SOME NOTES ON *MYSIS RELICTA* AND ITS RELATIVES IN NORTHERN ALASKA*

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Introduction

FOR about one month in the summer of 1961 I had the opportunity to make field studies on *Mysis relicta* (Crustacea, Peracarida) in northernmost Alaska. This crustacean was first recorded there in 1953 by John L. Mohr from Nuwuk Pond, Point Barrow. It has also been recorded from the ocean and from Elson Lagoon in the same area (Banner 1954, MacGinitie 1955).

Since the days of Sven Lovén (1862) *Mysis relicta* has been considered a marine-glacial relict in freshwater lakes of northern North America, Europe, and Siberia. Its geographical distribution coincides in general with formerly glaciated areas. It is mostly found in deep clear lakes with relatively low temperatures in their depths. Furthermore, it was supposed to have a marine ancestor, *M. oculata,* which turned into the "form" or "variety" *relicta* when parts of a former arctic sea became freshwater lakes. In recent times the literature has been a little confusing on this point (Ekman 1953, pp. 132, 133, 172; W. M. and O. S. Tattersall 1951, p. 345; Segerstråle 1957, 1962; Holmquist 1959). I agree with the Tattersalls that *M. relicta* Lovén 1862 is a species quite distinct from *M. oculata* (O. Fabricius) 1780, but I also recognize two more species hitherto confused with *M. oculata,* namely *M. litoralis* (Banner) 1948 and *M. polaris* Holmquist 1959, owing to comparative morphological studies. Furthermore, I question whether *M. relicta* is really a relict, a true remnant.

The confusion between *M. oculata* and *M. litoralis,* and between *M. litoralis* and *M. relicta,* has unfortunately resulted in erroneous *Mysis* records in the Barrow, Alaska region where all three species occur together; and probably also *M. polaris.* This, in conjunction with the abundance of freshwater lakes on the Alaskan Arctic Slope, seemed to make this area highly suitable for field studies on the mysids concerned.

I wish to thank the Director of the Arctic Research Laboratory, M. C. Brewer, and the Assistant Director, J. F. Schindler, who helped to make the survey of various localities possible and gave advice and encouragement; I also thank the laboratory personnel who contributed to the investigations and especially Ulf Lettevall, my field and laboratory assistant. Ulrik Røen kindly identified the entomostracans and verified the calanoid copepods and Kjeld Holmen kindly identified freshwater plants.

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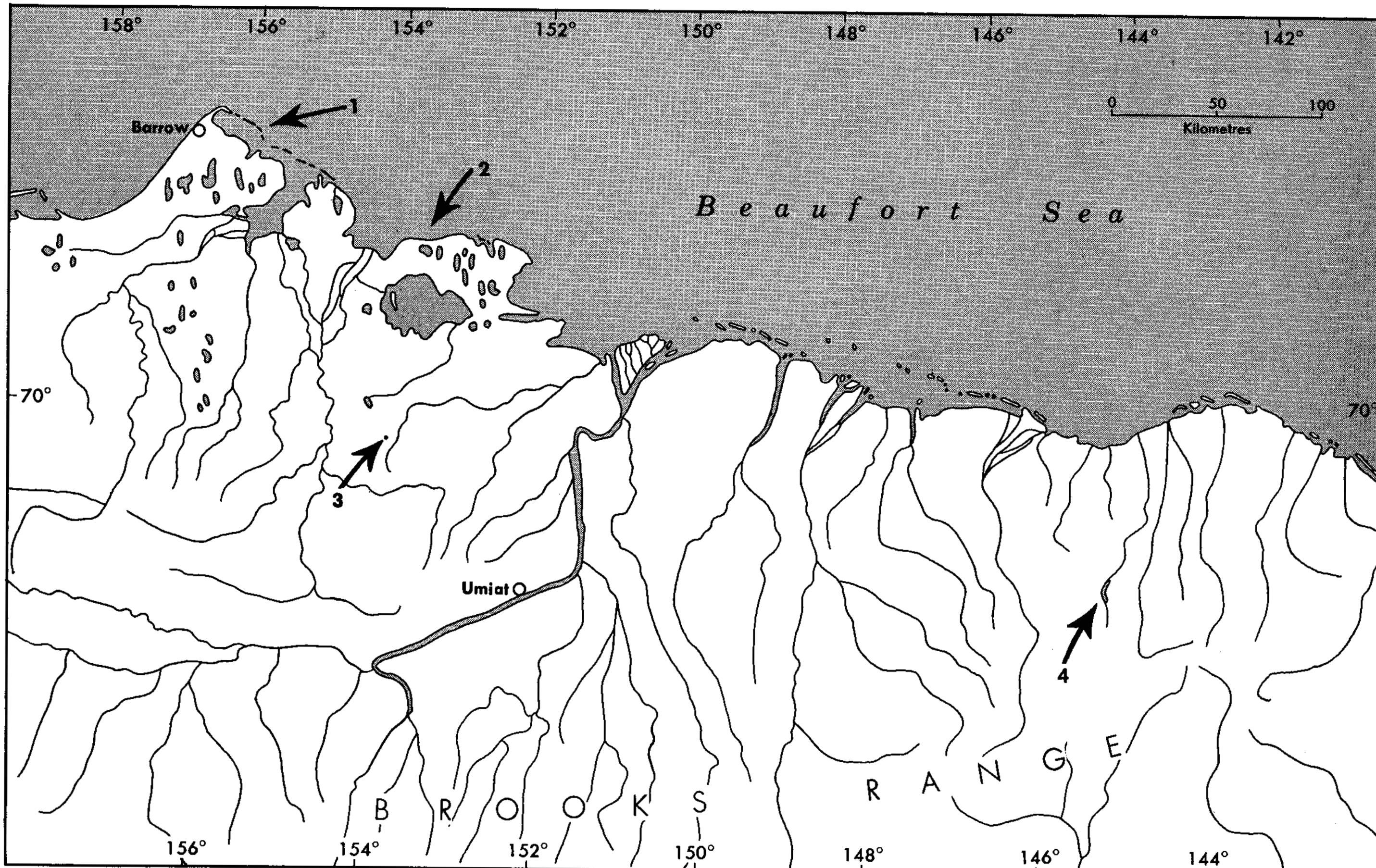

Fig. 1. Part of the Alaskan Arctic Slope. (1) Barrow area, (2) Teshekpuk Lake area, (3) the "unnamed" lake, (4) Lake Peters and Lake Schrader.

The area

The Alaskan Arctic Slope (Fig. 1) is very flat tundra country that reaches its northernmost point at 71°23'N. Except for local glaciation in the Brooks Range it was apparently never glaciated. However, it is covered with innumerable lakes, a characteristic that often indicates former glaciation. The lakes of northern Alaska probably originated in different ways. Most of them seem to be thaw sinks and thaw lakes as described by Black and Barksdale (1949), Hopkins (1949), Livingstone (1954), and Carson and Hussey (1960) and are typical of the much-discussed "oriented lakes" of Alaska (Fig. 2). Teshekpuk Lake (Fig. 5), by far the largest lake on the Arctic Slope, may have originated as a bay of the Arctic Ocean but its shape suggests also a fusion with thaw lakes (*see* Livingstone 1954, p. 548). In the foothills of the Brooks Range the lakes become less numerous and apparently also deeper. (*see* Black and Barksdale 1949, p. 111, Livingstone *et al.* 1958).

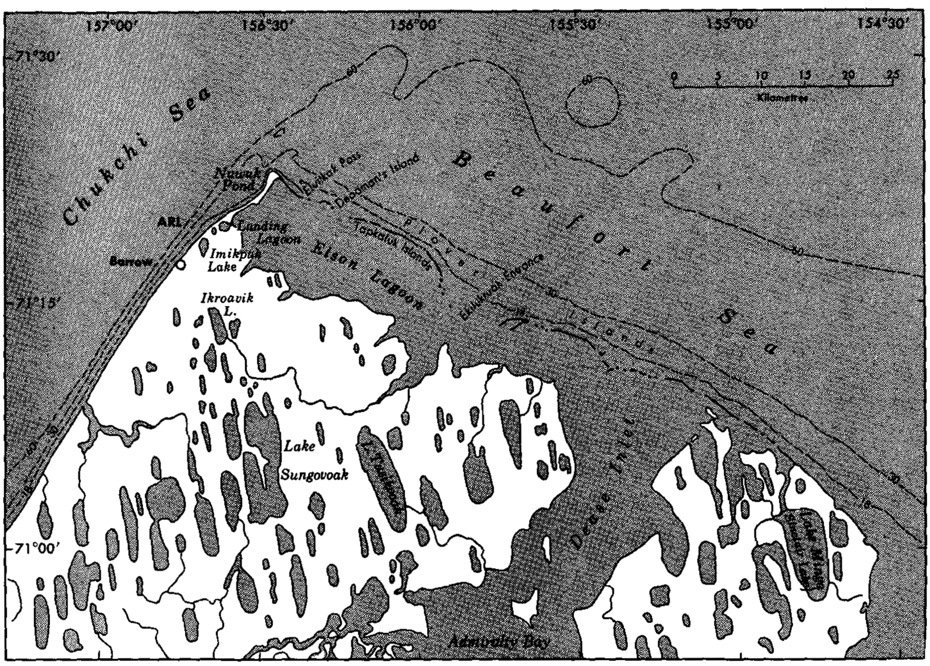

Fig. 2. The Barrow area (from U.S. Geological Survey sheets Barrow, Meade River, and Teshekpuk).

The continental shelf off northern Alaska is quite shallow. According to Carsola (1954, p. 371) it "originated before the Pleistocene . . . is unique in being the shoalest shelf of comparable size in the world". The coastline has apparently undergone changes during and after the Ice Age. During the glaciations the continental shelf may have been dry land to a large extent, but MacGinitie (1955, p. 10) speaks of many old beach lines in the coastal plain, "showing that the area has been uplifted and depressed in relation to the sea" (*see also* MacCarthy 1958). There are indications that at least parts of the coastal areas have been submerged in later periods. At present the shoreline is retreating owing to erosion, which is accelerated by the melting of exposed ground ice (MacCarthy 1953).

There is no tide of any importance in the Barrow area, but currents are recorded. The surface flow seems to follow the coast, in the Chukchi Sea from southwest to northeast and in the Beaufort Sea from east to west. The two currents meet at Point Barrow and continue northwards for some distance (La Fond 1954, p. 100).

The climate of northernmost Alaska is severe. Frost and snow can occur in any month. During the warmest month the average air temperature is around 4°C. and the mid-winter temperature averages −25°C. The mean annual precipitation is fairly low, about 110 mm. Nevertheless, the relative humidity is rather high. There is no shelter from the wind anywhere on the Arctic Slope, and quite calm days are scarce. The prevailing winds are from the northeast, but winds from the southwest are also frequent.

The surface temperature of the ocean not far from shore off Barrow was only 4°C. on August 12, 1961. There was no pack-ice in sight on that date. According to MacGinitie (1955, p. 19) surface temperatures as high as 7°C. have been recorded, but this seems to be exceptional. The temperature found in August 1961 is probably quite near to the summer average. The sea is frozen along the shore for more than half the year. Ice generally begins to form in October or November and persists until some time in July. Then it depends on wind and currents how far from shore the pack-ice will be found. The large amounts of fresh water supplied by the rivers to the coastal waters may affect the thickness of the ice, which is generally 1.5 to 2 m.

The ice provides protection from heavy wave action during storms for most of the year, but in periods without such cover the effects of heavy storms may be disastrous to many marine animals (MacGinitie 1955, p. 25). On the other hand, the ice will act unfavourably through scouring in shallow areas. The near-shore bottom in the Barrow area consists of gravel, sand, and clay. No algal belts are found, which in the shallower parts may be owing to ice scouring but also to the lack of solid rocks (*see* Taylor 1954, p. 373; Mohr *et al.* 1957).

Below freezing temperatures prevail under the ice in winter, the salinity being at least 30‰. Brewer says: "it is doubtful if frozen ground within the first hundred feet of depth extends outward more than a few tens of feet from the edge of the Arctic Ocean although frozen ground may be present at greater depths" (1955a, p. 503) and again: ". . . if the sediments beneath the Ocean contain fresh water at a distance of approximately 400 ft. off shore, they should be frozen; if the formations contain sea water, they should not be frozen to the depth studied even though they would be classed as permafrost by definition" (1955b, p. 503). These facts are of importance in considering the animals native to these waters and bottom substrata. They must endure freezing temperatures during a large part of the year, but they are not in a frozen state since sea water and their body fluids do not freeze at 0°C.

Inland the permafrost extends several hundred metres down (*see* Brewer 1955a, p. 503) and only the upper few decimetres of the surface thaw in the summer. A lake, however, which is deep enough not to freeze to the bottom in winter, i.e., is deeper than 2 m., constitutes a heat reservoir and causes unfrozen ground underneath. Brewer (1958, p. 238) shows in a diagram from the shallow Imikpuk Lake of Barrow (appr. 3 m. deep) that the temperature does not reach 0°C. until a depth of about 58 m. (*see also* Livingstone *et al.* 1958, p. 199). Furthermore, a large lake delays freezing in the fall, but also retards warming up in the spring.

Localities with *Mysis relicta*

In the area outlined above *Mysis relicta* has been found in abundance in only three localities. Two of them were already recorded by Mohr (1953) and Banner (1954), i. e., Nuwuk Pond and Elson Lagoon. The third is Teshekpuk Lake, where *M. relicta* was taken in the summer of 1961.

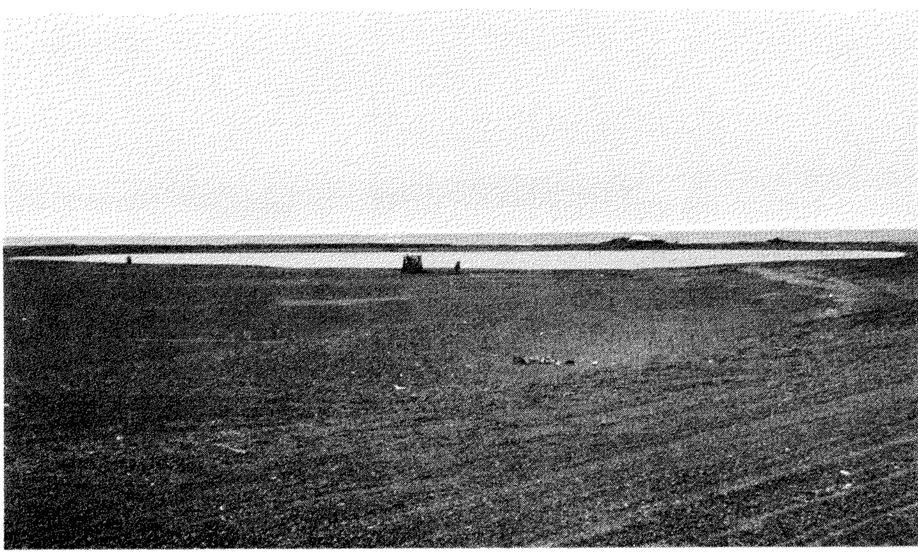

Fig. 3. Nuwuk Pond, August 5, 1961.

Nuwuk Pond (Figs. 2 and 3) is the most interesting of these localities. It is situated at Point Barrow on the gravelly end of the peninsula that separates Elson Lagoon from the ocean to the west and that forms the northernmost point of Alaska. The pond is only about 170 by 150 m. but has a depth of 5 m. This is remarkable, not only in comparison with the tundra lakes but also with the nearby large Elson Lagoon, which is not deeper than about 3 m. There are deeper holes in the sea, e.g., Eluitkak Pass at the eastern end of the gravelly spit has a greatest depth of about 13 m., and immediately west of Point Barrow there is a depth of some 10 m. It could be thought that Nuwuk Pond has been formed by such a hole having been cut off from the sea. The pond has neither inlet nor outlet. Sea water may reach it during heavy storms, but this probably does not happen regularly.

Temperature, salinity (provided that the composition of the salts in its water is the same as of those in sea water) and conductivity found during the investigations on August 5 and 10, 1961 are given in Fig. 4. The high salinity of the deep water, around 65‰, is remarkable. The upper layer was only slightly brackish with a salinity of the surface water of only 5‰ on July 19. The halocline had been displaced about 1 m. downwards between the first and second thorough investigation, and the salinity of the surface layers had become a little higher. There had been some wind in the interval, which may be the reason for this.

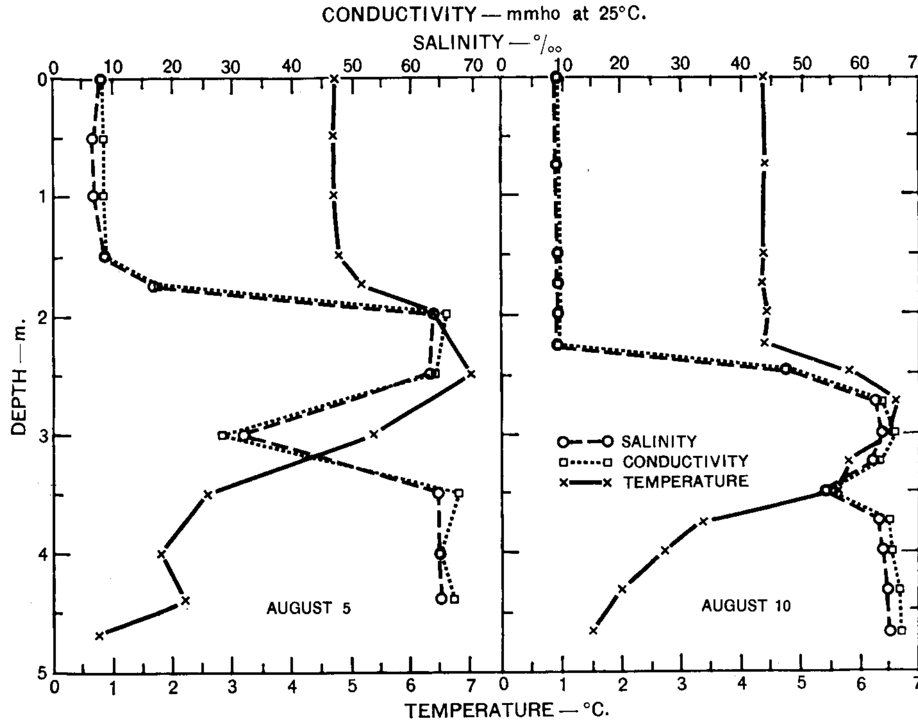

Fig. 4. Nuwuk Pond; conductivity, salinity, and temperature, August 1961.

Quite interesting was an intermediate layer at 3 and 3.5 m. with salinities of only 32‰ and 53‰, respectively, that was found on both occasions. Such a layer, taking only salinity into consideration, must cause unstable conditions in relation to the more saline upper layer. This would be confirmed by the salinity of the intermediate layer being appreciably higher on August 10 than on the 5th. It is not known where this intermediate water originated from. It may have been forced in by some agency through the sandy and gravelly surroundings.

Temperature variations could cause unstable conditions as well (*see* Fig. 4). The highest temperature, 6.5 to 7°C., was found at a depth of 2.5 to 3 m. It will depend on the relations between salinity and temperature how unstable the conditions can become in a pond like this. At least the bottom water, below about 4 m., may retain stable conditions throughout, if no such limited irruption of more diluted water occurs there too at some time or other, as it apparently did at a depth of about 3 m. before August 5, 1961.

The high salinity of the deep water is probably not caused by evaporation and low precipitation, but more by freezing in winter leading to dilution in the upper layers and a concentration of the salts in the deeper parts. The relative smallness of the water mass may be a contributing factor. According to Brewer (pers. com.) the ice on the pond attains a maximum thickness of about 1.8 m. This means that quite a large part of the water mass is turned into ice, consequently the rest becomes fairly salty.

Bottom hauls from the deepest part filled the net with black mud and some sand, but there was no odour of H_2S. Above 3 m. very little mud but more gravel was obtained. A yellowish tough clay was met with near both the western and eastern shores at a depth of about 2 m.

Mysis relicta seems to be quite abundant in this pond. One haul from 4 m. to 0.5 m. yielded nearly 2500 specimens and another from about 3 m. to 1 m. more than 550 specimens, most of which were young. Dredge hauls from 5 m. and from between 4 m. and 5 m. contained few specimens. They may have been caught when the net was taken up, but this is not certain since *Mysis* dwells preferably along the bottom, at least in shallow water.

No other mysids were found in the pond, not even its near relatives *M. litoralis* and *M. oculata*. An amphipod, *Gammarus*, was very abundant in the gravelly shore zone, and specimens of *Pseudalibrotus* were also taken. From bottom tows at the middle of the pond (appr. 5.2 m. to 3 m.) small ovigerous females of an oedicerotid were found in association with small gammarids. A small *Halicryptus spinulosus* (Priapuloidea) and a specimen of a spionid worm (Polychaeta) were taken in the clayey areas. A few plankton hauls were carried out with a closing net (kindly lent by Dr. Durham of the University of California). Unfortunately, the exact depth at which the net worked is not known, but the depth was between approximately 3.5 and 2.5 m. In one tow 21 small *M. relicta* were caught, in another only a small *Gammarus*. All contained innumerable small copepods and nauplius larvae. Some surface plankton hauls contained diatoms, copepods, nauplius larvae, and a few tintinnids. Filamentous algae were not scarce in dredge hauls along the bottom from about 3 m. downwards.

What happens to the animals and algae that do not hibernate as resting stages of some kind during the winter in this pond requires further study. The amphipods, mysids, and others, which apparently prefer the upper, more diluted layers in summer, must endure a salinity of around 65‰. There is no indication of even a thin layer of diluted water in the diagram in Mohr *et al.* (1962, Fig. 4). The activity and metabolism of the animals can be expected to slow down during this time when only freezing temperatures are found throughout and this may prevent or alleviate probable damage.

The supply of oxygen seems to be adequate at all times. Its replenishment in the deeper layers in summer is probably not dependent on wind and wave action, but brought about by activities of the numerous filamentous and other algae living in the pond. Most likely they have sufficient light for assimilation in summer and they may even be active below the ice during the lighter periods of the winter (*see* Apollonio 1961). The low temperatures in winter serve to reduce the oxygen consumption. The graph in Mohr *et al.* (1961, Fig. 7) shows a content of dissolved oxygen of at least 2ml.O_2/l. (about 3 mg./l.) at approximately the 4-m. depth in April under ice thicker than 1 m. This value is high for such a small body of water under existing conditions, but in the light of the above not unexpected.

Elson Lagoon is a large shallow area. It is about 55 km. long and in the western part about 10 km. wide. Farther east it narrows to about 5 km., and from its easternmost part Dease Inlet and Admiralty Bay extend far inland. Elson Lagoon is separated from the Arctic Ocean in the northwest by the Point Barrow Peninsula and in the northeast by the Plover Islands and a chain of others. There are some wide openings connecting it with the open sea, e.g., Ekilukruak Entrance, and that between Deadmans Island and the Tapkaluk Islands. Eluitkak Pass in the northwestern part is not very wide but around 13 m. deep. Elsewhere the depth of Elson Lagoon does not exceed 3.5 m. According to MacGinitie (1955, p. 16) there is quite a strong current in Eluitkak Pass, but no signs of currents through the other openings. The chain of islands probably protects the lagoon from ocean waves (*see* MacCarthy 1953, p. 51).

Investigations were carried out on July 21 and 26 in the northwestern corner of Elson Lagoon. In spite of the relative shelter of the sandspit, waves rose and increased quite quickly with the wind. On July 26 the salinity was about 29‰ at all depths. On July 21 it was 23.2‰ at the surface and 29.6‰ at a depth of 3 m. indicating an inflow of fresh water. The corresponding temperatures were 4.1°C. and 3.6°C. and on the windy day, July 26, a uniform 6°C. was found at all depths. The open ocean had a surface temperature of only 0.6°C. and a salinity of 29.9‰ on the same day.

The bottom of the lagoon is very even and a greatest depth of 3 m. was found in the northwestern corner. A yellowish-brown to grey clay or mud was found farther from the shore and the bottom appeared to be overgrown with a velvety coat of finely ramified filamentous algae. Some ulvaceans (green algae) were also taken here and specimens looking like small laminarioids (brown algae). Closer to the shore the mud became blackish, the carpet of fine algae disappeared and increasing amounts of sand and gravel formed the transition to the entirely gravelly shore.

The fauna looked quite marine: hydroids, a sea anemone, bryozoans, polychaetes (among others *Pectinaria* and *Lepidonotus*), the priapulid worms *Halicryptus spinulosus* and *Priapulus caudatus,* bivalves, snails, amphipods represented among others by numerous *Gammarus* and a few *Gammaracanthus*, a few specimens of the isopod *Mesidotea entomon*, decapod larvae, a few euphausiids (*Thysanoëssa raschi*), some medusae and *Sagitta* (Chaetognatha). Three species of mysids were taken. *M. relicta* and *M. litoralis* appeared to be quite abundant in about equal numbers. There were many large specimens but only few very young ones. The latter belonged mostly to *M. litoralis*. The brood of *M. relicta* did not seem to have escaped yet from the brood pouch and that of *M. litoralis* appeared to have recently started. There were seven young of *M. oculata*.

The question arises as to which animals are permanent residents in the lagoon and which are brought in by currents. Only protracted investigations could provide the answer. However, bottom-living, especially slow-moving animals could be assumed to be residents and also species with pelagic larvae whose stocks can be renewed from time to time, but it is more difficult to say which of the entirely pelagic animals may be indigenous. Members of the genus *Mysis* are not truly pelagic animals, although at times they behave as such. Generally they seem to stay in or on the uppermost detritus layer of the bottom, but they also swim around occasionally in the water and then are subject to be carried away by currents or wave action. The large number of *M. relicta* and *M. litoralis* (about 200 specimens in nine dredge hauls) found in Elson Lagoon seems to indicate that they most probably are resident there, whereas the seven very young specimens of *M. oculata* suggest that they were brought in by currents.

Interesting comparisons between these results and those from the open sea can be made. The greatest depth found in the ocean in 1961 was 8 m. Seven dredge hauls on July 18 off the Laboratory at Barrow from 6 to 0 m. yielded only six small specimens of *M. litoralis*, four hauls east of Nuwuk from 7 to 0 m. on July 26 gave four young *M. litoralis* and nine hauls off the airstrip from 8 to 0 m. on August 12 gave seven small *M. oculata*. No *M. relicta* were taken in the ocean.

Samples taken earlier by other workers are available. Part of sample No. 665 of the A.R.L. was re-examined. It was taken by MacGinitie on Sept. 30, 1949 as "plankton haul near shore" and has been recorded by Banner (1954, p. 127) as containing *M. relicta*. The sample contains nearly 2000 young specimens, 11 to 12 mm. long and of the 500 specimens re-examined only four were *relicta*, the other nearly 500 specimens were *litoralis*. I do not think that the proportion would be altered much if still more specimens were re-examined.

Dr. Mohr and the United States National Museum kindly lent other samples, some of which have been reported in my paper of 1959 (Table 3). The remaining are as follows (details after Banner 1954):

Red 2. 70°08′N. 143°54′W.; Aug. 9, 1953. 1 *M. litoralis*
Red 3. 70°03′N. 145°14′W.; Aug. 9, 1953, 7.3 m. 25 *M. litoralis*.
Red 4. 70°12′N. 145°55′W.; Aug. 10, 1953. 7 *M. litoralis*.
Red 5. 70°11′N. 146°15′W.; 1953; 0.23 m. 1 *M. litoralis*, 33 *M. relicta*.
Red 6. 70°15′N. 146°50′W.; August 10, 1953; 4.6 m. 24 *M. litoralis*, 3 *M. relicta*.

Table 1. Inland waters investigated, summer 1961.

Lake	*Situation*	*Greatest*			*Temperature* °C.	*Cl*⁻ mg./l.	*Conductivity* m mho at 25°C.	*Hardness* $CaCO_3$ mg./l.	*pH*	*at depth* m.	*Transparency* m.	*No. of hauls*	*Date*
		length km.	*width* km.	*depth noted* m.									
					1.0	87	0.180	68	6.8	0			
Imikpuk,	71°20′N.	1	0.7	2.5	1.1	88	0.180	68	6.8	1	—	6	July
Barrow	156°39′W.				1.2	87	0.180	68	6.9	2			22
					1.4	89	0.180	68	6.9	2.25			
Landing	71°20′N.				8.8	2,500	—	—	8.7	0			
Lagoon,	156°38′W.	1.5	1.2	1.7	8.9	2,500	—	—	—	1	—	6	July
Barrow					9.6	2,500	4.300	701	8.6	1.5			24
Ikroavik,	71°14′N.	4	1.5	2.1	4.8	28	0.045	17	6.0	0	low	7	August
Barrow	156°38′W.				5.0	28	0.044	17	5.9	2			2
Tusikvoak	71°05′N.	12.5	3.5	2.5	6.5	93	0.204	84	7.9	0	0.9	3	August
	156°06′W.				6.7	94	0.204	84	7.8	1.75			13
Sungovoak	71°06′N.	14	4.5	2.0	7.0	88	0.175	51	7.7	0	1.75	2	August
	156°30′W.												13
Unnamed	70°01′N.	1.5	1.5	16.0	9.5	6	0.028	34	7.7	0	6.4	4	August
lake	153°53′W.				8.6	6	0.028	34	7.4	5			9
Lake	69°19′N.	6.5	1.5	49.5	—	—	—	—	—	—	low	5	July
Peters	145°00′W.												27
Lake	69°23′N.	8	2	54.5	9.3	6	0.033	34	7.0	0	3.7	7	July
Schrader	145°00′W.				5.9	11	0.045	51	6.9	48.5			28
					5.8	28	0.102	68	7.8	0			
Teshekpuk	70°35′N.	45	33	5.2	5.8	29	0.102	68	8.0	1.5	0.95	5	August
	153°30′W.				5.8	29	0.102	68	8.0	3.0			11
					6.0	29	0.104	86	8.0	4.5			
					5.9	10,900	20.200	—	7.9	0			
Minga	71°00′N.	12	4.5	2.0	5.9	11,100	20.200	—	7.9	1	low	7	August
	154°46′W.				5.8	11,200	20.200	—	7.9	2			3
					4.7	4,400	8.100	—	8.0	0			
					4.7	4,400	8.200	—	8.1	0.5			
					4.7	4,400	8.100	—	8.1	1.0			
					4.8	4,400	8.300	—	8.1	1.5			
Nuwuk					5.2	9,200	17.200	—	8.6	1.75			
Pond,	71°23′N.	0.17	0.15	5.2	6.4	36,900	66.000	—	8.1	2.0	2.5	4	August
Barrow	156°28′W.				7.0	36,500	64.000	—	8.0	2.5			5
					5.4	18,200	28.500	—	8.2	3.0			
					2.6	37,300	68.000	—	8.0	3.5			
					1.8	37,300	65.000	—	8.0	4.0			
					2.2	37,600	67.000	—	8.0	4.4			
					0.8	—	—	—	—	4.7			

Red 8. 70°31′N. 148°50′W.; Aug. 10, 1953; 12.8 m. 27 *M. litoralis.*
Red 11. 70°43′N. 150°59′W.; 1953; 8.2 m. 33 *M. litoralis,* 1 *M. relicta.*
Red 12. 70°40′N. 151°50′W.; Aug. 11, 1953. 4 *M. litoralis,* 15 *M. relicta.*
Red 15. 70°57′N. 154°16′W.; 7.3 m. 1 *M. relicta.*
Red 16. 70°57′N. 154°16′W.; Aug. 12, 1953; 6.1 m. 4 *M. litoralis,* 1 *M. relicta.*

In addition there is a sample taken by Mohr and Horvath on July 13, 1952, at "beach opposite Barrow base". It contains 10 *M. relicta.*

From these samples it may be gathered that most of the *Mysis* specimens taken in the open sea belong to *litoralis* and that *relicta* is only rarely met with. However, "beach opposite Barrow base" and similar localities could also refer to the shore of Elson Lagoon. Further details of the *Red* stations 5 and 12 are desired. At least station 12 seems to be not very different from Elson Lagoon.

It is quite remarkable that no *M. oculata* were found in these older samples and that only a few young specimens were taken by me off the Barrow airstrip and in Elson Lagoon. The reason could be that there are no real algal belts in this area. This species is commonly found among algae in the Disko Bugt area of West Greenland in quite shallow water. *M. polaris* was not found at all. Perhaps it must be sought at greater depths. Little is known about this species since only two specimens have been recorded, one from the Kara Sea, the other from the Arctic Ocean, probably north of Alaska (*see* Holmquist 1959).

About the same conditions may prevail in the coastal areas of the sea and in Elson Lagoon, though some modifications are to be expected in the latter owing to the sheltered position and the outflow from the rivers. Generally, melting starts inland before the ice has disappeared from the shore. Quite probably we have a vestige of the conditions described by Thorson for Greenland (1936, pp. 86-7): "this fresh water is pressed down below the still unbroken ice on the surface of the fjords, and on account of the resulting pressure may penetrate still deeper into the water layers than might be expected considering the slight specific gravity of the fresh water". This process would cause a definite change in the conditions in the water inhabited by the mysids. However, with less precipitation and with a lower speed in the rivers the effect may not be as pronounced in northern Alaska (*see* MacGinitie 1955, p. 20). Thorough investigations of temperature, salinity, and oxygen content of Elson Lagoon would be appreciated. Anyhow, it is probably correct to assume that conditions in springtime are quite variable here and in the open sea, that they are more stable in summer and quite stable during the long winter. Temperatures may be below freezing in winter but in summer they may rise to about 6°C.

An interesting lake at about 71°N. 154°46′W., locally called "Lake Minga" and on the maps named Sinclair Lake (Fig. 2) was examined for the main part by my assistant on August 3, 1961. The lake is about 12 km. long, 4.5 km. wide in the broadest northern part and it narrows to about 2.5 km. at the southern end. No depth greater than 2 m. was found and mud from the deepest part smelled unmistakably of H_2S; near shore the bottom was hard and clayey.

Seven dredge hauls produced some fine, filamentous algae, a few polychaetes and their tubes, many *Halicryptus spinulosus,* copepods, mostly *Eurytemora raboti,* but also *Limnocalanus johanseni,* two specimens of euphausiids, namely *Thysanoëssa inermis* and *Th. raschi,* further seven specimens of *Mysis litoralis* and six of *M. relicta.* The water had a uniform temperature of about 6°C. and was muddy, indicating that it had apparently been disturbed by recent stormy weather. Its salinity was 19.7‰ at the surface, 20.0‰ near the bottom at 1-m. depth, and 20.30‰ at 2 m., the deepest place; pH was a uniform 7.9. The relatively high salinity of Lake Minga and the presence of, e.g., euphausiids, were quite unexpected. As far as I know

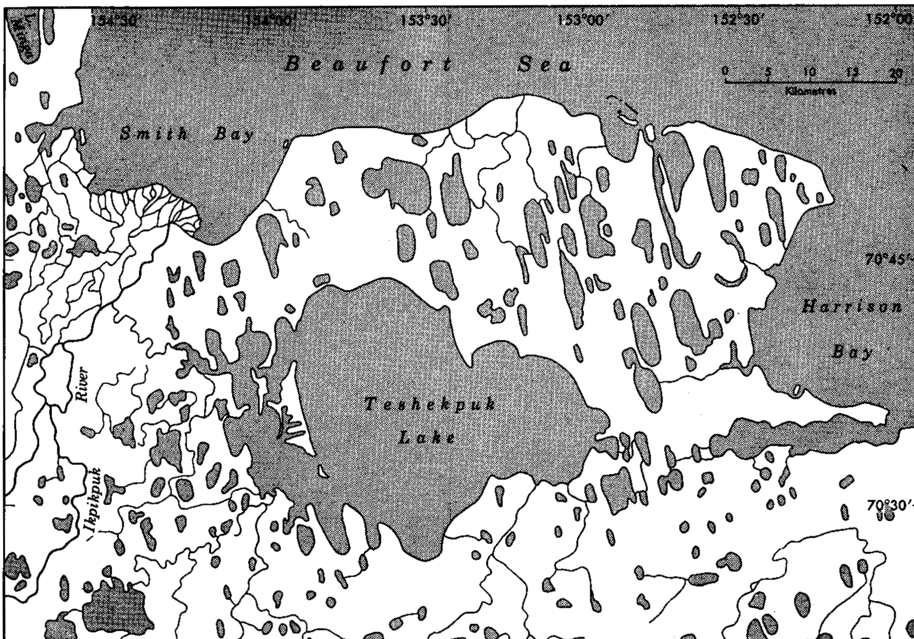

Fig. 5. Teshekpuk Lake (from U.S. Geological Survey sheets Teshekpuk and Harrison Bay).

euphausiids have never been recorded from an inland water. According to the map the relatively wide outlet of the lake is about 4 km. long and does not open directly into the ocean. It may be possible that the euphausiids had been washed in together with salt water during the recent storm. This could also explain the scanty findings of mysids in the lake. The shallowness of the lake, though it could perhaps be deeper than 2 m. in some places, would suggest that it freezes almost to the bottom, and the presence of H_2S in the bottom mud indicates that there will be a deficiency of oxygen. The numerous *Halicryptus spinulosus* on the other hand would indicate that at least these creatures live through the winter there.

Another observation makes it appear likely that the pelagic animals had been washed in. The stomach contents of whitefish obtained on the same date consisted of many euphausiids and copepods, *Eurytemora raboti*, but it was quite apparent that the euphausiids had been eaten first and then the fish had filled up on copepods. Furthermore, *Eurytemora raboti* has been recorded only from Nuwuk Pond, although several plankton investigations in Alaska have been reported (Mohr *et al.* 1961 and Johnson 1956, 1958). This suggests that the migratory fish had quite recently entered Lake Minga from the ocean. It would be most unusual if the euphausiids were indigenous and abundant in the lake itself and if the mysids were so much scarcer than the euphausiids. It is not at all likely that either *Mysis relicta* or *M. litoralis* is a true inhabitant of Lake Minga nor that they entered the lake on their own accord.

Fig. 6. Northern shore of Teshekpuk Lake, August 11, 1961.

Teshekpuk Lake, which is by far the largest of all the lakes on the Alaskan Arctic Slope, is about 45 km. long and 33 km. broad (Figs. 5 and 6), but its depth is astonishingly small. Soundings made some 10 km. from the northern shore gave a depth of only 5 to 5.2 m. Only small streams run into the lake and the outlet, which joins the delta of the Ikpikpuk River, is inconsiderable.

The bottom material obtained in the dredge was a yellowish-brown to greyish mud. There was no indication of H_2S, which seems to show that there is no lack of oxygen in the depths, not even at the end of the long winter stagnation period. The analyses showed that the water is entirely fresh with a low content of chloride ions; its transparency was only 95 cm. This and the uniform water characteristics found over practically the whole depth (*see* Table 1) show that wind and wave action cause thorough mixing of the entire water mass and also stir up the bottom sediments.

Teshekpuk Lake, like the other lakes, freezes over in late September or

October and the ice breaks up in July. On July 29, 1961 about one-half of it was still covered with ice. The lake was investigated on August 11 and by then the water had already warmed up to 6°C. down to the bottom. The same thermal regime as described by Brewer (1958) for Imikpuk Lake may prevail here, which would mean a temperature of about 1°C. throughout the winter for the deeper layers of the water.

Five dredge hauls yielded more than 400 specimens of *Mysis relicta.* No other mysids were found. For the rest, the samples contained some chironomid larvae, some oligochaetes, small pisidians (Bivalvia), and a few specimens of the ostracod genus *Iliocypris.* A surface plankton sample contained much detritus, tintinnids, and *Dinobryon* (Protozoa), rotatorians of the genera *Keratella* (2 spp.) and *Kellicottia.* A sample from nearer the bottom contained the same animals and also filamentous algae, nauplius larvae, and copepods, i.e., *Limnocalanus grimaldii* (or rather *L. macrurus, see* Holmquist 1963).

Localities without *Mysis*

Some properties of the lakes investigated are given in Table 1. For several lakes the data found in 1961 can be compared with earlier records. For Imikpuk or Fresh Lake at Barrow see Prescott (1953), Comita and Edmondson (1955), Comita (1956), Brewer (1958), and Carson and Hussey (1960); for Ikroavik Lake see Prescott (1953), Wohlschlag (1953), Livingstone *et al.* (1958), and Carson and Hussey (1960); for Lake Peters see Hobbie (1960) and for Lake Schrader see Hobbie (1960 and 1961). Many of the investigations reported are just as sporadic as my own, but they may indicate the main features of the lakes.

Most of the lakes examined are quite shallow, only 1.7 to 2 m. deep. The main part of Landing Lagoon is only 1 m. deep and probably freezes to the bottom, but a small area near its former connection with Elson Lagoon is 1.7 m. deep. There it has been dammed and provided with an artificial outlet. Probably owing to this it is now only slightly brackish, with a salinity of about 5‰. The fauna also indicates that it is no longer part of the sea. It contains oligochaetes, chironomid larvae, *Daphnia pulex, Branchinecta paludosa,* and a small gammarid. A plankton sample had unidentified nauplius larvae, *Limnocalanus johanseni, Notholca,* some *Keratella,* tintinnids, and filamentous algae, among others *Spirogyra.*

The other shallow lakes, i.e., Imikpuk, Ikroavik, Tusikvoak, and Sungovoak, are at least 2 m. deep or more. Since the ice is usually not thicker than 1.5 to 2 m., these lakes do not freeze to the bottom. For Ikroavik Lake for instance this would be indicated by the fish that have been found in it (Wohlschlag 1953). I caught some sticklebacks in dredge hauls in this lake as well as in Lake Tusikvoak; one of sticklebacks from the latter was attacked by a fish leech.

Prescott (1953) reported variations in the algal flora and apparently they are also found in the fauna. For instance, young specimens of *Branchinecta paludosa* were abundant in Imikpuk Lake (July 22), scarce in Ikroavik Lake

(August 8), and absent from Lake Tusikvoak and Lake Sungovoak (August 13). In Lake Tusikvoak several large specimens of a red *Hydra* were found, but none in any of the other shallow lakes. Oligochaetes were only taken in Imikpuk Lake and the Landing Lagoon, but chironomid larvae in all. No plankton tows were made in these lakes but *Limnocalanus johanseni* was found in the dredge hauls from Imikpuk and Sungovoak lakes, two young *Eurytemora* sp. in Lake Tusikvoak, *Cyclops navus* in Imikpuk Lake and *Cyclops scutifer* in Ikroavik Lake, *Limnocythere sancti-patrici* in Lake Tusikvoak, *Prionocypris glacialis* in Lake Sungovoak, *Daphnia pulex* in Imikpuk Lake, ephippians from supposedly the same species in Ikroavik Lake, and *Eurycercus glacialis* in Lake Tusikvoak; *Lepidurus arcticus* was taken in Imikpuk and Ikroavik lakes.

The chemical properties of these lakes show some, but not very remarkable differences and the chemico-physical characteristics do not suffice to explain the absence of mysids, unless the shallow depths, which allow freezing to, or nearly to the bottom, and which also permit rapid warming of the water after the ice disappears, are the cause.

The other three lakes investigated are much deeper: the unnamed lake at 70°08′N. 153°53′W. is at least 16 m. deep, Lake Peters is 50 m. deep and Lake Schrader reaches 57 m. in the deepest part. They are also farther inland. The altitude of the unnamed lake is not known. It lies in the lower foothills of the Brooks Range. The altitude of the other two is about 850 m. and they are situated in the Franklin Mountains in the eastern part of the Brooks Range.

Considerable differences between the faunas and floras of these three lakes were found, even between those of lakes Schrader and Peters, where they may be caused by the water of the former being much clearer than that of the latter. The dredge hauls indicate a much richer fauna in the former. They contained *Daphnia pulex, D. longiremis, Cyclops capillatus,* and *Diaptomus* sp. The contents of a dredge haul from a depth between 49 and 54.5 m. were remarkable. They included besides many pisidians and oligochaetes a few chironomid larvae and the turbellarians *Otomesostoma auditivum* and *Mesostoma* sp., many bright-red hydras, numbers of hydrachnids, and filamentous algae. Only single mites and no hydras were found in hauls from depths between 15.5 and 49 m. Between 4.5 and 8 m., and 5.9 and 13.5 m. hydras appeared again but only in small numbers, as well as a few mites. The hydras from between 49 and 54.5 m. appeared quite vigorous and were budding freely.

The unnamed lake was found to be very different from all others investigated by me in Alaska and also in West Greenland (*see* Holmquist 1959). The transparency of its water is with 6.4 m. the highest recorded in Table 1. The dredge collected great quantities of mosses, mainly *Scorpidium scorpioides,* the characean *Nitella* and some filamentous algae, many oligochaetes, chironomid larvae, the triclad *Dendrocoelopsis piriformis, Otomesostoma auditivum,* many pisidians and *Sphaerium,* snails of the genera *Valvata* and

Lymnaea, copepods (*Cyclops magnus*), ostracods (*Cyclocypris globosa*), and cladocerans (*Eurycercus glacialis*), a few specimens of an amphipod (*Gammarus*), mites, trichopterous larvae, dipterous larvae, empty tubes of bryozoans, and some small young fish. There was also a clump of snail eggs.

The unnamed lake lies in an area that was probably not glaciated in contrast to the valley of Lake Peters and Lake Schrader. The much more varied fauna and flora could perhaps be explained by the greater age of the lake or by the area having been habitable for a long time.

There is, however, nothing in the chemico-physical properties nor in the composition of the fauna that would indicate a reason for the absence of mysids from these three lakes. They are deep enough for mysids to thrive in. The mysids would be able to withdraw to darker parts when necessary and the temperature is in all probability quite constant in the deeper parts. There is nothing either to indicate that the oxygen content will be very low during the long winter. The reasons for the absence of mysids must be sought elsewhere, probably in the means of dispersal of the animals, their history, or the history of the lakes.

Discussion

Various Alaskan localities were examined in 1961 to discover their suitability as habitats of *Mysis*. The results illustrate well the different aspects of the *Mysis* problems. The Alaskan area differs from others where *M. relicta* has generally been met with in that it was never glaciated and where the dispersal of the species could hardly have been influenced by former glaciations.

In Alaska *M. relicta* has been found in entirely fresh water (Teshekpuk Lake, 29 mg. CL^{-}/l.), in marine water with varying salinity (Elson Lagoon, 12,900 to 16,700 mg. Cl^{-}/l.), in a metahaline pond with a fairly diluted upper layer in summer that is supposed to be frozen in winter (Nuwuk Pond, 2,500 to 37,600 mg. Cl^{-}/l.). The animals are certainly euryhaline and it would be an obvious conclusion that they would be abundant also in the open sea. However, the results in Alaska indicate that *M. relicta* there prefers inland waters, whether fresh, brackish, or euhaline to metahaline. In some way or other the inland waters provide a more sheltered habitat. The salinity conditions of Nuwuk Pond are most interesting; how the mysids adjust their osmoregulation when migrating between the different layers is a mystery.

Earlier investigations have shown that members of the genus *Mysis* are adversely affected by a sudden rise in temperature when they have no possibility to escape to an area of low temperature, but they tolerate a steady temperature of 17 to 18°C. (Holmquist 1959, pp. 178-80). Nuwuk Pond has provided evidence that *M. relicta* tolerates a temperature close to —2°C. I do not think, however, that the animals would survive freezing into solid ice, as has been stated for certain molluscs, chironomid larvae, and others (*see* Nordenskiöld 1897, Scholander *et al.* 1953).

The shallowness of the waters with *M. relicta* is noteworthy, it is about 3 m. for Elson Lagoon and 5 m. for Teshekpuk Lake and Nuwuk Pond. However, with the exception of Nuwuk Pond, they cover extensive areas and on the Alaskan Arctic Slope there is no kind of protection from the cold winds, which quite probably counteract any warming by insolation. The winter temperatures of salt water in this area are lower than 0°C. below the ice. The period of break-up and immediately after is probably the time of greatest variation in temperature in Elson Lagoon. The difference between maximum and minimum temperatures during the year may amount to about 8°C. For a freshwater lake, such as Teshekpuk Lake, it is presumably less. Nuwuk Pond is a much smaller body of water. Brewer has made available some unpublished temperature records obtained by the Arctic Ice and Permafrost Project of the U.S. Geological Survey during one winter. The most stable conditions seem to occur in depths below about 3.5 m., i.e., in the highly saline water where the difference in temperature may amount to 3 to 5°C. The intermediate water at about 2.5 m. has apparently the greatest variation in temperature, amounting to about 9°C., disregarding the frozen layers. These values provide evidence for the variations in temperature that are well within the tolerance limits for *M. relicta*. During warm and calm spells, which do not last for long periods of time, *Mysis* has always the possibility to tide over in the surface layer of the bottom substratum in the deeper parts where the temperature will probably not change as fast as in the open water or near the shore.

The mysids may be fairly sluggish during the period of below-freezing temperatures; their rate of metabolism must then be very low, the summer is short and the maturation of the animals may be retarded. The quite large size of some subadult specimens in some samples could be an indication of this. In other samples, however, the ratio between adult and young specimens did not differ noticeably from that found in Scandinavian lakes for instance, indicating one generation only per year. It is remarkable that the samples from Elson Lagoon showed that the young did not escape from the brood pouch until late July. Otherwise they generally emerge from March until May. In Teshekpuk Lake all stages were represented, indicating an almost continuous propagation, i.e., conditions found also in other large lakes.

The shallow water of the *Mysis* habitats in northern Alaska accentuates another problem, that of their behaviour towards light. In my paper of 1959 (pp. 178-84) I pointed out that *M. litoralis* was abundant in shallow coastal waters of the Disko Bugt area, West Greenland, but in some Greenlandic freshwater lakes they occurred only at greater depths, not above 35 m. The transparency of the water was high. *M. litoralis* and *relicta* seem to react similarly to light and it was suggested that certain combinations of light and temperature could cause a change in ionic regulation and permeability, which might account for the different behaviour of the animals in fresh water and salt water. Such a process could explain the occurrence and abundance of *M. relicta* in the shallow Elson Lagoon and in the relatively shallow Nuwuk Pond with its saline water, as well as the presence of *relicta* in the shallow and entirely fresh Teshekpuk Lake, which has a low transparency of the water, caused by the frequent winds stirring up the bottom mud.

The means of dispersal in mysids are very restricted. The animals are not able to migrate up a stream, nor are they apt to be spread by birds or other agencies, except currents. The eggs develop in the marsupium and do not have a resting stage during which they could be dispersed. The only possibility of the animals becoming dispersed seems to be by being washed away by accidental floods, or when suitable connections are established temporarily between different water bodies.

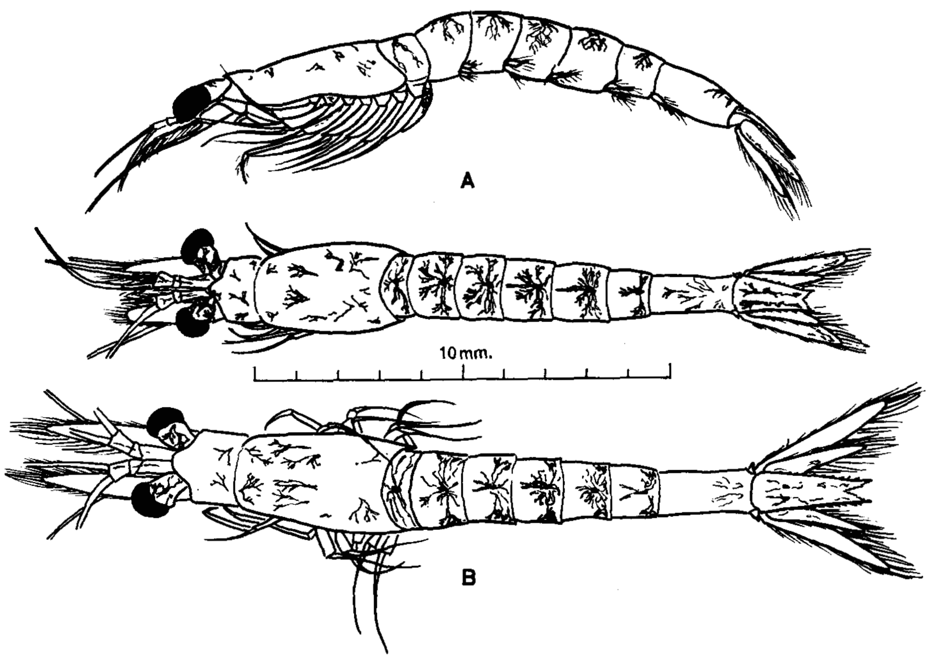

Fig. 7. *Mysis relicta* (A) and *M. litoralis* (B), both females from the same dredge haul. Elson Lagoon, July 26, 1961.

Various ways of dispersal seem to be illustrated in northern Alaska although this area was never glaciated and although it is supposed that no extensive transgressions or submergences occurred: (1) Teshekpuk Lake and Nuwuk Pond apparently had lentic connections once to the sea. (2) *M. relicta* is sparingly found along the coast. (3) The vast shallow shelf off Alaska and the prevailing currents may favour a dispersal along the coast and the commonly occurring pack-ice may render some shelter. (4) Its presence in Lake Minga shows how *M. relicta* can accidentally be washed away to new localities.

The absence of mysids from the lakes Imikpuk, Ikroavik, Tusikvoak, and Sungovoak could be explained by these lakes having originated as thaw lakes that were always isolated basins, and their absence from the unnamed lake, Lake Peters and Lake Schrader by the altitude of these lakes, which prevented any close connections with other habitats of *M. relicta*.

One problem highly accentuated by the investigations of the Alaskan localities is why generally only one species, either *M. relicta* or *litoralis*, is found in localities where both could be expected to thrive. In my paper of 1959 (p. 193) I have already sought an explanation and suggested historical criteria. In northern Alaska *M. relicta* and *litoralis* live in about equal numbers in Elson Lagoon. They are easily distinguished from each other (Fig. 7). This itself is good evidence for their being two different species, the more so as no intermediates whatever were found. *M. litoralis* is apparently not uncommon along the coast, and *M. relicta* is at least occasionally found there. In Teshekpuk Lake, not very far from Elson Lagoon, and in Nuwuk Pond, quite close to the lagoon, only *M. relicta* is found. *M. litoralis* has been taken in freshwater but apparently prefers marine to freshwater habitats and it should at the very least be expected in Nuwuk Pond. Here historical criteria alone cannot apply. Perhaps the extreme conditions prevailing there add to the severity of possible competition between the two species.

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