Glacial relicts in changing environments
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Distribution of Glacial Relict Crustacea in Some Michigan Inland Lakes[1]

JOHN E. GANNON[2], DANIEL J. MAZUR[2], AND A. M. BEETON[3]
The University of Michigan

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[2]Present address: University of Michigan Biological Station, Pellston, MI 49769.
[3]Present address: Great Lakes and Marine Waters Center, University of Michigan, Ann Arbor, MI 48109.

Introduction

Mysis relicta Loven, Pontoporeia affinis Lindstrom, Limnocalanus macrurus Sars, and Senecella calanoides Juday (Figure 1) are constituents of the so-called "glacial relict" fauna. Glacial relicts (sometimes called "glacial opportunists") are descended from Arctic marine species that dispersed into fresh water during Pleistocene glaciation• and remained in fresh water after the glaciers receded (Dadswell, 1974; Segerstrale, 1976a). Although the glacial relicts retain close affinities with their marine relatives, they are considered separate freshwater species. They are cold stenotherms which inhabit many lakes in arctic, sub-arctic and cold-temperate regions of North America and Eurasia (Pirozhnikov, 1958; Dadswell, 1974; Segerstrale, 1976b). They are generally abundant in the Laurentian Great Lakes (Henson, 1966; Robertson, 1966). These organisms are indicators of oligotrophic conditions conditions (Dadswell, 1974; Gannon and Stemberger, 1978) and are important food sources for cold-water fishes, especially salmonids (Scott and Crossman, 1973).

Published accounts of glacial relicts in Michigan's inland lakes are lacking. The main purpose of this report is to document the occurrence of glacial relicts in eight inland lakes that lie near the Lake Michigan coast of northwestern lower Michigan (Figure 2). We will also discuss changes in the complement of glacial relicts that took place in some of the lakes between the 1950's and 1975.

Glacial relict crustaceans have limited means of dispersal. They do not possess any diapause stage during their life history and are not known to employ passive dispersal methods. Since they swim weakly against a current, active dispersal is essentially limited to movement through standing water bodies (Dadswell, 1974). Once these species have dispersed into a lake, their survival depends upon their tolerance of the physicochemical and biological environment.

Glacial relicts evidently reached most areas they presently inhabit, including the Laurentian Great Lakes, by migrating through proglacial waters that were sluiced up ahead of an advancing glacier (Dadswell, 1974; Segerstrale, 1976a). They may have initially reached our study lakes in this manner, since these bodies of water existed in pre-glacial times (although their basins were re-shaped and deepened by glacial activity). In any case, the glacial relicts have been present in all of the study lakes since the occurrence of a high-water period about 3,500 years ago, when these lakes were part of Lake Michigan. The study lakes were subsequently separated from Lake Michigan by lower water levels and sand bar and dune formations (Scott, 1921; Martin, 1957; Dorr and Eschman, 1970).

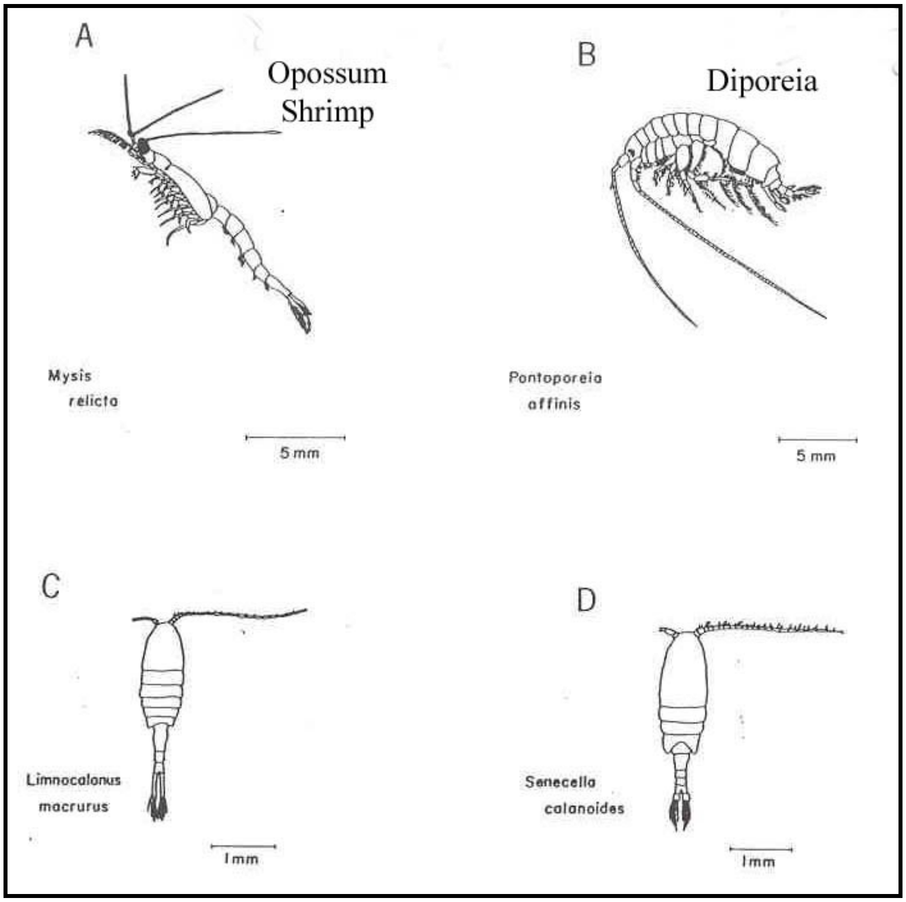

FIG. 1. Four glacial relict crustaceans: (a) Mysis relicta (Mysidacea); (b) Pontoporeia affinis (Amphipoda); (c) Limnocalanus macrurus (Copepoda: Calanoida); (d) Senecella calanoides (Copepoda: Calanoida). Mysis and Pontoporeia were redrawn from Pennak (1953) and Limnocalanus and Senecella were redrawn from Torke (1974).

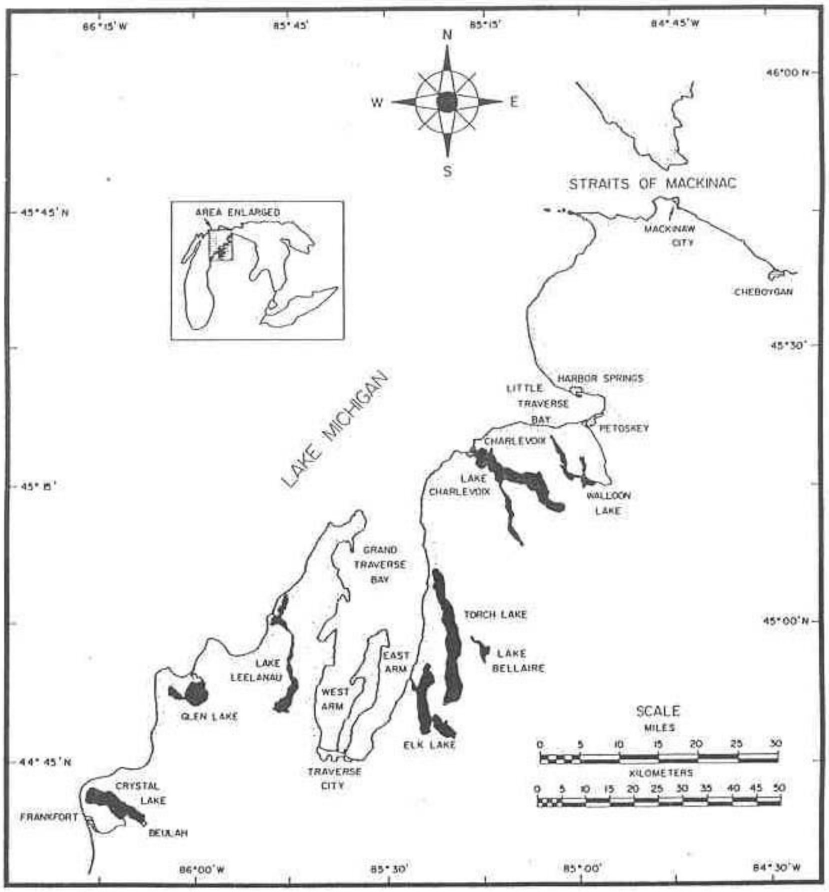

FIG. 2. Location map of the study area in northwestern lower Michigan.

Methods

Basic data for this report came from two surveys of each of the eight lakes (Figure 2). The lakes were sampled in the summer of either 1955 or 1958, and in June and October, 1975. In the earlier sampling period collections were made with 0.5 m diameter net made of No. 2 bolting silk (366 μm mesh size) except in Crystal Lake, where a No. 32 gut gauze (600 μm) net was used. Organisms were collected in the deeper regions of each lake as determined by a bathythermograph or sonic fathometer. Plankton nets were towed horizontally very slowly at several depths, but primarily near the bottom. In most lakes, the net was actually towed along the bottom part of the time so that bottom material was picked up. The plankton samples were preserved in 10% formalin and examined qualitatively for all crustacean species.

Samples in 1975 were taken from the deepest portion of each lake and from several shallower stations as well. Stations were located by sonic fathometer with the aid of a hydrographic map and compass. Plankton samples were obtained day and night with both vertical and deep horizontal tows of a 0.5-m diameter, No. 6 mesh (239 pm) net. The sediment-water interface was also sampled with a sled-mounted net. All plankton samples were narcotized with carbonated water (Gannon and Gannon, 1975) and preserved in 5% buffered formalin.

Benthic organisms were collected with a Ponar grab in the larger lakes and with an Ekman grab in the smaller lakes. Sediments were washed through a No. 30 (600 µm) screen and the benthic organisms were preserved in 5% formalin.

Zooplankters were identified and enumerated in a chambered counting cell (Gannon, 1971) under a Bausch and Lomb stereozoom microscope. Identifications were made according to Yeatman (1959) for cyclopoid copepods, Wilson (1959) for calanoid copepods, Brooks (1957) for Daphnia, Deevey and Deevey (1971) for Eubosmina, and Brooks (1959) for remaining Cladocera.

Concurrent physiochemical samples were collected during June, 1975 at the central, deep station in each lake. Temperature was measured with a Whitney resistance thermometer and light transparency was determined with a standard white Secchi disc. Water chemistry samples were collected at the surface, top of the hypolimnion, and near bottom with a 3-liter Kemmerer bottle. Dissolved oxygen, alkalinity, pH, and specific conductance were measured in the field within twelve hours of sample collection. Dissolved oxygen was determined titriometrically by the azide modification of the Winkler method (APHA, 1971). Alkalinity was measured titriometrically with bromocresol green-methyl red as the indicator solution (APHA, 1971). Specific conductance was determined on an Industrial Instruments Model RC-16B2 conductivity bridge, and pH was measured potentiometrically on a Beckman Model N pH meter. The remainder of samples were returned to the laboratory for analysis. Calcium, magnesium, sodium, and potassium were measured on a Perkin-Elmer Model 305 atomic adsorption spectrophotometer (EPA, 1974). Total phosphorus, nitrate-nitrogen, ammonia-nitrogen and silica were determined on a Technicon Autoanalyzer II (EPA, 1974). Samples for chlorophyll a were extracted in the field with 90% acetone and placed in an ice chest for later measurement on a Turner Model III fluorometer (Strickland and Parsons, 1968).

Results

Zooplankton

In the 1950's, at least one of the glacial relicts (Mysis, Pontoporeia, Limnocalanus, and Senecella) occurred in each of the eight study lakes, and all four of the crustaceans inhabited Torch and Elk Lakes (Table I). Either Mysis or Pontoporeia was found in six of the eight lakes, and Limnocalanus in four. In 1975, all four of the species remained in Torch and Elk Lakes; either Mysis or Pontoporeia was again found in six of the lakes; and Limnocalanus was observed in three lakes (Table I). Species present in collections of a particular lake in the 1950's, but absent in 1975, included Limnocalanus in Crystal Lake, Mysis in Bellaire Lake, and Pont oporeia in Glen Lake. Conversely, species absent in a particular lake in the 1950's, but present in 1975, included Mysis in Lake Charlevoix and Pontoporeia in Crystal Lake.

TABLE I
COMPARISON OF PRESENCE (+) AND ABSENCE (—) OF DEEPWATER CRUSTACEANS IN EIGHT LAKES BETWEEN 1955 (OR 1958) AND 1975[1]

	Pontoporeia affinis		Mysis relicta		Limnocalanus macrurus		Senecella calanoides	
Lake	1950's	1975	1950's	1975	1950's	1975	1950's	1975
Torch	+	+	+	+	+	+	+	+
Elk	+	+	+	+	+	+	+	+
Charlevoix	+	—?	+	+	+			
Crystal	—?	+	+	+	+			
Leelanau	+	+	+	+				
Glen	+	+	+					
Walloon	+	+						
Bellaire	+							

[1]Data from 1975 consists of composite results from both plankton and benthos collections.

The 1950's sampling methods were directed primarily toward the four glacial relict species, although other crustacean plankters were also collected as the net was towed to the surface. The samples procured in 1975 provided more complete information on zooplankton species composition and abundance in these lakes. Qualitative species lists from the 1950's and 1975 were extremely similar, with one exception. Euhosmina coregoni, unrecorded in the 1950's, was present in Bellaire, Charlevoix, and Torch Lakes in 1975.

A relatively large assemblage (12-18 species) of limnetic Crustacea was collected in the study lakes during June, 1975 (Table II). Numbers of organisms per cubic meter were low in all of the study lakes, ranging from 359 in Torch Lake to 2,157 in Lake Charlevoix. Calanoid copepods were represented by four to six species. Diaptomus sicilis predominated in the deepest lakes (Crystal, Torch and Elk). I). oregonensis was most prevalent in Walloon and Bellaire Lakes and D. minutus in Glen Lake. The cyclopoid copepods, Cyclops bicuspidatus thomasi and Mesocyclops edax, were present in all of the study lakes. Cladocerans were represented by five to eight species, with Daphnia retrocurva, D. galeata mendotae, and Bosmina longirostris the predominant species (Table II).

Physicochemical Characteristics and Chlorophyl- a

The lakes were all thermally stratified during June, 1975. Water transparency was high, with Secchi disc depths ranging from 3.5 m in Lake Bellaire to 11.5 m in Torch Lake (Figure 3).

TABLE II

PERCENT COMPOSITION OF CRUSTACEAN SPECIES AND ABUNDANCE (INDIVIDUALS PER M') OF MAJOR GROUPS OF ZOOPLANKTON IN EIGHT LAKES[1]

Lake	Bell	Char	Crys	Elk	Glen	NLee	Torc	Wall
Cladocera								
Rosmina longirostris	13	13	+	1	14	10	1	6
Euhosmina coregoni	-1	35	0	0	0	0	+	0
Daphnia galeata mendotae	6	4	14	+	+	1	1	+
D. longiremis	0	9	0	0	14	3	1	17
D. retrocurva	20	12	+	+	+	21	+	7
Ceriodaphnia quadrangula	0	+	0	0	0	0	0	0
Diaphanosoma leuctenhergianum	+	0	+	+	0	+	0	+
Holopedium gibberum	0	+	0	0	+	0	0	7
Chydorus sphaericus	0	0	0	0	0	0	0	+
Leptodora kindtii	+	I	0	0	+	+	0	0
Cyclopoid Copepoda								
Cyclops bicuspidatus thomasi	10	16	15	6	16	5	13	7
Mesocyclops edax	+	4	+	19	4	+	+	+
Calanoid Copepoda								
Epischura lacustris	16	+	8	+	+	1 35	0	+
Diaptomus ashlandi	0	1	0	4	0	0	+	0
D. minutus	6	+	4	15	46	+	16	+
D. oregonensis	24	4	+	+	-1-	10	0	57
D. sicilis	+	+	67	29	6	13	54	+
Limnocalanus macrurus	0	+	0	+	0	0	11	0
Senecella calanoides	0	0	0	24	0	0	+	0
Mysidacea								
Mysis relicta	0	+	+	+	+	+	+	0
Amphipoda								
Pontoporeia affinis	0	+	+	+	0	+	+	+
Cladocerans/m^3	416	1,596	81	2	228	253	7	195
Cyclopoids/m^3	109	420	290	284	160	39	39	44
Calanoids/m^3	477	114	1,552	840	411	430	301	400
Total Crustaceans/m^3	1,054	2,157	1,962	1,154	799	750	359	702

[1]Data are from a vertical net tow from bottom to surface at a central, deep station, collected during June, 1975. A plus (+) indicates the species was present but comprised less than 1% of total zooplankton. Total crustaceans/m' includes the three major groups plus those comprising less than 1% of total.

Water chemistry data indicate that all of these water bodies are hard water, marl-forming lakes (Table III). Water color was bluish-green (IV to VIII on the Forel-Ule color scale) in most of the study lakes owing to marl turbidity in the water column. In two of the lakes (Bellaire and Charlevoix), a deeper algal green color (X to XV on the Forel-Ule color scale) was apparent. Marl precipitation was visible on firm substrates and on macrophytic vegetation near shore in all the lakes. Dissolved oxygen was high throughout the water column and nitrogen, phosphorus, and chlorophyll a concentrations were extremely low in all lakes. However, chlorophyll a was slightly higher in Lake Bellaire in comparison with the other lakes (Table III).

Discussion

The results of the sampling suggest that certain important changes in glacial relict populations took place in some of the study lakes between the 1950's and 1975. The appearance in 1975 of certain species absent in corresponding collections in the 1950's probably related simply to the much greater sampling effort in 1975 (recent introductions or large population increases seem most unlikely). However, the absence in 1975 of species observed in corresponding collections in the 1950's doubtless resulted from severe population declines, perhaps to extinction.

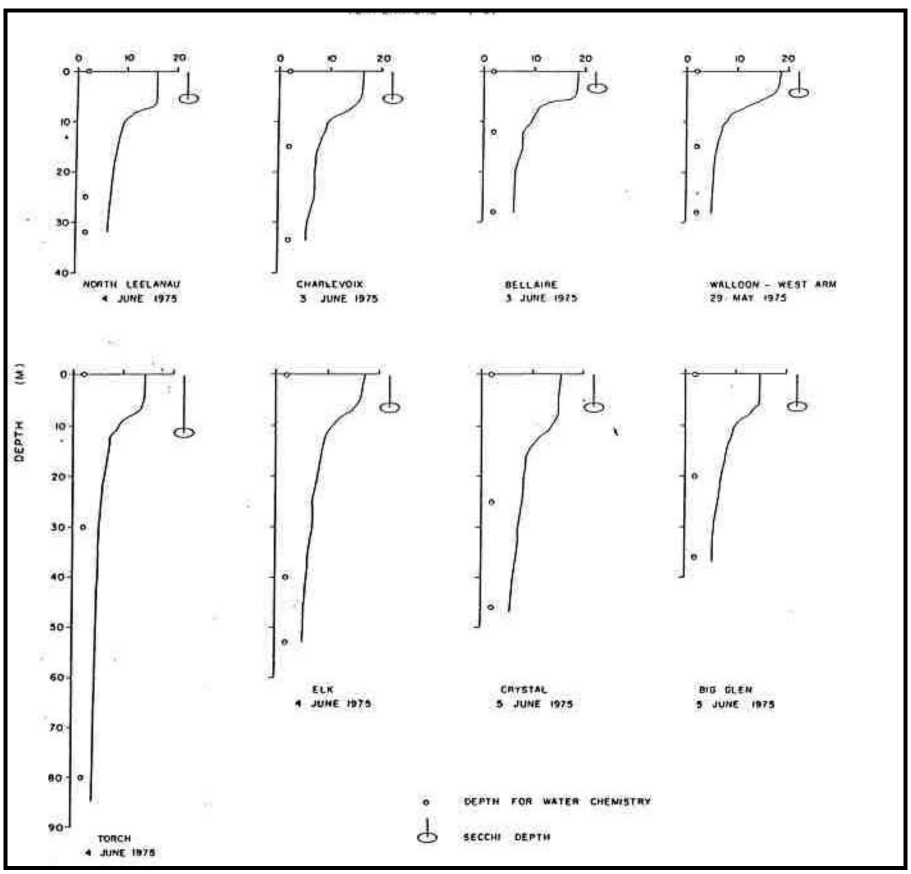

FIG. 3. Temperature (°C) and Secchi disc transparency (m) in eight lakes during early summer, 1975.

TABLE III

PHYSICOCHEMICAL CHARACTERISTICS AND CHLOROPHYLL a
IN EIGHT DEEP LAKES DURING EARLY SUMMER, 1975[1]

	Bellaire			Charlevoix			Crystal			Elk		
	S	H_t	H_b	S	H_t	H_b	S	H_t	H_b	S	H_t	H_b
Chlorophyll *a* (μg/l)	3.1	3.5	1.1	1.4	2.0	1.9	1.9	2.6	1.3	0.6	0.3	0.4
Oxygen (mg/l)	9.6	11.4	10.5	10.3	12.7	11.6	10.4	12.6	11.2	9.9	12.3	12.3
Oxygen (% Sat)	104	98	87	107	112	95	106	108	92	106	102	100
Alkalinity (mg/l)	163.0	167.5	172.0	144.0	145.5	148.0	116.0	118.5	119.8	139.0	141.0	142.0
pH	8.7	8.6	8.5	8.5	8.5	8.4	8.5	8.4	8.3	8.4	8.3	8.3
Conductivity (μmhos/cm)	332	338	342	308	312	319	335	348	350	288	296	292
Total-P (μg/l)	9	6	11	5	7	7	4	5	6	6	3	2
No_3-N (μg/l)	315	394	396	209	222	245	35	38	60	296	314	320
NH_3-N (μg/l)	11	10	12	75	10	24	9	6	16	14	9	27
Ca (mg/l)	40.5	41.5	44.9	42.2	42.7	39.1	36.7	35.7	35.7	29.1	32.1	35.9
Mg (mg/l)	11.9	11.8	11.9	11.0	11.2	11.3	16.0	16.2	16.1	11.5	11.2	11.3
K (mg/l)	0.9	0.8	0.9	1.3	1.2	1.0	0.9	1.0	0.9	0.7	1.0	0.8
Na (mg/l)	3.2	3.2	3.2	3.5	3.4	3.4	5.7	5.8	5.8	3.0	3.2	3.1
Cl (mg/l)	4.2	4.0	4.2	5.6	5.4	5.2	6.8	6.8	6.8	3.7	4.0	3.9
Si (mg/l)	2.8	3.1	3.8	2.0	2.1	2.3	2.3	2.4	2.6	3.2	3.4	3.5

	Glen			North Leelanau			Torch			Walloon—West Arm		
	S	H_t	H_b	S	H_t	H_b	S	H_t	H_b	S	H_t	H_b
Chlorophyll *a* (μg/l)	1.5	3.7	2.1	1.6	0.9	0.7	0.4	1.4	0.5	1.7	3.0	2.2
Oxygen (mg/l)	10.2	12.4	11.3	9.9	11.2	10.9	10.5	12.3	12.1	9.2	11.8	10.8
Oxygen (% Sat)	102	106	92	102	95	91	104	100	96	100	98	87
Alkalinity (mg/l)	139.0	139.8	141.5	152.0	152.0	152.0	135.0	143.0	143.0	128.0	129.0	133.3
pH	8.4	8.4	8.3	8.7	8.4	8.3	8.3	8.3	8.3	8.4	8.3	8.2
Conductivity (μmhos/cm)	278	290	288	336	346	350	289	288	293	266	275	277
Total-P (μg/l)	5	5	8	4	5	5	4	2	3	3	2	4
NO_3-N (μg/l)	18	19	39	192	222	220	376	380	390	196	271	222
NH_3-N (μg/l)	7	13	26	16	96	25	8	11	15	11	14	29
Ca (mg/l)	33.3	33.3	33.8	45.2	44.9	44.1	33.6	34.3	29.9	28.1	33.8	35.0
Mg (mg/l)	13.2	13.2	13.3	13.4	13.9	14.0	11.7	11.7	11.8	9.6	9.7	9.5
K (mg/l)	0.7	0.6	0.6	0.8	1.3	1.0	0.8	0.9	0.8	0.9	0.9	1.0
Na (mg/l)	2.5	2.5	2.6	3.8	4.2	3.9	2.9	2.9	3.0	1.7	1.7	1.7
Cl (mg/l)	1.4	1.4	1.4	3.5	4.1	3.5	3.2	3.3	3.2	3.3	3.4	3.5
Si (mg/l)	3.1	3.5	4.0	3.9	4.3	4.0	3.3	3.3	3.4	2.0	2.2	2.3

[1]S=surface, H_1 = top of hypolimnion, H_b = one meter off bottom (see Fig. 3).

Our physicochemical data on these eight, deep lakes strongly indicate that the lakes are still decidedly oligotrophic (Table III), and provide conditions suitable for these organisms (Dadswell, 1974). Since the limnological data base on these lakes is extremely meager, it is difficult to detect any trends in accelerated eutrophication which might explain the decline of glacial relicts in some lakes. Published (MDNR, 1971) and unpublished data from the Michigan Department of Natural Resources indicate that chemical concentrations at central, deep stations during early summer have remained similar to those reported here during the past two decades. However, data obtained later in the summer stratification period reveal that reduction in dissolved oxygen concentrations has occurred in the bottom waters of several of the study lakes in recent years. By late July, dissolved oxygen drops to about 40% saturation in Lake Bellaire. In contrast, the deepest waters in the other study lakes normally range between 50 and 80% saturation throughout the summer stratification period (MDNR, 1971; MDNR, unpublished data).

Mysis is known to survive in waters with lower dissolved oxygen concentrations than are found in Lake Bellaire (Dadswell, 1974). However, hypolimnetic dissolved oxygen may be sufficiently low in late summer to cause stress on Mysis in this water body.

Crustacean plankton species composition and abundance also indicate the oligotrophic nature of the eight lakes. With the exception of Lake Bellaire, at least one glacial relict crustacean was present in each lake during 1975. Furthermore, all species collected in those inland lakes are found in the oligotrophic offshore waters of the upper Great Lakes (Wells, 1960; Watson and Carpenter, 1974; Gannon et al., 1976).

The population status of these glacial relicts may be influenced by toxic substances and predation as well as trophic conditions. Many planktivorous fishes selectively feed on the larger species of crustacean plankton. Under conditions of intense predation, the larger species may be eliminated or at least reduced to insignificance by planktivores. Although available data indicate that the cold-water fishery has remained quite stable in these lakes during the past several decades, noteworthy increases in planktivorous rainbow smelt (Osmerus 'nordax) have been observed in Bellaire and Crystal Lakes (Laarman, 1976; Ylkanan,4 personal communication).

The decline of Mysis in Lake Bellaire may result from the combined influence of subtle changes in trophic conditions and fish predation. Since Lake Bellaire is the smallest water body in which Mysis was found, it is likely that this species would have eventually disappeared in the lake owing to natural eutrophication. However, its decline was probably accelerated by increases in population levels of the introduced planktivore, rainbow smelt.

Limnocalanus was collected in small numbers in Crystal Lake as recently as 1969 (J. J. Gannon, 1970) but was not obtained in 1975. The trophic state of Crystal Lake is still decidedly oligotrophic, and there have been no appreciable changes in water quality that may have adversely affected Limnocalanus populations (Gannon and Mazur, unpublished data). The decline of Limnocalanus in Crystal Lake appears to coincide with increases in the rainbow smelt populations (Laarman, 1976). Fish predation, primarily rainbow smelt, and hypolimnetic oxygen depletion apparently caused the decline of Lin:-nocalanus in Lake Erie (Gannon and Beeton, 1971).

The decline of Pontoporeia in Glen Lake is difficult to assess. Available data do not indicate any noteworthy changes in trophic conditions or populations of planktivorous fishes. Toxic substances, especially pesticides, should perhaps be examined in this water body since there is a high concentration of fruit orchards in this vicinity. Furthermore, application of copper sulfate for swimmer's itch control has occurred regularly in Glen Lake for the past two decades. Copper sulfate is known to be toxic to crustaceans (Sawyer, 1970) and may have adversely affected Pontoporeia populations in Glen Lake.

We did not detect any decline of glacial relict species in Lake Charlevoix between the 1950's and 1975. However, it apparently contained Senecella many years ago. Juday (1925) reported that a juvenile stage of Senecella was collected in Lake Charlevoix in 1894 by C. D. Marsh. Interpretation of the apparent decline of this species is not possible owing to lack of data.

Decline or disappearance of glacial relict populations should be viewed with concern. They appear particularly susceptible to change by adverse environmental disturbances, such as water quality degradation and introduction of exotic fish species. Furthermore, the glacial relicts may be candidates for the threatened or endangered species list for the State of Michigan and possibly other northern states owing to the scarcity of favorable habitats, i.e., sufficiently oligotrophic inland lakes.

Summary

Crustacean plankton populations were compared for the 1950's and 1975 in eight deep lakes of northwestern lower Michigan. Special attention was focused on four cold stenothermic species, Mysis relicta, Pontoporeia affinis, Limnocalanus macrurus, and Senecella calanoides. These crustaceans are considered glacial relicts and are found in many oligotrophic inland lakes of formerly glaciated regions. In 1975, the full complement of crustaceans observed in the 1950's were still present in five of the lakes. However, Mysis was absent in Lake Bellaire, Limnocalanus was not collected in Crystal Lake, and Pontoporeia was not found in Glen Lake. These organisms are important food sources for cold-water fish species, especially salmon-ids. Glacial relict crustaceans appear particularly susceptible to environmental disturbances, especially water quality degradation and predation from introduced fish species.

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