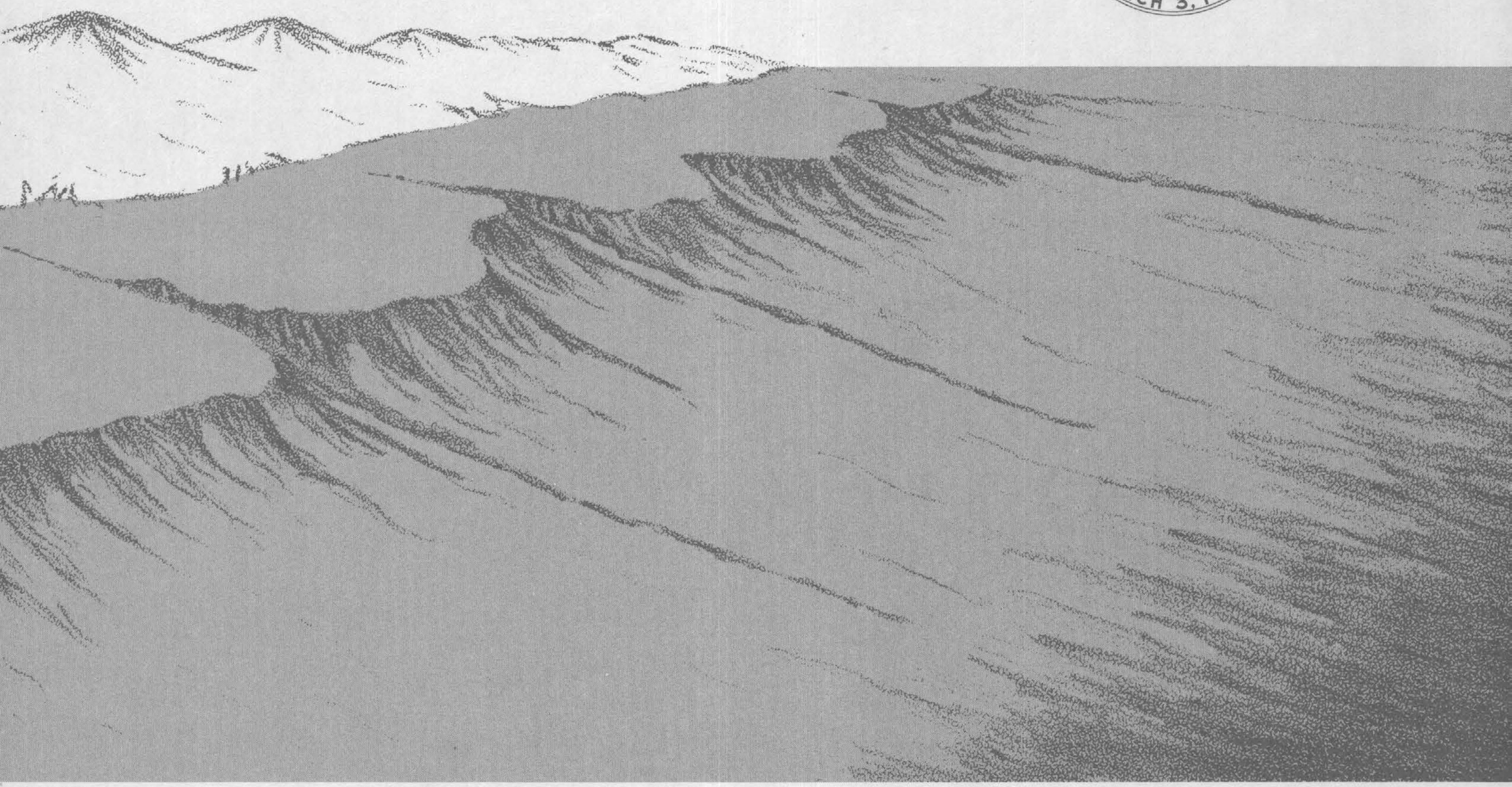
Atlantic Continental Shelf and Slope of the United States



Ostracode Zoogeography in the Southern Nova Scotian And Northern Virginian Faunal Provinces

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-E

Atlantic Continental Shelf and Slope of the United States—Ostracode Zoogeography in The Southern Nova Scotian And Northern Virginian Faunal Provinces

By JOSEPH E. HAZEL

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-E

Geographic distribution and temperature and depth tolerances of Recent Arctic–North Atlantic benthonic ostracodes with particular emphasis on the sublittoral species off the northeastern United States

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[For ease of identification, all plates in each group are the same color, and each group is a different color. Plates are in pocket]

TABLES

ATLANTIC CONTINENTAL SHELF AND SLOPE OF THE UNITED STATES—OSTRACODE ZOOGEOGRAPHY IN THE SOUTHERN NOVA SCOTIAN AND NORTHERN VIRGINIAN FAUNAL PROVINCES[1]

By Joseph E. Hazel

ABSTRACT

Ostracodes were identified from 236 bottom samples taken in the region from Nova Scotia to Long Island. There is a distinctive difference between the assemblages in the northern and southern parts of this region. Many sublittoral cryophilic species are not present south of Cape Cod or the Northeast Channel, and several thermophilic species are not found north of Cape Cod or Georges Bank. The ostracode assemblages in the southern part of the cold-temperate Nova Scotian province are a mixture of amphiatlantic cryophilic species and endemic, mainly thermophilic species; European forms make up approximately 50 percent of the species. Less than 25 percent of the species known from the mild-temperate Virginian province have been reported from European waters. More endemic species pass Cape Cod from the south than amphiatlantic cryophilic species do from the north. This is consistent with the fact that summer isotherms are more compressed than winter isotherms in the Cape Cod region, and the southern limit of distribution of most amphiatlantic species is regulated by summer high temperatures. The distribution data on which these interpretations are based are presented in a series of figures and over 60 species distribution maps.

INTRODUCTION

This study is concerned with the geographic distribution of diagnostic, mainly podocopid, ostracode species obtained from offshore bottom grab samples taken on the Atlantic shelf and slope in the southern Nova Scotian and northern Virginian faunal provinces (Long Island to Nova Scotia; fig. 1). This research was carried out as part of the U.S. Geological Survey-Woods Hole Oceanographic Institution program to study the marine geology of the Atlantic continental margin of the United States (Emery, 1966).

In this study the geographic spread of the taxa treated is of primary importance; temperature tolerances and depth ranges are also presented. The relationship of the taxa to substrate conditions in the study region (mostly sand) must await completion of sedimentological studies now in progress (Schlee and Pratt, 1966; Trumbull and others, 1966).

The Recent ostracodes of the Atlantic coast of the United States are poorly known (Hazel, 1967a), and the purpose of this report is to contribute to the establishment of a Recent datum to which Pleistocene and older distributions can be compared. It is assumed that the collections, supplemented by the available literature, are adequate to delineate the Recent teil provinces—the geographic range of a species during a small part of geologic time (Valentine, 1961)—of most of the taxa treated. The distribution of the species treated are presented in a series of maps, and their tolerances with respect to provinces, climatic zones, depth, and temperature are given on several plates.

ACKNOWLEDGMENTS

I am indebted to members of the U.S. Geological Survey and Woods Hole Oceanographic Institution who are assigned to the continental margin program for discussions of the results of their studies. W. M. Walker and P. C. Valentine of the U.S. Geological Survey deserve special thanks for their technical assistance in processing samples and organizing data. T. J. M. Schopf of Lehigh University provided unpublished temperature data. I am grateful to A. H. Cheetham of the U.S. National Museum and John Pojeta and P. C. Valentine of the U.S. Geological Survey for critically reading the manuscript.

PREVIOUS WORK

Brady (1866, 1868b, 1870), Brady and Norman (1889), Norman, (1877), Sars (1909), Stephensen (1913, 1936), Elofson (1941), Neale (1959, 1961, 1964), Hazel (1967a), Hazel and Valentine (1968), Whiteaves (1901), and Kindle and Whittaker (1918) have described, listed, or reviewed podocopid ostracode occur-

[1] Contribution 2156 of the Woods Hole Oceanographic Institution, based on work done under a program conducted jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

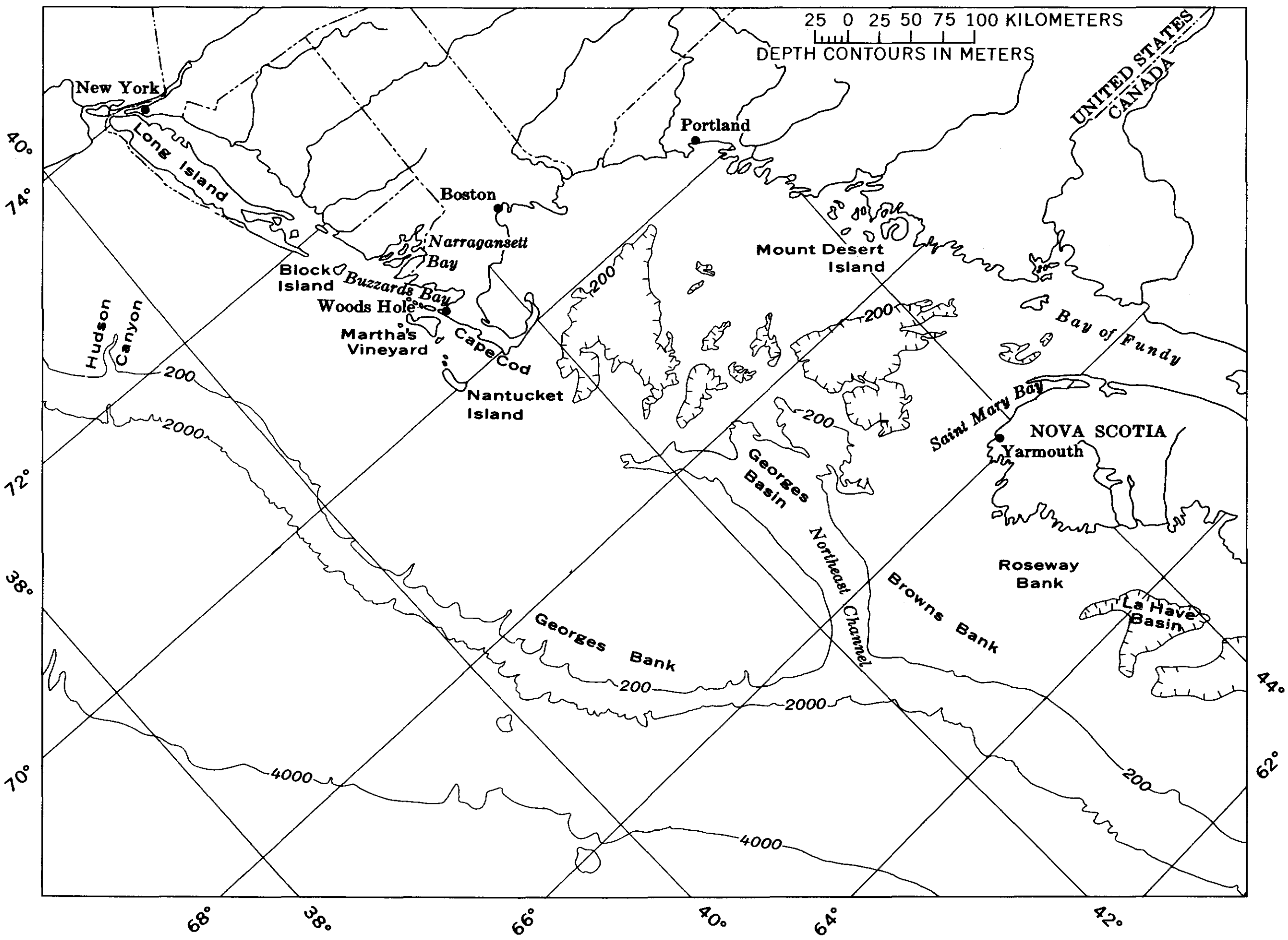


FIGURE 1.—Index map of the Atlantic coast from Long Island, N.Y., to Nova Scotia showing the more important geographic localities mentioned in this report.

rences along the Canadian and western Greenland coasts from the Gulf of St. Lawrence to about lat 80° N. Cushman (1906), Williams (1907), Blake (1929, 1933), Puri (1958a, 1958b), Williams (1966), Hazel (1967a), and Hazel and Valentine (1968) have described or listed ostracodes from the Gulf of Maine region to Long Island. In comparing the western Atlantic distributions of amphiatlantic species to those of the eastern Atlantic, the work of Elofson (1941) was invaluable; most of the eastern Atlantic map points for the species were taken from Elofson's maps and text or from references given therein. Elofson (1943), Wagner (1957), Vos (1957), Lange (1956), Neale (1959, 1964), and Hagerman (1965) were useful later references.

In the first work in the region of this study, Cushman (1906) described or listed 26 species from the Woods Hole, Mass., area. Most of the species were at Fishhawk station 7723 (see Sumner and others, 1913, for detailed localities of the stations) in Vineyard Sound at 24 meters. Unfortunately, Cushman's specimens are not available for restudy (Puri, 1958a). This is particularly troublesome because it is unlikely that some of the species Cushman reported as occurring in Vineyard Sound actually live in the area. In his study of the genus *Cushmanidea*, Puri (1958a) had Fishhawk 7723 and other stations reoccupied and, with the resulting material, revised the species Cushman assigned to *Cytheridea*. Through the courtesy of Dr. Puri, I was able to examine his faunal slide from Fishhawk 7723. The following is a list of the species present (Neocytherideidinae from Puri, 1958a) and the names Cushman seems to have used for them:

Reoccupied Fishhawk station 7723	*Cushman (1906)*
Pseudocytheretta edwardsi	*Pseudocytheretta edwardsi.*
Muellerina canadensis (Brady) aff. *M. lienenklausi* Ulrich and Bassler)	*Cythereis canadensis.*
Bensonocythere arenicola (Cushman) aff. *B* whitei (Swain)	*arenicola.*

Reoccupied Fishhawk station 7723	*Cushman (1906)*
Aurila aff. *A. amygdala* (Stephenson)	*Cythereis albomaculata* (Baird).
Hemicythere villosa (Sars)	*villosa.*
Finmarchinella finmarchica (Sars)	
Leptocythere angusta Blake	
Cyprideis sp.	?*Cytheridea punctillata* Brady.
Actinocythereis vineyardensis (Cushman)	*Cythereis vineyardensis.*
dawsoni (Brady)	*Cythere dawsoni* Brady.
aff. *A. gomillionensis* (Howe and Ellis)	
Puriana rugipunctata (Ulrich and Bassler)	
Cushmanidea elongata (Brady)	*Cytheridea rubra* Mueller.
seminuda (Cushman)	*seminuda.*
Hulingsina americana (Cushman)	*americana.*

In addition to the above taxa from the Vineyard Sound area, Cushman also reported several other species which are treated in the present study, that is *Baffinicythere emarginata*, *Loxoconcha impressa*, *Eucytheridea bradii* (=*Cytheridea papillosa*), *Elofsonella concinna*, and *Robertsonites tuberculata*. *Baffinicythere emarginata* and *Loxoconcha impressa* have been identified in my samples from the general area, thus confirming Cushman's identification. Cushman's *Cytheridea papillosa* is a *Krithe* (Puri, 1958a). It is questionable if Cushman actually found *Elofsonella concinna* and *Robertsonites tuberculata;* they do not occur in any of my samples from the Vineyard Sound area and have not been reported south of the Gulf of Maine. For the time being, Cushman's report of these taxa is considered to be based on misidentifications.

PRESENT WORK

Work on samples collected by U.S. Bureau of Commercial Fisheries ships and the RV *Gosnold* in connection with the U.S. Geological Survey—Woods Hole Oceanographic Institution program has added 236 more localities to the list of stations where ostracodes have been found in the Gulf of Maine–Georges Bank–Cape Cod region. For comparative purposes 25 new Arctic stations were also added in this study. These samples were collected by Captain R. A. Bartlett in the 1930's and 1940's and were used by Loeblich and Tappan (1953) in a study of the Arctic Foraminiferida. All the new stations and the identified ostracodes are listed on table 1.

Basically, the Nova Scotia to Long Island region was sampled on a 10-mile grid (Hathaway, 1966). About 600 samples, mostly from depths greater than 20 m, were processed, and ostracodes were found in 236 samples (fig. 2). Large areas in the central Gulf of Maine, middle part of Georges Bank, and on Nantucket Shoals were virtually devoid of ostracodes. Ostracodes occur principally on the outer parts of the shelf south of New England, outer parts of George Bank, Browns Bank, southwest of Nova Scotia, southern Bay of Fundy, and northern and western parts of the Gulf of Maine.

Over 100 species have been identified to the present time; however, many of these are rare and (or) have not yet been treated taxonomically or are in need of further taxonomic treatment. In this study, over 40 taxa are used which are considered to be important, that is, species which are useful in delineating the Virginian province from the Nova Scotian province, or species which occur commonly over the entire region and are therefore diagnostic for the region as a whole.

The samples used in the study, the amount of material processed, and the number of specimens of each species are given in table 1. Living and dead specimens were counted together. In most samples containing many ostracodes, specimens with appendages or at least some chitin remaining were observed for most species. In many samples, however, only dead specimens were observed, but living specimens were frequently found in nearby samples and the maps presented herein are considered to depict adequately the areas where the species live.

WATER TEMPERATURES FROM NOVA SCOTIA TO LONG ISLAND

Water temperatures in the region (Fritz, 1965; Schroeder, 1963, 1966; Emery, 1966; Schopf, 1967; Hicks, 1959) range from a minimum of less than 2°C on the Scotia Shelf to a maximum of over 20°C in inshores areas such as Narragansett Bay (pl. 1). The average surface temperature (pl. 1) for the warmest month in the Gulf of Maine–Scotia Shelf–Browns Bank area ranges from 12°C in the northern Gulf of Maine and lower Bay of Fundy to about 18°C in Cape Cod Bay. It is 12°C at the surface over most of the Scotia Shelf and averages as high as 15°C over Browns Bank. Average bottom temperatures (pl. 2) in the warmer months are usually between 6° and 7°C on Browns Bank and on the Scotia Shelf; however, temperatures as high as 10°C on the Scotia Shelf and 8°C on Browns Bank have been recorded (Fritz, 1965). Bottom temperature maps for depths less than 100 m are not available for the western Gulf of Maine, but temperatures are between 5° and 7°C in the warmest months at 100 m (Schopf, 1967) and, if the end point of a species range was found to be in this area and at depths less than 100 m, the temperature was interpolated between the surface and 100 m. Bottom temperatures in summer and

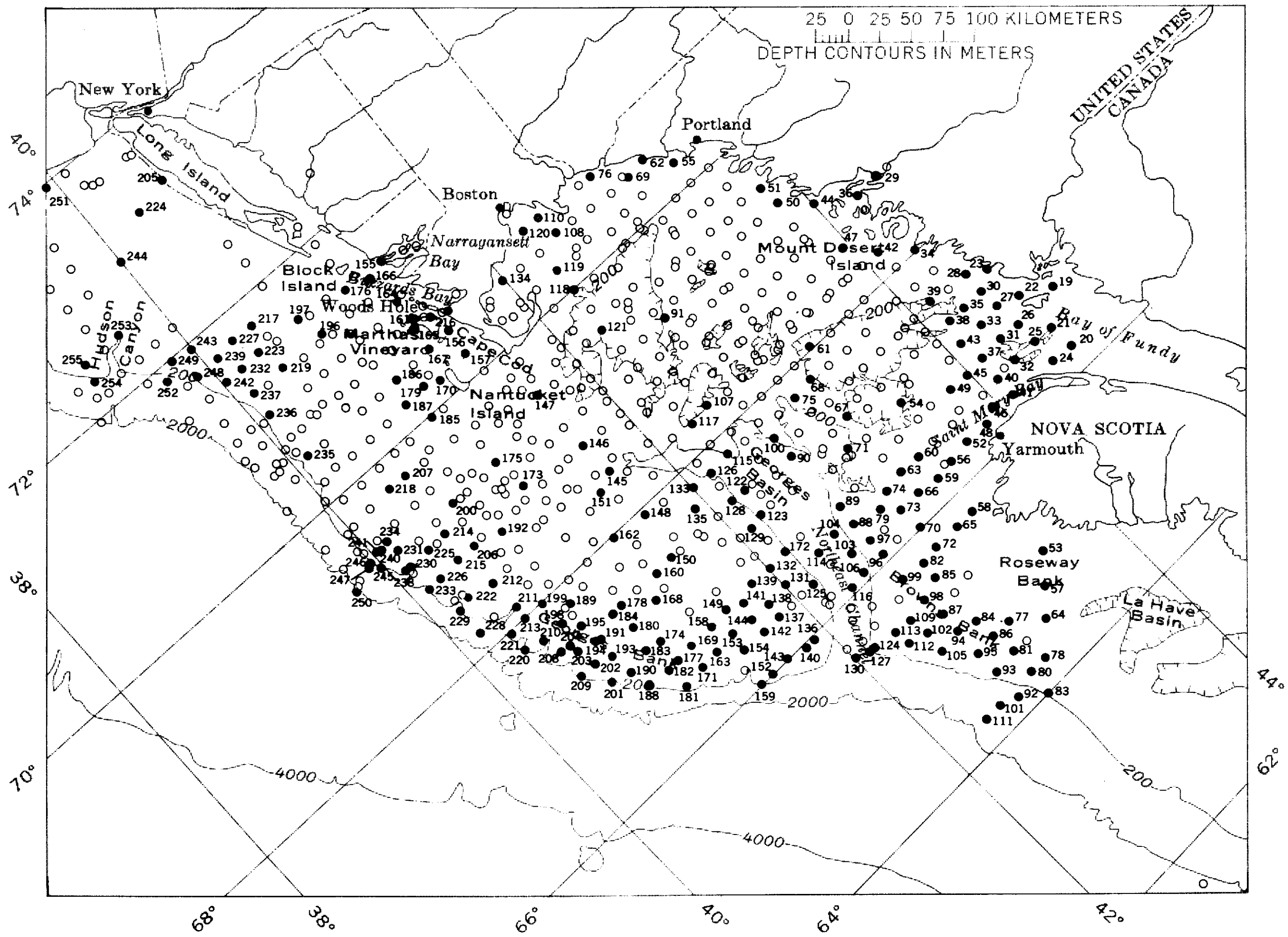


Figure 2.—Location of samples used in the Long Island to Nova Scotia area (○, indicates ostracodes absent; ●, indicates ostracodes present). See table 1 for the location of the numbered ostracode-bearing samples. See Hathaway (1966) for additional information about these and other stations used in the U.S. Geological Survey-Woods Hole Oceanographic Institution program.

winter are about 6°C in the Northeast Channel and deep basins of the Gulf of Maine.

In the coldest months the average surface temperature in the Gulf of Maine region north of Georges Bank is 3°–4°C (pl. 3). Average bottom temperatures on Browns Bank are between 3° and 5°C and on the Scotia Shelf between 2° and 4°C. In the western Gulf of Maine bottom temperatures are about 4°C (pl. 4).

The average surface temperature over Georges Bank in the warmest month is about 16°C and increases southwestward to 22°C south of Long Island. The maximum bottom temperature on Georges Bank is about 16°C and the average bottom temperature is 15°C on the shallow central part in the warmest months. To the south, east, and north, this average decreases to about 7°C between depths of 100 and 200 m. Another center of offshore high temperature is at middle shelf depths south of Martha's Vineyard where the temperature averages 14°C in the warmer months. South of Long Island the temperature averages 14°–15°C at 30 m. In some years temperatures in waters under 100 m may average 9°–10°C on the Scotia Shelf during this period (Fritz, 1965), and the region south of Long Island is warmest in November, averaging 14°–15°C at 30 m (Schopf, 1967; Fritz, 1965). At 200 m along Browns Bank the yearly temperature average is about 9°C with about a 5°C observed range, and at 200 m south of Northeast Channel the yearly average is about 10.5°C with an observed range of 5°C (Schroeder, 1963).

In the coldest months the average bottom temperature on Georges Bank is 4°C; in the area south of Martha's Vineyard, 3°C; and at depths of 100 m, from eastern Georges Bank to south of Long Island, 6°–7°C. At depths of 200 m, on the shelf edge south and east of the Cape Cod area, the yearly average is between 10° and 11°C with an observed range of 5°C, and on the Atlantic side of Browns Bank the yearly average is about 9°C, also with a 5°C range.

SUBSTRATE FROM NOVA SCOTIA TO LONG ISLAND

Studies of the sediments in the region are in progress, and preliminary reports have appeared (Schlee and Pratt, 1966; Trumbull and others, 1966; Hülsemann, 1967). For a summary of the sedimentologic studies prior to the initiation of the U.S. Geological Survey–Woods Hole Oceanographic Institution program, see Uchupi (1963). Over much of the region (fig. 3) where ostracodes were found, the substrate is mainly quartzose sand. Large patches of gravel are present in several areas, particularly Georges Bank, Nantucket Shoals, Northeast Channel, Browns Bank, and the Scotia Shelf. The deep basins in the Gulf of Maine are floored mainly with clay and silt; the western Gulf of Maine is largely silt, and a large area of silt-sized material is present on the shelf south of Martha's Vineyard.

HISTORICAL DEVELOPMENT OF FAUNAL PROVINCES

NORTH AMERICA

The Atlantic coast of North America was divided into biogeographic provinces as early at 1838 by Milne-Edwards. Working with Crustacea, he divided the coast into a polar region (Newfoundland northward), a Pennsylvanian region (Newfoundland to the Carolinas), and a Caribbean region (Carolinas southward).

In classic works, Dana (1853a, b) proposed a worldwide scheme of biogeographic kingdoms and provinces and climatic zones. The provinces were named after places, and the names of climatic zones were formed from the adjectives torrid, temperate, and frigid, used in the ancient Greek classification. From a nomenclatorial standpoint Dana's scheme for provinces and climatic zones is in many ways preferable to that used by some

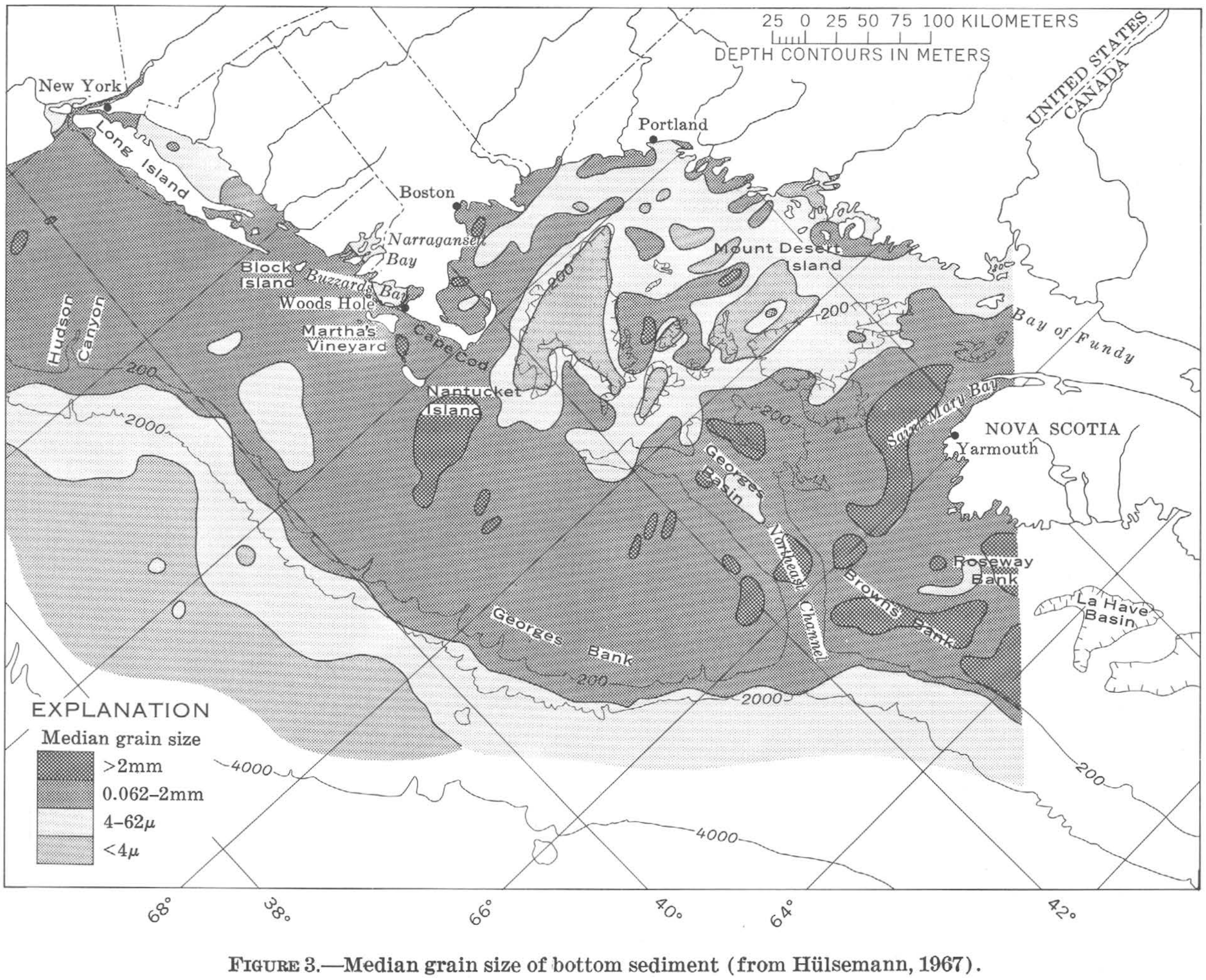


Figure 3.—Median grain size of bottom sediment (from Hülsemann, 1967).

authors today. It avoids such confusing terminology as "Boreal" and "Arctic" which have been used both for provinces and climatic zones. Dana's concept of biogeographic provinces, however, differs from that generally accepted by modern biogeographers (for example, see Valentine, 1961). Dana seems to have first set up his global scheme of climatic zones based on isocrymes at 6°F intervals (except for the lowest isocryme which was 9°F below the penultimate). The coasts and islands of the world therefore were first placed in a globe-encircling climatic zone, the coastal areas named, and then the crustacean assemblages found in the provinces discussed. Thus, Dana's provinces seem to be based on temperature and not on the distribution of animals. Dana (1853a, p. 1488) stated, however, that one of the objects of his study was "to compare different geographical positions in similar regions with one another, in order to arrive at their resemblances and differences, and deduce the several distinct zoological provinces * * *." He may have studied the assemblages found in the temperature-based climatic zones, judged that the zones did contain distinct assemblages in different areas, and then accepted them as provinces.

In most other works marine climate zones are not really based on temperature. Temperature is the underlying factor controlling the distribution of organisms, but it is the distribution of kinds of organisms that determines the provinces, and it is the boundaries between provinces upon which the climatic zone boundaries have been based.

The fact that temperature is the basic factor controlling the distribution of organisms should make an objective scheme based solely on temperature similar to that based on province boundaries. Compare Dana's (1853a) chart showing his climatic zones based on isocrymes to Hall's (1964) map showing marine climates "based on the duration of marine temperatures at the limits of molluscan species." Along the east and west coasts of North America, Dana's boundaries almost coincide with Hall's, although the nomenclature is different. It might be added here that Hall (1964, p. 232) chose Edward Forbes' (in Johnson, 1856) province terminology "because of priority." However, many of Dana's and Milne-Edward's terms are different from and predate those of Forbes.

Along the Atlantic coast, Dana (1853a) recognized a Floridian province from Key West to lat. 27°30′ N., a Carolinian province from there to Cape Hatteras, a Virginian province from Cape Hatteras to Cape Cod, and a Nova Scotian province from there to Cape Race, Newfoundland (fig. 4). Without comment, Dana (1853b) changed the name Nova Scotian to Acadian. The Floridian province was considered to be in the subtorrid region, the Carolinian in the warm-temperate region, the Virginian in the cold-temperate region, and the Nova Scotian in the subfrigid region. It is interesting to note that Dana recognized five temperate regions—warm-temperate, temperate, subtemperate, cold-temperate, and subfrigid—and that the temperate and subtemperate regions were not considered to be present on the American coast.

Dana considered the coasts north of Cape Race, Newfoundland, to belong to his Arctic kingdom (north frigid region) but applied no provincial terminology to this region. He (1853b) divided his Arctic kingdom into the north polar, Camtschatican, and Norwegian provinces, but did not mention the North American coast north of Newfoundland.

Woodward (1851–56) first used the term Transatlantic province for the Atlantic coast of the United States from some undescribed point in Florida to Cape Cod; the Gulf of Maine–Nova Scotia region was placed in the Boreal province; and the shores of the Gulf of St. Lawrence and Newfoundland and regions to the north were placed in the Arctic province.

Woodward (1851–56, p. 379) stated that Forbes considered the Atlantic coast of the United States to consist of two provinces, the Virginian and the Carolinian. He was apparently referring to Forbes' plate 31, a map of the distribution of marine life, and the accompanying discussion in Johnson (1856). Here Forbes used Carolinian province for the region from about the Georgia-Florida State line to Cape Hatteras, Virginian province for the region from Cape Hatteras to Long Island, Bostonian province from Long Island to Cape Race, Newfoundland, and Arctic province north of this and apparently including the Gulf of St. Lawrence. From the literature available to me it seems that the first use of Carolinian and Virginian should be attributed to Dana (1853a), although Forbes did not mention Dana's use of the terms.

Packard (1863, 1867) proposed that on the American coast there exists a characteristic fauna between the true circumpolar Arctic province and the Nova Scotian province. He stated that this fauna bears the same relationship to the Nova Scotian as the fauna of the Finnmark region of Norway does to the North Sea and Scottish seas. Packard called this fauna the Syrtensian or Labrador fauna. The name Labrador is preferable though Syrtensian has priority, because all the provinces along the American coast would have a geographic term as the root word. Packard considered the Labrador province to include the coast of Labrador, Hudson's Bay, the northern coast of Newfoundland, and the northern parts of the Gulf of St. Lawrence, with "outliers" to the south in the region of Dana's Nova Scotian

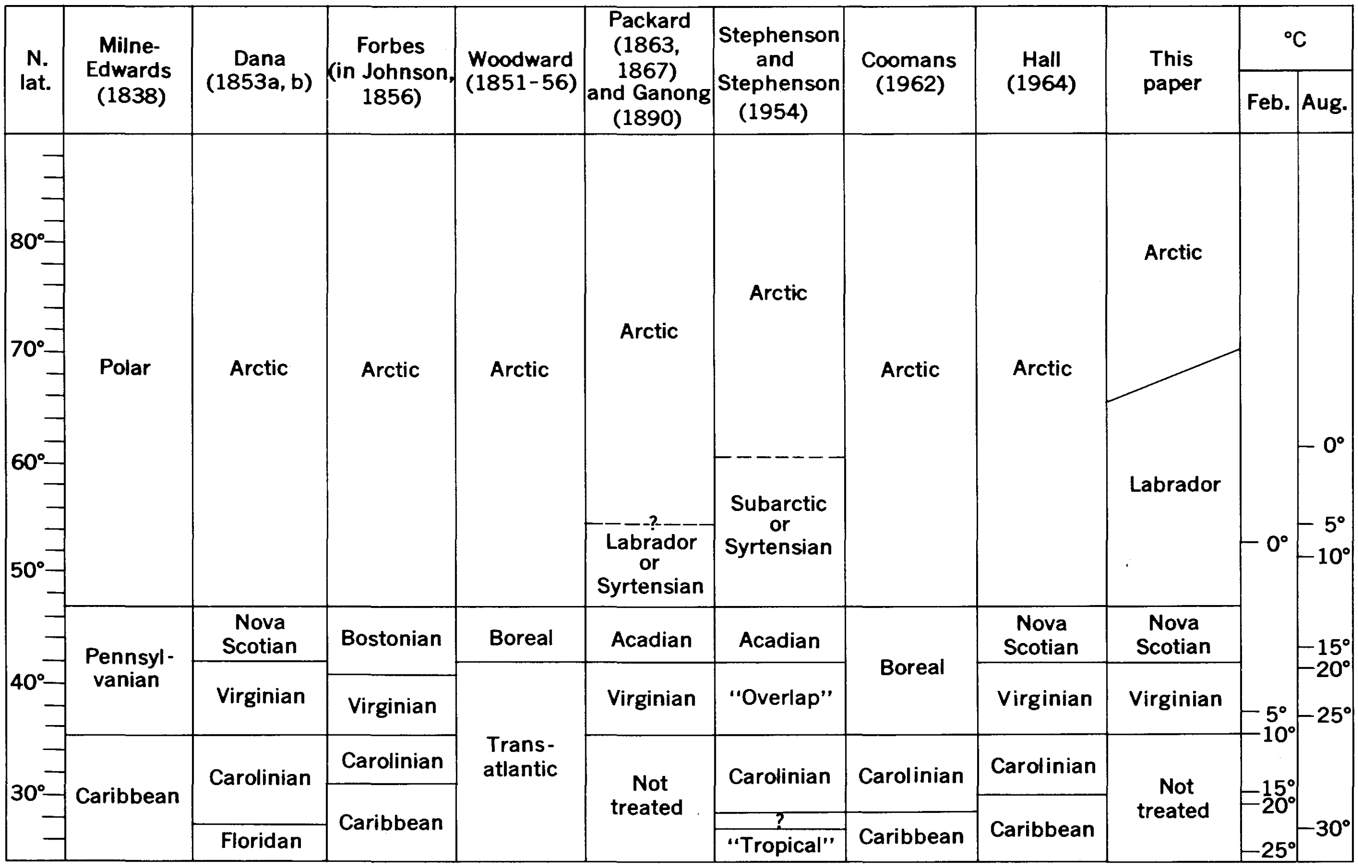


FIGURE 4.—Summary of the biogeographic schemes used by various workers on the Atlantic Coast of North America plotted against latitude. Average surface-water temperatures for August and February given in 5°C intervals.

province. Ganong (1890, p. 170, 171) stated that it is uncertain how far south on the northeast coast of Labrador the circumpolar Arctic fauna extends, "but certainly it does not on the surface reach the Straits of Bell Isle * * *." He considered the Syrtensian province to include the southern part of Greenland, all the northern part of the Gulf of St. Lawrence as far west as Anticosti Island, and the deeper part of the of the gulf north of a line drawn from Gaspé to the Magdalen Islands and thence to the north of Cape Breton. All the Newfoundland coast, except possibly a part of the southern shore, is included. Ganong also included some areas (Packard's "outliers") farther south in the Syrtensian that Dana and most modern workers would include in the Nova Scotian province.

Johnson (1934) stated that the Arctic province is bounded on the south by floating ice which descends as far south as Newfoundland. The Boreal province was said to encompass the region from northern Nova Scotia to Cape Cod, and the transatlantic province extends from the southern shore of Cape Cod to the vicinity of Cape Kennedy. The northern limit of the Caribbean province was placed at Jupiter Inlet or perhaps Cape Kennedy.

In 1954, Stephenson and Stephenson summarized their thoughts on the provinces of the North American coast after study of the intertidal fauna and flora from Florida to Labrador. They stated that they are in general agreement with the older workers on the biogeographic provinces but introduce some revisions based on new data. The Stephensons recognized an Arctic province "* * * whose southern limits cannot yet be defined, but which probably lies north of Labrador." Their subarctic province (= Packard's Labrador or Syrtensian province) occupies Labrador and southern Greenland, much of Hudson Bay, and the northern parts of Newfoundland and the northern Gulf of St. Lawrence. They stated that further work is needed in these regions in order to determine how distinct the Labrador province may be. The northern limits of ostracodes (fig. 5) and many other Crustacea (Stephensen, 1936; Dunbar, 1964; Squires, 1966) suggest that the northern boundary of the Labrador province is at about Disko Bugt in western Greenland and at the southeastern Baffin Island in eastern Canada.

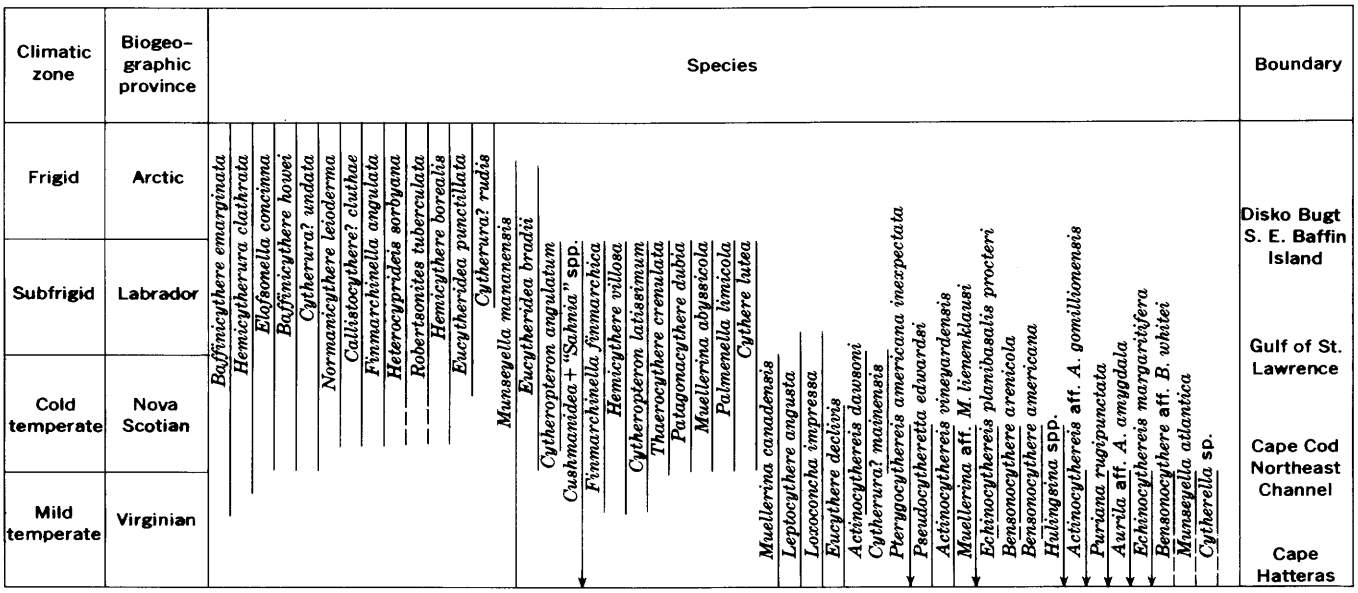


FIGURE 5.—Generalized diagram showing the distribution of ostracodes within the biogeographic provinces of the western North Atlantic. The northern limits of several species of ostracodes (for example, *Patagonacythere dubia, Thaerocythere crenulata, Hemicythere villosa, Cythere lutea*, and perhaps *Muellerina abyssicola*) and other Crustacea (Stephensen, 1936; Dunbar, 1964; Squires, 1966) suggest that the Arctic-Labrador provincial boundary falls at about Disko Bugt in Greenland and southeastern Baffin Island in Canada. The boundary between the Labrador and Nova Scotian provinces is less well marked by the ostracodes, but this is probably the result of incomplete collections as the ostracodes have not been described from the Atlantic coast of Newfoundland and are known from the Gulf of St. Lawrence almost entirely from the work of Brady (1870). *Cytherura? mainensis, Actinocytheresis dawsoni*, and *Muellerina canadensis* are not known north of the Gulf of St. Lawrence, and *Leptocythere angusta* and *Loxoconcha impressa* extend only to southeastern Labrador. The Nova Scotian-Virginian boundary is well marked by the termination of a large number of equatorward-expanding cryophillic and poleward-expanding thermophilic species. Study of collections from the area of the Virginian-Carolinian boundary is incomplete; however, several species seem not to extend south of the Cape Hatteras area, and several warm-temperate or tropical and subtropical genera, such as *Orionina, Neocaudites, Caudites*, and *Cytherelloidea*, do not seem to occur north of Cape Hatteras.
The marine climatic-zone nomenclature is modified from Dana (1853a).

The Stephensons' cold-temperate or Acadian province is virtually the same as Dana drew it (1853a), excepting the modifications of Packard (1867), Ganong (1890), and the Stephensons in the Gulf of St. Lawrence. They preferred, however, not to recognize the Virginian province because it does not seem to possess "* * * a distinctive population of its own, but to represent an overlap between the cold-temperate population of Cape Cod and the warm-temperate one south of Cape Hatteras."

The Stephensons recognized a warm-temperate fauna, the Carolinan province, from Cape Hatteras to Cape Kennedy (lat 28°30′ N.) and suggested that no marked subtropical province seems to be extant. They considered the tropical fauna to begin about at Jupiter Inlet (lat 27° N.).

Coomans (1962) took a different view of the Virginian province. He stated that only 10.5 percent of the Virginian mollusks are endemic to the province, whereas "it is agreed that this should be at least 50 percent for an autonomous zoogeographical province." Therefore, the Virginian cannot stand as a province. Because 129 or 62 percent of the Virginian mollusks are arctic or boreal species, Coomans suggested extending the Boreal province (Coomans used the term "Boreal" for both the European and North American cold-temperate faunas) south to Cape Hatteras. He considered the Arctic province to extend south to Cape Race, Newfoundland, and the southern boundary of the Carolinian province was placed at Cape Kennedy. Southern Florida was placed in the Caribbean province.

In his analysis of molluskan distributions, Hall (1964) suggested that the number of consecutive days or months when the water is at temperatures required for reproduction and early growth determines the limits of marine shallow-water provinces and, therefore, climatic zones. On this basis the Atlantic coast of North America is divided into five provinces—an Arctic province that extends south to about lat 47° N. (southern Newfoundland), the Nova Scotian from there to Cape Cod, the Virginian from Cape Cod to Cape Hatteras, the Carolinian from Cape Hatteras to lat 30° N. (near St. Augustine, Fla.), and the Caribbean from there south. In terms of climatic zones, the Arctic was designated "cold"; the Nova Scotian, "cold temperate"; the Virginian, "mild temperate"; the Carolinian, "outer tropical"; and the Caribbean, "inner tropical." Hall considered the warm-temperate zone to be absent on the North american east coast (see Dana, 1853a).

Figure 4 shows that province boundaries at southern Newfoundland (lat 47° N.), Cape Cod (lat 42° N.), and Cape Hatteras (lat 35° N.) have been generally accepted. The position of the southern boundary of the Carolinian province varies from one author to another, and most workers have not considered it necessary to recognize a Syrtensian or Labrador province between southern Newfoundland and the circumpolar Arctic province.

The above summary does not purport to be a complete review of the history of faunal provinces along the North American Atlantic coast. It only attempts to show the systems used by some workers in the last century and offers a comparison with the schemes used by some current workers.

In contrast to the rather stable nomenclature for the provinces, at least from Newfoundland to some point in Florida, the climatic zone terminology used for the Atlantic North American provinces has been quite variable. Not all authors who have treated the whole coast have presented opinions. Figure 6 shows a comparison of the terminology used by four authors. Dana (1853a), whose climatic zones are based on isocrymes, called the east coast subfrigid region (subfrigid being the coldest subdivision of his temperate regions) the Nova Scotian province. Stephenson and Stephenson (1954), following the scheme of Stephenson (1947), placed the Nova Scotian fauna in the cold-temperate zone. Hedgpeth (1957) used Boreal for the Nova Scotian on his map of the littoral provinces of the world, which is more in the nature of a map of faunas occurring in particular climatic zones than a map of provinces. Hall (1964) used cool-temperate for the Nova Scotian. Dana considered the middle two of his five subdivisions of the temperate region to be absent on the American coast (see p. E6) because of pinching out at Cape Hatteras. Hall stated that the warm-temperate zone is absent on the American coast, with mild-temperate assemblages meeting outer-tropical assemblages at Cape Hatteras.

Because these authors apply different terms to the same climates and most agree as to the placement of the major biogeographic boundaries, the different usage of climatic terms is basically a confusing battle of words.

The marine climatic zone terminology of Dana (1853a) is a modification of the ancient Greek terminology, has priority as a worldwide scheme, and is the most consistent as far as separating climatic terms from the geographic terms normally used for provinces. The Arctic and the Tropics are, after all, defined as places lying between certain parallels of latitude. The word arctic is suitable for a province because it is a place and at least the high-Arctic fauna tends to be circumpolar. The term "tropic," however, presents problems; it denotes a place but has usually been used in a climatic sense. In contrast to "arctic" it is not suitable as a province term because, with some rare exceptions, the shallow-marine species found in the Tropics off the various continents are not identical. "Torrid" has priority for marine climatic zone usage, but tropic is so entrenched in the literature that it probably will continue to be used as a climatic zone term.

Dana's fivefold division of his temperate regions is probably excessive for general usage; a threefold division that includes cold temperature and warm temperate, which are in general usage and Hall's (1964) intermediate mild-temperate seems satisfactory.

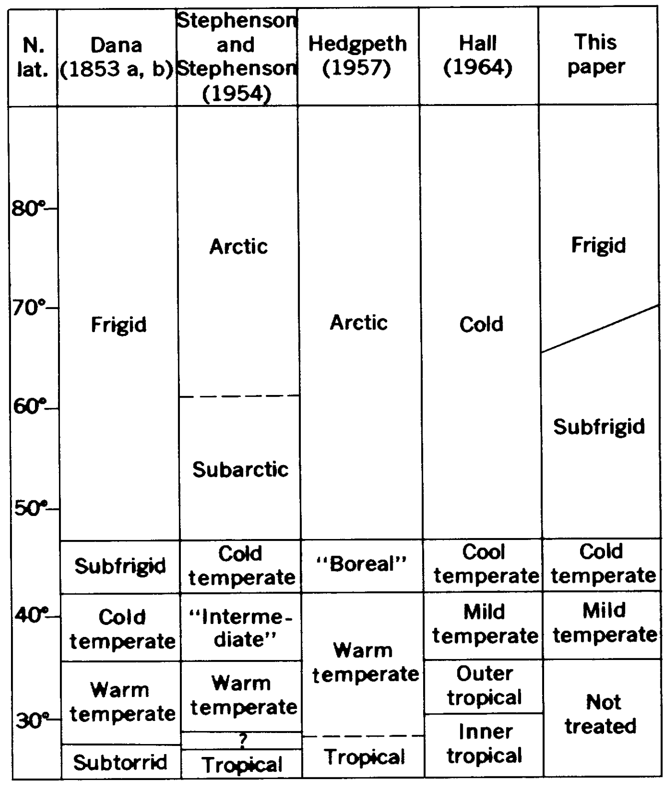


FIGURE 6.—Comparison of nomenclature used by some authors for the marine climatic zones of the northern Atlantic coast of North America.

EUROPE

Various schemes have been proposed for western European biogeographic provinces. Some of these are shown in figure 7. The Arctic circumpolar fauna seems to begin about at Novaya Zemlya and includes Franz Josef Land and most of Spitsbergen. The region from the Lofoten Islands, or perhaps North Cape, Norway, to Novaya Zemlya probably represents a transition region (see Ekman, 1953, p. 101; Packard, 1863; Hedgpeth, 1957) that probably also includes Bear Island, northern Iceland, and perhaps southwestern Spitsbergen and is equivalent to the American–West Greenland Labrador province. The term "boreal" has been considerably misused and does not have a geographic root. The term "Norwegian" (proposed by Dana, 1853b) or "Scandinavian" (proposed by Milne-Edwards, 1838) is probably better nomenclature for the faunas of the Norwegian coast from at least the Lofoten Islands to and including the Skagerrak and the Shetland Islands.

The Celtic province (proposed by Milne-Edwards, 1838) has been used by most authors for the faunas of the British Isles and the North Sea coast of Europe; its southern boundary has been placed either at the entrance to the English Channel (Forbes, in Johnson, 1856; Ekman, 1953; Hall, 1964) or, less likely, near Cape Finisterre (Dana, 1853a; Coomans, 1962). Dana (1853a, b) used the term "Caledonian" for the faunas of the northern part of the Celtic province. Ekman (1953) placed the faunas found from the southern entrance to the English Channel to northern Norway in the Boreal province.

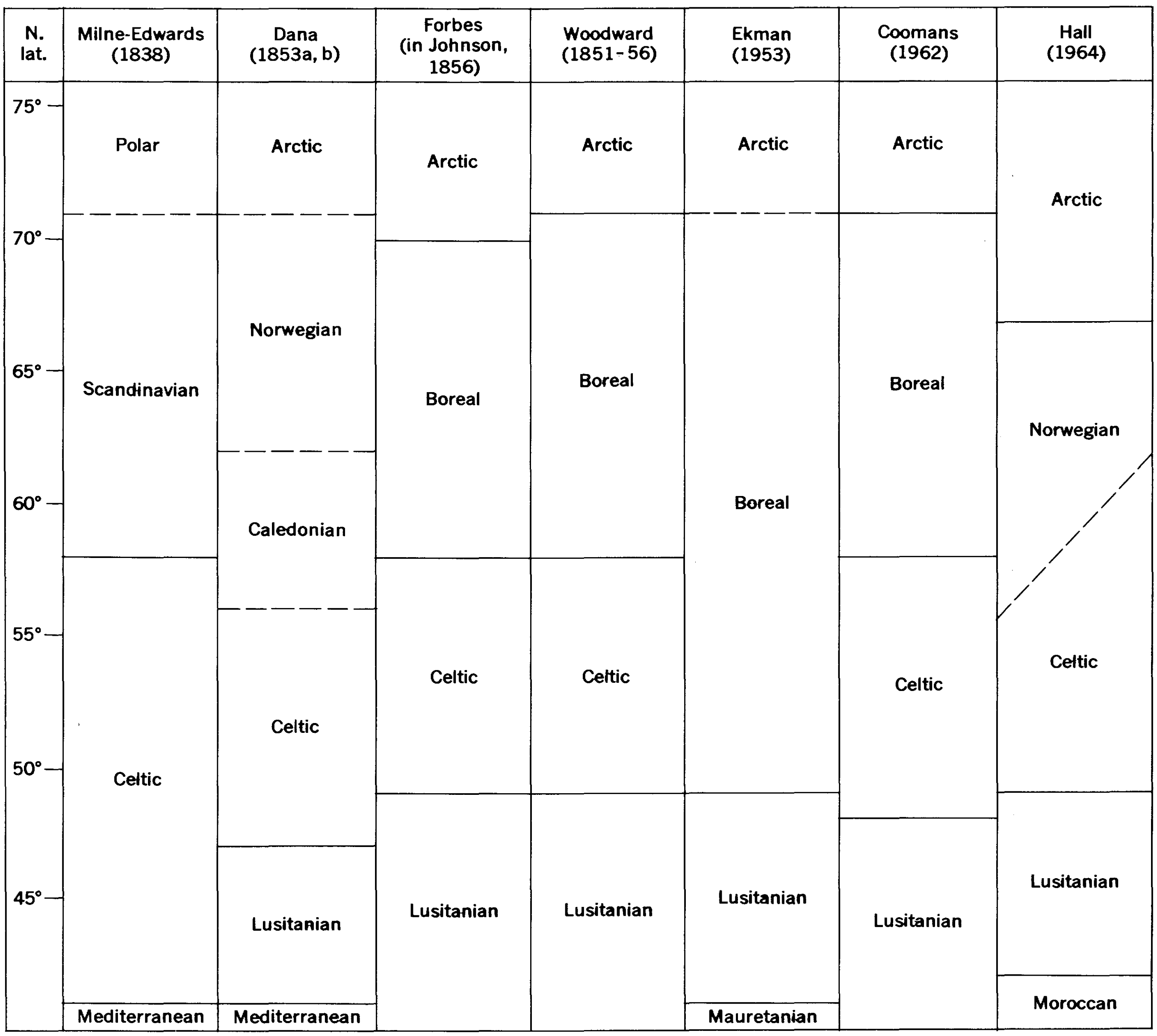


FIGURE 7.—Comparison of nomenclature used for western European faunal provinces by various authors.

The difficulty in assigning province boundaries in western Europe as compared to North America stems in part from the different hydrographic situations. The clockwise circulation of waters in the North Atlantic sends the warm waters of the Gulf Stream towards Europe and mitigates severe winters. The temperate climatic zones are much wider on the European coast than on the North American coast, where the warm waters of the Gulf Stream flow northward and the Labrador Current flows southward. This western Atlantic water circulation is coupled with the monsoon effect of general offshore winds in winter and onshore winds in summer (see Fleming, 1957). This makes for cold winters and hot summers and causes convergence of winter and summer isotherms at several points, which establishes strong temperature barriers for benthonic organisms. The absence of these strong isotherm compressions in western Europe allows species to disperse more widely, and the province boundaries are therefore considerably more gradational.

Correlation of European with North American provinces is difficult because of this hydrographic difference. In the Gulf of Maine region, the change in August surface-water temperatures from 12° to 19°C is accomplished in only 270 miles (approximately from northern coastal Maine to Cape Cod). Many cryophilic organisms which are expanding their range southward and are controlled by summer survival temperatures in this range will drop out in a rather short geographic distance. In Europe during the warmest month, it is 2,000 miles between the 12° and 19°C isotherms, that is, from northwest Norway to the Bay of Biscay. Figure 5 shows the biogeographic range of the amphiatlantic and endemic species in North America, and figure 8 gives the range of the amphiatlantic species in Europe.

The shallow waters off Cape Cod in February average about 4°C; however, it is also 4°C 300 miles to the south. Average water temperatures for the coldest month do not reach as low as 4°C off the British Isles. This temperature is reached off the Low Countries, and most of the coastal waters of Norway are about 4°C.

Thus, thermophilic shallow-water species that are possibly prevented from passing Cape Cod by the 3°C winter temperatures along the Massachusetts coast north of the Cape could live far north of the British Isles, if they occur in European waters. Cold-water species that live in the Gulf of Maine and are prevented from passing the Cape Cod area by the high summer temperatures on Georges Bank and in the Cape Cod Bay area, could extend to southern Ireland and England, if they live in European waters. Therefore, species that would not live sympatrically in North American waters could be found together in European waters.

In contrast, other cryophilic species that are controlled in their southern expansion by winter temperatures (that is, temperatures must be low enough for reproduction and repopulation to take place) may extend far down the American coast past Cape Cod if the critical temperature is 4°–5°C. The same species in Europe should not be found in the British Isles south of at least the Shetland Islands or the deep and cold lochs of Scotland.

Thermophilic species expanding to the north, whose northern limits are controlled off North America by the compression of summer isotherms at Cape Cod, would not, if they lived in Europe, reach as far north as the British Isles and would probably drop out at about Cape Finisterre or the Bay of Biscay. Thus, cryophilic species controlled equatorward by winter low temperatures and warm-water species controlled poleward by summer high temperatures can live together on the American coast, but theoretically would be allopatric on the coast of western Europe.

The last is a difficult theory to test with ostracodes simply because all the thermophilic ostracode species found only south of Cape Cod seem to be endemic to the coast of the United States. Many of the cryophilic, summer-controlled ostracode species which do not pass Cape Cod extend to southern Ireland and northern England and Europe, whereas a winter-controlled species, such as *Baffinicythere emarginata*, does not pass Scotland. This suggests that the Virginian-Nova Scotian boundary cannot be "correlated" faunally with any of the European temperate province boundaries because, depending on which types of species chosen, it could be the Scandinavian-Caledonian or the Caledonian-Celtic boundary. The bulk of the cryophilic ostracodes are controlled in their southern extent by summer survival temperatures, and most of those that stop before Cape Cod extend to southwestern Ireland and northern England or Scotland.

TEMPERATURE CONTROL OF SPECIES DISTRIBUTION

Hutchins (1947) proposed that species were controlled by temperature basically in two ways, survival temperatures and temperatures needed for reproduction and repopulation. To be sure, the duration of certain temperatures (Hedgpeth, 1957; Hall, 1964) is of importance to some if not most species. However, species extend north and south to points where certain maximum or minimum temperatures are reached. It is these temperatures, usually in August or September and February, that are most critical, at least for the assignment of temperature limits.

373-564 O—70——2

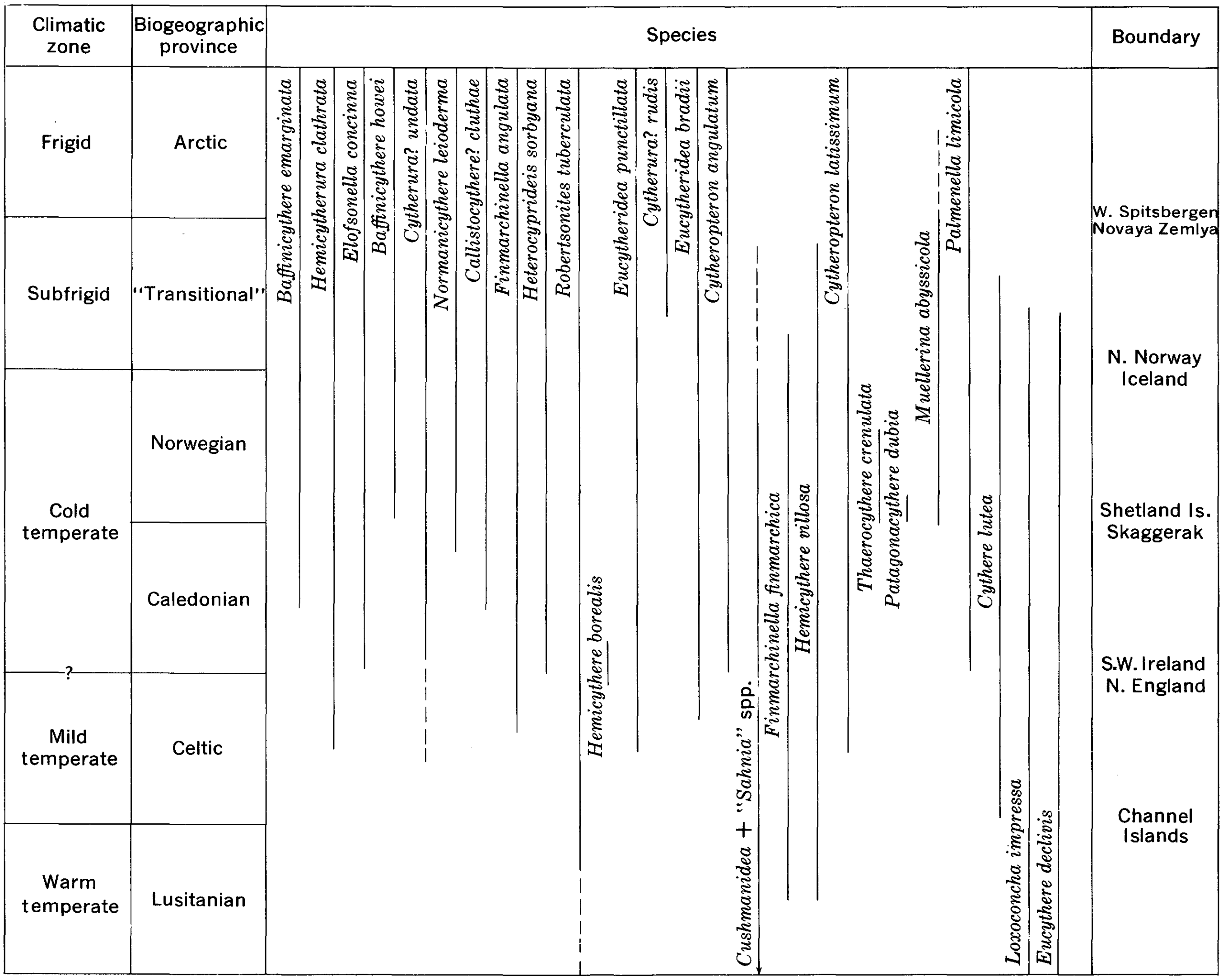


FIGURE 8.—Biogeographic range of amphiatlantic species in Europe. For comparative purposes the arrangement of species is the same as in figure 5.

Hutchins (1947) showed that there were four zonal types of species (fig. 9): (1) species which are controlled poleward and equatorward by killing winter and summer temperatures, (2) those which are controlled by reproductive repopulation temperatures poleward (summer) and equatorward (winter), (3) those which are controlled equatorward by summer survival temperatures and poleward by summer reproductive temperatures, and (4) species which are controlled poleward by winter survival temperatures and equatorward by winter reproductive temperatures.

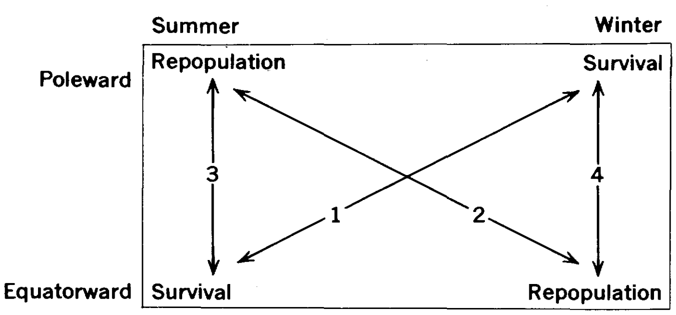


FIGURE 9.—Diagram showing the four types of temperature zonation of species. From Hutchins (1947). See text for discussion.

He considered all species which extend into the Arctic, where the water is of uniform coldness, Type 2 or Type 3 species, reasoning that if these taxa can tolerate continued cold conditions, then the only temperature that could be critical poleward would be in summer.

Because there are both maximum and minimum temperatures at the end points of a species range, it is not obvious which of the temperatures is controlling a particular species. Hutchins suggested that if a species occurs on more than one coast and if its distribution is well known, the controlling temperatures can be delineated because the maximum and minimum temperatures at a point on one coast will not occur together on another. A large number of the ostracode species found on the American coast at least as far south as the Cape Code area also occur in Europe and, if they are well known in both regions, the zonal types they represent can be determined by this method. Using Hutchins' principles of correlation, the zonal types represented by these species have been determined as closely as possible. For determination of the zonal type of sublittoral species, exact temperature tolerances are not usually necessary because the maximum and minimum temperatures occurring at a point on the American coast are usually geographically far apart on the European coast, and surface temperatures often are sufficient. For accurate determination of temperature tolerances, data on exact maximum and minimum bottom temperatures, at least in the area of the end points of a species range, are required but are often not available. On the basis of temperature data presented by Elofson (1941) for several of the taxa treated and data gathered in the present study, the tolerances for the amphiatlantic species have been determined as closely as possible. The zonal types represented by the amphiatlantic species (mostly Type 3), their temperature tolerances, and their depth range are given in table 2 (see section under Nova Scotian and Virginian amphiatlantic species, p. E13–E16, for further discussion; also see pls. 31–54 which are distribution maps of the amphiatlantic species from which the zonal types were determined).

For endemic species the determination of controlling temperatures is more difficult. However, along coasts where there is strong compression of isotherms in summer or winter at certain points, the controlling temperature can sometimes be inferred. If a species ceases its expansion, for example, at a point where winter isotherms are compressed and summer isotherms are not, it is likely that the species is controlled by winter temperatures.

OSTRACODES AND THE VIRGINIAN–NOVA SCOTIAN BOUNDARY

The Virginian and Nova Scotian faunal provinces are easily differentiated in the inshore and offshore areas on the basis of ostracodes (pls. 7–69; fig. 5). The shallow-water species *Aurila* aff. *A. amygdala* (pl. 7), *Actinocythereis* aff. *A. gomillionensis* (pl. 8; a new species,= *A. gomillionensis* of Williams, 1966), and *Puriana rugipunctata* (pl. 9) occur on the south side of Cape Cod but are absent to the north. *Enchinocythereis margaritifera* (pl. 13), *Cytherella sp.* (pl. 14), and *Munseyella atlantica* (pl. 12) occur mainly at outer sublittoral depths on southern Georges Bank and the shelf south of New England but are absent to the north. *Bensonocythere* aff. *B. whitei* (pl. 11; a new species, = *B. whitei* of Hazel, 1967a) does not occur north of Georges Bank. The genus *Hulingsina* (pl. 10) is restricted to the region south of Cape Cod, with one exception.

Some cryophilic species extend southward into the western Gulf of Maine but do not reach Cape Cod. These include *Baffinicythere howei* (pl. 15;=*B. costata* of Hazel, 1967a; see Hazel, 1967b), *Cytherura? undata* (pl. 16), *Elofsonella concinna* (pl. 18), *Cytherura? mainensis* (pl. 55), and *Cytheropteron latissimum* (pl. 17), *Palmenella limicola* (pl. 24), *Cytheropteron angulatum* (pl. 23), *Finmarchinella angulata* (pl. 21), *Cythere lutea* (pl. 22), *Eucytheridea bradii* (pl. 24), and *Patagonacythere dubia* (pl. 20). The above cryophilic species and some others extend south of Nova Scotia but do not pass and, for the most part, do not penetrate the Northeast Channel (pls. 15–25).

The warm summer and fall temperatures in the Cape Cod Bay—Massachusetts Bay area (Fritz, 1965; Schroeder, 1966) seem to be a barrier to many equatorward-expanding cryophilic species. On the outer shelf, the deep Northeast Channel and high summer temperatures on adjacent Georges Bank provide barriers to these species.

The thermophilic poleward-expanding shallow-water species may be halted by the low 3°C temperatures (Schroeder, 1963) in Cape Cod Bay and Massachusetts Bay or by the rapid change in summer temperatures in the Cape Cod area. On the outer shelf, thermophilic deep-water species are apparently halted by cold winter temperatures on eastern Georges Bank and in the Northeast Channel. More cryophilic than thermophilic species drop out at Cape Cod, and this is consistent with a stronger compression of summer than winter isotherms in the area.

The small assemblage, mainly *Muellerina abyssicola* (pl. 19), *M. canadensis* (pl. 56), and *Thaerocythere crenulata* (pl. 25), present in the deep Northeast Channel and Georges Basin area in zoogeographically more closely related to Nova Scotian province assemblages than to assemblages of the Virginian province, but is probably more appropriately included with what might be called an "Atlantic bathyal" province.

NOVA SCOTIAN AND VIRGINIAN AMPHIATLANTIC SPECIES

Many of the species discussed in the present study are also well known in Europe. All the amphiatlantic species occur in the Nova Scotian province, and most do not extend into the Virginian province (pls. 15–30).

TABLE 2.—*North-south limits, climatic-zone range, zonal type (Hutchins, 1947), temperature range, and depth range of 26 amphiatlantic species*

[All the species for which the zonal type could be determined are Type 3 (controlled equatorward by summer temperatures that can be tolerated) except the two species of *Baffinicythere* which seem to be Type 2 species (controlled equatorward by winter temperatures which must be low enough for reproduction). Seventeen of the species occur in the frigid climatic zone and the rest, except for the common deep-water inhabitant *Echinocythereis echinata* s.l., occur at least in the subfrigid climatic zone. None of the amphiatlantic species extend into the subtropical climatic zone, and only five have been recorded from tne warm-temperate zone. Normally sublittoral species which have submerged to bathyal depths at their southern extent (for example, *Robertsonites tuberculata* in the Bay of Biscay) are not considered to belong to the sublittoral climatic zone of that area]

Amphiatlantic species	North America		Europe		Climatic zones	Zonal type	Temperature range (° C)	Depth range (m)
	Northern	Southern	Northern	Southern				
Baffinicythere emarginata	Kane Basin	Block Island	Northern Spitsbergen.	Firth of Clyde	Frigid—mild temperate	2	<0–20	7–200
howei	do	Western Gulf of Maine.	Franz Josef Land	Shetland Islands	Frigid—cold tempreate	2	<0–14	24–146
Callistocythere? cluthae	do	Northern Gulf of Maine.	do	North Channel	do	3	<0–>7	20–300
Cythere lutea	Cape Dyer	do	Murmansk	Finistère	Subfrigid—mild temperate.	3	0±–22	0–89?
Cytheropteron angulatum	Ungava Bay	Browns Bank	Franz Josef Land	Southwestern Ireland.	Frigid—cold temperate	3	<0–>11	24–203
latissimum	Disko Bugt	Western Gulf of Maine.	do	Southern England	Frigid—mild temperate	3	<0–22	0–150
Cytherura? rudis	Smith Sound	Ungava Bay	Stor Fjord	Varanger Fjord	Frigid—subfrigid	?	<0–8	0–380
undata	Kane Basin	do	Northern Spitsbergen.	Devonshire	Frigid—cold temperate	3	<0–18	0–51
Echinocythereis echinata s.l.	Georges Basin	[1]	Lofoten Islands	Kattegat	Cold temperate	?	2–11	53–4, 700
Elofsonella concinna	Kane Basin	Western Gulf ot Maine.	Spitsbergen	Southwestern Ireland.	Frigid—Cold temperate	3	<0–19	0–200
Eucythere declivis	Bay of Fundy	Southern Virginia	Varanger Fjord	Gulf of Naples	Subfrigid—warm temperate.	?	3–25	0–225
Eucytheridea bradii	Wolstenholme Island.	Roseway Bank	Franz Josef Land	Thames Estuary	Frigid—mild temperate	3	<0–18	3–750
punctillata	Kane Basin	Gulf of St. Lawrence.	Northern Spitsbergen.	Suffolk	Frigid—mild temperate	3	<0–18	5–435
Finmarchinella angulata	North Star Bay	La Have Basin	Northwestern Spitsbergen.	Southwestern Ireland.	Frigid—cold termperate	3	<0–>11	0–116
finmarchica	Disko Bugt	Long Island	North Cape	Bay of Biscay	Subfrigid—warm temperate.	3	0±–>15	0–122
Hemicythere borealis	Kane Basin	Southwestern Nova Scotia.	[1]	Durham	Frigid—cold temperate	3	<0–13?	0–91
villosa	Cape Dyer	Martha's Vineyard	Bear Island	Bay of Biscay	Subfrigid—warm temperate.	3	<0–>15	0–?
Hemicytherura clathrata	Kane Basin	Georges Bank	Northern Spitsbergen.	Isle of Wight	Frigid—mild temperate	3	<0–14	0–170
Heterocyprideis sorbyana	do	Northern Gulf of Maine.	do	Southwestern Ireland.	Frigid—cold temperate	3	<0–18	0–435
Loxoconcha impressa	Southern Labrador	Southern Virginia	Varanger Fjord	Madeira	Subfrigid—warm temperate.	3	0±–25±	0–235
Muellerina abyssicola	Disko Bugt	Slope, 40° N., 68° W.	Southwestern Spitsbergen.	Skagerrak	Subfrigid—cold temperate.	3	0±–11	40–1, 60
Normanicythere leioderma	Kane Basin	Western Gulf of Maine.	Kong Karls Land	Isle of Skye	Frigid—cold temperate	3	<0–19	3–150
Palmenella limicola	Disko Bugt	Northern Gulf of Maine.	Franz Josef Land	Southwestern Ireland.	Frigid—cold temperate	3	0–12	5–200
Patagonacythere dubia	Holsteinborg	La Have Bank	[1]	Shetland Islands	Subfrigid—cold temperate.	3	0±–10	.5–205
Robertsonites tuberculata	Kane Basin	Northern Gulf of Maine.	Franz Josef Land	Bay of Biscay	Frigid—mild temperate	3	<0–18	9–400
Thaerocythere crenulata	Disko Bugt	Northeast Channel	Trondheim Fjord	Skagerrak	Subfrigid—cold temperate.	?	0±13	20–801

[1] Known only from one locality.

Baffinicythere emarginata (pl. 31) occurs in the Arctic province and thus tolerates temperatures below 0°C. It is a common constitutent of assemblages along the coasts of Canada and Greenland, and its distribution is well known in Europe. It occurs commonly in the Nova Scotian province and extends into the Virginian province as far south as Block Island and the eastern part of Georges Bank (pl. 26). The species occurs commonly in Narragansett Bay (Williams, 1966) in areas where bottom temperatures reach a maximum of about 20°C and a minimum of about 4°C (Hicks, 1959). In studying the European occurrences of the species, Elofson (1941) gave a temperature range of below 0°C to about 19°C. Thus, the species has approximately the same temperature tolerances on both sides of the Atlantic.

Is the southern limit of the species controlled by high summer temperatures it can tolerate or by low winter temperatures it must have for reproduction and repopulation? If its southern limit is controlled by summer temperatures too high for survival, theoretically *Baffinicythere emarginata* could be found as far south as the Bay of Biscay off Europe. However, its southernmost occurrence is at a depth of 50 m in Loch Fyne in the Firth of Clyde, Scoltand (Robertson, 1875). Average surface temperatures in August in this area are about 14°C, and in February the average surface temperature is about 7°C. I have no data on maximum or minimum bottom or surface temperatures in the area, but it seems clear that *Baffinicythere emarginata* is controlled equatorward not by high survival temperatures but by low winter temperatures needed for reproduction (apparently less than about 5°C). In Hutchins' (1947) terminology, *B. emarginata* is a zonal Type 2 species.

This species is interesting also because it may be an example of equatorward emergence, a theoretical possibility with Hutchins' Type 2 and 4 species which are governed equatorward by winter temperatures needed for reproduction. The deepest known occurrence of this species is in the Arctic province off eastern Greenland at 200 m (Elofson, 1941). In this general area the bottom temperature at 200 m is below 0°C in the warmest months (Schroeder, 1963). In the southern Nova Scotian and Virginian provinces (the species also occurs in the Gulf of St. Lawrence (Brady, 1870) but no depth data are given), *B. emarginata* occurs in six areas; Browns Bank–Roseway Bank, Scotia Shelf, northern Gulf of Maine, western Gulf of Maine, northeastern Georges Bank, and the Cape Cod–Narragansett Bay area (pl. 26). Figure 10 shows deepest occurrence and the warmest and coldest average bottom temperature in each of these areas. The lower depth limit decreases from 200 to 38 m equatorward as the bottom average high temperature increases from about 0° to about 14°C; there is only about a 5.5°C difference in the bottom average low temperature. On the basis of the available data, *Baffinicythere emarginata* is emerging toward the equator, the reason being that it is eurythermal but apparently dependent on winter temperatures lower than about 5°C for reproduction and early growth.

This emergence of the lower depth limit is apparently in response to the particular present hydrographic-climatic situation along the Atlantic coast. The outer sublittoral areas of the shelf are under the influence of the Gulf Stream, and the bottom temperature is always above 5°C south of Cape Cod. However, in inner sublittoral areas the bottom temperature falls to 4°C in winter.

In the western Atlatnic, *Elofsonella concinna* (pls. 18, 32) is distributed from Cape Frazer to 43°19′ N. in the Gulf of Maine (table 1, Gos 1021, 37 m). Here the average surface temperature in August is about 16°C and in February about 3°C. The bottom temperature in February here is about 4°C and in August probably near 14°C. In Europe (pl. 32), *E. concinna* occurs in the Arctic and as far south as off southwestern Ireland (Norman, 1891, no depth given) which is far south of the 4°C winter surface isotherm. The average surface temperature in the area in August is about 15°C and in February 9°C. The yearly average bottom temperature at 200 m off southwestern Ireland is 10.5°C with only a 2°C range (Schroeder, 1963). *Elofsonella concinna* is most commonly found at inner sublittoral depths, and the bottom temperature where *E. concinna* occurs off Ireland is probably between 11° and 15°C. These data indicate that the species is controlled equatorward by summer temperatures and, in Hutchins' (1947) terminology, is a Type 3 species. The temperature tolerance in terms of averages for the coldest and warmest months is probably between <0° and 14°C, although the absolute maximum is higher and Elofson (1941) gives an upper limit of 19°C.

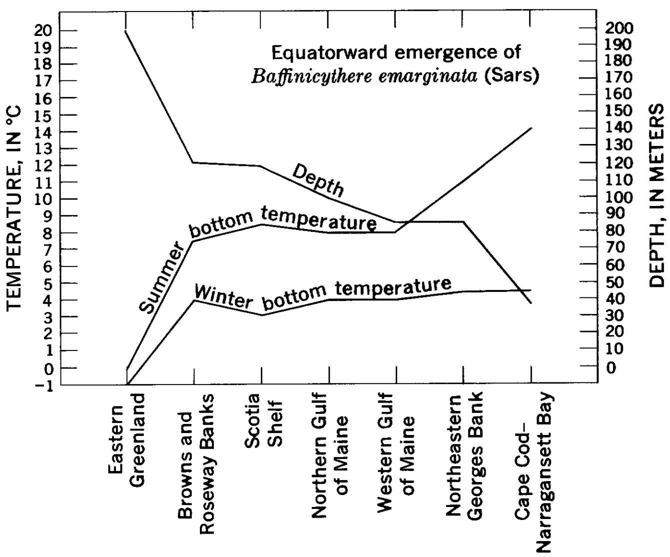


FIGURE 10.—The apparent equatorward emergence of the lower depth limit of *Baffinicythere emarginata* (Sars). The maximum depth decreases from 200 to 38 m from eastern Greenland (Elofson, 1941) to south of Block Island (table 1, Gos 1258); the bottom average high temperature increases from about 0°C to 14°C, but the bottom average low temperature increases only from about −1°C to 4.5°C.

Palmenella limicola (pls. 24, 33) occurs as far south in the western Atlantic as off Muscongus Bay, Maine, at 64 m. The average surface temperature here in August is 14°C and in February 4°C. The average bottom temperature at 100 m in this area is about 7°C in the warmest months and 4°C in the coldest months. By interpolation, the average bottom temperature at 64 m in the warmest months would be about 10°C. In Europe (pl. 33), *P. limicola* occurs as far south as off southwestern Ireland at 200 m (Norman, 1905). The yearly average bottom temperature off southwestern Ireland at 200 m (Schroeder, 1963) is about 10.5°C with a 2°C range. Thus, the temperature tolerance of the species, in terms of seasonal average temperature, is about <0°–11°C. Elofson (1941) gave an upper maximum limit of 12°C for the species. *Palmenella limicola* appears to be a Type 3 species, controlled by summer temperatures to the south. The species is commonly found in shallow waters in frigid-subfrigid regions, at depths of 20 m in the waters off Kong Karls Land, Svalbard, 5–30 m in the fjords of Finnmark, Norway, and 13–18 m off eastern Greenland. At its southernmost occurrence it seems to inhabit only deeper waters and thus may be undergoing equatorward submergence.

Baffinicythere emarginata, *Elofsonella concinna*, and *Palmenella limicola* were used to demonstrate the procedure for determining the zonal type (Hutchins, 1947) of a species. Determination of zonal type is best if bottom temperatures are available, at least at the critical southern or northern limits of the range of a species. However, these may not be required to determine the zonal type because the August and February surface temperatures coincident on one coast are far apart on the other. Therefore, if the species is common and reasonably well collected, the zonal type is easily determined. For an accurate estimate of the actual limiting temperatures, it is imperative to have bottom temperature data.

Most of the amphiatlantic species in the Nova Scotian and, in fewer numbers, in the Virginian province also occur as far north as the Arctic province. Most of these are Hutchins' Type 3 species, limited southward by summer high temperatures. The fact that they do occur in the circumpolar Arctic province easily explains their presence on both sides of the Atlantic. The amphiatlantic species treated are listed in table 2 with their geographic end points on either side of the Atlantic and their zonal type. The distributions of most of these species in both Europe and North America are shown on plates 31–54.

Several of the amphiatlantic species do not occur in the Arctic province (pls. 48–54). These are *Thaerocythere crenulata* (pl. 48), *Cythere lutea* (pl. 50), *Loxoconcha impressa* (pl. 49), *Hemicythere villosa* (pl. 51), *Patagonacythere dubia* (pl. 52), *Finmarchinella finmarchica* (pl. 53), and, possibly, *Mullerina abyssicola* (pl. 54) (depending upon whether the Spitsbergen locality given by Brady and Norman, 1889, is on the southwestern coast of Spitsbergen or not). These forms tolerate 0°C or slightly lower temperatures and therefore are not limited northward by winter temperatures. They only occur, however, in areas where the summer surface temperatures are above freezing at least 3 or 4 months of the year and, therefore, are possibly dependent on above-freezing temperatures for reproduction and early growth.

With the possible exception of *Eucythere declivis* (the distribution of this species is difficult to map because G. S. Brady and his associates considered *E. argus* (Sars) a synonym), none of the species studied that occur only in the temperate provinces of the western Atlantic are amphiatlantic.

NOVA SCOTIAN AND VIRGINIAN ENDEMIC SPECIES

Cytherura? mainensis Hazel and Valentine, has been found in several inner sublittoral samples from the Gulf of Maine and Scotia Shelf (pl. 55, 60). Its southern limits seems to be about 43°19′ N., and it has not been found north of the Gulf of St. Lawrence (*Cytherura undata*, var., of Brady, 1870). Thus, it may be an endemic North American species restricted to the Nova Scotian province. Of the common species in the Nova Scotian province, this is the only one apparently endemic to eastern North America that does not also occur in the Virginian province.

Several endemic species occur commonly in both the Virginian and Nova Scotian provinces. These include the two most common and, usually, most abundant species found, *Muellerina canadensis* (pl. 56) and *M.* aff. *M. lienenklausi* (pl. 57) (a new species=*M. lienenklausi* of Hazel, 1967a). The species are closely related and, because they occur commonly together, attention must be paid to details in order to consistently distinguish them (see Hazel, 1967a).

Muellerina canadensis was described from the Gulf of St. Lawrence by Brady (1870) and subsequently was reported from Godhavn and Holsteinborg Harbors, Greenland, and the Davis Strait (Norman, 1877; Brady and Norman, 1889). However, the illustrations and description in Brady and Norman (1889) seem to be of another genus, probably a *Munseyella* (rather than a *Leptocythere* as suggested by Blake, 1933). I am confident that what I (Hazel, 1967a) illustrated as *Muellerina canadensis* is conspecific with what Brady (1870) illustrated. Thus, *M. canadensis* is known from at least as far north as the Gulf of St. Lawrence and possibly, but not probably, to Disko, Greenland. *Muellerina* aff. *M. lienenklausi* occurs at least as far north as the Bay of Fundy. Southward *M.* aff. *M. lienenklausi* has been in samples taken off Cape Hatteras. A single specimen of what may be *Muellerina canadensis* has also been found off Cape Hatteras (*Murrayina canadensis* of Hulings, 1966, from off Virginia is actually *Muellerina* aff. *M. lienenklausi*). *Muellerina canadensis* is known from samples taken at depths from 7 to 801 m. It occurs, however, in a higher percentage of samples taken from depths of 100 to 250 m than in samples from greater or shallower depths. *Muellerina* aff. *M. lienenklausi* was not found in samples taken deeper than 235 m, and it occurs in a higher percentage of inner and middle shelf samples than outer shelf samples (fig. 11).

In the study area, both species occur in areas where minimum to maximum bottom temperatures are 2°C to about 20°C. *Muellerina* aff. *M. lienenklausi* does not occur in the central parts of the Gulf of Maine, in the Northeast Channel, or on the continental slope, but *M. canadensis* does. Otherwise, the geographic distribution of these species is very similar. These two endemic species seem to be mild-temperate to cold-temperate forms with *M. canadensis* possibly, but doubtfully extending north into the subfrigid Labrador province.

Two of the more eurythermal endemic species are *Leptocythere augusta* Blake (pl. 58, 60) and *Munseyella mananensis* Hazel and Valentine (pl. 59, 60). *Leptocythere angusta* is found from at least as far south as off Virginia (*Callistocythere reticulata* of Hulings, 1966) to southern Labrador. It seems to be basically a mild- and cold-temperate species that extends into the southern part of the subfrigid Labrador province. *M. mananesis* may extend north into the Arctic province, but perhaps as a different subspecies (Hazel and Valentine, 1969).

The large cytherettid *Pseudocytheretta edwardsi* Cushman (pl. 61) is common in shallow waters in the Vineyard Sound–Buzzards Bay–Narragansett Bay area (Cushman, 1906; Williams, 1966). It is rare in my samples, however, which were taken mostly at depths greater than 20 m. *P. edwardsi* may be an indicator for the Virginian province if it is not conspecific with *P. tracyi* (Blake) which was described from Mount Desert Island, Maine. I have not been able at determine how to distinguish the two species. Juveniles of a large smooth cytherettid were found in only one of my samples from the Nova Scotian province (table 1, Gos 1062, taken off Yarmouth, Nova Scotia). Tentatively, *P. tracyi* is considered to be a synonym of *P. edwardsi.* Types of neither species are available for study.

Pterygocythereis americana inexpectata (Blake) (pl. 62) is a rather common form, particularly as juveniles,

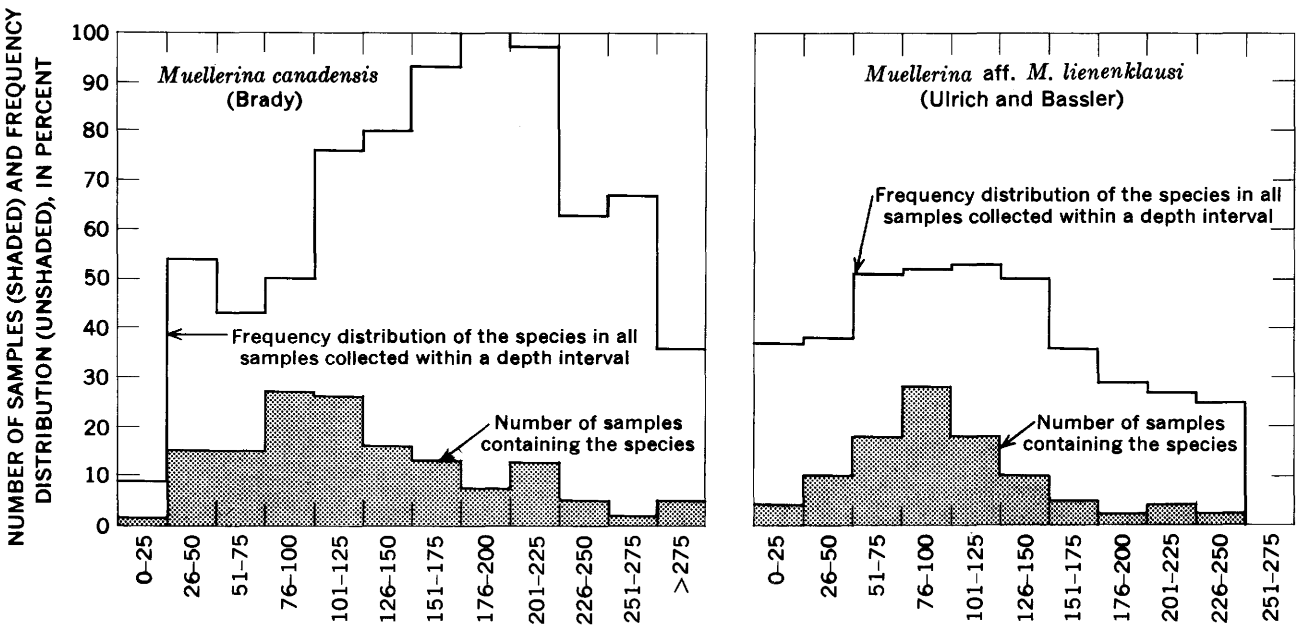


FIGURE 11.—Depth "preference" of *Muellerina canadensis* and *M.* aff. *M. lienenklausi* (=*M. lienenklausi* of Hazel, 1967a). The shaded histograms show the number of samples containing the species at 25-m depth intervals. This plot is similar for both species (although *M. canadensis* has a greater depth limit, 801 versus 235 m), but this similarity is merely a reflection of the preferential sampling at middle shelf depths. The unshaded histograms, however, based on the frequency distribution of the species in all samples collected within a 25-m depth interval, indicate that, although these species are common at nearly all depths in the sublittoral zone, the "preferred" habitat of *M. canadensis* is 100–225 m, whereas *M.* aff. *M. lienenklausi* is most commonly found at 50–150 m.

in samples from the Virginian and Nova Scotian provinces.

Two species of *Actinocythereis* are rather widely distributed over the area. These are *A. vineyardensis* (Cushman) (pl. 63) and *A. dawsoni* (Brady) (pl. 64); *A. vineyardensis* tends to occur in deeper waters. *A. vineyardensis* does not occur in the ostracode-rich samples taken off Nova Scotia where bottom temperatures are as low at 2°–3°C in winter; however, *A. dawsoni* occurs frequently in this area. *A. dawsoni* also occurs in the Gulf of St. Lawrence (Brady, 1870), and the species seems more tolerant of colder temperatures. *A. vineyardensis* occurs at least as far south as the Cape Hatteras area, whereas *A. dawsoni* may not occur further south than the northern part of the Viginian province.

Two species of the apparently endemic genus *Bensonocythere* occur in both the Nova Scotian and Virginian provinces. *B. arenicola* (Cushman) (pl. 65) and *B. americana* Hazel (pl. 66) occur in several samples but are never abundant in any one sample. They range from off Nova Scotia to south of Long Island.

The neocytherideidine genera, "*Sahnia*" (a genus with no valid type species, pl. 67), *Hulingsina* (pl. 10), and *Cushmanidea* (pl. 68) are fairly common, primarily in inner sublittoral samples, in the area. These are incompletely studied at present, and several species of *Hulingsina* and *Cushmanidea* may be represented. "*Sahnia*" is represented by at least two species, "*S.*" *foveolata* Brady and "*S.*" *fasciata* of Cushman (1906).

There was only one occurrence of "*Sahnia*" in the Nova Scotian province, off St. Mary Bay, Nova Scotia. This form, larger than the ones to the south, could be "*S.*" *foveolata* (Brady), described from the Gulf of St. Lawrence. The smaller species occurs commonly in the Virginian province and is probably what Cushman (1906), Williams (1966), and Hulings (1966) refer to "*S.*" *fasciata* (Brady and Robertson).

Except for one occurrence, *Hulingsina* is confined to the Virginian province (pl. 10).

Echinocythereis planibasalis procteri (Blake) was found chiefly in the Gulf of Maine area (pl. 69), but it also occurs on Georges Bank (table 1, W81; in table 1 of Hazel (1967a), this occurrence is erroneously indicated as *E. margaritifera*). Fossils of this species, but perhaps not the same subspecies, have been found in the late Miocene of Virginia and North Carolina. Off Europe, *Echinocythereis* does not extend north of the Lofoten Islands (pl. 47) on the Norwegian coast. Off North America, no *Echinocythereis* has been reported north of the occurrences of *E. planibasalis procteri* (pl. 69). Thus, *Echinocythereis* seems to be a primarily tropical to cold-temperate genus. In contrast to *Echinocythereis*, the closely related genus *Rabilimis* seems to be chiefly a frigid and subfrigid taxon (pl. 47). It is known from only two localities in cold-temperate regions; one is off the Isle of Lewis, Scotland (Brady, 1868a), and the other from the Skagerrak (Elofson, 1943). Each locality yielded only one empty valve. Except for these two occurrences, there is no overlap between the distribution of *Echinocythereis* and *Rabilimis*.

Actinocythereis aff. *A. gomillionensis* is rare in offshore samples but occurs commonly in Narragansett Bay (Williams, 1966) (pl. 8) and has been seen in samples from Buzzards Bay, Vineyard Sound, Hadley Harbor, and off Cape Hatteras. It is a southern form related to *A. bahamensis* (Brady) and is a common fossil in upper Miocene, Pliocene, and Pleistocene deposits along the Atlantic coast.

Recent species referred to the genus *Haplocytheridea*, probably erroneously, do not seem to occur north of Cape Cod. Williams (1966) reported what is probably "*Haplocytheridea*" *bradyi* (Stephenson) (as "*H.*" *setipunctata* (Brady)) from Narragansett Bay (pl. 9). It was not in my offshore samples.

The thaerocytherine genus *Puriana* seems restricted to tropical to mild-temperate waters. *P. rugipunctata* (pl. 9) occurs in Narragansett Bay (Williams, 1966), Vineyard Sound, Hadley Harbor, and off Nantucket.

The genus *Aurila* is represented in the study area by *Aurila* aff. *A. amygdala* (pl. 7). Williams reported it as common in Narragansett Bay. The species also is known from Pamlico Sound, N.C. (Williams, 1966), and the west coast of Florida (Benson and Coleman, 1963; Hulings and Puri, 1964). *Cythere albomaculata* reported by Cushman (1906) is undoubtedly this species, as I have seen *Aurila* aff. *A. amygdala* in a sample from Cushman's reoccupied Fishhawk Station 7723. It also occurs off Woods Hole (Cushman, 1906) and Martha's Vineyard.

Bensonocythere aff. *B. whitei* (Swain) seemingly is restricted to the Virginian province and in this study was found in several samples (pl. 11) from Georges Bank and areas south of New England.

Only one platycopid species was found in the present study, a *Cytherella* which could not be assigned with any confidence to a described species. It occurs primarily on the outer shelf south of New England (pl. 14).

Also characteristic of the deeper areas of the northern Virginian province is *Munseyella atlantica* Hazel and Valentine (pl. 12) and *Echinocythereis margaritifera* (Brady) (pl. 13). These species have been found on the south side of Georges Bank and in the Hudson Canyon area south of New England.

Echinocythereis margaritifera (pl. 13) is interesting because the available data, much less than desired, suggest that the species is submerging poleward. *E. margaritifera* occurs in the Gulf of Mexico off Louisiana and Mississippi (Curtis, 1960) and western Florida (Benson and Coleman, 1963), off Cape Hatteras (Duke University collections). It was found on the shelf and upper slope south of New England in the present study.

Curtis reported the species from her offshore biofacies at depths greater than 27 m. Based on her data, the bottom temperature at 27 m would be about 20°C in February and 26°C in August. Benson and Coleman found the species at depths as shallow as 20 m, at which depth the bottom temperature would be about 21°C in winter and about 26.5°C in summer (interpolation from the surface temperatures and the 200-m temperatures given by Schroeder, 1963).

Off Cape Hatteras (34°24′ N., 76°05′ W.), *E. margaritifera* was found at depths as shallow as 35 m. The bottom temperature in February would be near 11°C and in August about 24.5°C. In the area of the present study the species was found only along the edge of the shelf south of New England at depths greater than 110 m (the 82-m occurrence given in Hazel, 1967a, table 1, should be under *E. planibasalis*). The bottom temperature in the warmest months in the area of the shallowest occurrence (table 1, AB3 W34) averages about 8°C (Schopf, 1967) and in the coldest months about 6.5°C. Although these data from four scattered areas are not entirely convincing, they nonetheless suggest that the shallowest depths that *E. margaritifera* can inhabit are deeper toward the north.

The presence of thermophilic species such as *E. margaritifera* and *Munseyella atlantica* in deeper waters in the northern Virginian province is no doubt related to the fact that the outer shelf south of New England is under the influence of the Gulf Stream. In such hydrographic situations, poleward submergence is not an uncommon phenomenon. Cerame-Vivas and Gray (1966) have shown that assemblages characteristic of three biogeographic provinces are represented in the Cape Hatteras region. On the outer shelf, assemblages characteristic of the tropical Caribbean province are present; in inner shelf areas south of Cape Hatteras, assemblages characteristic of the Carolinian province are dominant; and in inner shelf areas north of Cape Hatteras, assemblages characteristic of the Virginian province are present.

Table 3 summarizes the distribution, temperature, and depth data available for the endemic species treated herein.

TABLE 3.—*North-south limits, climatic-zone range, temperature-tolerance range, and depth range of 19 species endemic to the western Atlantic*

[Only one species is known to occur in the frigid zone and one in the subfrigid zone. The remainder are restricted to cold-temperate or warmer climatic zones]

Endemic species	Distribution		Climatic zones	Temperature range (°C)	Depth range (m)
	Northern	Southern			
Actinocythereis dawsoni	Georges Bank	Hudson Canyon	Mild temperate	0±–19	3–185
aff. *A. gomillionensis*	Narragansett Bay	Florida	Mild temperate-subtropical	0–25±	2–136
vineyardensis	Mount Desert Island	Cape Lookout	Cold temperate-mild temperate	4–>20	26–231
Aurila aff. *A. amygdala*	Narragansett Bay	Florida Bay	Mild temperate-tropical	4–29	0–50
Bensonocythere americana	Bay of Fundy	40° N., 73° W	Cold temperate-mild temperate	4–16	13–111
arenicola	do	do	do	<4–20	2–139
aff. *B. whitei*	Georges Bank	?Cape Hatteras	Mild temperate	4–>20	23–114
Cytherella sp	do	Hudson Canyon	do	5–13	82–185
Cytherura? mainensis	Gulf of St. Lawrence	Western Gulf of Maine	Cold temperate	0±–14	24–87
Echinocythereis margaritifera	Georges Bank	Veracruz, Mexico	Mild temperate-tropical	6–27	20–235
planibasalis procteri	Bay of Fundy	Georges Bank	Cold temperate-mild temperate	3–20	12–89
Leptocythere angusta	Southern Labrador	Southern Virgnia	Subfrigid-mild temperate	0±–>15	3–170
Muellerina canadensis	Gulf of St. Lawrence	Cape Hatteras	Cold temperate-mild temperate	0–>20	7–801
aff. *M. lienenklausi*	Bay of Fundy	Northern Florida	Cold temperate-subtropical	2–>20	3–240
Munseyella atlantica	Georges Bank	Hudson Canyon	Mild temperate	6–13	86–235
mananensis	Baffin Bay	do	Frigid-mild temperate	<0–>13	20–201
Pseudocytheretta edwardsi	Scotia Shelf	Southern Virginia	Cold temperate-mild temperate	3–>20	3–123
Pterygocythereis americana inexpectata	Bay of Fundy	?Cape Kennedy	Cold temperate-subtropical	2–20	3–245
Puriana rugipunctata	Narragansett Bay	Caribbean	Mild temperate-tropical	4–29	2–73

REFERENCES CITED

Benson, R. H., and Coleman, G. L., II, 1963, Recent marine ostracodes from the eastern Gulf of Mexico: Kansas Univ. Paleont. Contr., Arthropoda, art. 2, p. 1–52.

Blake, C. H., 1929, New crustacea from the Mount Desert region: Philadelphia, Wistar Institute Press, Biol. Survey Mount Desert Region, pt. 3, p. 1–34.

——— 1933, Order Ostracoda: Philadelphia, Wistar Institute Press, Biol. Survey Mount Desert Region, pt. 5, p. 229–241.

Brady, G. S., 1866, On new or imperfectly known species of marine Ostracoda: Zool. Soc. London Trans., v. 5, p. 359–393.

——— 1868a, A monograph of the Recent British Ostracoda: Linnean Soc. London Trans., v. 26, no. 2, p. 353–495.

——— 1868b, Ostracoda from the Arctic and Scandinavian seas: Annals and Mag. Nat. History, 4th ser., v. 2, p. 30–35.

——— 1870, Recent Ostracoda from the Gulf of St. Lawrence: Annals and Mag. Nat. History, 4th ser., v. 6, p. 450–454.

Brady, G. S., and Norman, A. M., 1889, A monograph of the marine and fresh-water Ostracoda of the North Atlantic and of Northwestern Europe—Section I, Podocopa: Royal Dublin Soc. Sci. Trans., 2d ser., v. 4, no. 2, p. 63–270.

Cerame-Vivas, M. J., and Gray, I. E., 1966, The distributional pattern of benthic invertebrates of the continental shelf off North Carolina: Ecology, v. 47, no. 2, p. 260–270.

Coomans, H. E., 1962, The marine mollusk fauna of the Virginian area as a basis for defining zoogeographical provinces: Beaufortia, v. 9, no. 98, p. 83–104.

Curtis, D. M., 1960, Relation of environmental energy levels and ostracod biofacies in east Mississippi delta area: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 4, p. 471–494.

Cushman, J. A., 1906, Marine Ostracoda of Vineyard Sound and adjacent waters: Boston Soc. Nat. History Proc., v. 32, no. 10, p. 359–385.

Dana, J. D., 1853a, Crustacea: U.S. Exploring Expedition [Report], 1838–1842, v. 14, pt. 2, p. 690–1618.

——— 1853b, On an isothermal oceanic chart, illustrating the geographical distribution of marine animals: Am. Jour. Sci., ser. 2, v. 16, p. 153–167, 314–327.

Defant, Albert, 1961, Physical oceanography, Volume 1: New York, Pergamon Press, 729 p.

Dunbar, M. J., 1964, Euphausids and pelagic amphipods, distribution in North Atlantic and Arctic waters: Am. Geog. Soc., Serial Atlas of the Marine Environment, Folio 6, 2 p., 8 pls.

Ekman, Swen, 1953, Zoogeography of the sea: London, Sidgwick & Jackson, 417 p.

Elofson, Olof, 1941, Zur Kenntnis der marinen Ostracoden Schwedens, mit besonderer Berücksichtigung des Skagerraks: Zool. Bidrag från Uppsala, v. 19, p. 215–534.

——— 1943, Neuere Beobachtungen über die Verbreitung der Ostracoden an den skandinavischen Kusten: Arkiv Zoologi, v. 35A, no. 2, p. 1–26.

Emery, K. O., 1966, Atlantic Continental Shelf and Slope of the United States: U.S. Geol. Survey Prof. Paper 529–A, 23 p.

Fleming, R. H., 1957, General features of the oceans: Geol. Soc. America Mem. 67, v. 1, p. 87–108.

Fritz, R. L., 1965, Autumn distribution of groundfish species in the Gulf of Maine and adjacent waters, 1955–1961: Am. Geog. Soc., Serial Atlas of the Marine Environment, Folio 10, 3 p., 20 pls.

Ganong, W. F., 1890, Southern invertebrates on the shores of Acadia: Royal Soc. Canada Trans., sec. 4, no. 7, p. 167–185.

Hagerman, Lars, 1965, The ostracods of the Øresund, with special reference to the bottom-living species: Ophelia, v. 2, no. 1, p. 49–69.

Hall, C. A., 1964, Shallow-water marine climates and molluscan provinces: Ecology, v. 45, no. 2, p. 226–234.

Hathaway, J. C., ed., 1966, Data file, continental margin program: Woods Hole Oceanographic Inst. Ref. 66–8, v. 1, sample collection data, 184 p.

Hazel, J. E., 1967a, Classification and distribution of the Recent Hemicytheridae and Trachyleberididae (Ostracoda) off northeastern North America: U.S. Geol. Survey Prof. Paper 564, 49 p.

——— 1967b, Corrections for Classification and distribution of the Recent Hemicytheridae and Trachyleberididae (Ostracoda) off northeastern North America: Jour. Paleontology, v. 41, no. 5, p. 1284–1285.

Hazel, J. E., and Valentine, P. C., 1969, Three new ostracodes from off northeast North America: Jour. Paleontology, v. 43, no. 3, p. 741–752.

Hedgpeth, J. W., 1957, Marine biogeography: Geol. Soc. America Mem. 67, v. 1, p. 359–382.

Hicks, S. D., 1959, The physical oceanography of Narragansett Bay: Limnology and Oceanography, v. 4, no. 3, p. 316–327.

Hulings, N. C., 1966, Marine ostracod from western North Atlantic Ocean off the Virginia Coast: Chesapeake Sci., v. 7, no. 1, p. 40–56.

Hulings, N. C., and Puri, H. S., 1964, The ecology of shallow water ostracods of the west coast of Florida: Stazion. Zool. Napoli Pubb., supp. v. 33, p. 308–343.

Hülsemann, Jobst, 1967, Der Kontinental-Schelf-geologische Grenze Land/Meer: Umschau in Wissenschaft u. Technik, v. 4, p. 105–111.

Hutchins, L. W., 1947, The bases for temperature zonation in geographical distribution: Ecological Monographs, v. 17, p. 325–335.

Johnson, A. K., 1856, The physical atlas of natural phenomena: Edinburgh and London, Blackwood & Sons, 137 p., 35 pls.

Johnson, C. W., 1934, List of marine Mollusca of the Atlantic Coast from Labrador to Texas: Boston Soc. Nat. History Proc., v. 40, no. 1, p. 1–204.

Kindle, E. M., and Whittaker, M. A., 1918, Bathymetric checklist of the marine invertebrates of eastern Canada with an index to Whiteaves' catalogue: Canada Biol. Board, Contrib. Canadian Biology, Sessional Paper 38a, p. 229–294.

Lange, Wolfgang, 1956, Grundproben aus Skagerrak und Kattegat, mikrofaunistisch und sedimentpetrographisch untersucht: Meyniana, v. 5, p. 51–86.

Loeblich, A. R., Jr., and Tappan, H. N., 1953, Studies of Arctic Foraminifera: Smithsonian Misc. Colln., v. 121, no. 7, 150 p.

Milne-Edwards, H., 1838, Mémoire sur la distribution géographique des Crustacés: Annales Sciences Naturelles (Zool.), 2d ser. v. 10, p. 129–174.

Neale, J. W., 1959, *Normanicythere* gen. nov. (Pleistocene and Recent) and the division of the ostracod family Trachyleberididae: Palaeontology, v. 2, pt. 1, p. 72–93.

——— 1961, *Normanicythere leioderma* (Norman) in North America: Palaeontology, v. 4, pt. 3, p. 424.

——— 1964, Some factors influencing the distribution of British Ostracoda: Strazione Zool. Napoli Pubb., supp. v. 33, p. 247–296.

Norman, A. M., 1877, Crustacea, Tunicata, Polyzoa, Echinodermata, Actinozoa, Foraminifera, Polycystina, and Spongida (of the H.M.S. *Valorous* Cruise, 1875): Royal Soc. London Proc., v. 25, p. 202–215.

——— 1891, Notes on the marine Crustacea Ostracoda of Norway: Annals and Mag. Nat. History, ser. 6, no. 7, p. 108–121.

——— 1905, Irish Crustacea Ostracoda: Irish Naturalist, v. 14, p. 137–155.

Packard, A. S., Jr., 1863, A list of animals dredged near Caribou Island, southern Labrador: Canadian Naturalist, v. 8, p. 401–429.

——— 1867, Observations on the glacial phenomena of Labrador and Maine, with a view of the recent invertebrate fauna of Labrador: Boston Soc. Nat. History Mem. 1, no. 8, p. 210–303.

Puri, H. S., 1958a, Ostracode genus *Cushmanidea:* Gulf Coast Assoc. Geol. Socs. Trans., v. 8, p. 171–181.

——— 1958b, Ostracode subfamily Cytherettinae: Gulf Coast Assoc. Geol. Soc. Trans., v. 8, p. 183–195.

Robertson, David, 1875, Notes on the recent Ostracoda and Foraminifera of the Firth of Clyde, with some remarks on the distribution of Mollusca: Geol. Soc. Glasgow Trans., v. 5, no. 1, p. 112–153.

Sars, G. O., 1909, Crustacea: Report of the second Norwegian Arctic Expedition in the "Fram," 1898–1902, no. 18 p. 1–47, Society of Arts and Sciences of Kristiania.

Schlee, J. S., and Pratt, R. M., 1966, Glacial history of the Gulf of Maine [abs.]: Am. Assoc. Adv. Sci., Ann. Mtg., Sec. E, Geology and Geography, Program, p. 32.

Schopf, T. J. M., 1967, Bottom-water temperatures on the continental shelf off New England: U.S. Geol. Survey Prof. Paper 575–D, p. 192–197.

Schroeder, E. H., 1963, North Altantic temperatures at a depth of 200 meters: Am. Geog. Soc., Serial Atlas of the Marine Environment, Folio 2, 11 p. 9 pls.

——— 1966, Average surface temperatures of the western North Atlantic: Bull. Marine Sci., v. 16, no. 2, p. 302–323.

Squires, H. J., 1966, Distribution of decapod Crustacea in the northwest Atlantic: Am. Geog. Soc., Serial Atlas of the Marine Environment, Folio 12, 4 p., 4 pls.

Stephensen, K., 1913, Grønlands Krebsdyr og Pycnogonider—Conspectus Crustaceorum et Pycnogonidorun Groenlandiae: Medd. om Grønland, v. 22, no. 1, p. 1–479.

——— 1936, Crustacea Varia—The Godthaab Expedition 1928: Medd. om Grønland, v. 80, no. 2, p. 1–38.

Stephenson, T. A., 1947. The constitution of the intertidal fauna and flora of South Africa, Part III: Natal Mus. Annals, v. 11, pt. 2, p. 207–324.

Stephenson, T. A., and Stephenson, Anne, 1954, Life between tide-marks in North America—[Parts] IIIA, B, Nova Scotia and Prince Edward Island: Jour. Ecology, v. 42, no. 1, p. 14–45, 46–70.

Sumner, F. B., Osburn, R. C., and Cole, L. J., 1913, A biological survey of waters of Woods Hole and vicinity—Section I, Physical and zoological: U.S. Bur. Fisheries Bull., v. 31, p. 1–442.

Trumbull, J. V. A., Schlee, J. S., Hathaway, J. C., Ross, D. A., and Hülsemann, Jobst, 1966, Continental shelf sediments off northeastern United States [abs.] Am. Assoc. Adv. Sci. Ann. Mtg., Sec. E, Geology and Geography, Program, p. 35.

Uchupi, Elazar, 1963, Sediments on the continental margin off eastern United States: U.S. Geol. Survey Prof. Paper 475–C, p. 132–137.

U.S. Hydrographic Office, 1944, World atlas of sea surface temperatures [2d ed.]: Hydrog. Office Pub. 225, 49, p.

——— 1958, Oceanographic atlas of the polar seas—Part II Arctic: Hydrog. Office Pub. 705, 143 p.

Valentine, J. W., 1961, Paleoecologic molluscan geography of the Californian Pleistocene: California Univ. Pubs. Geol. Sci., v. 34, no. 7, p. 309–442.

Vos, A. P. C. de, 1957, Liste annotée des ostracodes marins des environs de Roscoff: Archives Zoologie Expérimentale et Générale, v. 95, no. 1, p. 1–73.

Wagner, C. W., 1957, Sur les ostracodes du Quaternaire Récent des Pays-Bas et leur utilization dans l'étude géologique des dépôts Holocénes: The Hague, Mouton and Co., 259 p.

Whiteaves, J. F., 1901, Catalogue of the marine Invertebrata of eastern Canada: Ottawa, Canada Geol. Survey, 272 p.

Williams, L. W., 1907, A list of the Rhode Island Copepoda, Phyllopoda, and Ostracoda with new species of Copepoda: Rhode Island Comm. Inland Fisheries, 37th Ann. Rept. p. 69–79.

Williams, R. B., 1966 Recent marine podocopid Ostracoda of Narragansett Bay, Rhode Island: Kansas Univ. Paleont. Contr., Paper 11, p. 1–36.

Woodward, S. P., 1851–56, A manual of the Mollusca, or, a rudimentary treatise of recent and fossil shells: London, John Weale, 484 p.

U.S. GOVERNMENT PRINTING OFFICE: 1970 O—373-564