Barriers to Range Extension of Atlantic and Pacific Salmon in Arctic North America

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ABSTRACT. The long arctic coastlines between Alaskan salmon stocks and the Mackenzie River, and between Atlantic salmon of Ungava and Hudson Bay, are seen as major barriers to range extension as the rivers on these coastlines are not capable of being colonized. The potential of subarctic fresh water as spawning and nursery areas for anadromous salmon may be worth testing in the Hudson Bay and Mackenzie drainages. The possible reasons for exclusion of sockeye, chinook and coho salmon from arctic Alaskan coastlines and Atlantic salmon from arctic coastlines in northern Quebec are discussed. The arguments are based upon the North American situation but may have some bearing on the situation in northern U.S.S.R. The rapidity with which civilization is modifying northern waters is emphasized.

RÉSUMÉ: *Barrières à l'extension de domaine des Saumons de l'Atlantique et du Pacifique dans l'Amérique du Nord arctique.* L'auteur voit les longues côtes arctiques, entre le domaine du Saumon en Alaska et le Mackenzie, et entre le domaine du Saumon atlantique en Ungava et la mer d'Hudson, comme des barrières majeures à l'extension du domaine de ces espèces, car les rivières de ces côtes ne peuvent être colonisées. Il vaudrait peut-être la peine de vérifier le potentiel des eaux douces subarctiques comme aires de frai et d'élevage du saumon anadrome dans les bassins de la mer d'Hudson et du Mackenzie. L'auteur discute les raisons possibles de l'exclusion du sockeye, du chinook et du coho des côtes arctiques de l'Alaska, et du saumon atlantique des côtes arctiques du Québec nordique; ses arguments se basent sur la situation en Amérique du Nord, mais ils sont peut-être valables pour la situation en URSS nordique. L'auteur souligne enfin la rapidité avec laquelle la civilisation est en train de modifier les eaux nordiques.

РЕЗЮМЕ. *Препятствия на пути расширения местообитаний атлантического и тихоокеанского лососей в арктической Северной Америке.* Протяженные арктические берега между аляскинским стадом лосося и рекой Макензи и между Унгавским районом атлантического лосося и Гудзоновым заливом образуют главное препятствие на пути расширения местообитаний этой рыбы, поскольку реки названных побережий не могут быть колонизованы. Что касается субарктических рек, то в бассейнах Гудзонова залива и р. Макензи их потенциал как возможных нерестилищ и мест выращивания мальков анадромного лосося заслуживает изучения. Рассматриваются вероятные причины отсутствия нерки, чавычи и кижуча в реках арктической Аляски и атлантического лосося — в реках северного Квебека. При этом аргуметы основываются на положении в Северной Америке, однако они имеют определенное отношение и к ситуации на севере СССР. Пздчеркивается быстрота, с которой реки и водные бассейны севера изменяются под влиянием деятельности человека.

BACKGROUND

A paper by Dymond and Vladykov (1933) discussed the distribution of salmonid fishes in North America and Asia and a companion paper (Anderson 1933) presented a map (Fig. 1) of the life zones of North America. Dymond and

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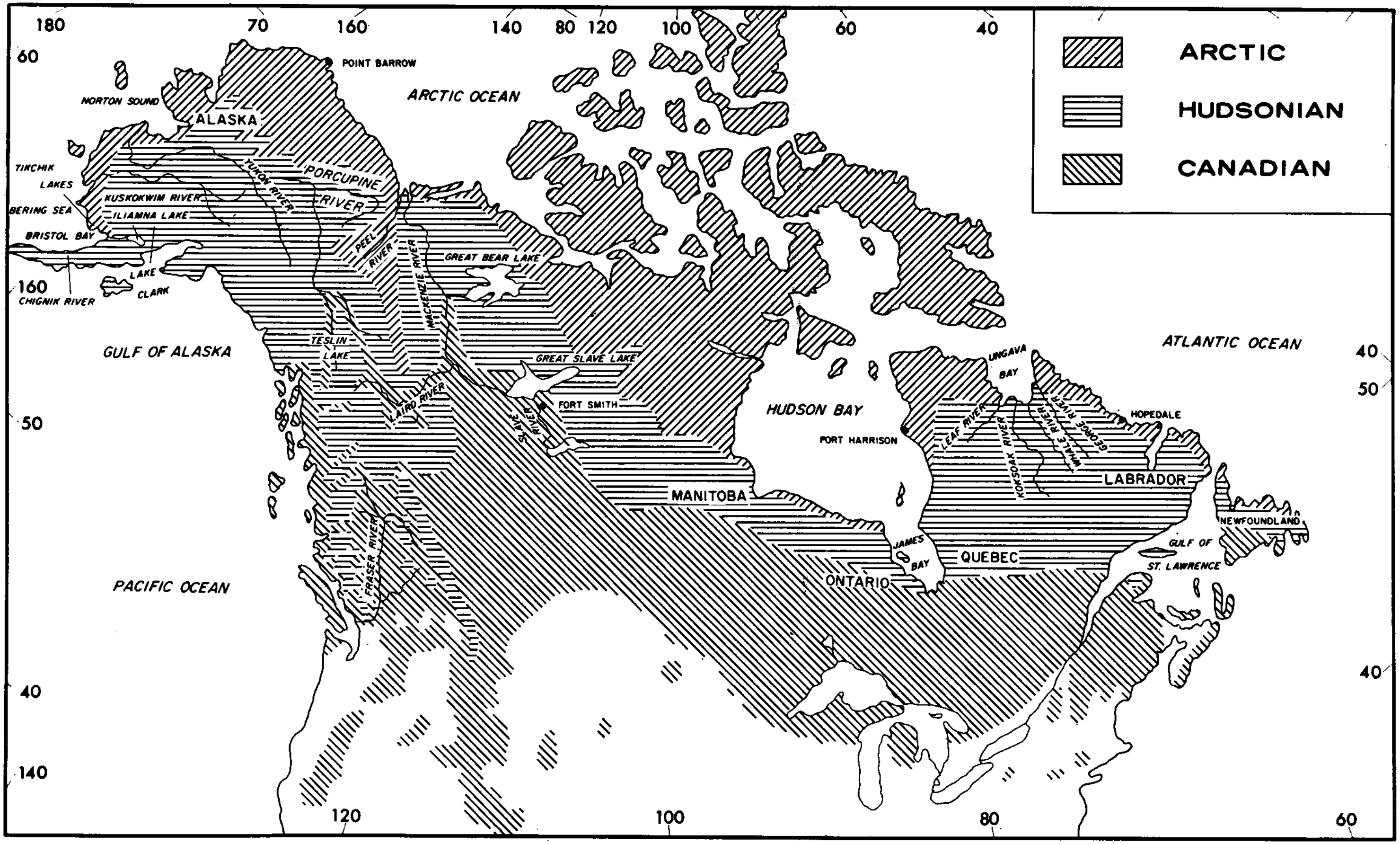

FIG. 1. Life zones of Canada and Alaska (approximating Anderson 1933).

Vladykov (1933) referred to the possible existence of chum salmon (*Oncorhynchus keta*) in the Mackenzie system, and showed graphically the presence of Atlantic salmon (*Salmo salar*) in Ungava Bay while Anderson's map showed the waters of both of these regions to drain non-arctic life zones. The boundary between Anderson's Arctic and Hudsonian zones corresponds closely to the northern limit of treelike conifers (Hustich 1953). The Yukon River drains land mainly classified as Hudsonian (Fig. 1) and the presence of large runs of chinook salmon (*Oncorhynchus tshawytsha*) there caused the author to question why chinooks were not using the Laird River as a spawning area, and why Atlantic salmon were absent from Hudson Bay which receives many rivers draining subarctic or Hudsonian lands. A more recent reference (Lindsey 1956) documented the existence of spawning runs of pink salmon (*Oncorhynchus gorbuscha*) in the lower Mackenzie and chums as far upstream as Fort Smith on the Slave River. The speculations in this paper are based on the fact that Pacific salmon do enter the Arctic Ocean and at least chums, which originate in rivers draining into the Arctic Ocean do not conduct their entire salt water feeding in northern waters but rather find their way into the major salmon feeding grounds of the Pacific (Neave 1964).

ATLANTIC SALMON

Those large rivers (George, Whale, Koksoak and Leaf) which have their flow originating in Hudsonian land and drain into Ungava Bay support Atlantic salmon according to Power (1969). He suggested that climatic conditions in fresh water impose a northern limit on salmon and that at least 100 days at a mean air temperature of 43°F. or higher seems necessary for reproduction. He also supposed that salmon may be prevented from entering Hudson Bay by the distance it is necessary to travel through arctic sea water. The Hudsonian zone (Fig. 1) includes half of the east coast of Hudson Bay below Port Harrison and almost the whole of the Ontario and Manitoba shorelines on the bay. Rivers at the tip of James Bay have their flows originating entirely in the Canadian zone in common with rivers which are home to salmon in the Maritimes. Separating those areas of Hudsonian life zones accessible from the sea in northern Quebec are hundreds of miles of coastline classified as arctic and containing few rivers of any consequence. Those rivers which do drain the northern tip of Quebec have their entire watersheds within the arctic zone. The natural mechanism of range extension, by species which home to the natal river as faithfully as salmon, must be by occasional wanderers reaching new rivers in sufficient numbers to breed successfully. As the distance between the home river and the possible new river is increased, it would be reasonable to assume that the likelihood of establishment would decrease. This distance must be between rivers that are capable of colonization.

Dunbar (1954) refers to sudden upswings in the marine climate which may have allowed such species as capelin (*Mallotus villosus*) to enter Hudson Bay from the Atlantic in recent times and thrive even after marine cooling; capelin were abundant in Ungava Bay during the marine warming of the 1800s but are rare there now. The distribution of the copepod *Acartia clausi* which is found in James Bay and southern Hudson Bay as well as in southern Labrador and the Gulf of St. Lawrence presents another interesting example of a similar situation (Dunbar 1954). Such changes in marine climate would be expected to warm land masses and their associated waterways and facilitate the extension of the salmon's range. A trend such as this has been observed in the northern U.S.S.R. where salmon have extended their range eastwards to the Kara River concurrent with a general warming of the climate during this century (Netboy 1968). I have found only one reference to the presence of landlocked salmon in the Hudson Bay drainage although in many cases they are present just over the height of land in the St. Lawrence, Atlantic or Ungava drainages in similar climatic and geographical locations. LeJeune and Legendre (1968) report having obtained a female specimen identified as Atlantic salmon with a freshwater life history of approximately 10 years from a river draining to Hudson Bay. The specimen appeared to have spawned several times. Since the headwaters of the Leaf River and the stream from which the specimen was taken are in close proximity, headwaters transfer of the freshwater forms referred to by Power (1958) may be involved here. The relative absence of landlocked salmon probably indicates that the northern tip of Quebec, since the recent series of glaciations of the area, has always been a barrier to the range extension of Atlantic salmon. Reasons for the climate limitation on the range of salmon referred to by Power (1969) are suggested by the observations at Scottish fishways which show that salmon do not move up or downstream in water at a temperature below about 40°F. (Netboy 1968). There is also evidence that salmon fry will not begin to feed at all in water below 50°F. (Francois 1965). In many streams in the arctic portion of Quebec the temperature may never get as high as that.

Arctic char (*Salvelinus alpinus*) and Atlantic salmon are both taken from rivers in the Hopedale region of Labrador and in the Ungava rivers. Anadromous arctic char is found, at least sparingly, in some of those waterways entering Hudson Bay from subarctic lands (Hunter 1966). Char, where abundant, have formed a traditional protein source for the native people and the effects of a possible man-made invasion of Atlantic salmon must be considered. Char spawn in lakes for the most part and since salmon are predominantly river spawners there does not appear to be a serious conflict. Char are halted in their upstream migrations by very minor obstacles (Leim and Scott 1966) whereas salmon with their ability to jump make use of nursery water upstream from formidable waterfalls. Salmon spend a considerable proportion of their adult winters in salt water, returning either as grilse after one sea winter or as salmon after two sea winters. Overwintering of char in the sea is unknown, and consequently their period of rapid growth is limited to a few months in summer each year (Hunter 1966); char spend more than 10 years reaching an average weight of 8 pounds after their first visit to sea following 5 to 7 years in fresh water as juveniles. Tagged char have been captured as far as 80 miles from their home river (Hunter 1966) whereas salmon have been captured well over 3000 miles from their river of origin (Netboy 1968). Although the productivity of both salmon and char is limited by available nursery water and salmon have a similarly long juvenile fresh water life in cold environments (Power 1958, 1969), salmon appear to use salt water feeding grounds much more efficiently.

Brook trout (*Salvelinus fontinalis*) is found throughout those areas of Hudson Bay I have considered as possible nursery waters for Atlantic salmon (MacCrimmon and Campbell 1969). Competition between salmon and trout in southern waters is diminished as trout tend to be an upper river species, especially in warm weather, while salmon tend to be a middle river species.

The approximate present ranges of sea-run brook trout are shown in Fig. 2 (after MacCrimmon and Campbell 1969), char (after Hunter 1966) and Atlantic salmon (after Leim and Scott 1966). Also indicated are those areas which I think might support Atlantic salmon in the event that man aids the species in overcoming the colonization blockage presented by hundreds of miles of uninhabitable coastline in northern Quebec. Potential spawning sites in the Hudson Bay Lowlands portions of some of the large rivers may be much less abundant than in the upper reaches of the same rivers which lie in the Canadian Shield. Many of the rivers, especially those on the east coast of Hudson Bay, present natural obstacles to anadromous fish at some point in their flowage. Future hydro developments at some of these sites may, if coupled with fish passage facilities,

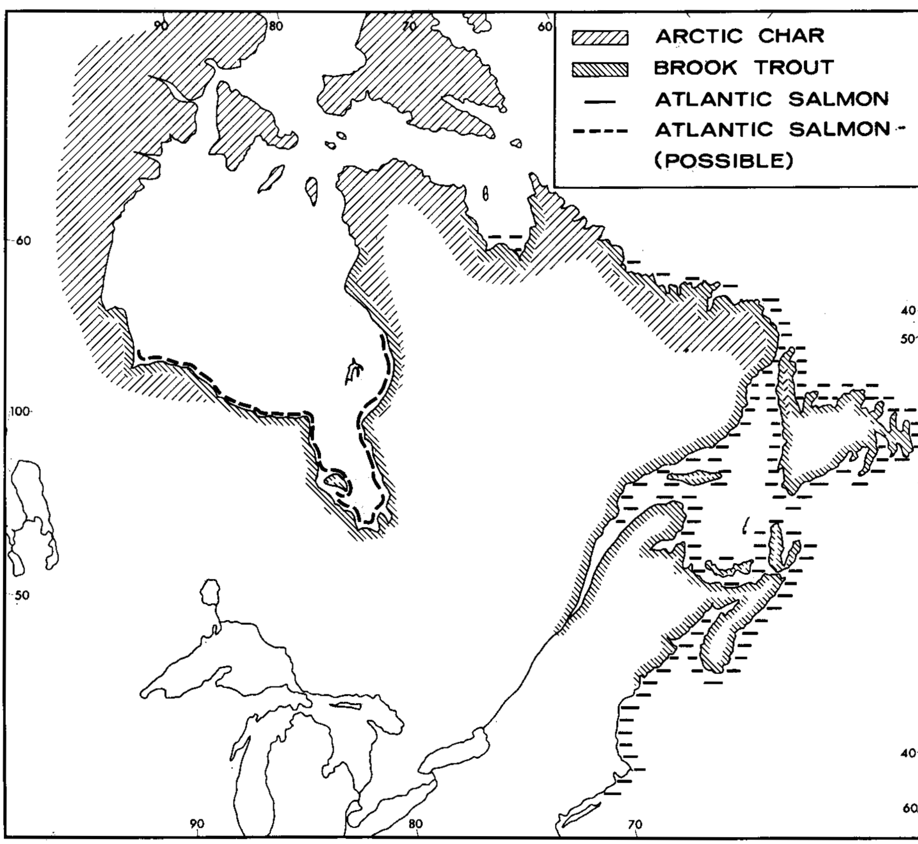

FIG. 2. Present and possible overlapping ranges of anadromous salmonids in eastern Canada.

open up even more nursery areas than are naturally available to anadromous species. It is almost certain now that some of the James Bay rivers will be so developed in the very near future.

Investigations in Hudson Bay show that its waters are fairly productive but that most of this productivity is in the form of phytoplankton and zooplankton (Dunbar 1970). Using this material as a food base are a number of species which are common feed for salmon such as capelin, Greenland cod, sand lances and various sculpins. Both capelin and Greenland cod are thought to be present in abundance (Dunbar 1970). A Hudson Bay population of salmon might be similar to that in the Baltic Sea with few fish migrating all the way to the north Atlantic, however if feed were not present in satisfactory abundance salmon could be expected to find their way through Hudson Strait to the rich feeding areas off Greenland. Considering the readiness with which Atlantic salmon form landlocked populations in oligotrophic lakes (Greeley 1955; Scott 1967) an unsatisfactory abundance of food in Hudson Bay would seem unlikely.

Introductions of pink and chum salmon were made in southern Hudson Bay and James Bay in 1955 and 1956 (Ryder *et al.* 1964). Although these introductions were unsuccessful, experience with pink salmon in Newfoundland in the last decade (Blair 1968) might give such attempts more of a chance for success today. Davidson and Hutchinson (1938) felt that the more closely the habitat, to which a race of sockeye is transferred, approximates the habitat where the race originated, the better the chance of survival. With this in mind, Atlantic salmon present more possibilities in Hudson Bay than do Pacific salmon. If introductions were attempted on the east coast of Hudson and James bays stock from the Ungava rivers, which rise in the same land mass and present similar habitats, would seem to be the logical choice.

PACIFIC SALMON

Almost 80 years ago (Bean 1894) one species of Pacific salmon was known to extend its migrations well to the eastward of Point Barrow. Dymond and Vladykov (1933) examined a specimen which they identified as *Oncorhynchus sp.* from Great Slave Lake; they also referred to reports of chum being taken as far west as the estuary of the Lena in the northern U.S.S.R. Lindsey (1956) referred to the presence of pink salmon in the lower Mackenzie and chums as far up the Slave River as Fort Smith as well as non-anadromous rainbow trout (*Salmo gairdneri*) in the upper Peace River. Lindsey suggested that postglacial barriers to species moving from Pacific to Arctic watersheds or vice versa were mechanical rather than ecological. The only Pacific salmon which has entered waters draining to the Arctic Ocean by headwaters transfer appears to be *Oncorhynchus nerka* (sockeye) which is present (as landlocked kokanee) in Arctic Lake at the headwaters of the Peace River according to McPhail and Lindsey (1970). They also state that most of the fish species in the upper Mackenzie spread there in postglacial times from the southern refuge of the Mississippi drainage and were able to colonize the northern latitudes because of a temperate climate created all the way to the Arctic Ocean by the warm water flowing from the south. McPhail and Lindsey (1970) suggest that ecological barriers seem to be important in the dispersal of fish in the north west but they say that the nature of the ecological barriers is not clear.

The fact that anadromous Pacific salmon have not moved from the Pacific to the arctic watershed by headwaters transfer is not surprising as spawning adults rarely ascend streams to their ultimate source. Even if a spawning pair or a few young salmon found themselves in a watercourse discharging into the Arctic Ocean, the possibilities of a large enough return to facilitate successful reproduction is remote.

To reiterate what has been said above concerning Atlantic salmon, the spread of the range must be an extension through salt water to nearby streams which are amenable to colonization. Chinook, sockeye and coho salmon (*Oncorhynchus kisutch*) are encountered only sporadically north of Norton Sound in Alaska (McPhail and Lindsey 1970) and thus do not appear to spawn successfully in rivers draining entirely arctic land (Fig. 1). The possibility of wanderers from a thousand miles away ever arriving in sufficient numbers to find each other and spawn in the immensity of the upper Mackenzie system is extremely remote. These species would not encounter the Mackenzie during feeding forays as these would have to be carried out in what Dunbar (1953, 1970) denotes as subarctic sea off the north Alaskan coast. Judging from the very small area of the Bering Sea which Dunbar describes as subarctic, the major and traditional feeding grounds of the Pacific salmon would appear to be in temperate sea regions. In fact Neave (1964) reports the presence of maturing chums in the Gulf of Alaska which subsequently migrated to the far northern coastal areas of Alaska and the U.S.S.R.

Brett (1952) found Pacific salmon to have a marked intolerance to low temperatures as compared with other salmonids and found the juvenile life stages to be more affected by this stress than adults. Perhaps only the pinks and chums have been able to colonize their way from stream to stream to the Mackenzie because of their independence from freshwater life stages. This independence stems from the fact that the seaward migration of these species commences immediately after hatching and thus there is little need for them to withstand the extreme conditions in the fresh waters which drain arctic land. In areas of Alaska which are mainly classified as subarctic or Hudsonian, streams taking their water supply from very cold springs create an environment for sockeye which may suggest one reason for the inability of this species to colonize water draining arctic land. Holmes (1933) reported observing partially developed sockeye embryos, which had not yet hatched, being dug out of the gravel by the spawning activities of adults one year after the eggs had been deposited in spring fed areas of the Chignik River in Alaska.

The potential of waters in the Mackenzie system to serve as spawning and nursery areas for the 3 salmon species is suggested by the similarities and proximity of spawning and nursery areas now used in Alaska and the Yukon. Chinooks are found as high up the Yukon system as Teslin Lake (Lindsey 1956) and this area is climatically and physiographically very similar to the lands of the upper Laird River which drains to the Mackenzie. Chinooks and cohos both utilize the Porcupine River in an area with climate and land similar to that existing in the Peel River drainage. Sockeyes are not only resident in the lakes of the Bristol Bay region of southwestern Alaska but form a tremendous economic base for the area. The possible similarities between the limnological conditions of the Bristol Bay lakes and those of Great Slave Lake are indirectly suggested by the similarities in growth rate of lake trout (*Salvelinus namaycush*) in the two areas (Yanagawa 1967).

Lake trout are thought to spawn only every second year in both of these northern locations (Metsker 1967; McPhail and Lindsey 1970) which indicates a slow development rate compared with more southern populations. Perhaps more indicative of the suitability of Great Slave Lake, for raising juvenile sockeye, would be a comparison of whitefish (*Coregonus sp.*) growth there with that in the Bristol Bay lakes. The food of whitefish is more similar to that of young sockeye than is the diet of piscivorous lake trout. Rawson's (1947) data on whitefish from Great Slave Lake would suggest that growth there is somewhat slower than that reported in Lake Clark, Alaska (Metsker 1967). Yanagawa (1967) stated that growth rates of whitefish in the Tikchik Lakes (Bristol Bay region) were similar to those reported for fish from Great Bear Lake. Miller (1947), however, felt that most of these whitefish came from rivers and headwater lakes tributary to Great Bear Lake where growth would be faster than in the large colder body of water. In a recent study Pimlott *et al.* (1971) stated that fishes in large cold lakes such as Great Slave Lake grew so slowly that it would never be possible to take large harvests in northern latitudes. The largest of the Bristol Bay lakes (Iliamna) has a surface area of 1,042 square miles (Metsker 1967) while Great Slave Lake is 10,500 square miles (Rawson 1947); both lakes reach depths of over a thousand feet. If the probable similarities in limnological conditions between the Bristol Bay lakes and Great Slave Lake have any bearing on how juvenile sockeye will grow in the Mackenzie system, the area may have the capacity to support spawning runs numbering in the millions. These fish would have conducted their major growth at sea and, after spawning and dying, might considerably enrich nutrient poor areas of Great Slave Lake with elements delivered from the ocean (Foerster 1968).

We do not have definite knowledge concerning the limits of the energy of salmon on spawning runs. Most rivers are short, have serious waterfall obstacles or have access to them cut off by such barriers as are dealt with in this paper. The Mackenzie which is 2,525 miles long (Wynne-Edwards 1952) may demonstrate these limits if colonized by coho, chinook and sockeye, species not impeded by moderate waterfalls and rapids. The capacity of chinook and coho salmon to conduct upriver spawning migrations in the Yukon River, in excess of a thousand miles, is well documented (McPhail and Lindsey 1970). The sockeye run in the upper Fraser River is one of long distances through swiftly moving water. Sockeye have been encountered in the Yukon River 650 miles from the mouth (McPhail and Lindsey 1970) and these were thought to be wandering spawners which would be expected to lack the compelling direction of the homing instinct. The efforts potentially required of spawning sockeye to reach Great Slave Lake and of spawning chinooks to reach the Laird River system appear less of a problem when it is understood that current speeds in the Mackenzie are about half those in the Yukon River (Wynne-Edwards 1952).

The question of whether such introductions as have been suggested here would displace species which serve as traditional food resources for people living in the Northwest Territories would have to be considered carefully. Present knowledge suggests that the 3 species considered here do, in other areas of the north, coexist with most of the important food species found in the Mackenzie. Growth rates of lake trout and whitefish have already been mentioned. Northern pike (*Esox lucius*) is present in the Mackenzie system and is also encountered in the upper Yukon River system (Lindsey 1956). Inconnu (*Stenodus sp.*) are common in the Mackenzie system from the mouth to the rapids below Fort Smith although they are uncommon in the lower Laird (Wynne-Edwards 1952). Inconnu are also present in the Kuskokwim and Yukon rivers where sockeye and chinooks are found (McPhail and Lindsey 1970). Dolly varden (*Salvelinus malma*) are commonly found in the Laird River system and although this species has a reputation as a rapacious predator of young salmon McPhail and Lindsey (1970) feel that this is undeserved. The list of fishes found together with all Pacific salmon species (Yanagawa 1967) in the Tikchik Lake system in Alaska illustrates that, even though salmon draw on plentiful nutrients outside of the fresh water environment, they do not replace those fish which rely solely on indigenous nutrients.

The introduction of 3 new species of fish would increase the species diversity of this subarctic area, if not accompanied by any extinctions, and theoretically would increase the stability of ecosystems there. It is worth noting that one author (Simpson 1969) feels that if the earth's ecosystems are tending toward "long range" stabilization the first three billion years of their existence has been too short a time to reach that condition.

SUMMARY AND CONCLUSIONS

It is possible that all Pacific salmon did colonize the Mackenzie at some time in prehistory, and that Atlantic salmon were present in Hudson Bay. The post-glacial recolonization of the Mackenzie system has been mainly from the south and I conclude that chum and pink salmon have only been able to colonize their way to the Mackenzie because of their minimal dependence on the fresh water life stage. I believe that the other 3 Pacific salmon (chinook, sockeye and coho) are better adapted to use the enormous spawning and rearing grounds available in the Mackenzie system and may have the potential to supply a new fishery in the area. A similar situation exists in Hudson Bay and James Bay where Atlantic salmon could probably harvest the abundance of small marine life forms more efficiently than arctic char and brook trout do now. The kind of input required to test the hypotheses made in this paper is certainly of a more attractive nature than what appears to many southerners as the interminable welfare state in the north punctuated by such off-on projects as mining, pipeline construction and hydro-electric power development.

Stock for introduction should come from the most similar fresh water environments and should have had similar distances to travel in spawning runs as those required in the new area. Introductions should be in the form of surface-sterilized disease free eggs which are hatched in the new areas. Close track should be kept of the migratory populations in and out of the introduction areas by establishing counting fence procedures until the colony becomes self-sustaining. Such fences might also be operated to remove upstream migrating predators during the introductory years, which would give such experiments an extra margin of possibility for success.

The environment in the north is generally thought to be more fragile than that in the south. Commercial and sports fisheries for salmon, in the extended ranges dealt with in this paper, might bring considerable economic benefits to these areas. If they were developed before destructive natural resource exploitation these fisheries would dictate to some extent the care which would have to be taken during further development in order to protect the waterways from ruin.

REFERENCES

ANDERSON, R. M. 1933. The distribution, abundance and economic importance of game and fur-bearing mammals of western North America. *Proceedings of the 5th Pacific Science Congress*, 5:4055-75.

BEAN, T. H. 1894. Life history of the salmon. *U.S. Fish Commission, Bulletin* 12: 21-38.

BLAIR, A. A. 1968. Pink salmon find new home in Newfoundland. *Fisheries of Canada*, 21: 9-12.

BRETT, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. *Journal of the Fisheries Research Board of Canada*, 9: 265-323.

DAVIDSON, F. A. and S. J. HUTCHINSON. 1938. The geographic and environmental limitations of the Pacific salmon (Genus *Oncorhynchus*). *U.S. Bureau of Fisheries, Bulletin* 48: 667-92.

DUNBAR, M. J. 1953. Arctic and subarctic marine ecology: Immediate problems. *Arctic*, 6: 75-90.

———. 1954. A note on the climatic change in the sea. *Arctic*, 7: 27-30.

———. 1970. On the potential of the sea waters of the Canadian north. *Arctic*, 23: 150-74.

DYMOND, J. R. and V. D. VLADYKOV. 1933. The distribution and relationship of the salmonid fishes of North America and North Asia. *Proceedings of the 5th Pacific Science Congress*, 5: 3741-50.

FOERSTER, R. E. 1968. The sockeye salmon, *Oncorhynchus nerka*. *Fisheries Research Board of Canada, Bulletin* No. 162. 422 pp.

FRANCOIS, D. 1965. Canadian Atlantic salmon for New South Wales. *Atlantic Salmon Journal*, Winter: 22-24.

GREELEY, J. R. 1955. Survivals of planted Atlantic salmon in Lake George. *New York Fish and Game Journal*, 2: 1-12.

HOLMES, H. B. 1933. Natural propagation of salmon in Alaska. *Proceedings of the 5th Pacific Science Congress*, 5: 3585-92.

HUNTER, J. G. 1966. The arctic char. *Fisheries of Canada*, 19: 17-19.

HUSTICH, I. 1953. Boreal limits of conifers. *Arctic*, 6: 149-62.

LEIM, A. H. and W. B. SCOTT. 1966. Fishes of the Atlantic Coast of Canada. *Fisheries Research Board of Canada, Bulletin* No. 155, 459 pp.

LEJEUNE, R. and V. LEGENDRE. 1968. Extension d'aire du saumon d'eau douce (*Salmo salar*) au Québec. *Le Naturaliste Canadien*, 95: 1169-73.

LINDSEY, C. C. 1956. Distribution and taxonomy of fishes in the Mackenzie drainage of British Columbia. *Journal of the Fisheries Research Board of Canada*, 13: 759-89.

MACCRIMMON, H. R. and J. S. CAMPBELL. 1969. World distribution of brook trout, *Salvelinus fontinalis*. *Journal of the Fisheries Research Board of Canada*, 26: 1699-1725.

MCPHAIL, J. D. and C. C. LINDSEY. 1970. Freshwater fishes of northwestern Canada and Alaska. *Fisheries Research Board of Canada, Bulletin* No. 173, 381 pp.

METSKER, H. 1967. Iliamna Lake watershed freshwater commercial fisheries investigations of 1964. *Alaska Department of Fish and Game*, *Information Leaflet* No. 95, 50 pp.

MILLER, R. B. 1947. Great Bear Lake. In: North West Canadian Fisheries Surveys in 1944-1945. *Fisheries Research Board of Canada, Bulletin* No. 72, 94 pp.

NEAVE, F. 1964. Ocean migrations of Pacific salmon. *Journal of the Fisheries Research Board of Canada*, 21: 1227-44.

NETBOY, A. 1968. *Atlantic Salmon — A Vanishing Species?* London: Faber and Faber. 457 pp.

PIMLOTT, D. H., C. J. KERSWILL and J. R. BIDER. 1971. Scientific activities in fisheries and wildlife resources. *Science Council of Canada, Special Study* No. 15, 191 pp.

POWER, G. 1958. The evolution of the freshwater races of the Atlantic salmon (*Salmo salar* L.) in eastern North America. *Arctic*, 11: 86-92.

————. 1969. The salmon of Ungava Bay. *Arctic Institute of North America, Technical Paper* No. 22, 72 pp.

RAWSON, D. S. 1947. Great Slave Lake. In: North West Canadian Fisheries Surveys in 1944-1945. *Fisheries Research Board of Canada, Bulletin* No. 72, 94 pp.

RYDER, R. A., W. B. SCOTT and E. J. CROSSMAN. 1964. Fishes of northern Ontario north of the Albany River. *Royal Ontario Museum, Life Sciences, Contribution* No. 60, 30 pp.

SCOTT, W. B. 1967. *Fresh water fishes of eastern Canada, 2nd Edition.* Toronto: University of Toronto Press. 137 pp.

SIMPSON, G. G. 1969. The first three billion years of community evolution. In: *Diversity and Stability in Ecological Systems. Brookhaven Symposium in Biology No. 22.* Brookhaven National Laboratory, Upton, New York. pp. 162-76.

WYNNE-EDWARDS, V. C. 1952. Freshwater vertebrates of the arctic and subarctic. *Fisheries Research Board of Canada, Bulletin* No. 94, 28 pp.

YANAGAWA, C. 1967. Tikchik Lake system commercial freshwater fishery. *Alaska Department of Fish and Game, Information Leaflet* No. 109, 19 pp.