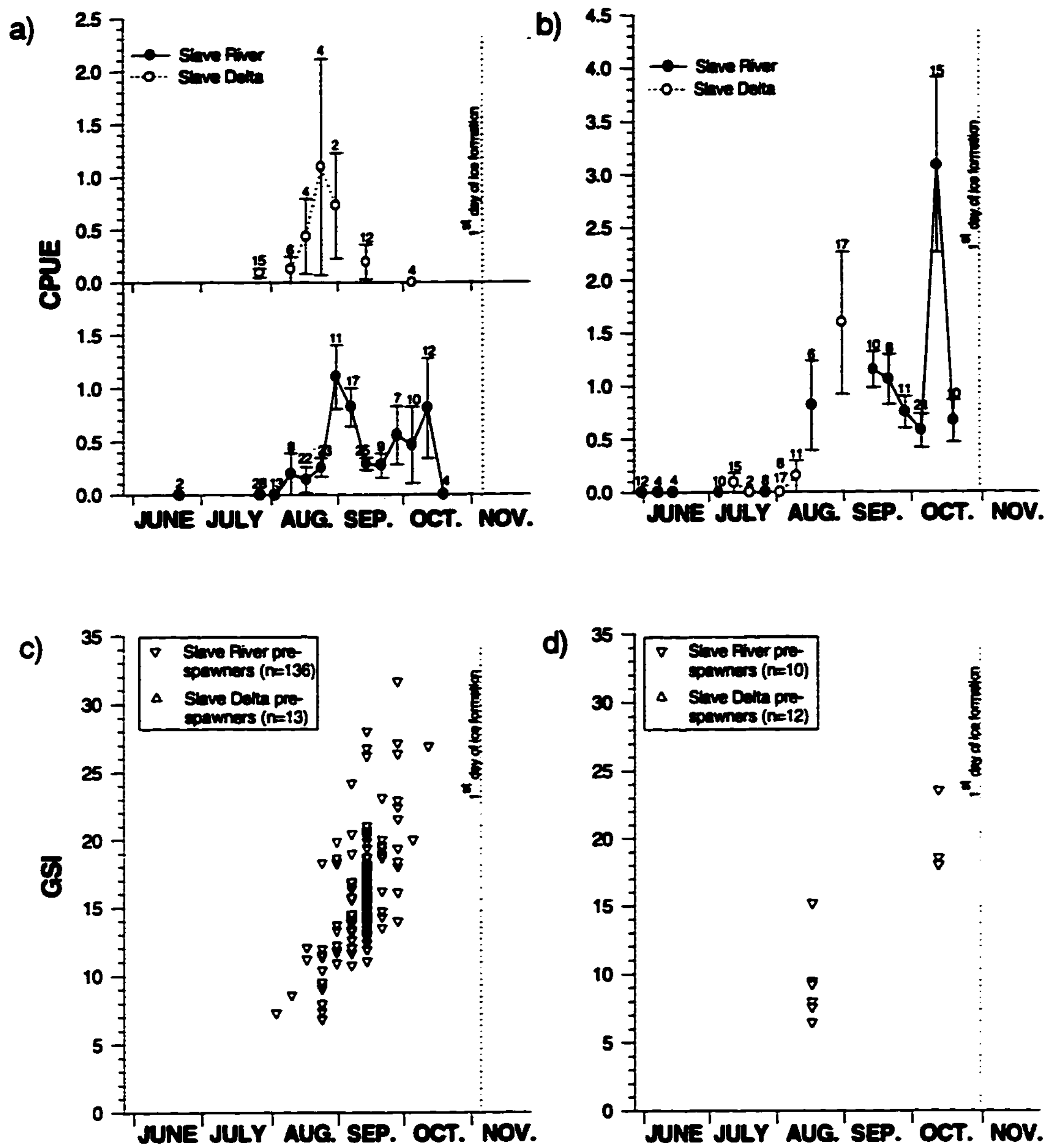


Figure 17. Seasonal changes in average weekly CPUE and female GSI [(gonad weight/body weight-gonad weight) X 100] of inconnu captured in the Slave River during 1994 and 1995.
a) average weekly CPUE - Slave River (solid circles),Slave Delta (open circles),1994.
b) average weekly CPUE - Slave River (solid cicles),Slave Delta (open circles), 1995.
c) female GSI - Slave River, Slave Delta, 1994.
d) female GSI - Slave River, Slave Delta, 1995.
First day of ice formation is indicated by a vertical dashed line. Vertical bars on CPUE plots represent one standard error; numbers represent number of nets from which average CPUE was determined within a given week.

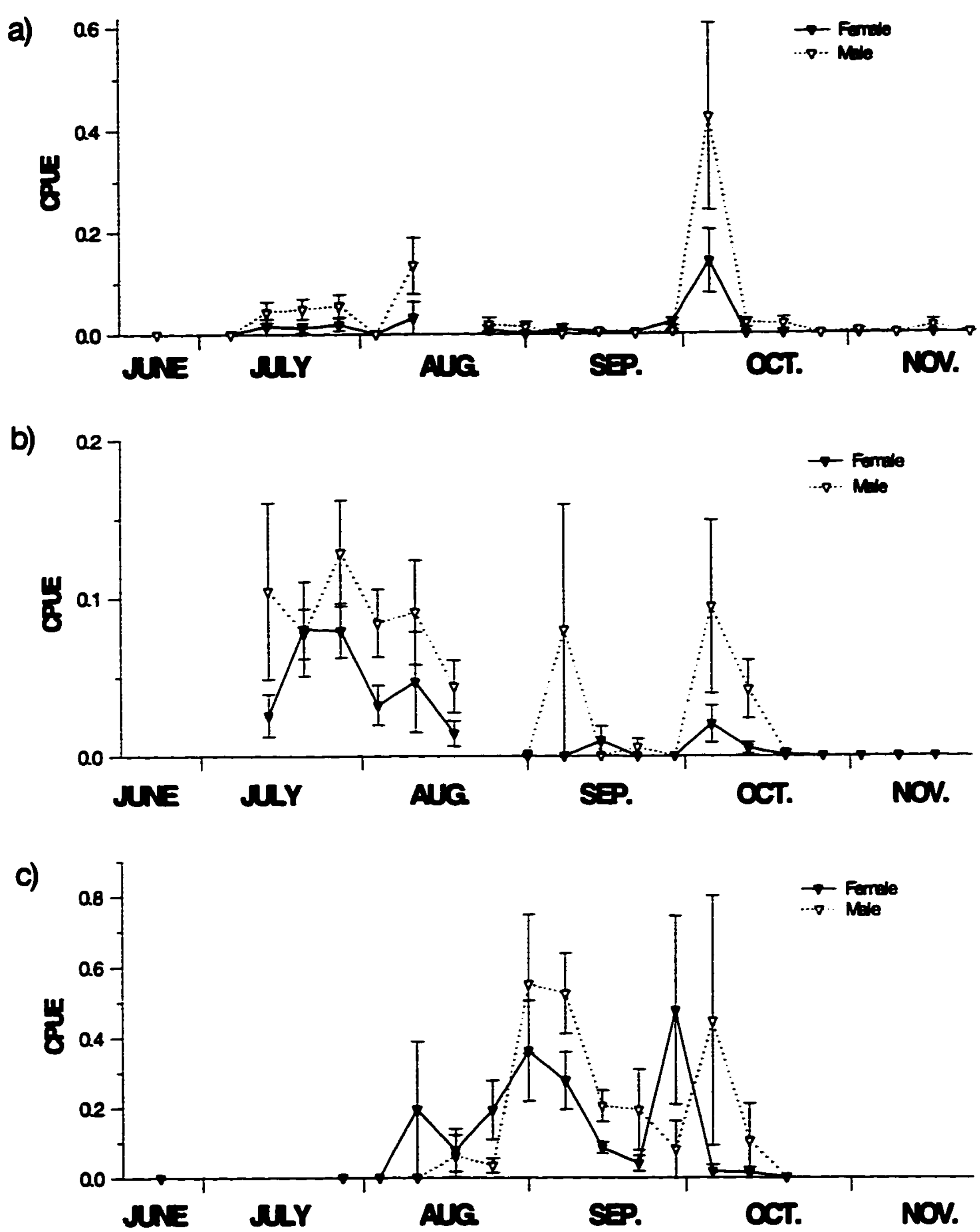


Figure 18. Seasonal changes in average weekly CPUE for female (solid triangles) and male (open triangles) inconnu captured in the Arctic Red Red River during a) 1992 and b) 1993, and in c) the Slave River during 1994. Vertical bars represent one standard error. Sample sizes are given in appendices E1, E2 and E3.

(Arctic Red River 1992), 2.45:1 (Arctic Red River 1993) and 1.84:1 (Slave River 1994). Migration timing was similar for both males and females in the Arctic Red River, and the pattern of seasonal change in relative abundance was nearly identical for both sexes Figure (18a,b).

In the Slave River females reached the Fort Smith area approximately one week earlier than males, and most appeared to have migrated from the area, or were no longer being captured in gillnets, one week earlier than the males (Figure 18c). However, for the October collection period, a large proportion of the captured inconnu were not sexed, thus making CPUE (by sex) appear abnormally low in some cases. If we estimate the CPUE by sex for the week of October 10-16, using overall CPUE for that week and sex ratios of the fish that were sexed it is apparent that both male and female CPUE peak at this time, as opposed to dropping off.

5.2 Migratory movements and timing based on radio telemetry

5.2.1 Arctic Red River

Because gillnetting revealed that nearly all inconnu (with exception of juveniles) were pre-spawners at the time when radio-tags were first applied, I was confident that radio-tagged fish were en route to spawning areas in the headwaters of the Arctic Red River. Nevertheless, radio-tagged inconnu dropped downstream following tagging (probably due to the stress of being handled) and most were detected in the slow-moving waters near the confluence of the Mackenzie and Arctic Red Rivers (Figure 19). On August 15, 3 (4C, 7B, 9B) of the 5 fish detected in Arctic Red River were upstream of the confluence, suggesting they had begun to recover. By September 3 one fish (2D), later shown to be an unspawned male, had moved upstream in the Mackenzie River to Fort Good Hope (345 km), where it was recaptured by a fisherman. No fish were detected when tracking was done by boat on September 4 along the lower 60 km of the Arctic Red River. Inconnu may have either been further upstream in the Arctic Red River by this time or, like fish #2, they had moved into the Mackenzie River. Two inconnu were located upstream in Arctic Red River during a tracking flight on September 16, just prior to expected time of spawning. Fish #4D had moved 175 km upstream and #10C had moved 217 km upstream. All recaptures of tagged fish

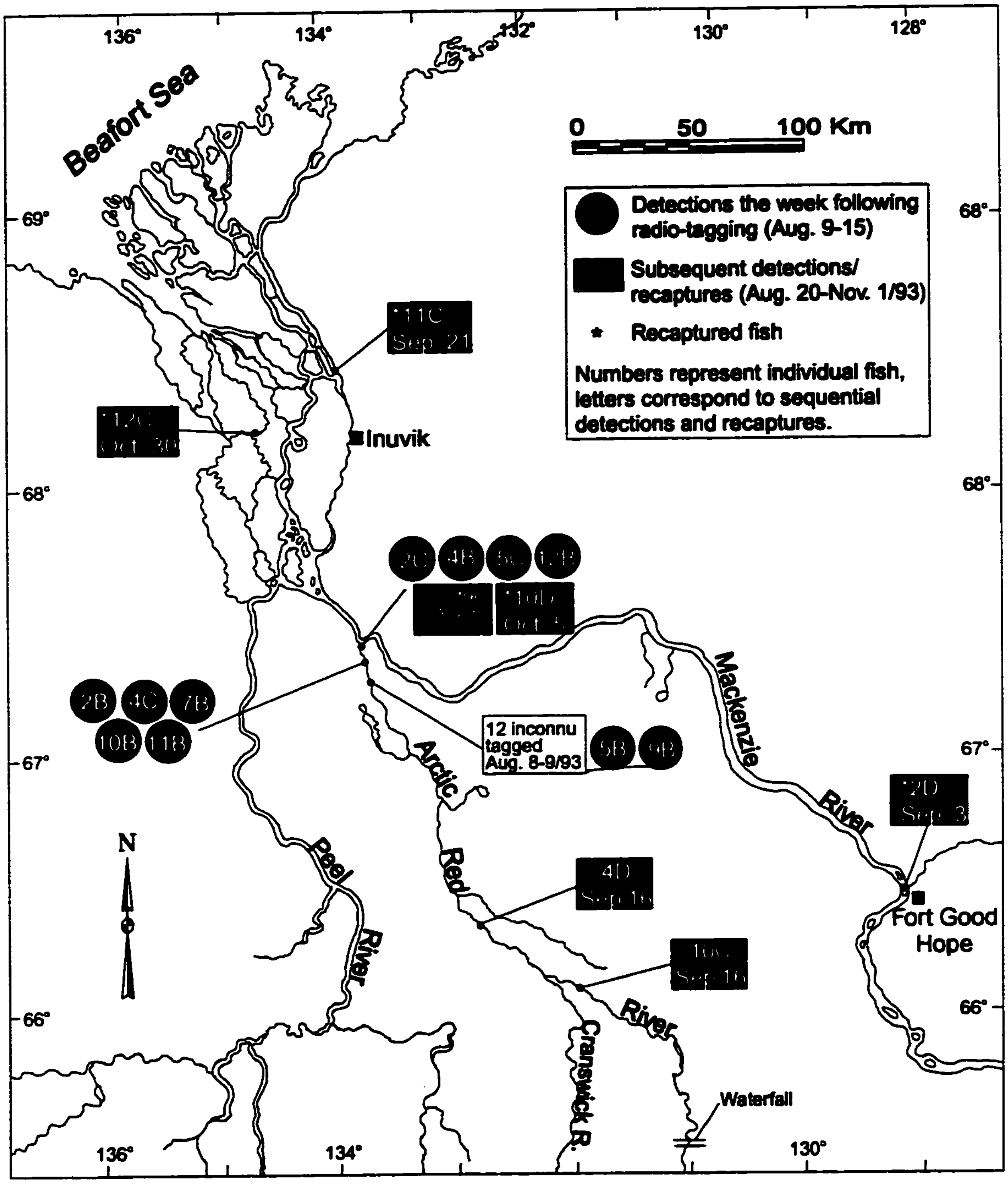


Figure 19. Detection and recapture locations of inconnu radio-tagged in the Arctic Red River in 1993. See figure 3 for additional place names.

occurred in September and October. Fish #5 and 9 were recaptured close to their release points sometime prior to September 16, and fish #11 was recaptured September 21 in the Mackenzie River Delta near Inuvik. Fish #10 (previously located 217 km upstream on September 16) was recaptured by a local fisherman at the mouth of Arctic Red River on October 5. Sampling revealed that this fish was a female that had completed spawning. Two flights were made through the Mackenzie Delta in November to try and determine overwintering areas but we were unsuccessful at locating any tagged inconnu. However, one fish (12C) was recaptured in the Aklavik Channel of the delta at the end of October.

Inconnu #1, 3, 6, 7and 8 were never detected or recaptured after the first week folllowing tagging. Assuming these fish did not died, they may have moved out of our tracking range and into the mainstem Mackenzie River or they may have been in deeper parts of the river during periods of tracking and were thus not detected.

5.2.2 Slave River

Between the dates of initial tagging (late August) and October 15, all inconnu detections or recaptures were concentrated within the 20 kilometer stretch of the Slave River between the Salt River and Rapids of the Drowned at Fort Smith (Figure 20). No radio-tagged inconnu were ever detected upstream of the Fort Smith area. Between October 16 and the 25th, nearly all inconnu were detected downstream of the Salt River, distributed throughout the lower reaches of the Slave River as far upstream as Long Island. No inconnu were detected in the Slave River after October 25, 1994, and it was presumed that all fish had entered Great Slave Lake.

Since tracking was done frequently during the suspected spawning period, I was able to look at pre-spawning movements of fish detected more than once before they began migrating out of the river. Fish # 5 exhibited a haphazard pattern of short upstream and downstream movements prior to spawning and exiting the river (Figure 20). More typically, however, it appeared that upon reaching the Fort Smith area, fish moved a short distance back downstream where they remained until spawning was completed. Most of the inconnu tagged in the Fort Smith area at the end of August were detected in the Cunningham Landing area during the first half of October prior to

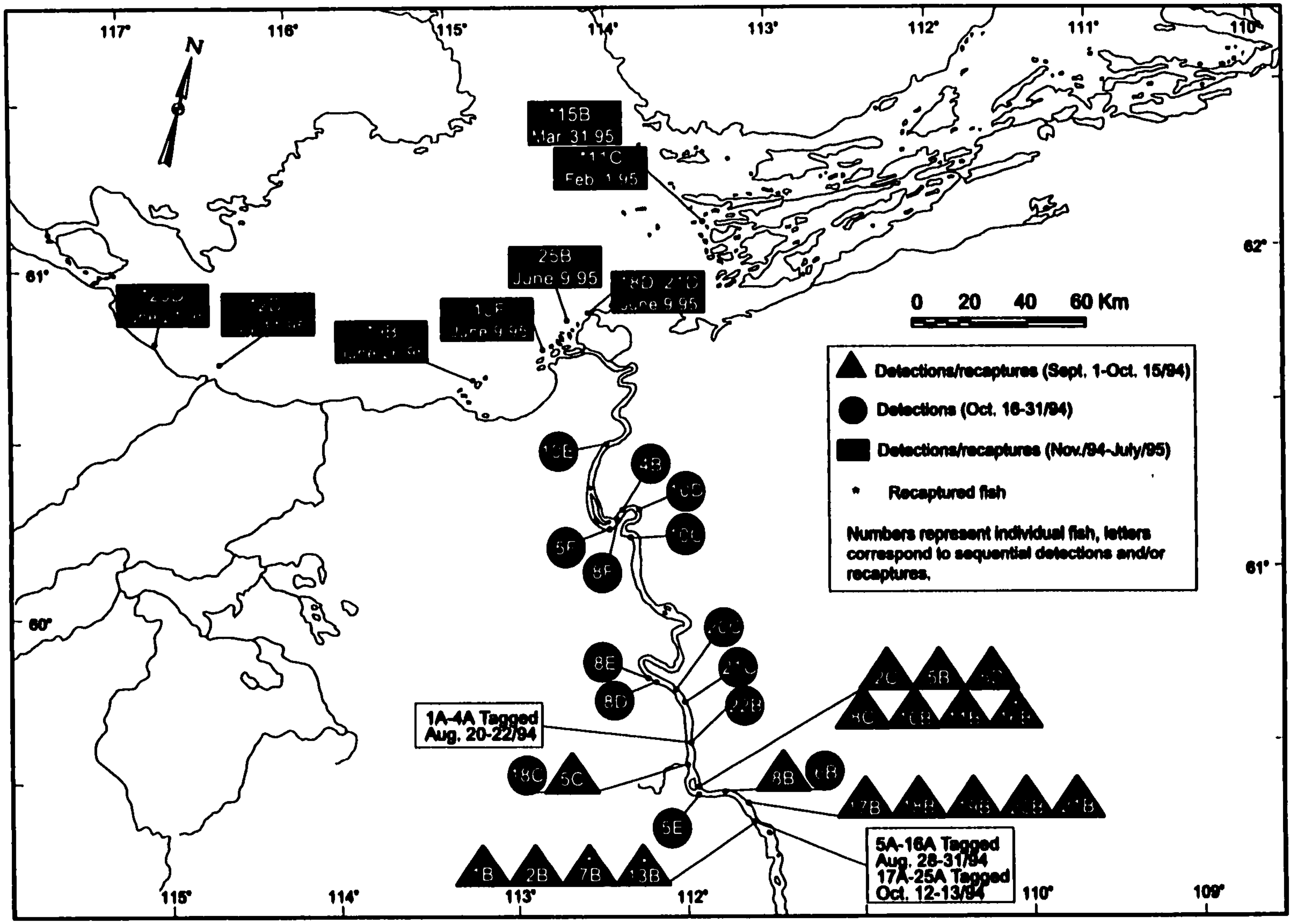


Figure 20. Detection and recapture locations of inconnu radio-tagged in the Slave River in 1994. See figure 4 for place names

migrating out of the river (2C, 5B-D, 8B-C, 10B, 11B, 16B), and none were detected in the Fort Smith area after October 9. Fish #2, tagged at Buffalo Crossing on August 20, moved upstream to the Fort Smith area by October 5 and then back downstream to Cunningham Landing by October 15. Given that no intensive tracking was conducted until October 6, some of these fish could potentially have been holding in the Cunningham Landing area for as long as a month. For example, fish #10 which was tagged at Fort Smith on August 31, was found at Cunningham Landing on October 6 and moved down to Pointe Ennuyeuse by October 18. Fish #8, which was tagged at Fort Smith Landing on August 30, was detected just upstream of Cunningham Landing on October 11, at Cunningham Landing on October 15, upstream of Grand Detour on October 18, and downstream of Pointe Ennuyeuse on October 25. Interestingly, this particular fish was recaptured a year later as a running-ripe male spawner near the Salt River on October 13, 1995.

With the exception of fish #8, all inconnu that were detected or recaptured in 1995 were found within Great Slave Lake itself (Figure 20). Of the two inconnu re-captured during the winter, both were found in the deeper area of the lake near the Simpson Islands at the edge of the east arm of Great Slave Lake on February 1 and March 31. Inconnu recaptured or detected in the summer months were generally found close to the shore or in the channels of river deltas and all were in the shallow southern basin of the lake (Figure 20). For example, fish #20 was re-captured on June 21, 1995 at Pointe de Roche on the south shore of the lake, well to the west of the Slave River. Fish # 2 was captured near the mouth of Hay River, on July 11, and fish #10 was captured at Burnt Island near Little Buffalo River on June 26. On June 9, fish #18 and #21 were detected 1 km north of the mouth of the Jean River, fish #25 was detected 3 km north of Resdelta Channel, and fish 10 was detected 3 km north of Steamboat Channel.

Inconnu # 1, 3, 12, 14, 23 and 24 were never detected or recaptured after initial tagging. Assuming these fish did not die, they may have been weakened by the tagging process and drifted downstream towards Great Slave Lake, they may have been in deeper parts of the river at the times when radio tracking was conducted and thus were not detected, or their transmitters could have failed.

5.3 Environmental conditions in relation to migratory patterns

The Slave and Arctic Red Rivers reached similar maximum temperatures (20-23 °C) during the summers of this study (Figure 21). As well, the seasonal changes in discharge were similar in both rivers, although it is up to 5-6 times greater in the Slave River than the Arctic Red (Figure 21). Discharge tended to decrease throughout the summer and fall, although there were occasional peaks associated with periods of high rainfall in upstream areas in both the Slave and Arctic Red Rivers. The Slave River discharge may also be influenced to some extent by the Bennett Dam upstream on the Peace River, which ultimately flows into the Slave. Inconnu enter the Slave and Arctic Red Rivers when discharge and water temperatures are relatively high (180-520 m^3 sec^{-1} and 15-21 °C respectively, Arctic Red River; 3500-4000 m^3 sec^{-1} and 18-21 °C respectively, Slave River). Inconnu in the Arctic Red River returned from spawning when water temperatures and discharge had dropped substantially, exiting the river close to the time of first ice formation. Spawning in the Arctic Red River appears to take place when temperatures are 0-4.5 °C, and when discharge is 55-160 m^3 sec^{-1}. Spawning in the Slave River also coincides with a decrease in water temperature (5-7 °C), but discharge is still relatively high (2600-4000 m^3 sec^{-1}).

5.4 Migratory behavior based on otolith microchemistry

The patterns of strontium concentration along the line-scans of inconnu otoliths differ markedly between rivers. The line-scans from inconnu of the Slave River all have flat strontium profiles of relatively low concentration (< 250 counts/1338 ppm) (Figure 22a,b). In contrast inconnu of the Arctic Red River show a more variable pattern (Figures 23a,b). The typical pattern of line scans from Arctic Red River inconnu is a flat Sr profile (similar to profiles of Slave River inconnu) from the nucleus to at least the first annulus, followed by an increase in Sr concentration that then oscillates on what appears to be an annual basis. Although the Sr level continues to alternate between high and low concentrations through to the outer edge of the otolith, it rarely drops back down to the levels seen near the core.

The age at which Arctic Red River inconnu first show a marked increase in otolith Sr concentration ranges from the 2nd to the 7th summer of growth. Although

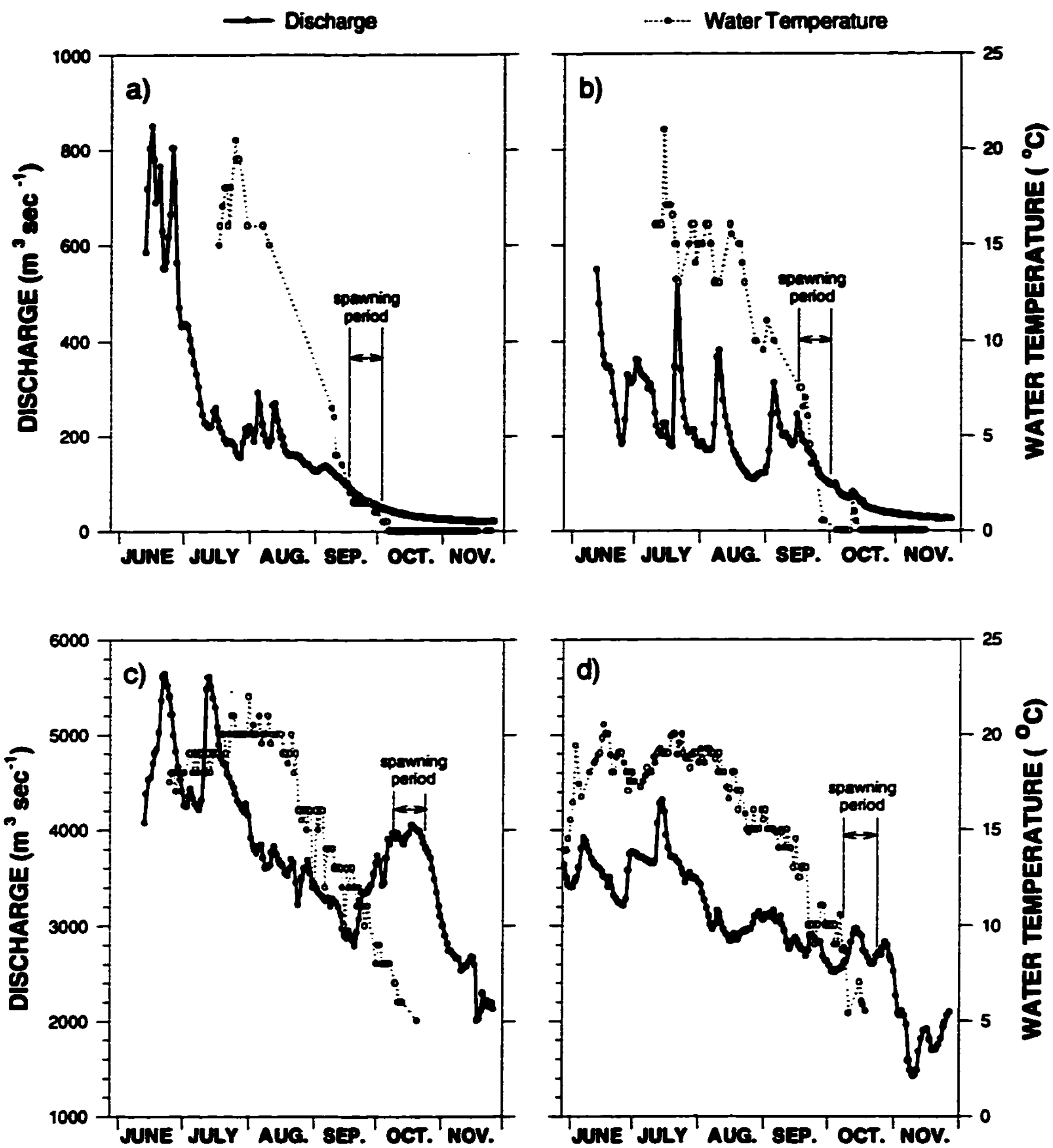


Figure 21. Seasonal changes in daily discharge (solid line) and daily water temperatures (dotted line) in the Slave and Arctic Red Rivers.
a) Arctic Red River 1992
b) Arctic Red River 1993
c) Slave River 1994
d) Slave River 1995
The estimated spawning period for inconnu from both rivers are marked by arrows.

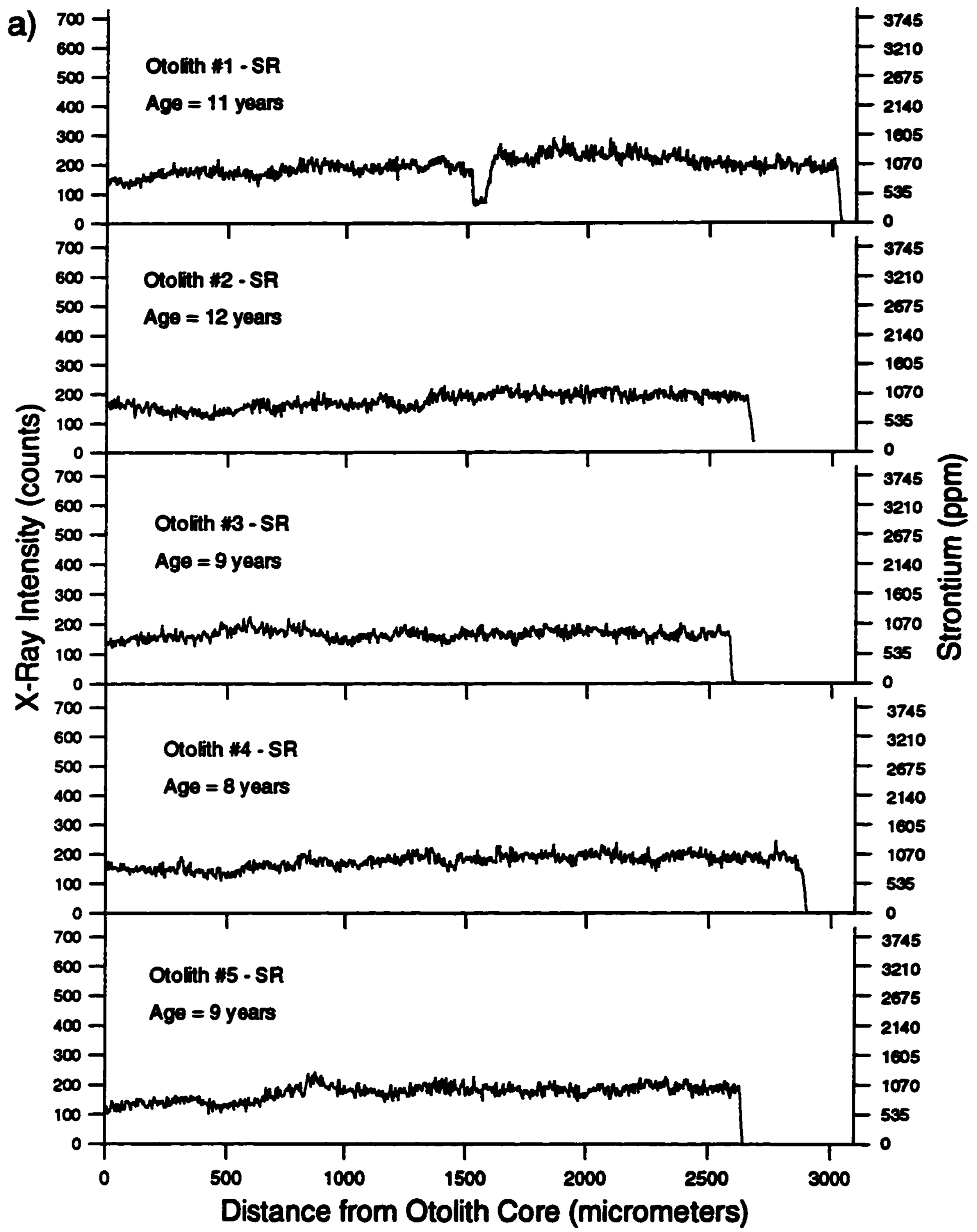
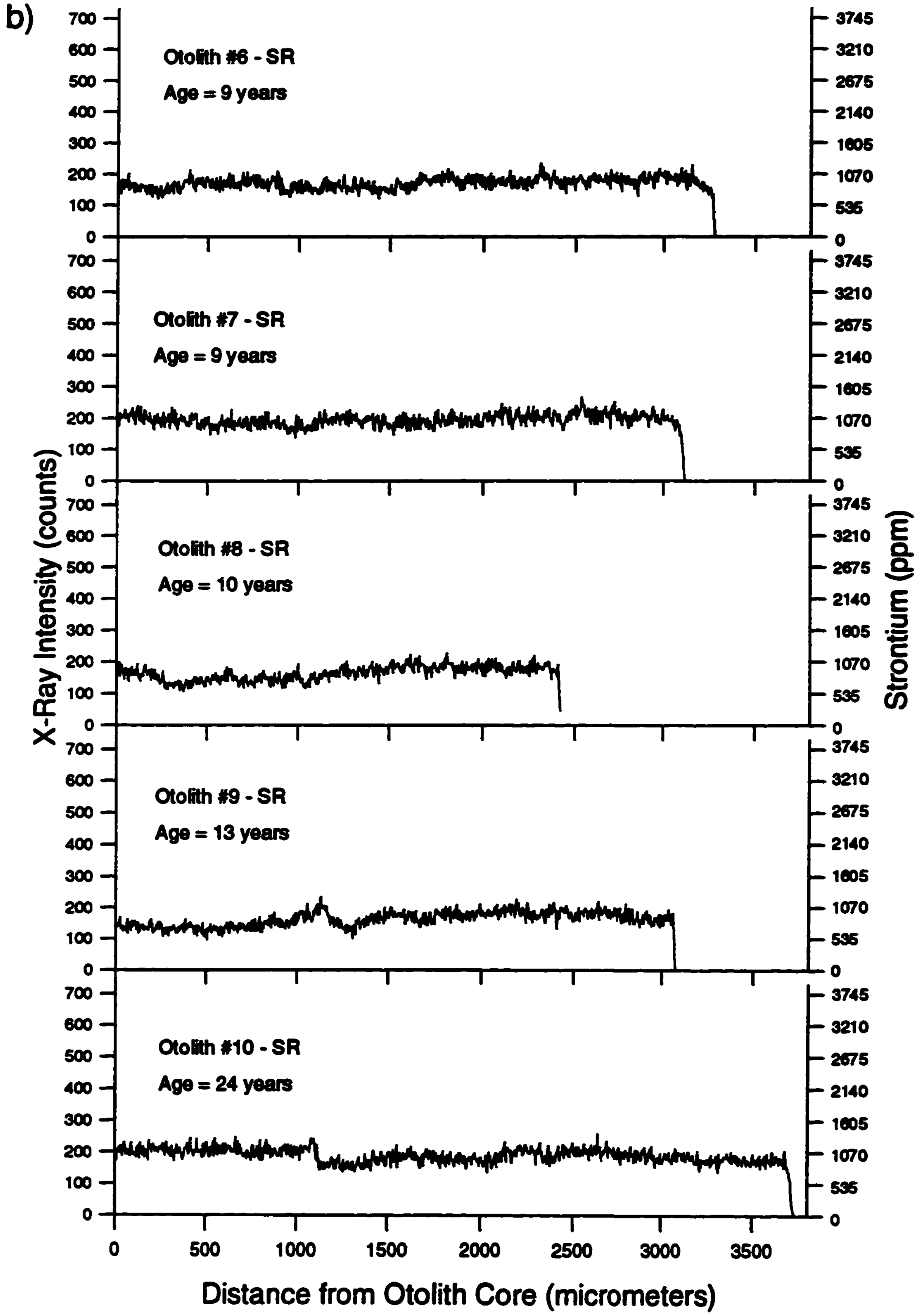


Figure 22. Strontium profiles from scanning microprobe line-scans of otoliths from a) male and b) female inconnu collected in the Slave River.


b)
Otolith #6 - SR
Age = 9 years
Otolith #7 - SR
Age = 9 years
Otolith #8 - SR
Age = 10 years
Otolith #9 - SR
Age = 13 years
Otolith #10 - SR
Age = 24 years
X-Ray Intensity (counts)
Strontium (ppm)
0
100
200
300
400
500
600
700
0
535
1070
1605
2140
2675
3210
3745
0
500
1000
1500
2000
2500
3000
3500
Distance from Otolith Core (micrometers)

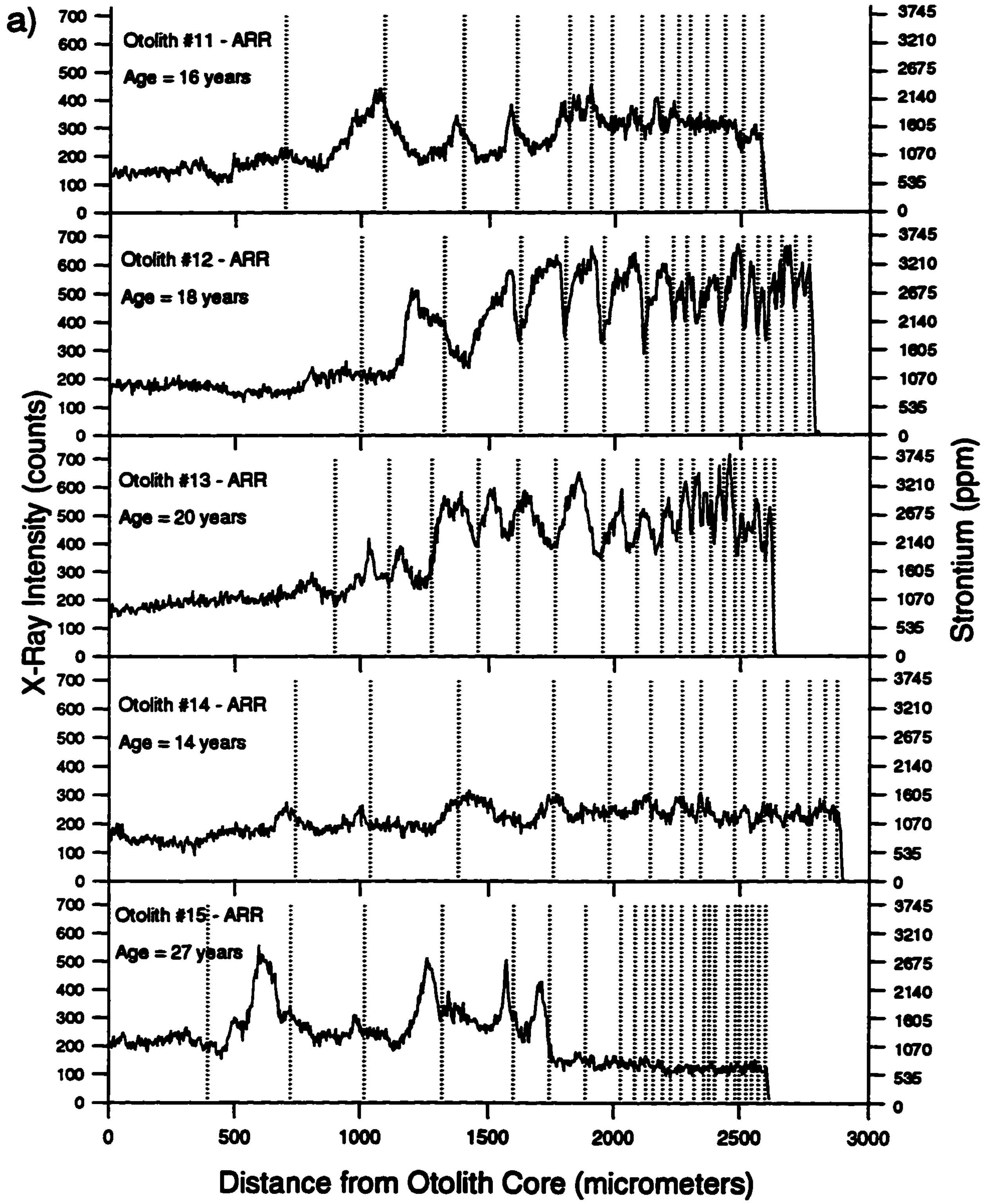
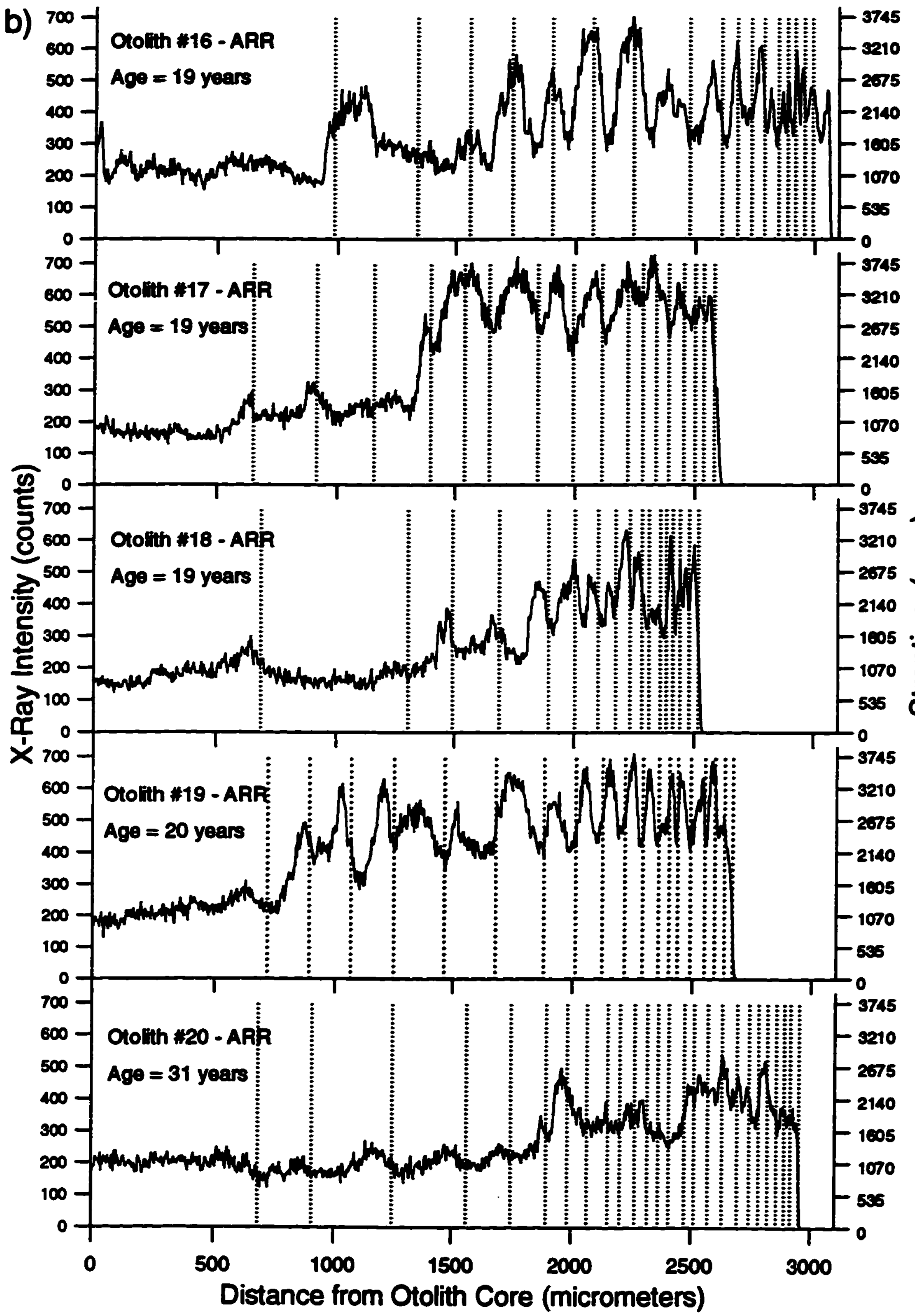


Figure 23. Strontium profiles from scanning microprobe line-scans of otoliths from a) male and b) female inconnu collected in the Arctic Red River. Annuli are marked with vertical dotted lines.


b)
Otolith #16 - ARR
Age = 19 years
Otolith #17 - ARR
Age = 19 years
Otolith #18 - ARR
Age = 19 years
Otolith #19 - ARR
Age = 20 years
Otolith #20 - ARR
Age = 31 years
X-Ray Intensity (counts)
Strontium (ppm)
0
100
200
300
400
500
600
700
0
535
1070
1605
2140
2675
3210
3745
0
500
1000
1500
2000
2500
3000
Distance from Otolith Core (micrometers)

there seems to be a wide range in the age at which Sr levels first peak, all strontium profiles of Arctic Red River inconnu show a strong oscillatory pattern that is clearly distinguishable from the flat profile characteristic of the Slave River inconnu.

Two of the inconnu otoliths from Arctic Red River had somewhat atypical Sr profiles. The line scan from inconnu #14 (Figure 23a) shows the oscillating pattern typical of other Arctic Red River fish, however it never displays the marked increases shown by the other fish from this river. The line scan from inconnu #15 (Figure 23a) shows the oscillating pattern of Sr variation during years 2 through 6. However, during the 7th year of growth, the Sr concentration dropped to the levels seen near the core of the otolith and remained low and constant through to the outer edge of the otolith

6. DISCUSSION

The results of this study indicate that both freshwater and anadromous forms of inconnu exist within the Mackenzie River system. Inconnu that migrate up the Arctic Red River were found to be anadromous, whereas those that enter the Slave River remain in fresh water throughout their lives. Both forms of inconnu are migratory, but the timing and distance of their spawning migrations, as well as their feeding/overwintering habitats, differed between the two rivers.

The three components of my study, gillnetting, radio telemetry, and otolith microchemistry analysis, along with the synthesis of historical data, complemented each other well. Gillnetting documented the general timing of migration into and out of the spawning rivers, and sampling of individuals captured in gillnets allowed me to determine the life history stage (immature, pre-spawner, post-spawner) of fish moving through the rivers at a given time. Gillnetting results showed that in both rivers there are defined seasonal movements of inconnu that appear to be associated with spawning. Radiotelemetry, supported by the historical distribution and tagging data, enabled me to determine the extent or distance of spawning migrations in each of the two rivers, and to define more precisely the time and location of spawning, and locations of overwintering and feeding areas. Finally, analysis of the strontium content of inconnu otoliths confirmed that inconnu from the Arctic Red River were anadromous and those from the Slave River lived entirely in fresh water; additionally, these analyses allowed me to infer the age of first seaward migration by anadromous inconnu.

6. 1 Migration patterns in the Arctic Red River

In the Arctic Red River, high catch rates of pre-spawners in July and August along with the steady increase in GSI of migrants over the summer, appeared to represent the upstream spawning run in that river. These results supported earlier studies that had noted large numbers of pre-spawning inconnu at the confluence of the Arctic Red and Mackenzie Rivers during the summer months and had suggested that inconnu spawn in the headwaters of the Arctic Red River (Hatfield *et al.* 1972a, Stein *et al.* 1973). Interestingly, inconnu were virtually absent from gillnet catches during September, suggesting that most had moved through the study area by this time and were en route to spawning areas further upstream. Radio-tracking on September 16 showed that two of the inconnu I radio-tagged in the lower part of the Arctic Red River had moved a substantial distance upstream (175 - 200 km), and it is likely that other, untagged individuals had also continued to move upstream. Although radio-tracking was not frequent enough to determine the upstream limit of migration or a holding pattern at a particular location in the river (generally considered indicative of a spawning area), there is still reason to believe these radio-tagged inconnu were close to or at their spawning grounds. The section of river where these inconnu were detected is characterized by relatively shallow, fast-flowing clear water and gravel substrate, which are known traits of preferred spawning habitat of inconnu (Alt 1969, 1988). Observations I made this fall (1996), further support the idea that this stretch of river is an important spawning area for inconnu. During that time I found large numbers of ripe inconnu just downstream (5-10 km) of the Cranswick River, the same area where I had located radio-tagged inconnu in 1993. This finding, coupled with direct observations of inconnu jumping out of the water on several occasions, provided good evidence that inconnu were using this region of the Arctic Red River to spawn.

Inconnu presumably spawned in the upper Arctic Red River towards the end of September. In early October (1992-93), large numbers of spent inconnu began moving through the study area, clearly representing the downstream post-spawning run in Arctic Red River. In contrast to the pre-spawning summer run, which was drawn out over 1.5-2 months, the post-spawning run was much more synchronous. Alt (1977) noted a similar pattern of movement for inconnu in Alaskan Rivers. The majority of post-spawners moved out of the Arctic Red River within 1-2 wk, although I occasinally captured spent individuals in November and December. Again, observations made in 1996 provide additional evidence regarding the time of spawning; running-ripe inconnu were found in the Arctic Red River between September 23-27, and the first spent individuals were gillnetted on September 25.

The differences in relative abundance between years, *i.e.*, the low summer maximum in 1992 and low fall maximum in 1993, may have been due to poor fishing effort during these two low periods. In 1992, the first year for this study, different sampling gear were initially tested, so gillnets were only used intermittently in July and August. Also, manpower was low during August, so nets could not be set as frequently as in other months. During 1993, a short cold spell at the end of September caused the lower 3 km of the Arctic Red River to become blocked with a layer of ice that was too thin for snowmobile travel and too thick for a boat to pass through. Thus, regular gillnetting stations could not be reached throughout the first half of October and, as a result, the major part of the fall post-spawning run could not be sampled. Despite these logistical difficulties, the temporal trends in catch rates and and corresponding GSI values were remarkably similar during both years.

Although gillnetting was continued in the Arctic Red River through to December 10 and November 15 in 1992 and 1993, respectively, inconnu were only occasionally captured in nets after October 15 (both years) and all were either immatures or spent adults. These results indicate that most post-spawning inconnu had moved out of the study area, presumably to overwintering/feeding areas in the Mackenzie Delta or along the Beaufort Sea coast, consistent with earlier speculations (Jessop and Lilley 1975; Mann 1975). In Alaskan rivers, all life history stages of anadromous inconnu overwinter in the lower reaches of larger rivers, with juveniles and non-spawning fish feeding in coastal inlets and estuaries of large rivers during the summer (Alt 1977). Two tracking flights were made through the Mackenzie Delta in November, 1993 to identify potential overwintering areas, but no radio-tagged inconnu were located. The recapture of one radio-tagged inconnu in the Aklavik Channel at the end of October, however, supported the idea that inconnu overwinter in larger channels of the delta. Unfortunately, the radio tags applied to inconnu in the Arctic Red River were only of 6-mo duration, precluding the identification of summer feeding areas.

Some of the radio telemetry results in the Arctic Red River were not consistent with expectations. For example, one fish (11C) was recaptured in the Mackenzie Delta on September 21, when inconnu were presumed to be at upstream spawning sites. This fish may have not recovered properly from the stress of being tagged and continued to drift downstream to its point of recapture, it may have been stressed to the point of foregoing spawning for the season, or it may not have been a spawner in the first place; without examination of the gonads, it is difficult to distinguish larger immature fish from spawners. Fish #2D moved upstream in the Mackenzie River to Fort Good Hope, although we had expected all tagged fish to move up the Arctic Red River. The tagging procedure may have caused disorientation during the post-tagging migration, or this fish may indicate that a portion of the inconnu found in the lower part of the Arctic Red River during the summer are transients, stopping to feed before continuing to migrate up the Mackenzie. Fish #5D and #9C were both recaptured near the mouth of Arctic Red River in early September. It would appear these fish also did not recover well from the tagging procedure, and therefore did not resume upstream migration.

6.2 Migration patterns in the Slave River

Inconnu in the Slave River follow a spawning cycle similar to those in the lower Mackenzie/Arctic Red River, but my gillnetting results indicate they begin to migrate upstream later in the summer and spawn later in the fall. Most pre-spawning inconnu migrated from Great Slave Lake into the Slave Delta between mid-August and mid-September, similar to the results of Tripp *et al.* (1981) and McLeod *et al.* (1985).

Catches of pre-spawning inconnu peaked in the upper Slave River (Buffalo Crossing to Fort Smith) in early September and again in mid-October. Inconnu do not occur upstream of the long stretch of rapids near Fort Smith (Boag and Westworth 1993). Tripp *et al.* (1981) suspected that the base of these rapids might be a major spawning area for inconnu, whereas McLeod *et al.* (1985) suggested as well both the Cunningham Landing area, and mid-river area (Point Ennuyeuse to Grand Detour) as potential spawning sites, so the increases in abundance I observed likely represented the arrival of inconnu to spawning grounds. The two peaks in abundance may have represented the arrival of two different spawning runs; alternatively, the September peak may be associated with a major influx of spawners, followed by minor movements or holding in one area prior to spawning and then a final movement (represented by the October peak) towards specific spawning sites.

Spawning probably occurred in mid-October and the sudden decrease in abundance indicated that inconnu moved rapidly downstream towards the end of October. Although I was not able to sample any spent inconnu during the out migration, I did observe substantial numbers of inconnu in running ripe condition (milt and eggs expelled from body with very little pressure) in mid-October of 1995 (in the Salt River area, approximately 20 km downstream of Fort Smith). Only a few ripe male inconnu were seen during 1994 (Fort Smith area, October 13 and 14), but during this year no gillnetting was done from October 15-20, and by October 21 inconnu appeared to have already moved downstream.

Radio-tracking generally supported the gillnetting data. Inconnu in the Slave River had been tagged once they had already migrated to what was thought to be the eventual spawning area. Most (10 of 16) inconnu tagged at the end of August 1994 were still in the general vicinity of the tagging sites when intensive tracking began on October 6, indicating that these fish had either held their upstream position for up to a month and a half or, if they had fallen downstream after tagging, they had returned to the area where they had originally been captured. This suggests that the majority of these inconnu successfully recovered from the tagging procedure. Following the mid-October tagging, detections or recaptures were made downstream of the tagging site. Since other inconnu were also beginning to move back downstream at this time, these radio-tagged fish could have simply dropped downstream due to the stress of handling, or they could have already spawned and were part of the downstream post-spawning run.

The continued presence of radio-tagged inconnu within the 20 km stretch between the Salt River and Rapids of the Drowned at Fort Smith through to mid-October suggests that they spawn somewhere within this stretch of river. From their radio-telemetry studies, McLeod *et al.* (1985) suspected that the base of the Rapids of the Drowned was one of several spawning sites for inconnu. Unfortunately, they were not able to determine the movements of radio-tagged inconnu that migrated into this area area because the fish were immediatly intercepted by the intense domestic fishery operating at the time. During my study few fisherman had nets near the rapids at Fort Smith, so I was able to monitor the subsequent movements of nearly all radio-tagged fish that migrated into the area. I found that all tagged inconnu moved downstream of Fort Smith after October 9 (many to the Cunningham Landing area), indicating that they may have spawned in the Fort Smith area and were beginning to move out of the river. The presence of ripe inconnu in gillnets set in the Fort Smith area during 1994 indicated that some inconnu may spawn there. However, other inconnu were not yet in spawning condition and, as mentioned previously, the first ripe inconnu were not seen until October 13. By this time most radio-tagged inconnu were already in the Cunningham Landing area, suggesting that they had moved into that area to spawn. I propose that migrating inconnu swim upstream until they reach the Rapids of the Drowned; some individuals may stay there to spawn, while others move back downstream in search of alternative spawning sites.

However, anecdotal information, and personal observations made in 1995 would both lead me to believe that the Fort Smith area is not as heavily used by spawners as other locations further downstream. During 1995, gillnetting was regularly done in the Fort Smith area until October 8. By the beginning of October the number of inconnu in that area had dropped and, according to local fishermen, "the run" was ending. No inconnu in spawning condition (ripe) were, however, observed during this time period (Pam Taylor, DFO Hay River; pers. comm.). Netting continued in the Salt River area for the remainder of October, where large numbers of ripe inconnu were captured, suggesting that spawning sites were located nearby. A similar pattern was observed in 1996, when inconnu left the Fort Smith area before coming into spawning condition, but were subsequently captured as ripe individuals at Cunningham Landing, at the Salt River and at Buffalo Crossing between from October 12-20 (Pam Taylor, pers. comm. and personal observation). In the stretch of river between Buffalo Crossing and Fort Smith, suitable spawning substrate of small cobble appears most extensive in the Cunningham Landing area, whereas other areas, including the base of Rapids of the Drowned near Fort Smith, contain mainly sand bars or mud bottom (personal observation). Suitable spawning substrate may be located further downstream, but this was not investigated during my study.

The progressive downstream dispersal of radio-tagged inconnu between October 16 and 25, 1994 coincided with decreasing gillnet catches, indicating that inconnu migrate out of the river at this time. After inconnu enter Great Slave Lake, they probably reside in offshore areas, since no tagged inconnu were located during subsequent tracking flights along the south shore of the lake or in the river. As well, radio-tagged inconnu were captured in the deep part of the lake during February and March, 1995 and during winter (November-April), most inconnu are taken from commercial fishing area 5 (Figure 24; Table 3) in the deep, East Arm of Great Slave Lake.

In contrast, all recaptures or detections made during June and July, 1995, were relatively close to shore in the shallow southern basin of the lake, indicating that inconnu spend the summer months feeding in this part of the lake. Fuller (1955), who collected gillnetting data over three summers (1944-46), also found inconnu were abundant off the south shore of Great Slave Lake, but were seldom found in deeper parts of the lake. The high commercial catches of inconnu in areas 1E and 3 (Figure 24) between May and October (Table 3) further suggest that the majority of inconnu feed in this part of the lake during summer. High summer catches of inconnu are also taken in area 5 (Table 6), but nearly all of these are caught between August and October, and are probably immature or non-spawning fish moving into this part of the lake to overwinter, since spawners are still within the rivers at this time of year.

6.3 Differences between migration patterns of inconnu from the Arctic Red and Slave Rivers

Anadromous inconnu using the Arctic Red River for spawning commence upstream migration to spawning areas 2-2.5 mo earlier than inconnu entering the Slave River, and there is approximately a 3 wk difference in the time at which inconnu spawn in these two rivers. Although inconnu first enter the Arctic Red River in early July, they probably commence upstream migration from overwintering/feeding areas (ca. 300-400 km downstream) in the spring, as has been documented for anadromous inconnu in

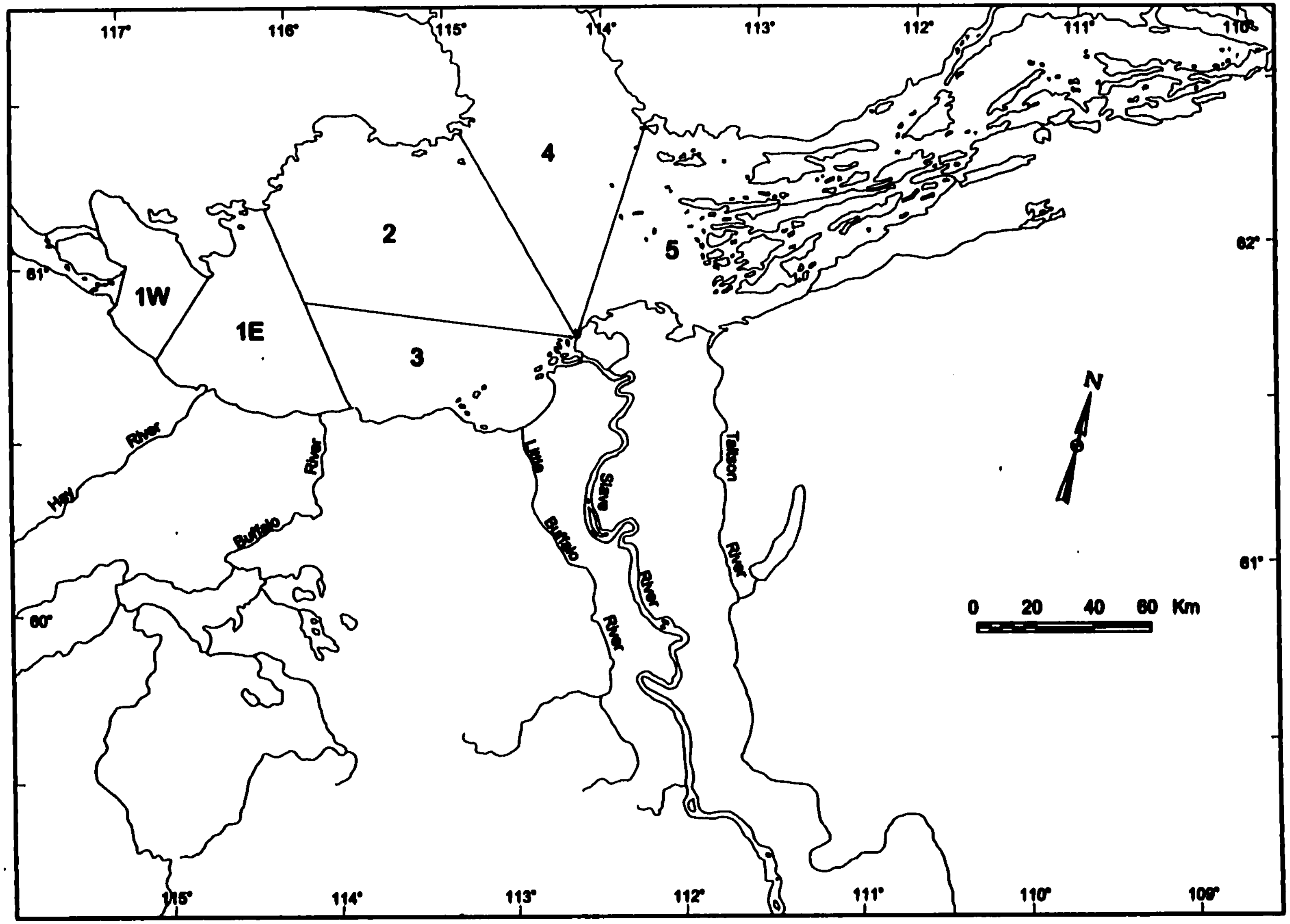


Figure 24. Commercial fishery management areas (1-5) on Great Slave Lake.

Table 3. Commercial catches (Kg) of inconnu on Great Slave Lake during summer (May-October) and winter (November-April), 1983-1995 (data obtained from Freshwater Fish Marketing Corporation, Winnipeg, Manitoba).

Year	Area 1E		Area 1W		Area 2		Area 3		Area 4		Area 5	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1983/84	2081	4275	697	3950	258	250	1926	.	1379	.	2156	.
1984/85	9427	8150	6339	3823	139	260	3731	.	3216	.	3526	11117
1985/86	3916	239	442	6525	421	118	10999	3316	4487	1068	11487	9873
1986/87	1476	3862	1112	2835	114	600	13490	.	2286	650	3553	23457
1987/88	20971	3721	49	791	131	4826	4606	.	197	294	7266	2336
1988/89	11761	2996	440	1901	89	2830	3665	2177	666	839	4463	8113
1989/90	7298	1489	1480	937	1313	286	9700	18	1951	641	19237	27813
1990/91	6829	668	112	934	127	174	7896	255	708	594	2778	21933
1991/92	6074	1148	1383	2494	250	392	1950	98	1197	281	1912	6114
1992/93	5922	1251	959	2176	273	1246	79	719	992	1044	138	.
1993/94	2264	477	34	1008	365	72	2224	92	887	1095	14100	2670
1994/95	3644	1272	248	522	176	103	3272	51	1208	2166	103	13547
Average:	6805.3	2462.3	1107.9	2324.7	304.7	929.8	5294.8	840.8	1597.8	867.2	5893.3	12697.3

Alaska, (Alt 1977). If so, they probably begin to migrate through the Mackenzie Delta around the time of break-up at the end of May. Although the Mackenzie River has usually broken up by this time, major channels of the delta don't break up until early June (Brunskill 1986). In contrast, inconnu from Great Slave Lake do not begin to move upstream through the Slave River Delta until August.

Inconnu appear to spawn in the Arctic Red River during the last two weeks of September, whereas those entering the Slave River begin spawning in mid-October, approximately 3 weeks later. Water temperature is probably an important determinant of spawning time in different rivers. Ice begins to form on the Slave River an average of 26 days later than the Arctic Red River, and in both rivers spawning takes place approximately 2-3 weeks prior to the average date of first ice formation (see Table 1). Water temperatures observed in both rivers at the time of spawning were well within the range of temperatures at which inconnu spawn in other rivers *e.g.*, various Alaskan rivers, 0-4 °C (Alt 1988); Ufa and Volga Rivers, 0.2-6 °C (Nikol'skii 1954); Ob River, 1.5-8.2 °C (Vork 1948, cited in Alt 1969). Turbidity in my study rivers decreased markedly once temperatures fell within this range (personal observation) and dissolved oxygen levels likely increased as well. Both are probably important factors in the successful development of whitefish eggs. Based on my results, it was unclear whether discharge is an important factor in determining when inconnu spawn. Alt (1988), however, noted that inconnu spawning grounds in Alaskan rivers were always located where the current speed was between 0.9 and 2.7 m sec^{-1}, so although overall discharge may not be of great importance, flow characteristics of specific spawning sites appear to be.

Given the importance of water temperature, differences in run timing of inconnu observed during this study were likely due, in part, to the latitudinal differences of the two spawning rivers. The Slave River is located further south and receives water from the Peace and Athabasca Rivers, both of which originate in the Rocky mountains of Alberta and Britsh Columbia. In contrast, the headwaters of the Arctic Red River are located much farther north in the Mackenzie Mountain Range, so this river cools down earlier in the fall and breaks up later in the spring. Inconnu may time the commencement of upstream migration so as to reach spawning grounds when temperature and flow characteristics are appropriate for egg rearing. If this is true, then inconnu that spawn in the Slave River should commence upstream migration approximately 26 d later than those that spawn in the Arctic Red River; that inconnu spawning in the Arctic Red River initiate upstream migration 2.5 mo earlier is probably explained by the extra distance that anadromous inconnu in the lower Mackenzie must travel to reach spawning grounds. Inconnu migrate at least twice as far to reach spawning grounds in the Arctic Red as compared with the Slave River.

Although there were differences in timing of upstream migration, inconnu in both rivers appeared to migrate earlier than neccessary. Inconnu migrating up the Slave River arrived in the vicinity of the spawning grounds 1-2 months before spawning actually took place. Recent (1996) radio telemetry studies conducted on the Arctic Red River found that inconnu had already arrived in the vicinity of their spawning grounds by early September (D. Chiperzak, DFO Inuvik; pers. comm.), and if inconnu in this river are capable of the average upstream rates of travel reported by other authors (Yukon River, Alaska, 13.8 km/day, Alt 1977; Kolyma River, Siberia, 30-35 km/day, Berg 1948; Slave River, 25.6 km/day, McLeod *et al.* 1985), then individuals entering the mouth of Arctic Red River from mid-July to early August could easily reach their spawning by mid-late August (*i.e.*, 1-1.5 mo before spawning). Dodson *et al.* (1985) observed similar behavior among lake cisco and lake whitefish in the James Bay area. They noticed that sexual maturation of these coregonids mainly occurred during upstream migration, and speculated that the higher water temperatures within the river might be neccessary for completion of gonad maturation for fall spawning. Similarly, Hokanson *et al.* (1973) found that low temperatures (2-4 °C) blocked maturation and ovulation in female brook trout. Given that most of the gonadal development of inconnu also occurs once they have entered the river (as indicated by the pronounced seasonal changes in GSI), it is quite possible that physiological constraints require them to migrate into spawning rivers when water temperatures are highest, even though they could spend more time in productive feeding areas prior to moving upstream.

Another possibility is that the migration timing of inconnu in these rivers is a "historical leftover" from migrations that were made during a different climatic period (e.g., Schmidt 1947). The spawning rivers of these fish may have been somewhat unpredictable, varying in length, with successive retreats and advances of glaciers during the last ice age so there may have been a selective advantage for earlier migrating individuals. Perhaps timing was fixed during that epoch and there has not been enough selection to change it.

6.4 Comparison of migration timing of males and females

My comparisons of seasonal changes in relative abundance of males and females suggest that both sexes migrate through spawning rivers at approximately the same time. Given the reproductive behavior of inconnu, it is not surprising to find that both sexes migrate at the same time. Like other species of whitefish, inconnu are broadcast spawners (Alt 1969). No effort is known to be put into digging redds or competing for suitable spawning partners (Alt 1969) as commonly occurs among salmon, trout and char (Scott and Crossman 1973). Large numbers of eggs are produced and they appear to invest little, if any, parental care. Thus, there would be no obvious advantage for males to arrive at the spawning grounds any earlier than the females.

6.5 Identification of freshwater and anadromous forms within the Mackenzie River system

Otolith microchemistry analysis confirm the existence of both freshwater and anadromous inconnu within the Mackenzie River system. The relatively flat, low concentration Sr profiles of otolith line scans from Slave River inconnu, indicate that these fish spend their entire life cycle within a low Sr environment (*i.e.*, freshwater). That this pattern was consistent among all 10 otoliths indicates that the migratory tendencies of these inconnu vary little. Halden *et al.* (1996) obtained similar profiles from known non-anadromous (land-locked) Arctic char. These findings are consistent with the hypothesis that inconnu from Great Slave Lake and adjoining tributaries complete their entire life cycle within freshwater (McPhail and Lindsey 1971; Scott and Crossman 1973).

In contrast, the line scans from Arctic Red River inconnu typically showed a flat, low-Sr profile near the core, followed by an oscillating pattern of high and low Sr concentrations through to the outer edge of the otolith. Such a pattern indicates that these fish, after spending 1-3 years as juveniles in a low-Sr environment, periodically move into a higher Sr environment, such as the estuary or sea, and are thus anadromous. The elevated Sr concentrations observed for anadromous inconnu otoliths were comparable to the levels seen for anadromous char that migrate to sea to feed in summer and move back into freshwater to overwinter (Halden *et al.* 1996).

There is some variabilty in the age at which inconnu first migrate to sea. Half of the inconnu analysed, appeared to migrate by their second summer, however, others did not migrate until as late as their sixth or seventh summer. These results are consistent with the capture of different-aged juveniles and adult inconnu in coastal areas during the summer months (*e.g.* Bond 1982; Hopky and Ratynski 1983; Lawrence *et al.* 1984; Bond and Erickson 1989). Although there is variation in the age at which inconnu first migrate to sea, all strontium profiles of Arctic Red River inconnu show an oscillatory pattern from the first annulus on. The initial oscillatory peaks, although not as high as the ones seen later in life, are distinguishable from the flat Sr profiles of the Slave River inconnu, and may represent earlier migrations into the Mackenzie estuary, where Sr content is likely intermediate between fresh- and sea-water.

Although most inconnu from Arctic Red River showed the pattem of Sr zoning described above, some variation was observed, suggesting there is flexibility in the life history strategies exhibited by inconnu from this river. For example, one individual (# 14) appeared to make only estuarine migrations throughout its life, as evidenced by the relatively low Sr concentrations of the oscillatory peaks. Another individual (#15) appeared to spend its first summer in freshwater and then migrated to sea during its second summer. Three more migrations were made between freshwater and sea water, but then from its 7th summer on, this fish remained in a freshwater environment. Interestingly this fish was the oldest male captured during the study. This kind of variation has also been seen in the Sr profiles of broad whitefish from the Arctic Red River (J. Babaluk, DFO Winnipeg; pers. comm.) and may be characteristic of anadromous coregonids within the lower Mackenzie.

Strontium levels of all Arctic Red River inconnu appeared to oscillate on an annual basis, peaking mainly during the wide growth zones, which correspond to summer. However, outer annuli were difficult to distinguish and otoliths would need to be stained or burned (Chilton and Beamish 1982) to accurately determine the positions of annuli along the entire length of strontium profiles. I therefore hesitate to make interpretations about the pattern of variation in Sr concentration without any further analysis. Although Sr levels oscillate between high and low concentrations once fish have made their first migration to sea, they rarely drop back down to the levels seen at the core of the otolith. Halden *et al.* (1996) suggested that Sr levels may persist for some time in the bloodstream once fish have returned to freshwater. Alternatively, inconnu may only migrate back to the estuary after spending time in the sea, rather than migrating further upstream to freshwater.

7. CONCLUSIONS

This study has shown that inconnu within the Mackenzie River system exhibit both a fundamental dichotomy and considerable intra-specific variation in migration patterns and habitat use. Inconnu from the Great Slave Lake area complete their entire life cycle within fresh water, feeding and overwintering in the lake and migrating up rivers such as the Slave and Buffalo to spawn. In contrast, inconnu from the lower Mackenzie and its tributaries are anadromous, moving longer distances between the sea and freshwater, and using a variety of habitats at different stages of their life cycle. Coastal areas are used mainly for feeding, whereas headwaters of freshwater tributaries, such as the Arctic Red River, are used for spawning. Although little winter data have been collected in the lower Mackenzie River system, the available information from this study, and others, suggests that the deeper parts of the Mackenzie Delta are important overwintering habitats.

The timing and distance of spawning migrations clearly differs between inconnu from the lower Mackenzie River and Great Slave Lake areas; furthermore, inconnu from these two areas do not appear to mix and most likely represent two different life history forms. Inconnu in the upper Mackenzie River may represent a third or "riverine", life history form, that does not mix with inconnu from other parts of the Mackenzie River system. Previous tag return information suggests that there may also be multiple spawning stocks in the Mackenzie River system, further complicating the population structure of this species.

This complex pattern of population variation is consistent with observations in other systems where inconnu of different life history types are known to exist (e.g., Yukon River system, Alt 1977, 1988; various rivers in Siberia, Berg 1948). Such variation seems to be a common characteristic of temperate and northern coregonines. For example, broad whitefish in North America (Reist and Bond 1988) and Siberia (Berg 1948) are thought to have three different life history forms (lacustrine, riverine and estuarine-anadromous). Similarly, anadromous and lacustrine forms are thought to exist for both North American lake whitefish, and least cisco (McPhail and Lindsey 1970); as well, anadromous and non-anadromous life history strategies have recently been suggested for Arctic cisco in the Mackenzie River system (Dillinger *et al.* 1992). Different life history forms also commonly occur in other salmonids, such as the chars (Hutchings and Morris 1985; McCart 1980), Atlantic salmon and brown trout (Jonsson 1985; Power 1969) and Pacific salmon (Foote *et al.* 1989; Randall *et al.* 1987).

Among these species, variation in life history and/or migratory patterns may be facultative, as indicated by the sympatric existence and interbreeding among anadromous and stream-resident individuals in brown trout and Arctic char (e.g., Jonsson 1985; McCart 1980), or by the varying degrees of anadromy shown by Atlantic salmon in the northern tributaries of Ungava Bay (Power et al. 1987). In other situations, however, a particular life history mode may be obligate, such as in land-locked, lake-dwelling Arctic char (e.g., Sprules 1952; Svenning and Grotnes 1991). In the case of inconnu of the Mackenzie River system, there are no geographic barriers to prevent seaward migration, so freshwater residency is likely facultative. Also, inconnu in the lower Mackenzie seem to show varying degrees of anadromy. Although most appear to migrate to sea, as evidenced by the analysis of Sr content in the otoliths, some may only migrate into the estuary and others initially migrate to sea but may then remain in fresh water after returning to spawn.

It is clear that the pattern of migratory behavior exhibited by inconnu fits with what has been observed for other salmonids. The interesting questions, however, are why has migration evolved within most of these species, and why do many exibit intra-specific variability/flexibility in their migratory strategies? Gross (1987) suggested that the differential productivity of marine and freshwater environments was the main factor driving the evolution of diadromous migration in fishes. He argued that moving between two habitats could influence fitness by altering growth (ultimately reproductive success) and survivorship; thus, migration should only evolve where the growth and survivorship benefits of exploiting a second habitat, along with the associated migration costs, outweigh the advantages of remaining in only one habitat.

Given this argument, it follows that variation likely exists within species when the degree of anadromy is dependent on several factors that can easily vary among populations. One such factor is the productivity of a given marine environment relative to the freshwater environment. Gross *et al.* (1988) found that the incidence of diadromy increases with the relative difference between marine and freshwater productivity. This finding is supported by the experimental work of Nordeng (1983), which demonstrated that Arctic char are able to facultatively respond to an increased freshwater food supply by not migrating. A second factor that may determine the degree of anadromy within a population is the migratory distance between marine habitat and freshwater spawning areas, something which can vary significantly among fish populations. Finally, within a given population, males and females could differ in their tendencies to migrate if there are significantly higher reproductive benefits accrued by females through increased growth (*i.e.*, increased fecundity with body size). This is well demonstrated in populations where resident and anadromous forms co-exist within the same rivers; sex ratios tend to be skewed towards males among residents and towards females within the migrants (e.g., Jonsson 1985; McCart 1980).

Gross's model would suggest that in the lower Mackenzie River area, anadromy evolved in inconnu because net benefits of moving between either the sea or estuary and freshwater breeding habitats, even with the cost of a long distance migration, were greater than the benefits of simply remaining in the freshwater habitat. The rivers in which these inconnu breed are quite deep, and have high turbidity (reducing light penetration) and high flow rates during the growing season, which should result in low productivity relative to the Mackenzie Estuary and coastal areas. Although the reasons are not well understood, the productivity of oceans and estuaries usually far exceeds that of fresh water in temperate and northern latitudes (Cole 1988; Gross 1988). For inconnu in Great Slave Lake, the combination of the lake's productivity (mainly concentrated within the shallow west basin, Brunskill 1986) and the significantly longer distance from the sea may make a fresh water life cycle more beneficial than an anadromous one. Great Slave Lake appears to function as a "freshwater sea" in that these inconnu still make spawning migrations into rivers that flow into the lake, returning to the lake to feed, a pattern analogous to that of anadromous inconnu in the lower Mackenzie River. This situation is probably unique (at least within North America), given that inconnu are not commonly found in any other large North American lakes.

Although this study has provided a better understanding of the patterns of migration and the population structure of inconnu in the Mackenzie River system, many questions about the biology of inconnu in this system still remain. Now that we know that inconnu within this river system are of two, possibly three, distinct migratory forms, this raises other questions: Are there any differences between these forms in terms of life history traits such as growth, age at maturity and fecundity, and if so, what are the biological and management implications? Are there any genetic differences beween forms (*i.e.*, are they reproductively separated or does some degree of mixing occur?); if so, what can these differences tell us about colonization and subsequent divergence of inconnu populations within the Mackenzie River system? Given the importance of this species for both domestic and commercial use, future research should focus on gaining detailed life history information and on determining the stock structure of this species within the Mackenzie. It is quite possible that inconnu, like other salmonids, exhibit spawning site fidelity, and thus may form multiple spawning stocks that are uniquely adaped to different rivers. An understanding of genetic structure is needed if we want to ensure the preservation of genetic diversity, and a knowlege of the life history variation/traits is needed to make predictive models for fisheries management. Without this information, one cannot accurately estimate densities and dynamics of populations or establish appropriate harvest rates or quotas. Protection of known critical habitats, along with further research in the above identified areas, will be essential to the continued availability of this important species.

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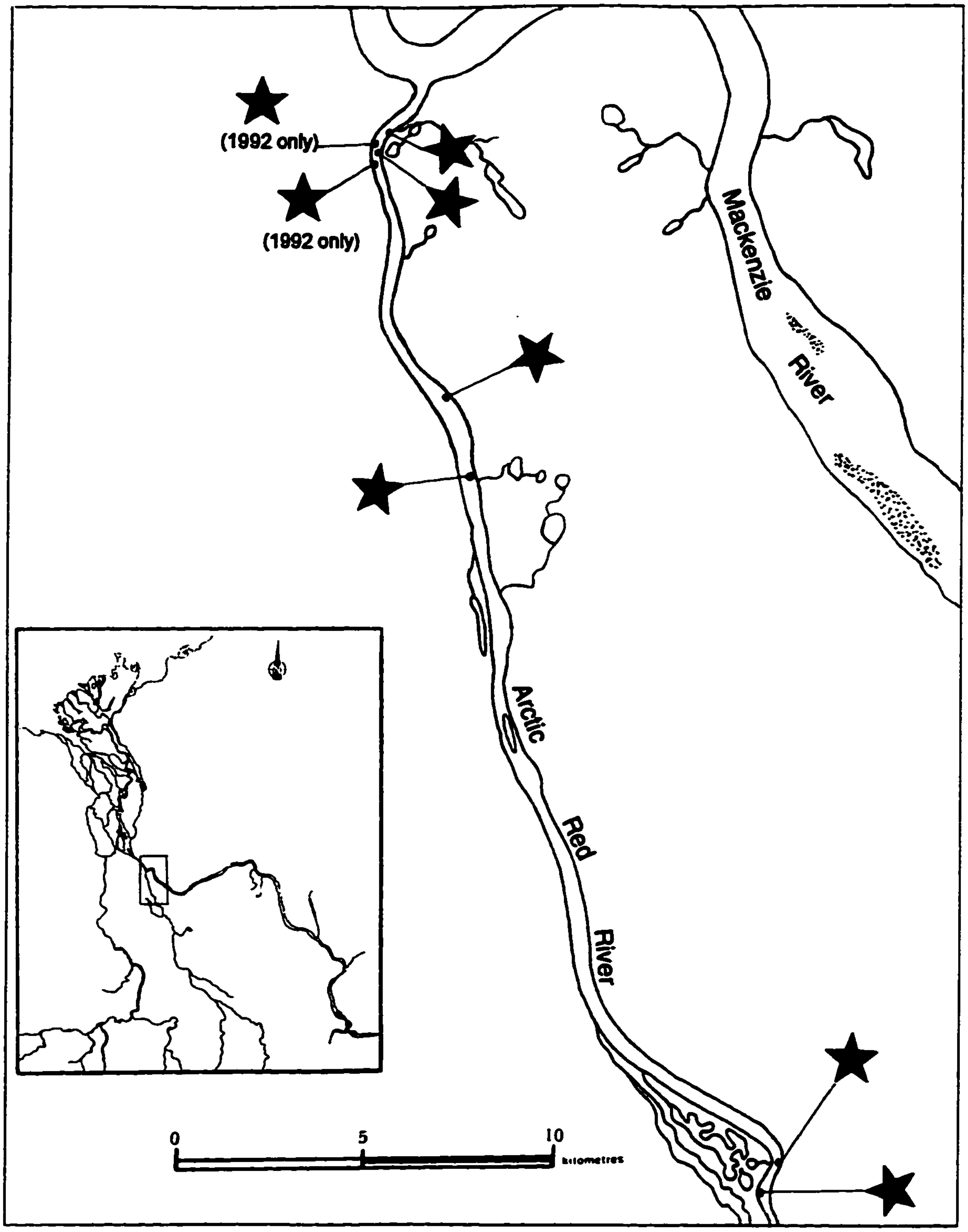

Appendix A. Most frequently used gillnetting stations (★) in the Arctic Red River during 1992 and 1993. Nets were occasionally set at other locations during the initial search for suitable netting locations and when conditions prevented the use of regular gillnetting stations.

Appendix B. A description of the relative stages of maturity used for inconnu.

	Female		Male	
Maturity Stage	Code	Description	Code	Description
Immature (virgin)	1	-Ovaries granular in texture -hard and triangular in shape -up to full length of body cavity -membrane firm -eggs distinguishable	6	-Testes long and granular -tubular and scalloped shape -up to full body length -putty-like firmness
Mature (spawner)	2	-Current year spawner -ovary fills body cavity -eggs near full size but not loose -not expelled by pressure	7	-Current year spawner -testes large and lobate -white to purplish color -centers may be fluid -milt not expelled by pressure
Ripe	3	-Ovaries greatly extended and fill body cavity -eggs full size and transparent -eggs expelled by slight pressure	8	-Testes full size -white and lobate -milt expelled by slight pressure
Spent	4	-Spawning complete -ovaries ruptured and flaccid -seed eggs visible -some retained eggs in body cavity	9	-Spawning complete -testes flaccid with some milt -blood vessels obvious -testes violet-pink in color
Resting	5	-Ovaries 40-50% of body cavity -membrane thin, loose, and semi-transparent -healed from spawning -seed eggs apparent with few atretic eggs -some eggs may be retained in body cavity	10	-Testes tubular, less lobate -healed from spawning -no fluid in center -usually full length -mottled and purplish in color
Unknown (virgin)	0	-cannot be sexed -gonads long or short and thin -transparent or translucent		

Appendix C. Correction factors used to standardize catch-per-unit-effort data to most commonly used mesh size (139 mm).

Corrections for 139 mm mesh size

Week	Location	Year	Mesh type (mm)		Mesh size correction factor
Aug. 8-14	Slave Delta	1995	multi-mesh (38-63.5)		*2.54062
Aug. 22-28	Slave River	1994	multi-mesh (38-63.5)		3.09022
Sep. 19-25	Slave River	1994	multi-mesh (38-63.5)		4.11106
Sep. 5-11	Slave River	1994	multi-mesh (38-63.5)		6.07011
Aug. 29-Sep. 4	Slave River	1994	multi-mesh (38-63.5)		9.42749
				Avg.(± Stdev):	5.04790
					(2.79384)
July 4-31	Slave Delta	1994	multi-mesh (38-101.5)		0.70129
Oct. 3-9	Arctic Red R.	1992	multi-mesh (38-101.5)		2.20134
July 4-31	Arctic Red R.	1993	multi-mesh (38-101.5)		5.87915
July 18-24	Arctic Red R.	1993	multi-mesh (38-101.5)		6.00560
July 4-31	Arctic Red R.	1992	multi-mesh (38-101.5)		*9.05462
Oct. 10-16	Arctic Red R.	1992	multi-mesh (38-101.5)		15.03257
July 11-17	Arctic Red R.	1992	multi-mesh (38-101.5)		*22.49433
				Avg. (± Stdev):	8.76698
					(7.65842)
Aug. 22-28	Slave River	1994	multi-mesh (76-101.5)		1.95920
Oct. 10-16	Slave River	1994	multi-mesh (76-101.5)		2.67545
Aug. 8-14	Slave Delta	1995	multi-mesh (76-101.5)		*3.37569
Oct. 17-23	Slave River	1995	multi-mesh (76-101.5)		6.95700
Aug. 29-Sep. 4	Slave River	1994	multi-mesh (76-101.5)		11.99862
Oct. 10-16	Slave River	1995	multi-mesh (76-101.5)		14.23107
				Avg. (± Stdev):	6.86617
					(5.18489)
July 11-17	Arctic Red R.	1993	101.5		4.19678
July 4-31	Slave Delta	1994	114.5		0.19039
Oct. 3-9	Slave River	1995	114.5		1.02732
Aug. 22-28	Slave River	1994	114.5		1.21923
Sep. 5-11	Slave River	1994	114.5		1.29179
Sep. 26-Oct. 2	Slave River	1995	114.5		2.23936
Oct. 10-16	Slave River	1995	114.5		2.57824
Sep. 19-25	Slave River	1995	114.5		2.65104
Oct. 10-16	Arctic Red R.	1992	114.5		3.20235
Sep. 26-Oct. 2	Arctic Red R.	1992	114.5		3.21824
Oct. 17-23	Slave River	1995	114.5		3.45368
				Avg. (± Stdev):	2.10716
					(1.10933)
Sep. 12-18	Slave Delta	1994	133.5		0.429707498

Corrections for 114.5 mm mesh size*

Week	Location	Year	Mesh type (mm)	Mesh size correction factor
Aug. 8-14	Slave Delta	1995	multi-mesh (38-63.5)	1.20571
July 11-17	Arctic Red R.	1992	multi-mesh (38-101.5)	10.67518
July 4-31	Arctic Red R.	1992	multi-mesh (38-101.5)	4.29707
Aug. 8-14	Slave Delta	1995	multi-mesh (76-101.5)	1.60201

* 139 mm correction factor was calculated by multiplying these values by the 114.5 mm correction factor (2.107)

Appendix D. Calculation of average ratio of Sr concentration (ppm) to Sr X-ray intensity (counts).

*Avg. Sr per Otolith (ppm)	Stdev. Sr (ppm)	**Avg. Sr per otolith (counts)	Stdev. Sr (counts)	Sr (ppm): Avg. Sr (counts)
887.33	89.8	166.96	14.89	5.31
980.33	96.8	204.96	12.92	4.78
755.33	23.71	141.96	12.23	5.32
822	96.14	142	10.17	5.79
795	124.72	167.04	11.66	4.76
803.67	88.79	139.88	9.85	5.75
744.33	58.79	146.73	13.67	5.07
1123	22.54	187.15	20.55	6
				Avg. ppm:counts ± Stdev = 5.35 ± 0.47

* Average Sr concentration (ppm) was determined from three point analyses done in the core area of each otolith.
** Average Sr X-ray intensity (counts) was determined from the intensities recorded in the first 100 um of the line-scans for each otolith.

Appendix E (1-5). Standardized catch-per-unit-effort data for inconnu gillnetted in the Arctic Red and Slave Rivers between 1992 and 1995. For column headings: F = female, M = male, U = sex undetermined, All = all individuals combined.

Appendix E1. Standardized weekly average catch-per-unit-effort values for inconnu captured in Arctic Red River during 1992.

Week	FAvg Wkly CPUE	FStderror	MAvg Wkly CPUE	MStderror	UAvg Wkly CPUE	UStderror	AllAvg Wkly CPUE	AllStderror	# Nets Set
June 13-19	.	.	.	.	.	.	.	.	0
June 20-26	0	0	0	0	0	0	0	0	2
June 27-July 3	.	.	.	.	.	.	.	.	0
July 4-10	0	.	0	.	0	.	0	.	1
July 11-17	0.015413209	0.014622254	0.043151043	0.020709696	0.021801201	0.014607536	0.080365452	0.027202716	10
July 18-24	0.012403006	0.008282717	0.049485572	0.01968678	0	0	0.061888578	0.022162394	10
July 25-31	0.019252382	0.012762025	0.055844657	0.022319806	0	0	0.07509704	0.025861509	8
Aug. 1-7	0	.	0	.	0	.	0	.	1
Aug. 8-14	0.031642885	0.031642885	0.134693692	0.055163617	0	0	0.166336577	0.066806502	2
Aug. 15-21	.	.	.	.	.	.	.	.	0
Aug. 22-28	0.008411101	0.008411101	0.018399283	0.013801697	0.007509911	0.007509911	0.034320295	0	15
Aug. 29-Sep. 4	0	0	0.013611714	0.009304887	0.004194365	0.004194365	0.01780608	0	16
Sep. 5-11	0.009100297	0.009100297	0	0	0	0	0.009100297	0	10
Sep. 12-18	0.003116762	0.003116762	0.004333875	0.003155965	0	0	0.007450636	0.0042949	23
Sep. 19-25	0.002331002	0.002331002	0	0	0	0	0.002331002	0.0023310	13
Sep. 26-Oct. 2	0.022828997	0.006610797	0.004332395	0.002375515	0.001564565	0.001564565	0.028725957	0.0074476	21
Oct. 3-9	0.141348541	0.062351922	0.423584635	0.181972058	0.186468992	0.076136372	0.751402168	0.2288886	14
Oct. 10-16	0	0	0.020221244	0.008431839	0.007769348	0.005409958	0.027990592	0.0086127	13
Oct. 17-23	0	0	0.018644166	0.012167444	0.000868056	0.000868056	0.019512222	0.0120973	12
Oct. 24-30	0	0	0	0	0	0	0	0	16
Oct . 31-Nov. 6	0	0	0.004547754	0.00398492	0	0	0.004547754	0.0039849	18
Nov. 7-13	0	0	0	0	0	0	0	0	13
Nov. 14-20	0	0	0.013201666	0.011731248	0	0	0.013201666	0.0117312	8
Nov. 21-27	0	0	0.00078125	0.00078125	0.0072835	0.004678975	0.0079345	0.0047255	6
Nov. 28-Dec. 4	0	0	0	0	0	0	0	0	3
Dec. 5-11	0	0	0	0	0.001953125	0.001953125	0.001953125	0.0019531	2

Appendix E2. Standardized average weekly catch-per-unit-effort for inconnu captured in Arctic Red River during 1993.

Week	FAvg Wkly CPUE	FStderror	MAvg Wkly CPUE	MStderror	UAvg Wkly CPUE	UStderror	AllAvg Wkly CPUE	AllStderror	# Nets Set
June 13-19	.	.	.	.	.	.	.	.	0
June 20-26	.	.	.	.	.	.	.	.	0
June 27-July 3	.	.	.	.	.	.	.	.	0
July 4-10	.	.	.	.	.	.	.	.	0
July 11-17	0.025780469	0.013513735	0.104531028	0.055679228	0.006036217	0.006036217	0.136347714	0.06414511	7
July 18-24	0.080566424	0.029794792	0.077553	0.015681115	0	0	0.158119424	0.028565859	10
July 25-31	0.079514959	0.017057038	0.128629544	0.033442	0	0	0.208144502	0.04131753	13
Aug. 1-7	0.032346684	0.01260184	0.08409827	0.021404907	0.199755557	0.078136741	0.31620051	0.069554373	21
Aug. 8-14	0.046889604	0.031689253	0.090934091	0.032874475	0.339686575	0.147535067	0.477510269	0.120168373	9
Aug. 15-21	0.014533894	0.007881083	0.044076861	0.016557011	0.007323458	0.005156379	0.065934213	0.025048648	14
Aug. 22-28	0.020873644	0.013667421	0.039118658	0.025431112	0	0	0.059992302	0.024499799	8
Aug. 29-Sep. 4	0.012873326	0.012873326	0.009932459	0.009932459	0	0	0.022805786	0.013384086	4
Sep. 5-11	0	0	0.079681275	0.079681275	0	0	0.079681275	0.079681275	2
Sep. 12-18	0.009447331	0.009447331	0	0	0	0	0.009447331	0.009447331	5
Sep. 19-25	0	0	0.005557254	0.005557254	0	0	0.005557254	0.005557254	17
Sep. 26-Oct. 2	0	0	0	0	0	0	0	0	7
Oct. 3-9	0.020158066	0.011709642	0.094207006	0.054666606	0	0	0.114365073	0.044436109	4
Oct. 10-16	0.005559747	0.003228756	0.039520658	0.017191814	2.61579E-05	2.61579E-05	0.045106564	0.018577313	14
Oct. 17-23	0	0	0.001586294	0.001586294	0	0	0.001586294	0.001586294	24
Oct. 24-30	0	0	0	0	0	0	0	0	16
Oct . 31-Nov. 6	0	0	0	0	0	0	0	0	8
Nov. 7-13	0	0	0	0	0	0	0	0	6
Nov. 14-20	0	0	0	0	0.008333333	0.008333333	0.008333333	0.008333333	5
Nov. 21-27	.	.	.	.	.	.	.	.	0

Appendix E3. Standardized average weekly catch-per-unit-effort for inconnu captured in Slave River during 1994.

Week	FAvg Wkly CPUE	FStderror	MAvg Wkly CPUE	MStderror	UAvg Wkly CPUE	UStderror	AllAvg Wkly CPUE	AllStderror	# Nets Set
June 13-19	.	.	.	.	.	.	.	.	0
June 20-26	0	0	0	0	0	0	0	0	2
June 27-July 3	.	.	.	.	.	.	.	.	0
July 4-10	.	.	.	.	.	.	.	.	0
July 11-17	.	.	.	.	.	.	.	.	0
July 18-24	.	.	.	.	.	.	.	.	0
July 25-31	0	0	0	0	0	0	0	0	28
Aug. 1-7	0	0	0	0	0	0	0	0	13
Aug. 8-14	0.194884582	0.194884582	0	0	0	0	0.194884582	0.194884582	8
Aug. 15-21	0.07821951	0.060999684	0.061872439	0.060558969	0	0	0.140091949	0.12092752	22
Aug. 22-28	0.194062473	0.064352572	0.035267226	0.020056381	0.026928627	0.024639561	0.258256325	0.066649465	23
Aug. 29-Sep. 4	0.362560461	0.143163619	0.551500249	0.196033589	0.190909091	0.190909091	1.104969801	0.299512638	11
Sep. 5-11	0.277279566	0.062093939	0.524754504	0.112973821	0.018556318	0.018556318	0.820590366	0.160284752	17
Sep. 12-18	0.085715175	0.015985463	0.20538331	0.044432026	0	0	0.291098465	0.056566778	25
Sep. 19-25	0.041547619	0.021858453	0.194349525	0.114859217	0.037363762	0.026753189	0.273260906	0.115139477	9
Sep. 26-Oct. 2	0.475945358	0.266535128	0.081168831	0.081168831	0	0	0.55711419	0.273862436	7
Oct. 3-9	0.01875	0.01875	0.445861466	0.354169297	0	0	0.464611466	0.357541533	10
Oct. 10-16	0.01498801	0.01498801	0.105959469	0.105959469	0.688912913	0.472136839	0.809860391	0.467896344	12
Oct. 17-23	0	0	0	0	0	0	0	0	4
Oct. 24-30	.	.	.	.	.	.	.	.	0
Oct . 31-Nov. 6	.	.	.	.	.	.	.	.	0
Nov. 7-13	.	.	.	.	.	.	.	.	0
Nov. 14-20	.	.	.	.	.	.	.	.	0
Nov. 21-27	.	.	.	.	.	.	.	.	0

Appendix E4. Standardized average weekly catch-per-unit-effort for inconnu captured in Slave Delta during 1994.

Week	FAvg Wkly CPUE	FStderror	MAvg Wkly CPUE	MStderror	UAvg Wkly CPUE	UStderror	AllAvg Wkly CPUE	AllStderror	# Nets Set
June 13-19	.	.	.	.	.	.	.	.	0
June 20-26	.	.	.	.	.	.	.	.	0
June 27-July 3	.	.	.	.	.	.	.	.	0
July 4-10	.	.	.	.	.	.	.	.	0
July 11-17	.	.	.	.	.	.	.	.	0
July 18-24	.	.	.	.	.	.	.	.	0
July 25-31	0.029699606	0.0177619	0.019358298	0.019358298	0.037465753	0.037465753	0.066523658	0.041823532	15
Aug. 1-7	.	.	.	.	.	.	.	.	0
Aug. 8-14	0.030737303	0.030737303	0.092211909	0.092211909	0	0	0.122949213	0.122949213	6
Aug. 15-21	0	0	0.433438417	0.357992749	0	0	0.433438417	0.357992749	4
Aug. 22-28	0	0	1.091419249	1.024432397	0	0	1.091419249	1.024432397	4
Aug. 29-Sep. 4	0.419127124	0.193814634	0.306470679	0.306470679	0	0	0.725598004	0.500285514	2
Sep. 5-11	.	.	.	.	.	.	.	.	0
Sep. 12-18	0.177530051	0.167729431	0.012675744	0.004716992	0.002717391	0.002717391	0.192923186	0.168423334	12
Sep. 19-25	.	.	.	.	.	.	.	.	0
Sep. 26-Oct. 2	.	.	.	.	.	.	.	.	0
Oct. 3-9	0	0	0	0	0	0	0	0	4
Oct. 10-16	.	.	.	.	.	.	.	.	0
Oct. 17-23	.	.	.	.	.	.	.	.	0
Oct. 24-30	.	.	.	.	.	.	.	.	0
Oct . 31-Nov. 6	.	.	.	.	.	.	.	.	0
Nov. 7-13	.	.	.	.	.	.	.	.	0
Nov. 14-20	.	.	.	.	.	.	.	.	0
Nov. 21-27	.	.	.	.	.	.	.	.	0

Appendix E5. Standardized average weekly catch-per-unit-effort for inconnu captured in Slave Delta and Slave River during 1995.

Week	Slave Delta AllAvg Wkly CPUE	Slave Delta AllStderror	Slave Delta # Nets Set	Slave River AllAvg Wkly CPUE	Slave River AllStderror	Slave River # Nets Set
May 29-June 5	.	.	0	0	0	12
June 6-12	.	.	0	0	0	4
June 13-19	.	.	0	0	0	4
June 20-26	0.089753903	0.089753903	15	.	.	0
June 27-July 3	0	0	2	.	.	0
July 4-10	.	.	0	0	0	10
July 11-17	0	0	17	.	.	0
July 18-24	0.148618476	0.148618476	11	0	0	2
July 25-31	.	.	0	0	0	8
Aug. 1-7	.	.	0	0	0	8
Aug. 8-14	1.587618483	0.669575263	17	.	.	0
Aug. 15-21	.	.	0	0.813897449	0.417910481	6
Aug. 22-28	.	.	0	.	.	0
Aug. 29-Sep. 4	.	.	0	.	.	0
Sep. 5-11	.	.	0	.	.	0
Sep. 12-18	.	.	0	1.148350425	0.169339342	10
Sep. 19-25	.	.	0	1.056270934	0.232549382	8
Sep. 26-Oct. 2	.	.	0	0.746477934	0.149832517	11
Oct. 3-9	.	.	0	0.575189885	0.156361387	21
Oct. 10-16	.	.	0	3.077994476	0.825577925	15
Oct. 17-23	.	.	0	0.663151616	0.196065904	10
Oct. 24-30	.	.	0	.	.	0

Appendix F. Gonadosomatic indices for female inconnu collected in the Slave River and Slave Delta (1994 1995) and in the Arctic Red River (1992-1993). Dates based on the Julian Calendar.

Slave River				Slave Delta				Arctic Red River			
1994		1995		1994		1995		1992		1993	
Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI
222	7.29	228	7.58	210	5.71	222	4.6096	193	9.00	194	3.79
230	8.58	228	7.94	211	6.26	222	4.6823	196	4.64	195	3.63
233	12.04	228	9.40	212	9.19	222	7.5812	200	5.78	197	6.52
234	11.17	228	9.23	225	9.05	222	12.853	204	5.11	199	2.59
235	9.33	228	15.19	241	11.7	222	19.444	207	4.86	199	5.24
235	9.52	230	6.45	241	18.1	223	5.5556	208	4.26	199	3.34
235	6.81	285	17.99	241	11.2	223	11.327	224	8.49	199	3.94
235	7.38	287	18.03	257	19.2	223	12.853	239	13.61	200	3.3
236	7.84	287	23.50	257	15.1	224	8.2437	252	11.61	200	7.87
236	11.95	287	18.54	257	14.8	225	4.878	257	15.37	200	6.28
237	18.3			257	15	225	6.383	262	1.42	200	3.91
237	6.85			258	13.4	225	9.0643	271	2.48	200	4.02
237	9.05			259	13.7	225	13.506	271	2.03	200	6.27
237	7.93							271	2.10	200	5.37
238	9.23							271	1.67	200	8.46
238	11.33							273	2.42	200	6.01
238	11.52							273	2.26	200	5.67
238	10.4							273	1.69	201	3.23
241	10.9							274	1.74	201	6.87
241	9.25							274	2.14	202	4.84
242	11.71							274	2.18	203	5.89
242	18.66							274	2.08	208	5.87
243	11.85							274	2.11	208	5.91
244	12.2							274	2.21	208	6.39
246	18.26							275	1.64	208	5.85
246	18.29							275	1.57	208	6.88
246	13.72							275	1.71	209	6.43
246	18.41							275	1.91	209	6.39
246	19.89							275	1.64	209	5.97
249	13.3							275	2.44	209	10.29
249	16.9							275	1.81	210	7.14
250	12.63							275	2.87	211	6.93
250	13.83							277	2.08	211	4.94
250	13.26							277	1.96	211	5.64
250	12.03							277	1.55	211	13.24
250	18.99							277	1.69	211	8.52
251	10.76							277	2.57	212	6.75
252	16.38							277	2.47	212	6.68
252	16.77							277	3.00	212	4.87
252	13.37							277	2.21	215	7.91
252	13.23							277	2.55	215	8.92
252	15.76							277	2.24	215	7.74
252	13.93							278	2.26	215	9.14
252	11.68							278	2.26	215	8.84

Appendix F (continued)

Slave River				Slave Delta				Arctic Red River			
1994		1995		1994		1995		1992		1993	
Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI
252	11.67							278	1.88	216	5.65
254	14.51							278	2.21	216	8.06
254	13.89							278	1.85	216	4.61
254	14.13							278	2.02	217	7.02
254	16.93							278	2.80	218	8.67
254	14.23							278	2.20	218	9.94
254	16.7							278	2.50	218	13.9
254	20.46							279	2.31	222	7.5
254	14.42							279	1.88	228	13.81
254	24.21							279	2.19	232	13.46
255	15.57							279	2.31	233	11.87
255	13.93							282	2.49	233	12.5
255	16.9							284	2.34	239	16.4
255	18.54							322	1.16	239	20.49
255	17.16									239	13.9
255	15.6									239	18.2
255	11.06									243	13.58
256	20.28									260	4.17
256	12.99									278	1.89
256	13.77									280	2.23
256	14.97									280	1.93
256	19.42									283	1.74
256	14.81									285	2.28
256	15.28									285	1.66
256	18.71									285	2.09
256	17.94									285	2.12
257	12.81									285	2.19
257	14.24									285	2.35
257	12.4									285	2.28
257	15.42									285	2.27
257	13.4									286	2.36
257	11.92									291	1.72
257	16.21									291	1.88
257	15.32									291	2.02
257	16.39									291	1.51
257	13.84									291	2.74
257	17.62									291	2.02
257	14.4									291	2.22
257	14.7										
258	15.87										
258	15.55										
258	16.83										
258	18.11										
258	17.82										
258	15.57										
259	12.82										

Appendix F (continued)

Slave River				Slave Delta				Arctic Red River			
1994		1995		1994		1995		1992		1993	
Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI	Date	GSI
259	13.73										
260	14.43										
260	16.55										
260	19.4										
260	16.01										
260	18.74										
260	17.41										
260	20.72										
260	18.71										
260	26.75										
260	18.22										
261	15.72										
261	16.26										
261	18.04										
261	21.05										
261	15.19										
261	26.23										
261	28.02										
261	14.09										
261	13.12										
261	1.39										
261	19.88										
265	18.71										
265	14.31										
265	14.76										
265	20.5										
265	19.3										
266	18.9										
266	13.51										
266	19.56										
266	23.12										
266	20.03										
274	16.21										
275	31.65										
275	19.37										
275	21.54										
275	27.14										
275	22.92										
275	22.43										
275	16.1										
275	13.99										
275	18.04										
275	18.38										
275	26.35										
287	20.01										
287	26.91										

Appendix G1. Tagging, detection and recapture locations of inconnu radio-tagged in the Artic Red River in 1993.

Fish #	Frequency	Event	Date	Coordinates
1A	49.822	Tagged	8-Aug	67-21-05N 133-43-00W
2A	48.210	Tagged	8-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-24-00N 133-46-00W
-C		Detected	15-Aug	67-27-00N 133-45-00W
-D		Recaptured	3-Sep	66-23-00N 128-45-00W
3A	48.010	Tagged	9-Aug	67-21-05N 133-43-00W
4A	48.051	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-27-00N 133-45-00W
-C		Detected	15-Aug	67-24-00N 133-46-00W
-D		Detected	16-Sep	66-02-45N 131-55-87W
5A	48.070	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-21-05N 133-43-00W
-C		Detected	15-Aug	67-27-00N 133-45-00W
-D		Recaptured	16-Aug to 15-Sep	67-27-00N 133-45-00W
6A	48.110	Tagged	9-Aug	67-21-05N 133-43-00W
7A	48.130	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	15-Aug	67-24-00N 133-46-00W
8A	48.150	Tagged	9-Aug	67-21-05N 133-43-00W
9A	48.190	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	15-Aug	67-21-05N 133-43-00W
10A	48.230	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-24-00N 133-46-00W
-C		Detected	16-Sep	66-13-92N 133-35-94W
-D		Recaptured	5-Oct	67-27-00N 133-45-00W
11A	48.250	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-24-00N 133-46-00W
-C		Recaptured	21-Sep	68-32-00N 133-52-00W
12A	48.090	Tagged	9-Aug	67-21-05N 133-43-00W
-B		Detected	9-Aug	67-27-00N 133-45-00W
-C		Recaptured	30-Oct	68-09-00N 134-42-00W

Appendix G2. Tagging, detection and recapture locations of inconnu radio-tagged in the Slave River in 1994.

Fish #	Frequency	Event	Date	Coordinates
1A	49.170	Tagged	20-Aug-94	60-06-34N 112-14-04W
-B		Detected	9-Oct-94	60-01-05N 111-53-32W
2A	49.350	Tagged	20-Aug-94	60-06-34N 112-14-04W
-B		Detected	5-Oct-94	60-01-05N 111-53-32W
-C		Detected	15-Oct-94	60-01-40N 112-07-33W
-D		Recaptured	11-Jul-95	61-02-00N 115-45-00W
3A	49.270	Tagged	22-Aug-94	60-06-34N 112-14-04W
4A	49.230	Tagged	22-Aug-94	60-06-34N 112-14-04W
-B		Detected	18-Oct-94	60-49-00N 113-02-00W
5A	49.190	Tagged	25-Aug-94	60-01-05N 111-53-32W
-B		Detected	9-Oct-94	60-01-40N 112-07-33W
-C		Detected	11-Oct-94	60-06-13N 112-13-29W
-D		Detected	15-Oct-94	60-01-40N 112-07-33W
-E		Detected	18-Oct-94	60-01-20N 112-05-00W
-F		Detected	25-Oct-94	60-44-00N 113-10-00W
6A	49.290	Tagged	28-Aug-94	60-01-05N 111-53-32W
-B		Detected	18-Oct-94	60-02-30N 112-01-00W
7A	49.210	Tagged	30-Aug-94	60-01-05N 111-53-32W
-B		Recaptured	3-Oct-94	60-01-05N 111-53-32W
8A	49.330	Tagged	30-Aug-94	60-01-05N 111-53-32W
-B		Detected	11-Oct-94	60-02-30N 112-01-00W
-C		Detected	15-Oct-94	60-01-40N 112-07-33W
-D		Detected	18-Oct-94	60-20-00N 112-34-00W
-E		Detected	18-Oct-94	60-21-00N 112-38-00W
-F		Detected	25-Oct-94	60-47-00N 113-09-00W
-G		Recaptured	13-Oct-95	60-06-13N 112-13-29W
9A	49.250	Tagged	30-Aug-94	60-01-05N 111-53-32W
-B		Recaptured	26-Jun-95	61-07-25N 114-05-00W
10A	49.470	Tagged	31-Aug-94	60-01-05N 111-53-32W
-B		Detected	6-Oct-94	60-01-40N 112-07-33W
-C		Detected	18-Oct-94	60-45-00N 112-58-30W
-D		Detected	18-Oct-94	60-49-00N 112-56-00W
-E		Detected	25-Oct-94	60-58-00N 113-15-00W
-F		Detected	9-Jun-95	61-20-00N 113-45-00W
11A	49.120	Tagged	31-Aug-94	60-01-05N 111-53-32W
-B		Detected	9-Oct-94	60-01-40N 112-07-33W
-C		Recaptured	1-Feb-95	61-45-00N 113-00-00W
12A	49.100	Tagged	31-Aug-94	60-01-05N 111-53-32W
13A	49.140	Tagged	31-Aug-94	60-01-05N 111-53-32W
-B		Recaptured	5-Oct-94	60-01-05N 111-53-32W
14A	49.570	Tagged	31-Aug-94	60-01-05N 111-53-32W
15A	49.550	Tagged	31-Aug-94	60-01-05N 111-53-32W
-B		Recaptured	31-Mar-95	61-45-00N 113-00-00W
16A	49.590	Tagged	31-Aug-94	60-01-05N 111-53-32W
-B		Recaptured	15--Oct-94	60-01-40N 112-07-33W

Appendix G2 (continued)

Fish #	Frequency	Event	Date	Coordinates
17A	49.750	Tagged-	12-Oct-94	60-01-05N 111-53-32W
-B		Detected	15-Oct-94	60-02-14N 111-54-33W
18A	49.630	Tagged	12-Oct-94	60-01-05N 111-53-32W
-B		Detected	15-Oct-94	60-02-14N 111-54-33W
-C		Detected	18-Oct-94	60-05-00N 112-14-00W
-D		Detected	9-Jun-95	61-25-00N 113-35-00W
19A	49.910	Tagged	13-Oct-94	60-01-05N 111-53-32W
-B		Detected	15-Oct-94	60-02-14N 111-54-33W
20A	49.870	Tagged	13-Oct-94	60-01-05N 111-53-32W
-B		Detected	15-Oct-94	60-02-14N 111-54-33W
-C		Detected	18-Oct-94	60-18-30N 112-25-00W
-D		Recaptured	21-Jun-95	60-54-00N 116-09-00W
21A	49.790	Tagged	13-Oct-94	60-01-05N 111-53-32W
-B		Detected	15-Oct-94	60-02-14N 111-54-33W
-C		Detected	18-Oct-94	60-16-00N 112-22-00W
-D		Detected	9-Jun-95	61-25-00N 113-35-00W
22A	49.610	Tagged	13-Oct-94	60-01-05N 111-53-32W
-B		Detected	18-Oct-94	60-10-30N 112-16-04W
23A	49.770	Tagged	13-Oct-94	60-01-05N 111-53-32W
24A	49.390	Tagged	13-Oct-94	60-01-05N 111-53-32W
25A	49.370	Tagged	13-Oct-94	60-01-05N 111-53-32W
-B		Detected	9-Jun-95	61-20-00N 113-45-00W

Appendix H. Water temperatures in the Slave River (1994-1995) and in the Arctic Red River (1992-1993).

Slave River				Arctic Red River			
1994		1995		1992		1993	
Date[†]	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)
176	17.5	149	13.9	198	15	192	16
177	18 *	150	13.9	199	16	194	16
178	18 *	151	14.5	200	17	195	16
179	17 *	152	15.5	201	18	196	21
180	18 *	153	16.4	202	18	197	17
181	18 *	154	19.4	203	16	199	17
183	18 *	156	17.4	204	18	200	16.5
185	19 *	157	16.7	206	20.5	201	15
186	19 *	161	18 *	207	19.5	202	15
187	18 *	163	18.5	208	19.5	203	13
188	19 *	164	18.6	212	16	208	15
189	18 *	165	18.9	219	16	209	16
190	19 *	166	19 *	222	15	210	16
191	19 *	167	19.8 *	252	6.5	211	14
192	18 *	168	20.5 *	253	6	212	15
193	18 *	169	20 *	254	4	213	15
194	19 *	170	20 *	255	4	214	15
195	18 *	171	18.9 *	257	3.5	216	16
196	19 *	172	18 *	260	2.5	217	16
197	19 *	173	18 *	261	2	218	15
198	19 *	174	18.8 *	262	2	220	13
199	20 *	175	19 *	263	1.5	221	13
200	20 *	176	19 *	264	1.5	222	13
201	20 *	177	19 *	265	1.5	227	16
202	19 *	178	18.5 *	266	1.5	228	15.5
203	18 *	179	18 *	268	1.5	231	15
204	20 *	180	17 *	269	1.5	232	15
205	21 *	181	18 *	270	1.5	233	14
206	21 *	181	17.5 *	271	1.5	234	13
207	20	182	18 *	273	1	239	10
208	20	183	17.5 *	274	1	240	10
209	20	186	17.2	277	0.5	243	9.5
210	20	187	17.5	278	0.5	245	11
211	20	188	17.8 *	279	0.5	248	10
212	20	189	18.2 *	280	0	260	7.5
213	22 *	190	18 *	281	0	261	7.5
214	20	191	18 *	282	0	262	6.5
215	20.5	192	18.8 *	283	0	263	7
216	20	193	18.5 *	284	0	264	6
217	20	194	19 *	285	0	265	4.5
218	21 *	195	19.2 *	286	0	266	3.5
219	19.5	196	19 *	287	0	267	3.5
220	20	197	19 *	288	0	271	0.5
221	20	198	19 *	289	0	272	0.5
222	21	199	19 *	290	0	278	0
223	19.5	200	19.9 *	291	0	280	0
224	20 *	201	20 *	292	0	281	0

[†] Julian Date

* Temperature recorded by Water Survey of Canada.

Appendix H (continued)

Slave River				Arctic Red River			
1994		1995		1992		1993	
Date[†]	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)
226	20 *	202	20 *	293	0	282	0
227	20 *	203	18.9	294	0	283	0
228	20 *	204	19.5 *	295	0	284	0
229	19	205	20 *	296	0	285	2
230	19	206	19 *	297	0	286	1
231	18.5	207	18.75	298	0	287	0.5
232	19	208	18.8	299	0	289	0
233	20	209	18.2	300	0	291	0
234	18	210	18.9 *	301	0	292	0
235	19 *	211	19 *	302	0	293	0
236	16	212	19 *	303	0	294	0
237	16	213	18.5 *	304	0	295	0
238	15.5	214	19.2	305	0	296	0
239	16 *	215	18.7	306	0	297	0
240	15	216	18.5	307	0	298	0
241	16 *	217	19.2 *	308	0	299	0
242	16 *	218	19.2 *	309	0	300	0
243	12	219	19 *	310	0	301	0
244	12	220	19 *	311	0	302	0
245	16 *	221	18.7 *	312	0	303	0
246	15	222	18 *	313	0	304	0
247	16 *	223	19 *	314	0	305	0
248	16 *	224	18 *	315	0	306	0
249	12	225	18 *	316	0	307	0
250	14	226	17.2 *	317	0	308	0
251	14	227	16.6	318	0	309	0
252	14	228	17.1	319	0	310	0
253	14 *	229	18 *	320	0	311	0
254	13	230	18 *	321	0	312	0
255	13	231	17 *	322	0	313	0
256	13	232	16 *	323	0	314	0
257	13	233	17 *	327	0	315	0
258	12	235	15.8 *	329	0	316	0
259	10	236	15 *			317	0
260	13	237	14.8 *			318	0
261	12	238	15 *			319	0
262	13 *	239	16 *				
263	13 *	240	15 *				
264	12 *	241	15 *				
265	11	242	15 *				
266	12	243	16 *				
267	11	244	15.5 *				
268	11 *	245	16 *				
269	10	246	15 *				
270	11 *	247	15 *				
274	8	248	15 *				
275	9	249	15 *				
276	9	250	14.8 *				

[†] Julian Date

* Temperature recorded by Water Survey of Canada.

Appendix H (continued)

Slave River				Arctic Red River			
1994		1995		1992		1993	
Date[†]	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)	Date	Temp (°C)
277	8	251	14 *				
278	8	252	15 *				
279	8	253	14.8 *				
280	8 *	254	14 *				
281	8	255	15 *				
283	7	256	14 *				
284	7	257	14 *				
285	6	258	13 *				
286	6	259	14.5 *				
287	6	260	12.5 *				
294	5	261	12.5 *				
		262	13 *				
		263	13 *				
		264	13 *				
		265	10 *				
		266	10 *				
		267	10 *				
		268	9 *				
		269	10 *				
		270	10 *				
		271	11 *				
		272	11 *				
		273	10 *				
		274	10 *				
		275	10 *				
		276	10 *				
		277	9 *				
		278	10 *				
		279	9 *				
		280	10.5 *				
		281	8.7				
		282	8.8				
		284	5.4				
		289	7				
		290	6				
		291	5.8				
		292	5.5				

[†] Julian Date

* Temperature recorded by Water Survey of Canada.