World Distribution of Brook Trout, *Salvelinus fontinalis*

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During the past century, the endemic range of the brook trout, *Salvelinus fontinalis* (Mitchill), has been extended to include western North America and the continents of Europe, Asia, Africa, and South America. Water temperature appears to be the most important single factor limiting the geographic range, but adequate precipitation and suitable spawning areas are necessary also for the establishment of self-sustaining populations. It is improbable that, with the possible exception of Asia, the present range of the brook trout will be greatly extended through further attempts at introduction.

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INTRODUCTION

THE ENDEMIC RANGE of the brook or speckled trout, *Salvelinus fontinalis* (Mitchill), has, since 1872, been greatly extended to include waters in western North America, South America, Eurasia, Africa, and New Zealand.

The species, which early immigrants to eastern North America erroneously named a trout rather than a char because of a similarity to the European *Salmo trutta* Linnaeus (Rhead, 1902), was first described by Mitchill in 1814 from specimens captured near New York City (Jordan and Evermann, 1896). Although DeKay (1842) later assigned the generic *Baione* to the brook trout, the use of *Salvelinus* has persisted as it has for the Arctic char (*S. alpinus*) and the dolly varden (*S. malma*), these species being indigenous to the extreme northern and western parts, respectively, of North America. However, it is probable that the native ranges of *S. alpinus* and *S. fontinalis* overlap in the coastal streams between the Churchill and Nelson rivers on the west coast of Hudson Bay (Sprules, 1952).

Primarily because of differences in the external appearance of brook trout living in different waters, various specific names have been given to local representatives including *fontinalis*, *alleghaniensis*, *nigrescens*, *canadensis*, *hoodii*, *immaculatus*, *hudsonicus*, and *agassizi*. Rather spectacular differences in the appearance of the Aurora trout (*S. timagamiensis* (Henn and Rinkenbach)) has led to a more persistent recognition of this local form as a distinct species, but Vladykov (1954) suggests that it may be considered to be a colour variety of *S. fontinalis*. The American Fisheries Society (1960) now recognizes only *fontinalis* as the specific name for the brook trout.

The objectives of this paper are: (1) to consolidate and update knowledge on the native distribution of *S. fontinalis* (Mitchill); (2) to record attempts

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to introduce the species beyond its endemic range; and (3) to document the present world distribution of native and naturalized populations. From a consideration of the biology of the species and the ecological conditions where native and naturalized populations now exist, evidence is presented to identify those environmental conditions which affect the welfare of local populations and would seem to limit the potential world distribution of self-sustaining populations of the brook trout.

NATIVE RANGE

The westerly limit of the native range of the brook trout occurs in Manitoba (Fig. 1). Although believed until recently to extend northward to include only Kettle Rapids and the Weir and the Limestone rivers on the Nelson River system (Doan, 1958), Keleher and Kooyman (1957) found this species farther northward in the lower waters of the Seal, North Knife, South Knife, and Churchill rivers. Other native populations are present, also, near the eastern boundary of Manitoba in the Gods River system as far south as the Island Lake, Red Sucker, Stull, and Echoing rivers (Keleher and Kooyman, 1957; Benedictson, personal communication).

In northwestern Ontario, Ryder et al. (1964) collected brook trout in the Patricia District and upstream in the Severn and Fawn rivers as far as Big Trout Lake; also in the Winisk River as far as Winisk Lake; in the lower reaches of the Attawapiskat River; and in the Albany River at least to the Fort Hope–Miminiska region. Brook trout occur naturally in Lake Nipigon (Dymond, 1926) but are absent from both the Nelson River watershed of Ontario (Ryder et al., 1964) and Lake of the Woods (Evermann and Latimer, 1910). Although endemic populations are absent from southwestern Ontario (Urquhart, 1957), they exist in streams tributary to the Great Lakes (Scott, 1954) and northward to include the rivers flowing into James Bay (Vladykov, 1933) and the east coast of Hudson Bay at least to Povungnituk (McAllister, 1964). This latter information extends the known range of brook trout northward over 50 miles from the previous northern-most point of Payne Lake reported by Légèndre and Rousseau (1949). Bell (1886) stated that Eskimos captured brook trout in a stream just south of Cape Wolstenholme, but this record lacks confirmation.

Brook trout are found throughout Quebec (Légèndre, 1954) and have been collected as far north as the Ungava region in the George River at Helen Falls, Koksoak River, Lake Aigneau and vicinity, the lower 12 miles of the Larch and Kaniapiskau rivers, the Guignais River, the lower parts of the Whale River (Power, 1966), and the Leaf River (Dunbar and Hildebrand, 1952). On the Labrador coast, brook trout occur along the coast as far north as Nain (Dymond, 1947; Backus, 1957). They also occur naturally in all suitable waters in Newfoundland (Scott and Crossman, 1964), Prince Edward Island (White, 1930), New Brunswick (Scott and Crossman, 1959), and Nova Scotia (Livingstone, 1951).

In the New England States, brook trout are widely distributed (Hubbs and Lagler, 1947) including Cape Cod (Bigelow and Schroeder, 1953). At one time, the range included Long Island, New York (Mitchill, 1815) and extended into the suitable waters of the State of New Jersey (Fowler, 1920). Most of the streams of Pennsylvania were inhabited by brook trout (Fowler, 1940; Miller, personal communication) as well as those streams in the counties of Ashtabula and Geauga in Northeastern Ohio (Trautman, 1957) and the northern and western counties of Maryland (Barry, personal communication).

Native brook trout are still present in headwater streams of the Appalachians in the eastern third of West Virginia (Beall, personal communication) and in approximately 40 western counties of Virginia including the tributaries of the Holston River (Séguin, 1956; Martin, personal communication). In Tennessee, the species inhabits headwater streams of the Tennessee, Holston, and Little Tennessee rivers above an altitude of 900 m (Wilkins, personal communication). It is found naturally in the western part of North Carolina (Cornell, personal communication), in the mountainous northeast corner of South Carolina in Oconee, Pickens, and Greenville counties (Archer, personal communication), and in the headwaters of the Broad, Savannah, Chattahoochee, and Catawba rivers located in the northeast section of Georgia (Jordan et al., 1930; Malone, personal communication).

In Michigan, brook trout were indigenous to waters of the Upper Peninsula, but found in the Lower Peninsula only to the north of a line between Grand Traverse Bay on Lake Michigan and Thunder Bay on Lake Huron (Séguin, 1956). In Minnesota, brook trout were supposedly abundant in the lower reaches of rivers which flow into Lake Superior and in some small lakes above Beaver Bay and Grand Marais (Eddy and Surber, 1947). Brook trout were claimed as native fish in the St. Croix River and the small tributaries of the Mississippi River south of St. Anthony Falls (Eddy and Surber, 1947; Surber, 1931; Carlander, 1954).

The brook trout was found originally throughout Wisconsin (Brasch et al., 1966), and in the Upper Iowa River drainage system in the northeastern part of Iowa (Harlan and Speaker, 1956). O'Donnell (1935) stated that in the past, native brook trout were found in the Kishwaukee, Pecatonica, and Apple river systems of northern Illinois, but were no longer present by that date.

Sea-run brook trout occur within the native range of brook trout. McAllister (1964) observed sea-run fish off the eastern shore of Hudson Bay in the area of Broughton Island. Anadromous brook trout also occur in Ungava Bay (Dunbar and Hildebrand, 1952), on the Labrador coast (Stearns, 1884), and along the coast of Newfoundland (Scott and Crossman, 1964), the Gulf of St. Lawrence, the outer coast of Nova Scotia, the Bay of Fundy, and Prince Edward Island (Smith and Saunders, 1958; Leim and Scott, 1966; White, 1930). Sea-run brook trout or "coasters" also occur in certain rivers along the Maine coast (Bigelow and Schroeder, 1953) and Cape Cod (Bigelow and Schroeder, 1953; Mullan, 1958).

Reductions have occurred in the native range of the brook trout because of changes in the aquatic environment (Fig. 1). In Minnesota, the species is now self-sustaining only in streams of the north-central and northeastern parts (Swenson, personal communication). Brook trout were originally found throughout Wisconsin, but this range has been reduced to include only the east-central and northern portions (Brasch et al., 1966).

Although the brook trout was once native to the waters of northern Illinois (Séguin, 1956; O'Donnell, 1935), Harth (personal communication) states that this species is no longer present since a small put-and-take programme was discontinued in the late 1940's. Native brook trout populations of northeastern Ohio (Kirtland, 1838) had disappeared by 1945 (Trautman, 1957). With dwindling habitat suitable for the brook trout, the Ohio Division of Wildlife terminated its brook trout stocking programme in 1962 (Lakes, personal communication).

Brook trout probably occurred naturally in nearly all of the streams of Pennsylvania, but because of pollution, siltation, and the warming of many waters caused by deforestation (Hazzard (year unknown)) the range of brook trout has been substantially reduced. In New Jersey, where the species was found in nearly all counties, native brook trout populations now exist only in headwater streams of the northwestern counties of Sussex, Warren, Morris, and Passaic (Hayford, personal communication).

NATURALIZED DISTRIBUTION

NORTH AMERICA

United States of America

The distribution of the brook trout has been greatly extended in the United States to include waters of several states west of the Mississippi River (Fig. 1). As early as 1872, Seth Green's trout farm at Caledonia, New York, sent eggs to the California Fish Commission which were distributed in the North Fork of the American River, the headwaters of the Alameda Creek, and the San Andreas Reservoir (Evermann and Bryant, 1919). By 1880, the introduction of brook trout had also been made to Colorado, Utah, Wyoming, and Hawaii. However, as self-sustaining brook trout populations were not established in Hawaii, introductions to that state were discontinued in 1896 (Needham and Welsh, 1953). Ohio, Minnesota, West Virginia, and Michigan, by 1880, were attempting to extend the native range of brook trout within their boundaries by stocking suitable waters.

Attempts to introduce brook trout into 20 states lacking native populations have resulted in their establishment in 14 states (Table 1). Government agencies in these states, excepting Alaska, Nebraska, New Mexico, and North Dakota, continue to stock the species. Among those states from which native populations have declined or disappeared, Iowa, Illinois, and Ohio have discontinued brook trout plantings in favour of the rainbow trout, *Salmo gairdneri* Richardson. The introduction of brook trout has not been attempted in

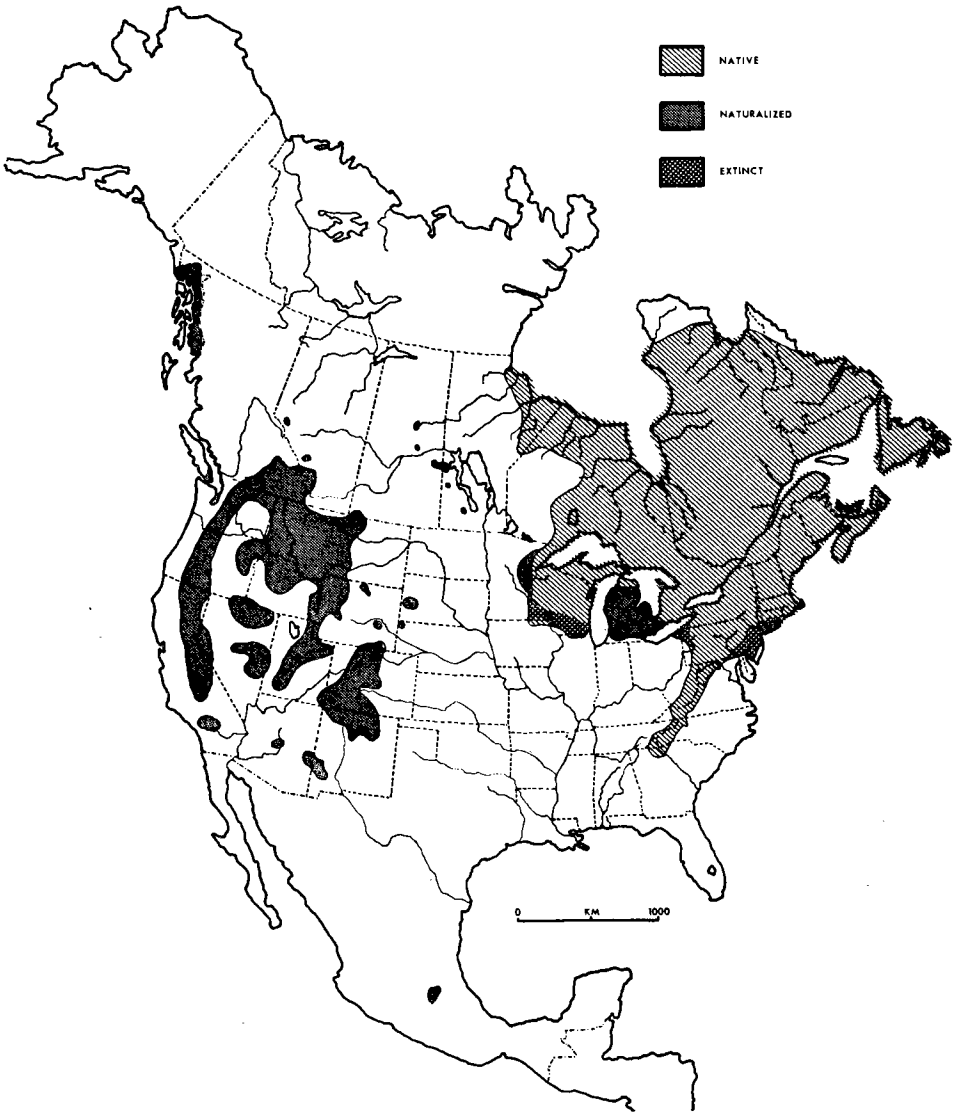

FIG. 1. Distribution of *Salvelinus fontinalis* in North America.

Texas, Oklahoma, Missouri, Mississippi, Florida, Arkansas, Alabama, Louisiana, or Kansas.

CANADA (TABLE 2)

Native or naturalized brook trout populations are resident in all provinces of Canada except the Yukon and Northwest Territories. The transfer, in 1908, of 35,000 ova from Quebec to the Fraser River Hatchery in British Columbia was the first attempt to establish brook trout outside its native

TABLE 1. The history and the present status of the brook trout in the United States of America.

State	Population: native or introduced	Year of introduction	Naturalized distribution	Current stocking programme
Alabama	–	–	–	–
Alaska	Introduced	1920	Yes	No
Arizona	Introduced	Prior to 1930	Yes	Yes
Arkansas	–	–	–	–
California	Introduced	1872	Yes	Yes
Colorado	Introduced	1874	Yes	"
Connecticut	Native	–	–	"
Delaware	Introduced	1950	No	"
Florida	–	–	–	–
Georgia	Both	Unknown	Yes	Yes
Hawaii	Introduced	1876	No	No
Idaho	"	1908	Yes	Yes
Illinois	"	Late 1800's	No	No
Indiana	"	Prior to 1931	No	"
Iowa	Both	1930's	Yes	"
Kansas	–	–	–	–
Kentucky	Introduced	About 1965	No	Yes
Louisiana	–	–	–	–
Maine	Native	–	–	Yes
Maryland	Both	Unknown	Yes	"
Massachusetts	Native	–	–	"
Michigan	Both	1879	Yes	"
Minnesota	Both	1878	Yes	"
Mississippi	–	–	–	–
Missouri	–	–	–	–
Montana	Introduced	1894	Yes	Yes
Nebraska	"	1882	"	No
Nevada	"	1880	"	Yes
New Hampshire	Native	–	–	"
New Jersey	Both	Prior to 1884	Yes	"
New Mexico	Introduced	1892	Yes	No
New York	Native	–	–	Yes
North Carolina	Both	Unknown	Yes	Yes
North Dakota	Introduced	1955	No	No
Ohio	Both	1868	No	No
Oklahoma	–	–	–	–
Oregon	Introduced	Late 1890's	Yes	Yes
Pennsylvania	Both	1916	Yes	"
Rhode Island	Native	–	–	"
South Carolina	Both	Unknown	Yes	"
South Dakota	Introduced	1886	"	"
Tennessee	Both	Unknown	"	"
Texas	–	–	–	–
Utah	Introduced	1875	Yes	Yes
Vermont	Native	–	–	"
Virginia	Both	About 1900	Yes	"
Washington	Introduced	1894	"	"
West Virginia	Both	1878	"	"
Wisconsin	Both	Unknown	"	"
Wyoming	Introduced	1880	"	"

TABLE 2. History and the present status of brook trout in Canada.

Province	Population: native or introduced	Year of introduction	Naturalized distribution	Current stocking programme
Alberta	Introduced	1930's	Yes	Yes
British Columbia	Introduced	1908	"	"
Manitoba	Both	1942	"	"
New Brunswick	Native	–	–	"
Newfoundland	Native	–	–	"
Northwest Territories	–	–	–	–
Nova Scotia	Native	–	–	Yes
Ontario	Native	–	–	"
Prince Edward Island	Native	–	–	"
Saskatchewan	Introduced	Late 1920's	Yes	"
Yukon Territory	–	–	–	–

range (Department of Marine and Fisheries, 1908; Clemens and Wilby, 1961). The subsequent distribution of fry led to naturalized populations in several waters in the southeastern part of the province and on Vancouver Island (Clemens and Wilby, 1961; Carl et al., 1959). An active brook trout stocking programme is still maintained by the British Columbia Department of Recreation and Conservation (Terpenning, personal communication).

Brook trout were widely introduced to Alberta sometime during the 1930's, and became established in the Highwood and Elbow rivers as well as in high altitude tributaries (1500 m elevation) of the Red Deer and North Saskatchewan rivers in the National Parks at Banff and Jasper (Miller, 1950). The Department of Lands and Forests of Alberta now stock only relatively small numbers of brook trout each year in suitable waters (Paetz, personal communication).

In Saskatchewan, brook trout have been planted in some 20 streams of the Cypress Hills (1200 m elevation) in the southwestern part of the province between 1931 and 1958. Those in which brook trout have become naturalized include Bear, Belanger, Little Frenchman, Battle, Bone, and Loch Lomond creeks (Symington, 1959; Marshall, personal communication). In the Mossy River drainage of Nipawin Provincial Park, nine streams have been stocked since 1934 but only three, Lost Echo, McDougal, and White Gull, have known naturalized populations of brook trout. Marshall (personal communication) states that although the present naturalized distribution does not include La Ronge nor the lower Red Deer River, self-sustaining stocks of brook trout are found in four rivers of the Pasquia Hills (elevation 750 m) namely the Otosquen, Pasquia, Prairie, and Fir rivers. The Department of Natural Resources still continues an active brook trout stocking programme (Johnson, personal communication).

Brook trout have been stocked in Manitoba since 1942, when ova were obtained from hatcheries at Dorion, Ontario, and Spokane, Washington

(Benedictson, personal communication). Naturalized populations have been established in the Birch and Steeprock rivers of the Porcupine Mountain Forest Reserve, in streams of the Duck Mountain Forest Reserve, as well as Stoney Creek near Neepawa (Benedictson, personal communication; Keleher and Kooyman, 1957).

Mexico

Although the breeding and propagation of brook trout in Mexico was considered as early as 1937 by Berriozabal (1937), the species was not introduced until 1945 when streams near El Zarco, State of Mexico, were stocked (Mexico, Department of Fisheries, personal communication). Chávez (personal communication) states that brook trout reproduce naturally in those streams at elevations near 3000 m, although certain lakes and streams must be replenished periodically with hatchery-reared stocks. Apparently, the brook trout is considered of minimum importance and more emphasis has been placed on stocking programmes utilizing the rainbow trout, *S. gairdneri*.

EUROPE

(Table 3)

The British Isles

The first introduction of brook trout to the British Isles occurred in the spring of 1869, when Livingstone Stone of the Cold Spring Trout Hatchery in New Hampshire, USA, sent a consignment of ova to Frank Buckland, Her Brittanic Majesty's Commissioner for Fisheries; a second shipment of 10,000 eggs was sent in 1871 to John Parnaby, owner of the Troutdale Fishery near Keswick (de Bunsen, unpublished data). Today, the only hatchery in the United Kingdom which rears brook trout commercially is the Chirk Fisheries Station, Chirk, near Wrexham, North Wales (Campbell, personal communication).

Although brook trout have been extensively introduced to many waters of the British Isles, such as the lochs in the estate of Maclaine of Lochbuie, Island of Mull, Scotland (MacLean, 1923), the species has become firmly established in only a few localities (de Bunsen, unpublished data) (Fig. 2). Naturalized populations exist in England in the County of Surrey at Haslemere on the Surrey Trout Farm, and in the ponds of Sir Hildebrand Harmsworth. In Scotland, a population has been established in a small loch at Ochtertyre Estates near Crieff, Perthshire. In Wales, a naturalized population exists at Llyn-y-Tarur, near New Town, Montgomeryshire. Stocks of brook trout which are either precarious, or recently introduced, are found in the Fisheries Biological Association tarns on Claife Heights near Lake Windermere and the Chew Reservoirs, Bristol, England. In Scotland, recently stocked brook trout are present in a pond near Tayfield, Fife, and at Fincastle Loch in Perthshire; they have never been introduced into Ireland (de Bunsen, unpublished data).

TABLE 3. Introductions and present status of the brook trout in Europe.

Country	Year of introduction: First	Year of introduction: Successful	Source	Survival	Current stocking programme	Naturalized distribution
Austria	After 1879	After 1879	Germany	Yes	Yes	Yes
British Isles	1869	1869	USA	"	No	Yes
Bulgaria	1930	1930	Czechoslovakia	"	Yes	Unknown
Czechoslovakia	Prior to 1890	Prior to 1890	Unknown	"	Yes	Yes
Denmark	About 1900	About 1900	Germany	"	No	"
Fed. Rep. Germany	1879	1879	USA	"	"	"
Finland	1898	1967	USA & Denmark	Unknown	"	No
France	1883 approx	1883	USA	Yes	"	Yes
German Dem. Rep.	1879	1879	USA	Yes	Yes	Yes
Hungary	Before W.W.II	none	Germany	No	No	No
Italy	1891	After W.W.II	Denmark	Yes	"	Yes
Netherlands	Prior to 1883	None	Unknown	No	"	No
Norway	1870	1918	Unknown	Yes	"	Yes
Poland	After 1879	After 1879	Germany	"	Yes	"
Roumania	Before 1900	Before 1900	Austria	"	"	"
Spain	1934	After W.W.II	France	"	"	Unknown
Sweden	1891	1891	Germany	"	"	Yes
Switzerland	1883	1883	Germany	"	"	Yes
USSR	Prior to 1914	After 1930	Unknown	"	Unknown	No

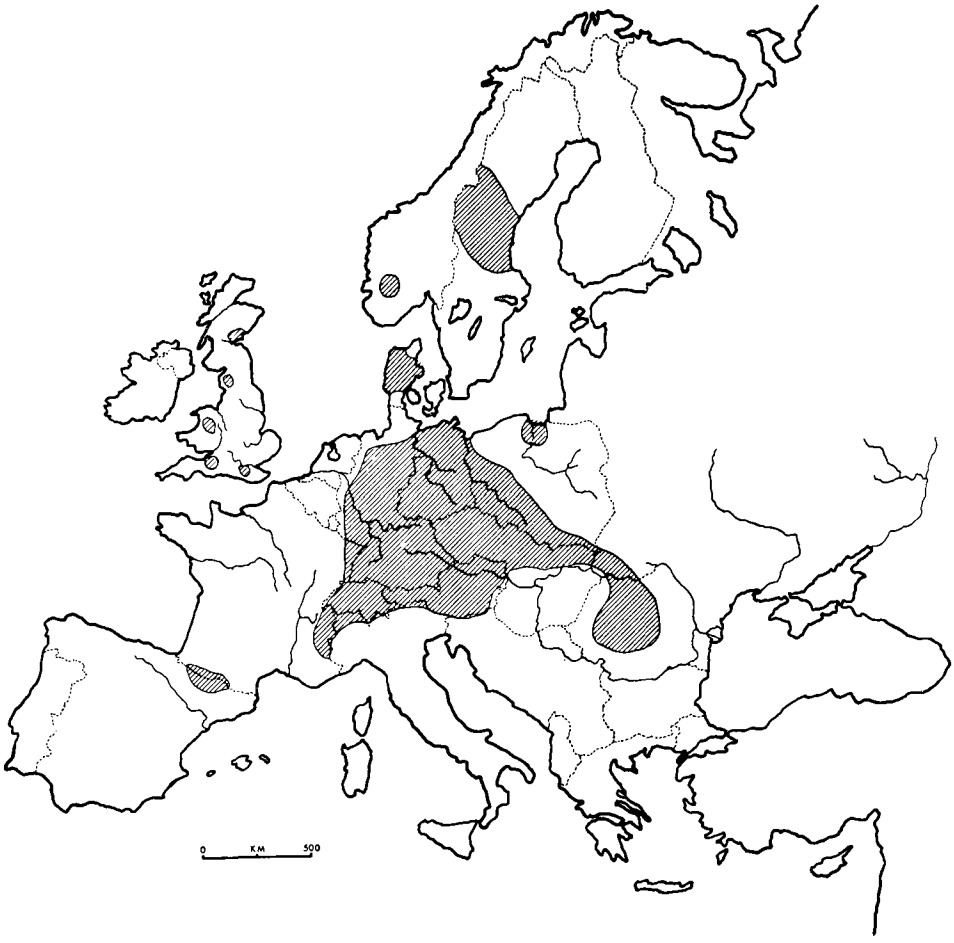

FIG. 2. Naturalized distribution of *Salvelinus fontinalis* in Europe.

AUSTRIA

Brook trout, probably of German origin, were introduced into Austria shortly after 1879. The species has now been naturalized in nearly all of the Austrian provinces including Vorarlberg, Tyrol, Salzburg, Upper Austria, Lower Austria, Styria, and Carynthia (Kähsbauer, personal communication).

BULGARIA

The first attempt to introduce brook trout into Bulgaria was made in 1930, when eyed ova were imported from Czechoslovakia and hatched in government ponds near the town of Samokov in western Bulgaria (Zashev, personal communication). This introduction was a failure but, in 1959, another attempt was made to populate several closed mountain lakes with brook trout, care being taken to avoid hybridization with brown trout (Zashev,

personal communication). Over 1 million brook trout fry are produced each year by state hatcheries and, since 1962, some have been planted in a mountain lake at 1500 m altitude. Although 4-year-old fish, averaging 600–700 g and individuals weighing up to 1500 g are caught, Zashev states that it is too early to consider brook trout naturalized in Bulgaria.

Czechoslovakia

Brook trout were first stocked prior to 1890 in Black Lake of the Šumava Mountains in southwestern Bohemia (Lohinský, personal communication). Fish are now planted mostly in valley reservoirs of northern Bohemia and suitable streams and brooks throughout the country. Naturalized populations have developed in the High Tatra Mountains of northern Slovakia, in middle and eastern Slovakia, in the Hrubý-Jeseník Mountains of northern Moravia, in the Bohemian-Moravian Highland, and in the Krkonoše and Jizerské mountains of northern Bohemia (Lohinský, personal communication). Lohinský states that brook trout show the best rate of growth in Lake Štrbské Pleso in the High Tatra Mountains, where specimens have attained 500 mm in total length and 1000 g in weight.

Denmark

Brook trout are presumed to have been first introduced into trout farms of central Jutland from Germany about 1900 (Larsen, personal communication). Naturalized populations have developed downstream from several trout farms after the escape of individuals. Successful plantings of this species have recently been made in the River Skjern å and the Randers fjord and other populations are found in cool tributaries of the River Lindenborg å and Hald Lake. In 1966, two specimens were caught in the Ringkøbing fjord, one specimen in spawning dress (Larsen, personal communication).

Finland

Importations of brook trout ova to Finland were made in 1898, 1901, 1904, 1906, and 1912 from Germany to the Evo Research Station (Toivonen, personal communication, 1967). There is no evidence that plantings of fry and fingerlings of this early stock made in small lakes and rivers of the area established naturalized populations.

Planting experiments with yearling trout from the USA and 2-year-old fish from Denmark, begun in 1967, are too recent for an evaluation of success (Toivonen, personal communication).

France

Importation of brook trout (saumon de fontaine) ova from the United States to France first occurred about 1883 (Anonymous, 1884). Although brook trout were liberally planted, no naturalized populations have become established in lentic waters such as the upper Seine River, the tributaries of the Rupt-de-Mad in Lorraine, or in the streams of the Alps or the Vosges

(Vivier, 1955). However, brook trout are naturalized in high altitude mountain lakes of the Alps within the province of Dauphiné (Lac Lutel, Domenon, and Prénol), and in other lakes and streams at elevations between 1800 m and 2300 m in the Alps within the province of Savoie, where brown trout are not present. Naturalized populations of brook trout are established in the Pyrenees Mountains in the upper drainage basins of the Aspe and Gaube streams at elevations of approximately 2400 m, and in ponds at Sturzelbronn and Mouterhouse near Bitche (Moselle) (Vivier, personal communication).

Germany

First introductions of brook trout into Germany were made in 1879. Livingstone Stone sent a quantity of eggs to von Behr of the German Fishery Association (von Behr, 1883). In 1885, the Association sent brook trout ova to a hatchery at Boitzenburg, Mecklenburg which is now situated in the German Democratic Republic (East Germany) (Dem Borne, 1885). Naturalized populations of brook trout are found throughout the Republic in small streams, but they are more numerous in Thüringen and the Werra River and its tributaries (Steffens, personal communication). Several hatcheries produce brook trout for stocking small ponds and streams.

Naturalized populations of brook trout are now present throughout the Federal Republic of Germany (West Germany) in brooks, cold fast-running streams, and mountain lakes (Liebmann and Reichenbach-Klinke, personal communication, 1967). Though the Federal Government does not stock brook trout, several fisheries associations carry out private lake plantings. Liebmann and Reichenbach-Klinke state that, in some waters, brook trout cross with brown trout (*Salmo trutta* L.) and give rise to the sterile hybrid (Tigerfisch).

Hungary

Széky (personal communication) states that, although brook trout were introduced privately before World War II, the species is not known to exist in Hungarian waters at the present time.

Italy

The first attempt to introduce brook trout to Italy was made in 1891 when fry were planted in Lake Idro, Lombardia, North Italy. This early introduction, as well as one made in 1935, to streams of the Valley of Aosta (Piedmont) were failures (Tortonese, personal communication). After World War II, the Fishery Council of the Aosta Valley obtained brook trout ova from Denmark and placed them in a local hatchery. Fry were planted with some success in this northern section of Italy, and naturalized populations have become established in at least two lakes of the Aosta Valley (elevations of 1940 m and 2542 m) where competition from other salmonids does not occur (Tortonese, personal communication).

THE NETHERLANDS

Brook trout eggs were imported on two occasions prior to 1883 (Anonymous, 1884) but both of these attempts were failures. The species is not present in the waters of the Netherlands although rainbow trout, *S. gairdneri*, have been successfully introduced and are being propagated for angling purposes (de Groot, personal communication).

NORWAY

Between the years 1870 and 1919, brook trout (bekkerøye) were introduced to Norwegian waters at several locations but, as far as is known, no naturalized populations have resulted (Rosseland, personal communication). However, 1000 brook trout fry released in 1918 in a small tarn at Dyrdal, Øyfjell, in the Telemark district have given rise to self-sustaining populations in local creeks and rivers at about 600–1000 m above sea level (Grande, 1964). In the downriver sections of the naturalized brook trout distribution, Grande (1964) found this species co-existing with brown trout.

POLAND

Although the exact date and location of the first introduction to Poland is not known, brook trout eggs were imported from Germany in the last decade of the 19th century (Sakowicz, personal communication). A very limited stocking programme exists utilizing offspring from brood stocks kept at the Trout Pond Farm of the Polish Anglers Society in Opole voivodship, and in the River Laboratory of the Inland Water Fisheries at Gdańsk-Oliwa. Naturalized populations of brook trout exist in a few mountain lakes and rivers, most notably a tributary of the Warta River near Biedrusko, and a small stream near Jelenia Góra, Wroclaw voivodship in western and northwestern Poland. However, the high vulnerability of this species to angling pressure and natural hybridizing with brown trout, *S. trutta*, limit its numbers (Sakowicz, personal communication).

ROUMANIA

According to Banarescu (personal communication) brook trout of Austrian origin were stocked in tributaries of the Somesul Mic River of Cluj county (i.e., Negrutza, Dumitreasa, and Irisoara rivers) near the end of the 19th century. Fish ponds for artificial breeding of salmonids existed in the village of Racatau, near the Negrutza River, until World War I. Naturalized reproducing populations are still found in the Negrutza River and the following waters: a tributary of Crisul Repede R. in the Bihor Mountains (Western Carpathians), Gudea Mica rivulet (a tributary of the Upper Mures River in Transylvania), the Putna rivulet (tributary of the Moldova River in Moldavia), and in the Upper Bistritza River within Moldavia (Banarescu, personal communication).

Spain

Brook trout were first imported to Spain from Switzerland in 1934, when ova were placed in the hatchery of the Monastery of Piedra (Elegido, personal communication). These fish, however, were lost during the Spanish Civil War of 1936 to 1939. After World War II, fry were obtained from France and placed in streams of the Pyrenees. However, it is not known if these plantings have resulted in the establishment of naturalized populations. Fish hatcheries in Spain are currently engaged actively in the culture of brook and rainbow trout (Elegido, personal communication).

Sweden

Fertilized brook trout ova (bäckröding) were introduced from Germany during the winter of 1891–92 to the province of Jämtland (Svardson, 1964). During the following 15 years, the species was planted in about 120 different waters, most of them in Jämtland, but some also in the provinces of Halsingland and North Dalarna (Svardson, 1964). Naturalized populations have resulted. Alm (1920) states that brook trout have succeeded in certain rivers, lakes, and tarns of the provinces of Örebro, Kopparberg, and Jämtland. Self-sustaining stocks of brook trout occur, also, in small tarns and brooks of the province of Norrland (Hanström and Johnels, 1962; Montén, personal communication).

Switzerland

In 1883, a number of brook trout eggs were sent to Switzerland by the German Fishery Association and hatched in the Roveray Fish Cultural station situated near Allaman (Goll, 1887). In 1885–86, Fred Mather of Cold Spring Harbor, New Hampshire, USA, sent 10,000 brook trout ova to the Government of Switzerland (Clark, 1887). Although naturalized populations of brook trout do exist in Switzerland, intensive stocking of both native and introduced salmonids is required because of the loss of habitat suitable for reproduction (Swiss Fisheries Department, personal communication).

Union of Soviet Socialist Republics

Brook trout were introduced to the USSR prior to 1914, when 700 fry were stocked in two small lakes and a river in the province of Pontoaralokaspian (Werygin, personal communication). These plantings failed, but in the 1930's the rearing of brook trout was initiated in certain pond-fish farms of the USSR including the "Ropsha" farm near Leningrad, two fish farms in the West Ukraine and Lithuania, as well as the ponds of the Institute of Fisheries and Fish Industry (GOSNIORH) at Leningrad (Savvateeva, personal communication) Werygin states that self-sustaining populations of brook trout have not been recorded from the natural waters of the USSR.

ASIA

India

Brook trout were introduced to India when, in 1963, eyed ova from the United States were placed in trout ponds of the Harwan Trout Farm in the State of Kashmir (Tripathi, personal communication). This stock was successfully bred in 1966 and brood stock was made available to other trout farms of the Kashmir Valley (Tripathi, personal communication).

Japan

Although attempts were made to introduce salmonids to Japan prior to 1900, the first successful introduction of brook trout occurred in 1901 when eggs were transported from the United States to the Nikko Hatchery and the resulting fry were planted in the Yugawa River, Nikko City (Shiraishi, personal communication). This species has become naturalized in Kotoku Numa, Yuniko Lake, Yugawa River all located near Nikko City, in Tochigi Prefecture, and in Myozinike Pond, Nagano Prefecture (Shiraishi, personal communication.)

SOUTH AMERICA

Argentina

The first introduction of brook trout (trucha de arroyo) to South America occurred in 1904 when ova were shipped from the United States to a hatchery in Argentina on the shores of Lago Nahuel Huapí (Thompson, 1939). Between the years 1904 and 1931 over 587,000 brook trout eggs were imported and the resulting fry and fingerlings were planted in lakes of Patagonia and Nahuel Nuapí National Park (Thompson, 1939). This species, as well as brown and rainbow trout, have become naturalized in nearly all suitable rivers and large lakes (General Paz, Fontana, Cardiel lakes) of the Patagonian Steppe (Mastrarrigo, personal communication) (Fig. 3). It is stated by de Plaza and Plaza (1949) that brook trout are abundant in the National Parks of Nahuel Huapí, Lanín, and Los Alerces, and according to Thompson (1939), brook trout are, in fact, the most numerous salmonid in Nahuel Nuapí.

Bolivia

Brook trout were introduced from Chile in 1948 and placed in the Pongo Hatchery (Terrazas, personal communication). Several rivers of the Cordillera Occidental and Altiplano were stocked and now, even though no regular stocking programme exists, self-sustaining populations have developed (Terrazas, personal communication).

Chile

The introduction of brook trout ova to Chile first occurred in 1935–36 but neither the source of stock nor the places of dissemination are known (Astete, personal communication). The culture and stocking of salmonids

FIG. 3. Naturalized distribution of *Salvelinus fontinalis* in South America.

is presently carried on by three federal fish hatcheries. Naturalized populations of brook trout are found mainly in the Province of Aconcaqua and in the following rivers of the high Cordillera mountain range (Astete, personal communication): Río Colorado, Estero Ojos de Aqua, Estero Piuquenes, Estero Juncal, Estero La Polvareda, and Estero Los Leones. Brook trout sport fisheries occur in the Negro River near Peulla, the Petrohue River flowing out of Todos los Santos Lake, and the Manso and Puelo rivers which flow from

Argentina (Heusser, 1964). Heusser (1964) states that some brook trout, as well as brown and rainbow trout, exist in Laguna de Inca near Portillo (elevation of 2700 m).

Colombia

Brook trout were introduced to Colombia on a very small scale in 1955 when fry from the United States were planted in the Río Teusacá, a slow-moving but cold-water creek, 15 miles from Bogotá (Gómez, personal communication). Some specimens ultimately were caught but it now seems that the species has disappeared from this river (Gómez, personal communication).

Ecuador

Though the source and date is not known, one attempt to introduce brook trout to Equador was made when fry were planted in the Río Toachi (Mino, personal communication). Although this introduction was a failure, the Department of Industry and Commerce is very interested in making further attempts to naturalize this species.

Peru

Salmonid species were first introduced to Peru in 1928 (Tovar S., personal communication). Brown and brook trout are held currently in Fish Culture Stations at Chucuito and Huaraz, State of Puno, near Lake Titicaca where both species have become naturalized in lakes and rivers above an elevation of 2500 m above sea level (Tovar S., personal communication). The culture of brown, rainbow, and brook trout is conducted also, in the states of Junín, Santa Eulalia, Cajamarca, Huaraz, and Huánuco encompassing elevated regions of the Andes (Tovar S., personal communication).

Venezuela

Weibezahn (personal communication) reports that brook trout were first introduced to Venezuela in 1937 from the USA. These introductions continued until 1942 with plantings in the lakes and rivers of the Andes/Venez. The species is stocked sporadically and is now naturalized in the Motatan, Chama, and Santo Domingo rivers in the State of Mérida, and in many small lakes in the Paramos of the Venezuelan Andes.

Falkland Islands

The introduction of trout to the Falkland Islands would seem to have been attempted during World War II when small quantities of eyed ova of brown, rainbow, and brook trout were brought from Chile (Arrowsmith and Pentelow, 1965). Brook trout are resident in one stream, the Moody Brook (Arrowsmith and Pentelow, 1965).

AFRICA

South Africa

Brook trout ova were imported from the USA to South Africa by air in 1950 and placed in a commercial trout hatchery in the Cape Province where a breeding stock was established (Smith, personal communication). Progeny were distributed to all suitable waters in the Cape Province including Steenbras Reservoir and the upper Witte River. However, no wild populations were established (Smith, personal communication).

A further importation of eggs from the USA was made in 1961 to establish brood stock at the Jonkershoek Hatchery but ultimate attempts to naturalize this species in local waters was again a failure. Male brook trout are now kept at the Jonkershoek Hatchery solely for crossing with the brown trout (*S. trutta*) to produce the "Tiger Trout" hybrid (Smith, personal communication).

The commercial hatchery in the Transvaal did not maintain its stock of brook trout for long as rainbow and brown trout were considered of greater importance (Smith, personal communication).

Kenya

A small consignment of brook trout ova were imported from England in 1949, but the stocking of waters at high altitude (2000 m) with fry subsequently hatched from these ova was a failure (Harrison et al., 1963). Again in 1961, ova were imported from the Paradise Brook Trout Co. of Pennsylvania, USA, and the fingerlings were stocked in a large high altitude reservoir in the Aberdare Mountains and a few rivers of this area (Watson, personal communication). Very few survivors have been seen in the reservoir but the species is known to have bred successfully in one of the rivers (Watson, personal communication).

Federation of Rhodesia and Nyasaland

The first attempt to naturalize brook trout in this area was made in 1908 when ova were imported from England and the fry placed in the Mlungusi River (Harrison et al., 1963). This attempt, and a 1955 planting of streams in the Inyanga area were failures (Harrison, 1963).

Tanzania (Tanganyika)

In 1953 and 1954, brook trout ova were obtained from the Jonkershoek Hatchery in South Africa and stocked in the Ndumbi and Rumakali rivers on the Elton Plateau (elevation of 2600 m) (Harrison et al., 1963). However, this experiment failed so, in 1958, these two waters were stocked with rainbow trout, *S. gairdneri* Richardson (Harrison et al., 1963).

AUSTRALIA AND NEW ZEALAND

Australia

Brook trout were introduced to mainland Australia, and by 1908 had succeeded in adapting themselves to certain waters, particularly those of the Snowny River district (Stead, 1906). Roughley (1951) and Weatherly and Lake (1967) make no mention of this species, and so it is assumed that brook trout are now absent, although brown and rainbow trout exist as self-sustaining populations on the mainland.

Although brook trout were introduced before 1907 to lakes Leake, Crescent, and Sorell in Tasmania, naturalized populations did not result (Lynch, personal communication). In 1962, 50,000 brook trout ova were received from the hatchery at Collingwood, Nova Scotia, Canada, and the progeny of these ova are still being artificially propagated at the Salmon Ponds in Tasmania. Liberations have been made since 1963 in suitable ponds, lagoons, and lakes of the State but, as of February 1967, there was no evidence to indicate that self-supporting stocks had been established in Tasmania (Lynch, personal communication).

New Zealand

The earliest planting of brook trout in New Zealand was made in 1877 near Auckland by an "Acclimatization Society" but this, and further attempts to naturalize the species in 1880 and 1881 were unsuccessful (Little, personal communication).

However, in 1890, the Horokoro in Rotorua was stocked with brook trout. This planting, as well as those made in the upper reaches of a few North Island streams and Lake Emily in mid South Island, have led to naturalized reproducing populations of brook trout (Little, personal communication).

DISCUSSION

Naturalized populations of brook trout have been established beyond its native range by introduction into the waters of 4 provinces and 14 states in North America and 19 countries in Eurasia, Central and South America, as well as New Zealand. The present discontinuity in distribution, whether considered on a local, continental, or world basis, may be considered to reflect the sensitivity of the species to environmental conditions rather than to represent a lack of attempts to establish the species more widely. The species does not, however, always enjoy the prestige in all parts of the world that it does within its native range.

An analysis of the pattern of world distribution suggests a positive relationship between the presence of self-sustaining populations and those environmental factors which affect water temperature, namely latitude, altitude, and precipitation. In general, plantings of brook trout have resulted in naturalized populations only in those areas offering, as well, geophysical and ecological conditions similar to those occurring within the native range.

A review of the literature reporting on laboratory and field investigations on the environmental requirements of salmonids reveals a general agreement that water temperature is the most important single factor limiting geographic distribution (Baldwin, 1951; Vladykov, 1963). The thermal range of water temperature tolerated by the brook trout under laboratory conditions extends from 0 C upwards to an ultimate upper incipient temperature of 25.3 C, or to 28.5 C for short intervals, depending on acclimation (Fry, 1947, MS, 1951). Observations made on natural populations confirm the prolonged existence of the species in water ranging from near freezing to about 24 C (Ricker, 1934; La Rivers, 1962).

Brook trout are not found regularly in lotic or lentic areas with temperatures much above 20 C if a lower temperature is available to them (Henderson, 1963), although trout in lakes may make temporary excursions from deeper and colder water into the warmer epilimnion during the period of summer stratification (Fry, MS, 1951). Brook trout, when placed in a thermal gradient in the laboratory select a temperature of 14–16 C (Graham, MS, 1948; Fisher and Elson, 1950). Observations by the authors tend to confirm that this preference occurs in stratified lakes but may not occur in streams where population density and habitat conditions may be more dominant in establishing the distribution of fish. It is of interest that the most suitable temperature for the general performance of the species would seem to lie in the range of the preferred temperature.

Davis (1961) states that temperatures of 11–14 C are most satisfactory for rapid growth of fingerlings and Baldwin (1951) cites an optimum growth rate for brook trout at 14 C. Fisher and Elson (1950) point out that the optimum temperature for the greatest response to an electrical stimulus coincides with the selected (or preferred) temperature. Graham (1949) found the cruising speed of brook trout to be greatest at 20 C, but at 16 C the species had the most efficient oxygen uptake for physical activity. Fisher and Sullivan (1958) calculated the spontaneous activity of brook trout to be at a maximum at that temperature selected in a temperature gradient.

It would seem, therefore, that although brook trout may survive over a wide range of sublethal temperatures, water in the 11–16 C range is best suited to their overall welfare, and at both higher and lower temperatures the fish exist at a relative disadvantage in terms of activity and growth (Baldwin, 1951). Although the effects of low temperature in nature have received little attention, brook trout within their native range can be self-sustaining in cold headwater streams and ponds which rarely, if ever, exceed 10 C, but with greatly inhibited growth.

Although brook trout may survive to maturity over a wide range of temperatures, water temperature becomes more critical at the time of spawning and egg incubation when, for successful natural reproduction, it must fall within a rather narrow range. Under natural conditions in Ontario, the brook trout spawns normally at about 9 C, the temperature of ground water where the gravel redds are located. Embody (1934) observed that brook trout eggs

fail to develop at temperatures above 13 C and suggested about 11.5 C as the safe upper limit. He observed, also, that a temperature above 4.5 C was necessary during incubation to the eyed stage but that egg development can be completed at temperatures as low as 1.7 C but with abnormally high losses and likely less robust fry. Incubation time is a function of water temperature and, within the temperature range considered suitable for egg incubation (4.5–11.5 C), the time from fertilization to hatch varies between about 7 and 13 weeks (Davis, 1961).

Evidence of the sensitivity of the brook trout to environmental influences is provided by observations on the species within its native range. In some areas south of the Pre-Cambrian Shield, where land-use patterns accompanying 200 years of settlement have caused marked ecological change, local populations have been eliminated. More commonly, in the southern Great Lakes drainage and southward, the local stream distribution of the species has become limited to headwaters because of loss of pristine habitat through erosion, siltation, and seasonally high water temperatures.

The native range of brook trout is delimited to the north both by the Arctic Ocean and a mean daily air temperature of −15 C in January (Department of Mines and Technical Surveys, 1957) and to the south by the isotherm marking a mean July air temperature not exceeding 21 C (Séguin, 1956). The area of distribution extends from the Atlantic Ocean westward to the line of 64 cm average annual precipitation (Visher, 1954) or to the place where the annual surplus precipitation becomes less than 10 cm (Séguin, 1956). Plantings of brook trout in the Central Plains of North America have generally led to the establishment of self-sustaining populations in proximity to sources of headwater streams where summer water temperatures remain tolerable. It would seem, therefore, that areas characterized by mixed deciduous or coniferous forests, or both, a cold temperate climate, cool spring-fed surface waters, and moderate precipitation are suited for the establishment of self-sustaining brook trout populations.

Naturalized populations of the species have been established by introduction only in those areas of the world where meteorological conditions are remarkably similar to those within its native range. Extension of the range in North America has proven possible only in elevated areas (at least 600 m above sea level) or where annual rainfall amounts to more than 42 cm, or both. Similarly in Europe, plantings have been the most successful in elevated areas of the Pyrenees and Alps, and of the Scandinavian and Carpathian mountains. The European distribution is delimited by a mean daily July air temperature of 24 C and an annual rainfall of 50 cm. In France, the species seems to adapt best to high mountain lakes and headwater streams where competition from other salmonids is least (Vivier, 1955). In South America, also, brook trout have been established in headwater streams of the Andes as well as inland lakes of the Patagonian Steppe. However, brook trout populations in Africa, Australia, and New Zealand appear unable to compete with the brown or rainbow trout, or both, and so have been largely unsuccessful.

In some instances, the introductions of brook trout beyond the native range have resulted in the establishment of naturalized populations in cold and relatively sterile environments often favourable for survival and reproduction but not necessarily conducive to good growth. For, example, in certain high altitude lakes of California, a combination of overpopulation, cold water temperature, and inadequate food contribute to slow growth and small fish (McAfee, 1966). Similar biological features are typical of trout introduced into high altitude or headwater streams on all continents and, consequently, the species may lack the prestige which it enjoys as a sport fish within its native range. However, in some areas of the world, such as Peru, Argentina, Venezuela, and Japan, naturalized populations of brook trout have been very successful in terms of growth and angling quality.

In conclusion, it may be stated that the brook trout, in spite of numerous unsuccessful efforts to establish it, is now widely naturalized in North America beyond its native range and on the continents of Eurasia and South America. The species, however, has not gained the respect as a food or sport fish afforded native salmonids or, where introduced, the exotic rainbow trout. Waters suited for the survival, reproduction, and favourable growth of brook trout are very limited beyond its native range because of the species low tolerance to adverse environmental conditions. Attempts to introduce it into habitats occupied by other salmonids have had only marginal success and, in cold environments, individuals show relatively slow growth and poor condition.

Because of the foregoing factors, it is improbable that, with the possible exception of Asia, the present range of the brook trout will be extended greatly through further attempts at introduction.

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