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Zooplankton Community Composition in the Nearshore Waters of Southern Lake Michigan

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ZOOPLANKTON COMMUNITY COMPOSITION
IN
NEARSHORE WATERS OF SOUTHERN LAKE MICHIGAN

by

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DISCLAIMER

FOREWORD

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GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by Universities, private firms, State, Federal, and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. actions in fulfillment of the Agreement between Canada and the United States of America on Great Lakes Water Quality of 1978.

This study was supported by a GLNPO grant to the University of Michigan at Ann Arbor for investigating the zooplankton community composition in nearshore waters of southern Lake Michigan.

ABSTRACT

Zooplankton samples collected in 1977 in the nearshore waters of southern Lake Michigan (0.4 km from shore) were analyzed to provide a bench mark on zooplankton community composition for comparison with future studies. Species composition, abundance, and distribution were investigated to determine the apparent response of the zooplankton community to water quality conditions. It is difficult to establish long-term trends on changes in zooplankton community composition commensurate with known changes in water quality in the nearshore waters of southern Lake Michigan because of the lack of historical zooplankton data. Instead, the effects of water quality conditions on zooplankton must be inferred by comparing community composition in nearshore waters impacted by pollutive discharges with less affected offshore waters.

Distribution and abundance of zooplankton in the nearshore waters of southern Lake Michigan is highly influenced by physical mixing of relatively high quality offshore waters with variously polluted harbor effluents nearshore. Rotifers were overwhelmingly abundant, comprising about 95% of total zooplankton. Total rotifers and crustacean plankton generally were most prevalent in nearshore waters exhibiting highest alkalinity, specific conductance, and nutrient chemistry and lowest turbidity and Secchi disc transparency. The predominant species (i.e., *Keratella cochlearis*, *K. crassa*, *Polyarthra vulgaris*, *Conochilus unicornis*, and *Bosmina longirostris*) also were most abundant in nearshore waters. The distribution of these species often was significantly correlated with physicochemical variables. The apparent response of the zooplankton community to nutrient enrichment was an increase in density of indigenous, eurytopic species rather than species shifts toward more eutrophic forms. This feature seems to be indicative of mesotrophy in the Great Lakes. Eutrophic indicator species (e.g., *Brachionus* spp., *Euchlanis dilatata*, *Trichocerca* spp., and *Acanthocyclops vernalis*) were rare and usually confined to harbor mouths. Besides *Bosmina longirostris*, no consistent statistically significant trends were noted between distribution of crustacean species and physicochemical variables. However, there still was a tendency for calanoid copepods to be more prevalent in more oligotrophic offshore waters.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

We thank Theodore Ladewski for providing computer and statistical assistance. We also acknowledge the U.S. Environmental Protection Agency for collecting the zooplankton samples and providing the physicochemical data.

INTRODUCTION

The extreme southern end of Lake Michigan is an area of contrasting water quality. Relatively high quality offshore waters and comparatively polluted nearshore waters mix in hydrodynamically complex patterns generated by currents and seiche activity (Mortimer 1975). There has been a long history of pollutive discharges in the lake from the Chicago metropolitan area, including industrial and domestic wastewater sources in the Indiana coastal waters (Torrey 1976).

This report concerns zooplankton community composition in the Indiana waters of southern Lake Michigan. The study was initiated by the United States Environmental Protection Agency (USEPA), Region V, as part of its water quality monitoring and surveillance program. Phytoplankton data were collected concurrently and are reported in Stoermer and Tuchman (1980).

The purpose of this report is to provide a benchmark on zooplankton composition, abundance, and distribution in the Indiana waters of Lake Michigan for comparison with future monitoring and surveillance efforts. Zooplankters have value as water quality indicators and have proved useful in complementing phytoplankton data to assess the apparent effects of water quality conditions on Great Lakes biota (Gannon and Stemberger 1978).

The Indiana coastline of Lake Michigan is intensely developed, with urban and industrial complexes located at Gary, Burns Harbor, and Michigan City. Effluent data from industrial and domestic sources for Gary and Burns Harbor are summarized by Snow (1974) and for Michigan City by JBF Scientific Corporation (1978). The only portion of relatively undeveloped coastline is the Indiana Dunes National Lakeshore located west of Michigan City.

Zooplankton investigations in southern Lake Michigan were reviewed by Gannon (1974a). In contrast with the rest of the lake, there is a comparatively long history of zooplankton investigations in the southern end of Lake Michigan. Unfortunately, sampling methods between studies have differed and most early investigations were only qualitative. Consequently, it is difficult to establish any long-term trends on changes in zooplankton community composition in comparison with known changes in water quality. Most information on the probable effects of pollution on zooplankton have been inferred by comparing zooplankton community composition between impacted nearshore waters and less affected offshore waters in more recent quantitative investigations (e.g., Gannon 1975, Stemberger and Gannon 1977). Johnson (1972) sampled zooplankton in 1970 and provided the most comprehensive information on zooplankton species composition, inshore distribution, and abundance in southern Lake Michigan. He reported a high biomass of zooplankton in the Indiana waters of Lake Michigan in comparison with other studies in offshore waters, which is apparently a response by the zooplankton community to nutrient enrichment. In addition to nutrient loading, toxic substances are known to be discharged into the Indiana waters of Lake Michigan (Snow 1974, Torrey 1976). The efects of toxic effluents on zooplankton have not been investigated. However, bottom sediments in Gary and Michigan City Harbor were toxic to zooplankton in laboratory studies (Gannon and Beeton 1969, JBF Scientific Corporation 1978).

MATERIALS AND METHODS

FIELD

Zooplankton samples were collected by USEPA personnel on 11 June, 20 August, and 24 September, 1977. Four transects were used with stations located 1/2, 1, 2, and 5 miles offshore. A 10-mile station on the Burns Harbor transect was sampled only in June (Figure 1).

Crustacean plankton were collected with a 0.5 m diameter, no. 6 (240 μm) mesh conical net. A standardized vertical tow was made from 10 m to the surface (or bottom to the surface at stations less than 10 m deep). A second tow was taken from the bottom to the surface at stations deeper than 10 m. Carbonated water was added promptly as a narcotizing agent (Gannon and Gannon 1975) and samples were preserved with 5% buffered formalin.

The standard tow aided comparison of data between stations because approximately the same volume of water was filtered by the net. The no. 6 mesh net was chosen because the filtration efficiency of that mesh size is near 100% (Gannon 1972, 1981), thereby improving the accuracy of abundance data. However, some of the smallest zooplankters (e.g., Chydorus sphaericus, Bosmina longirostris, Eubosmina coregoni, Ceriodaphnia spp., Tropocyclops prasinus mexicanus, and cyclopoid copepodids) may escape through the mesh and be undersampled.

Rotifer samples were collected with 8-liter Niskin bottles at 2 m and just off bottom. The water samples from each depth were pooled and concentrated in a filtering funnel fitted with 54 μm mesh screening (Likens and Gilbert 1970). The samples were narcotized with carbonated water and preserved in 5% buffered formalin.

It would be desirable to sample rotifers and crustacean plankton by the same methods. However, micro-crustaceans are too sparsely distributed to collect with a water bottle. Consequently, it was necessary to use a plankton net to sample these organisms. Rotifers are sufficiently concentrated so that reliable samples can be collected with a water bottle. Intercomparisons of rotifer data with chemistry and phytoplankton are most valid statistically since these limnological variables were obtained at the same depths using identical methods.

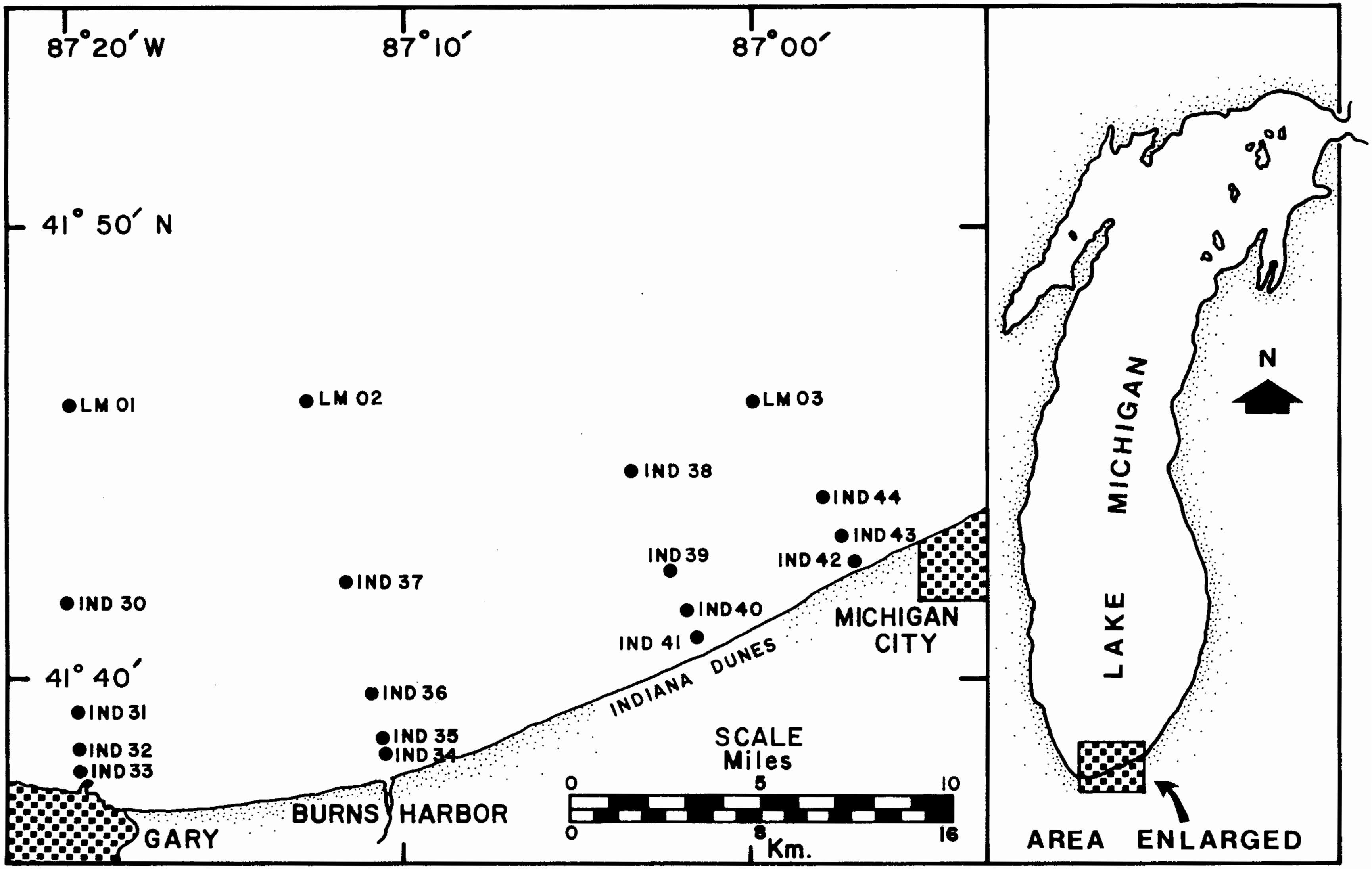

Figure 1. Location of sampling stations in southern Lake Michigan, 1977.

LABORATORY

Prior to micro-crustacean counts, each sample was adjusted to a constant volume in a graduated cylinder and poured into a 4-oz. jar. The cylinder was rinsed with an additional 10 to 20 mL of tap water and this was carefully added to the rest of the sample to a final volume of usually 100 mL. The sample was then randomly and thoroughly mixed with a large-bore, calibrated automatic pipette and the subsample quickly drawn from the middle of the sample. Aliquot sizes ranged from 1 mL to 10 mL depending on species numbers. A second, larger aliquot usually was withdrawn for enumeration of less common species. Subsamples were transferred to a chambered counting cell (Gannon 1971) and the entire contents, usually 150 to 300 individuals, were enumerated at 30 to 60x under a Wild stereomicroscope. Those organisms requiring higher magnification for identification were mounted in polyvinyl lactophenol, stained with lignin pink, and examined at 100 or 430x under an American Optical compound microscope. Data were calculated in numbers of individuals per m^3 and percent composition. The subsampling and enumeration procedure has proved to be accurate and reproducible (Gannon 1972, 1981).

Adult calanoid and cyclopoid copepods were identified to species according to Wilson (1959) and Yeatman (1959), respectively. Calanoid copepodids were included with the adults of that species except those in the family Diaptomidae. Cyclopoid copepodids were not identified to genus, although most were undoubtedly *Diacyclops*. Adult harpacticoid copepods were identified to species where possible with the use of Wilson and Yeatman (1959). All cladocerans are reported at the species level except *Diaphanosoma*. Two species, *D. leuchtenbergianum* Fisher and *D. brachyurum* (Liéven), were observed, with the former overwhelmingly most abundant. Brooks (1957) was used for *Daphnia*, and Deevey and Deevey (1971) for *Eubosmina*. The family Chydoridae was identified according to Frey (1959, 1962), Megard (1967), and Smirnov (1971). The remaining Cladocera were keyed according to Brooks (1959).

In preparation for rotifer counts, all samples were concentrated to 50 mL. Each sample was thoroughly mixed with a calibrated automatic pipette immediately before taking a subsample with the pipette from the center of the jar. Subsamples of 1, 3, or 5 mL were taken depending on the density of organisms so that the concentration of rotifers in each subsample included 200 to 400 individuals. Subsamples were transferred to a 5-mL Plexiglas, rectangular counting cell and all rotifers were enumerated under an American Optical compound microscope at 100x. Each subsample was then replaced in the jar, a second subsample was taken and enumerated, and the two counts averaged. A minimum of 300 rotifers per sample was routinely counted. Data were calculated in numbers of individuals per m^3 and percent composition at each station. The subsampling and counting procedure was tested and proved to be accurate and reproducible (Stemberger *et al*. 1979).

Identifications were made to species for most rotifers. Certain species of the genus *Synchaeta* were indistinguishable by gross morphology because of their contracted state and, therefore, identification of these organisms was determined by examination of the hard, chitinous mouth parts after sodium hypochlorite bleach was used as a clearing agent (Stemberger 1973). The main references used in identifying rotifers were Jennings (1903), Ahlstrom (1943), Voigt (1957), and Stemberger (1976).

RESULTS

PHYSICOCHEMISTRY

Physicochemical data were obtained concurrently with plankton collections by the USEPA. Contour plots for these data are presented in Appendices A-C. Those physicochemical variables that may be important in interpreting patterns of zooplankton distribution and abundance are discussed briefly here.

On 11 June 1977, temperatures were warmest (18°C) off Burns Harbor and Michigan City and gradually decreased (<15°C) offshore. Specific conductance was slightly higher (286 μmhos/cm) off Michigan City than elsewhere in the study area (276-284 μmhos/cm). Highest Secchi disc reading (4-6 m) were recorded at the outer stations off Gary, and lowest (>3 m) were near Burns Harbor. Nitrogen (ammonia and nitrate) was slightly higher off Burns Harbor (Appendix A).

Temperatures on 20 August 1977 were slightly cooler (<20°C) off Gary and warmer (>21°C) at the offshore stations. Specific conductance was highest (282 μmhos/cm) off Gary and Burns Harbor. Nitrogen (ammonia and nitrate) concentrations exhibited the same pattern as specific conductance. Secchi disc transparency was lowest (3 m) off the mouth of Michigan City Harbor and highest (4-5 m) at the outermost stations (Appendix B).

Most physicochemical variables were more evenly distributed on 24 September 1981. Temperature (17°C) and Secchi disc transparency (3 m) were considerably uniform throughout the study area. Specific conductance, nitrate, and ammonia-nitrogen were slightly higher off Gary (Appendix C).

ABUNDANCE AND DISTRIBUTION BY MAJOR GROUPS

Although rotifer and micro-crustacean data are not strictly comparable because different sampling methods were used, it is clearly evident that rotifers were predominant over crustacean plankton in the Indiana waters of southern Lake Michigan. Mean abundances by cruise are given in Table 1 and mean and maximum abundance for all cruises combined are presented in Appendix D. Rotifers consisted of over 90% of total zooplankton during the sampling period. Cladocerans were the predominant crustaceans in June and August but calanoid copepods were slightly more prevalent in September.

Cyclopoid copepods were a minor component of the plankton throughout the study period. Density of zooplankton (principally rotifers) was highest in June, approximately twice as high as in August, and four times higher than in September (Table 1).

TABLE 1. ZOOPLANKTON ABUNDANCE BY MAJOR GROUPS IN THE INDIANA WATERS OF SOUTHERN LAKE MICHIGAN DURING THE 1977 SAMPLING SEASON. DATA ARE BASED ON THE STANDARDIZED NET TOWS FOR MICRO-CRUSTACEANS AND THE POOLED NEAR SURFACE AND BOTTOM SAMPLES FOR ROTIFERS. THE AVERAGE DENSITY IN NUMBERS OF INDIVIDUALS PER M^3 AND AVERAGE RELATIVE ABUNDANCE IN PERCENT COMPOSITION OF TOTAL CRUSTACEA (%C) AND TOTAL ZOOPLANKTON (%Z) ARE PRESENTED FOR EACH SAMPLING DATE

	June			August			September		
	no./m^3	%C	%Z	no./m^3	%C	%Z	no./m^3	%C	%Z
Calanoid Copepoda	2,980	26.2	0.7	870	28.9	0.4	4,010	49.9	3.8
Cyclopoid Copepoda	1,780	15.7	0.5	130	4.3	0.1	360	4.5	0.3
Cladocera	6,620	58.1	1.7	2,010	66.8	1.0	3,670	45.6	3.5
Total Crustacea	11,390		2.9	3,010		1.5	8,040		7.6
Rotifera	386,700		97.1	190,800		98.5	97,700		92.4
Total Zooplankton	398,090			193,810			105,740		

Rotifer populations were dramatically higher at the nearshore stations off Burns Harbor and Indiana Dunes in the region where warmest water temperatures and highest specific conductance were observed. A maximum abundance of over 900,000 rotifers per m^3 was recorded at the 1 mile station off Indiana Dunes. In contrast, lowest rotifer densities (<100,000 per m^3) were observed at the offshore stations off the westernmost transect near Gary (Figure 2). Lowest temperatures and highest water quality conditions (i.e., lowest specific conductance, lowest nitrogen, and highest Secchi disc transparency) were recorded at these same stations (Appendix A).

Rotifer densities were highest (>200,000 per m^3) in the nearshore waters throughout the study area in August where highest specific conductance and

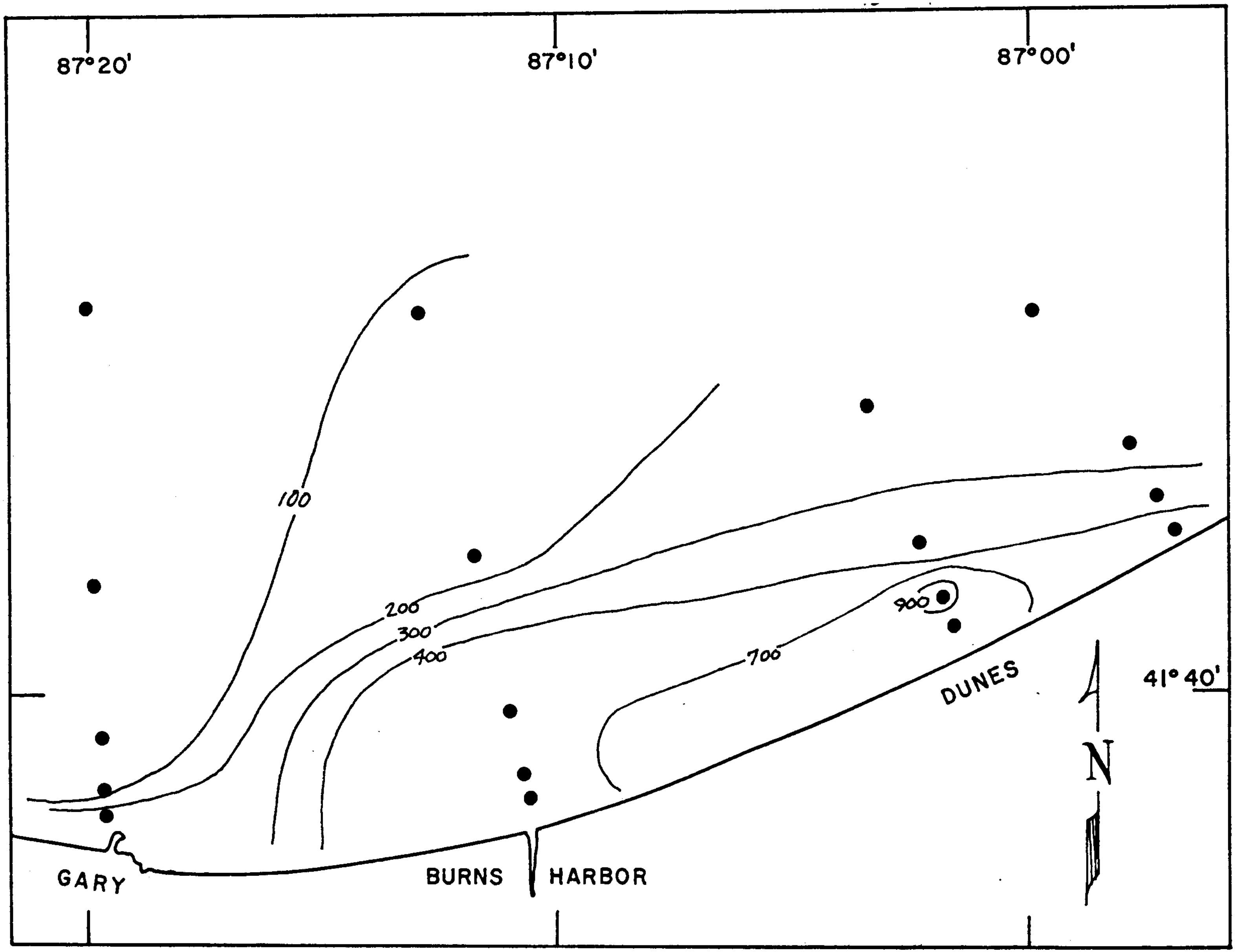

Figure 2. Distribution of total rotifers, June.

lowest Secchi disc readings were reported. Lowest rotifer densities (<100,000 per m^3) were recorded at the outermost stations off Gary and Burns Harbor where highest water quality conditions were observed (Figure 3, Appendix B).

Total rotifers were reduced in numbers in September, ranging near 100,000 per m^3 at most locations. Lowest numbers (<50,000 per m^3) were recorded at easternmost stations 1 to 2 miles offshore. A localized area of relatively high abundance (>200,000 per m^3) was at nearshore stations of Gary where specific conductance and nitrogen also were highest (Figure 4, Appendix C).

In contrast to the rotifers, patterns in total crustacean plankton distribution usually did not exhibit as strong similarities to the distribution of physicochemical variables. However, some distinct patterns of major groups of micro-crustaceans were discernible.

In June, highest (>20,000 per m^3) total Crustacea were recorded at the outermost stations off Indiana Dunes. Crustaceans also were locally prevalent (10 to 15,000 per m^3) at nearshore locations off Gary. Similar to the rotifers, lowest crustacean numbers (<5,000 per m^3) were observed at the outermost stations off Gary (Figure 5).

In contrast to rotifer distribution in August, crustacean plankters were more prevalent offshore than inshore. Crustacean densities generally were less than 2,000 per m^3 at 1/2 and 1 mile stations except off the Gary Harbor mouth (3,120 per m^3). Offshore stations had densities from 4,000 to over 6,000 per m^3 (Figure 6).

In September, patterns of crustacean abundance most resembled the distribution of rotifers and physicochemical variables (Figure 7, Appendix C). Crustaceans were locally prevalent (10,200 to 14,400 per m^3) off the Gary Harbor mouth. Elsewhere in the study area, crustacean densities were more uniformly distributed (4,700 to 8,200 per m^3).

In June, calanoid copepods were distinctly most prevalent (40-50% of total Crustacea) at westernmost offshore stations in June, and became relatively less abundant (<20%) eastward off Indiana Dunes and Michigan City (Figure 8). Calanoids were relatively most abundant (73%) in offshore waters in August. They were an especially infrequent (<10%) component of the crustacean plankton off Burns Harbor (Figure 9). The pattern was less distinct in September, with calanoids more evenly distributed (approximately 40-60%) throughout the study area. However, the highest proportion of calanoids was observed at outermost stations (Figure 10).

Cyclopoid copepods were relatively less abundant than calanoid copepods during the study period, but exhibited similar patterns of distribution. In June, cyclopoids were most abundant (>30%) in the westernmost offshore stations and were least prevalent (>10%) at all innermost stations (Figure 11). A similar pattern was observed in August (Figure 12). In September, cyclopoids were relatively most abundant at eastern outermost stations (Figure 13).

As in the copepods, trends in cladoceran distribution were most distinct

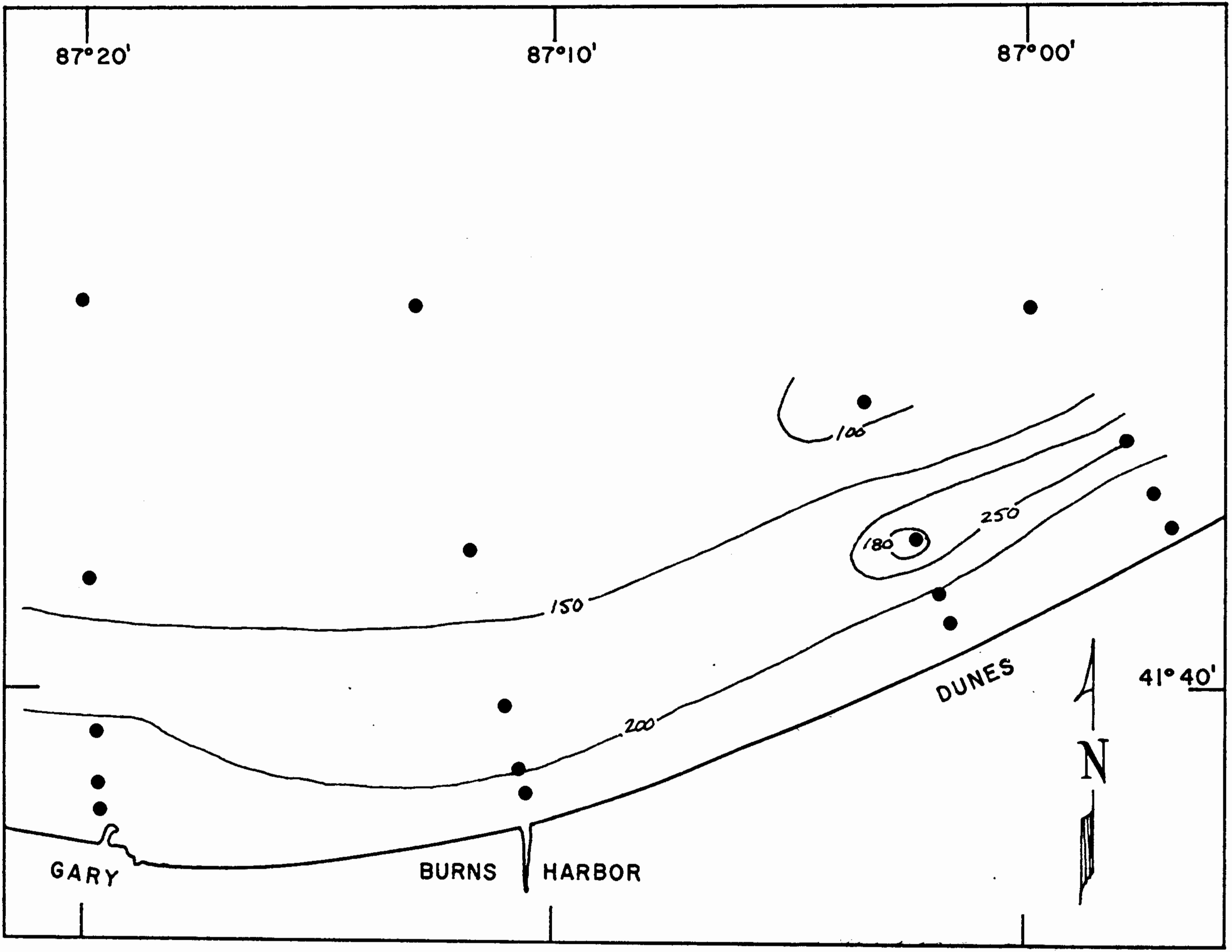

Figure 3. Distribution of total rotifers, August.

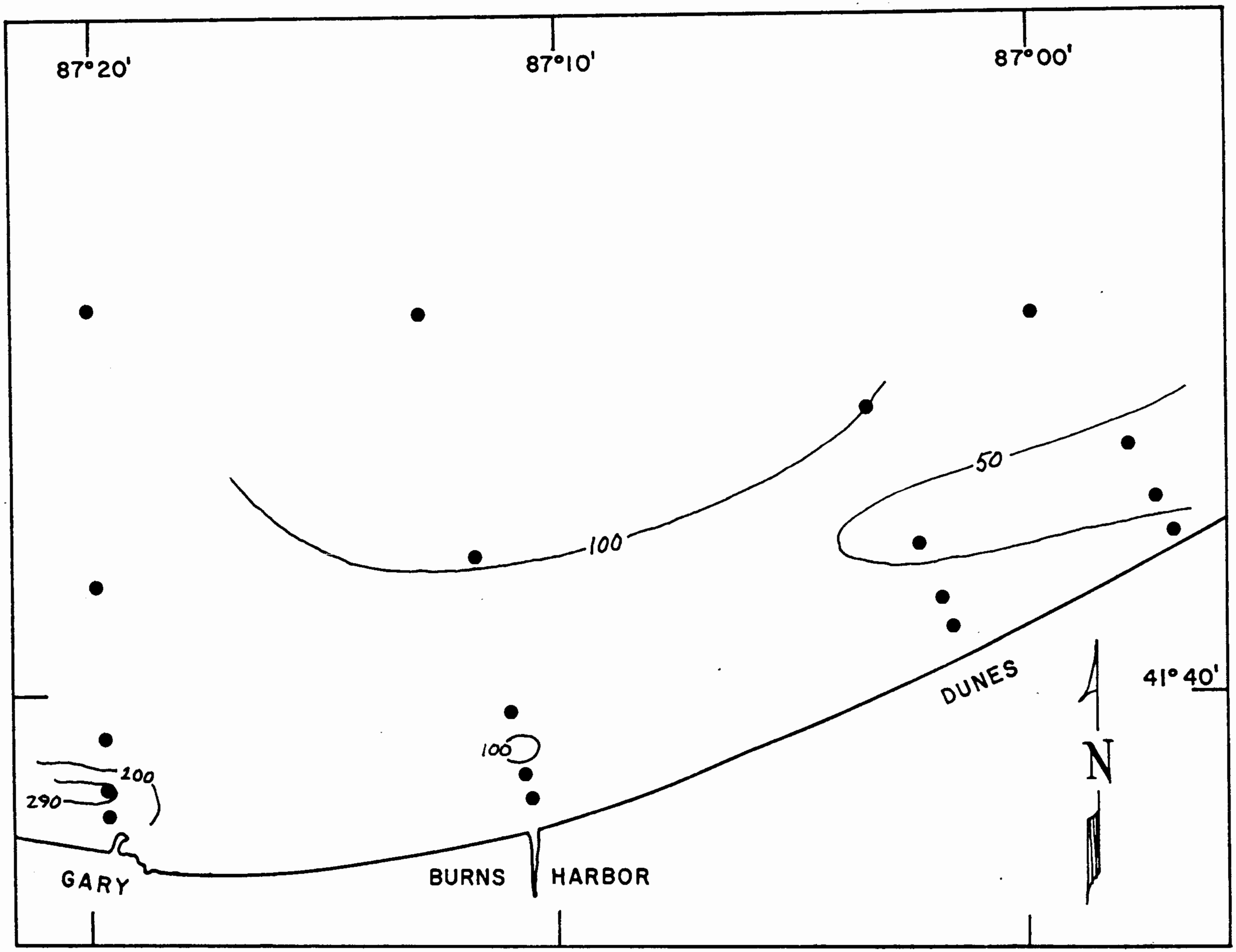

Figure 4. Distribution of total rotifers, September.

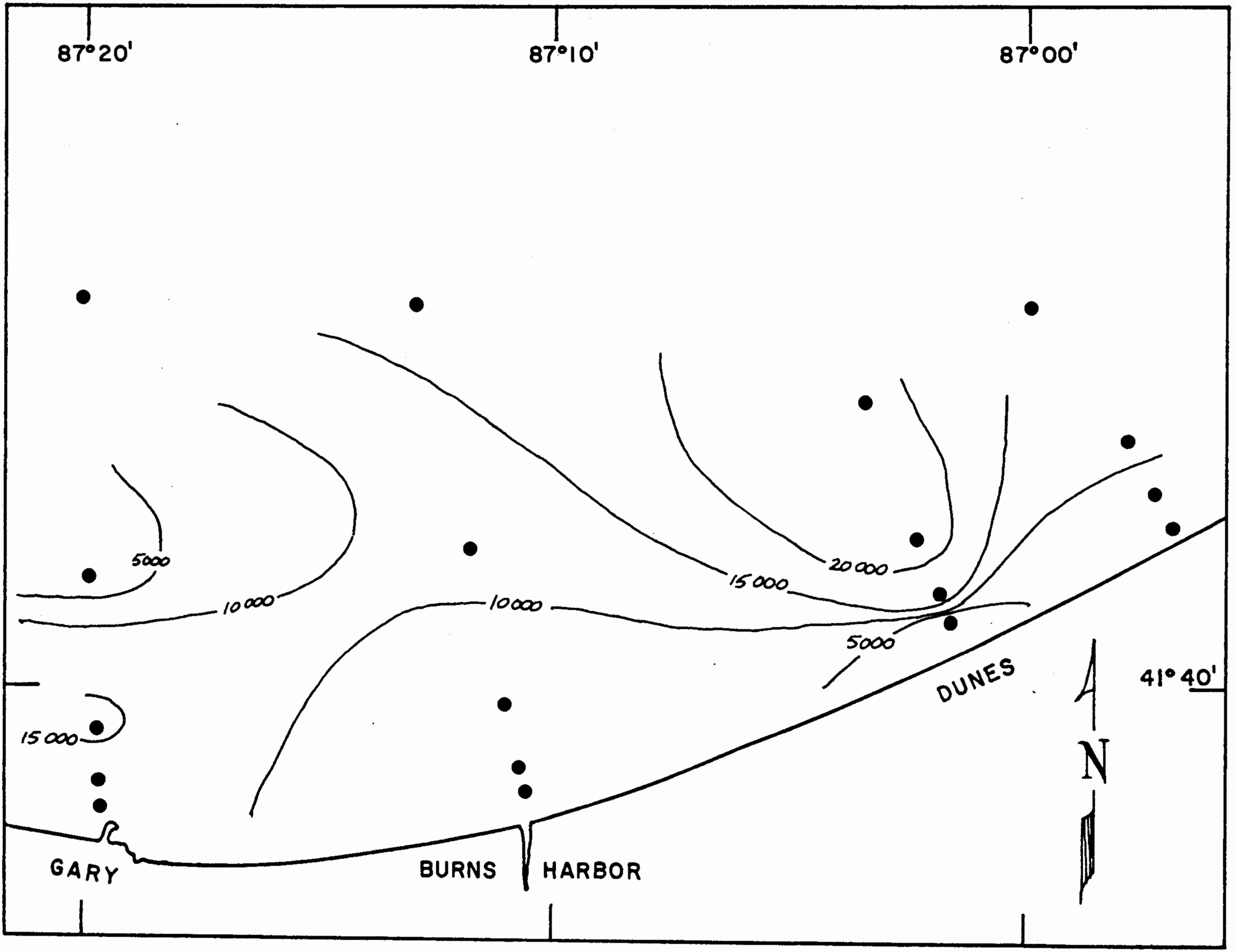

Figure 5. Distribution of total crustaceans, June.

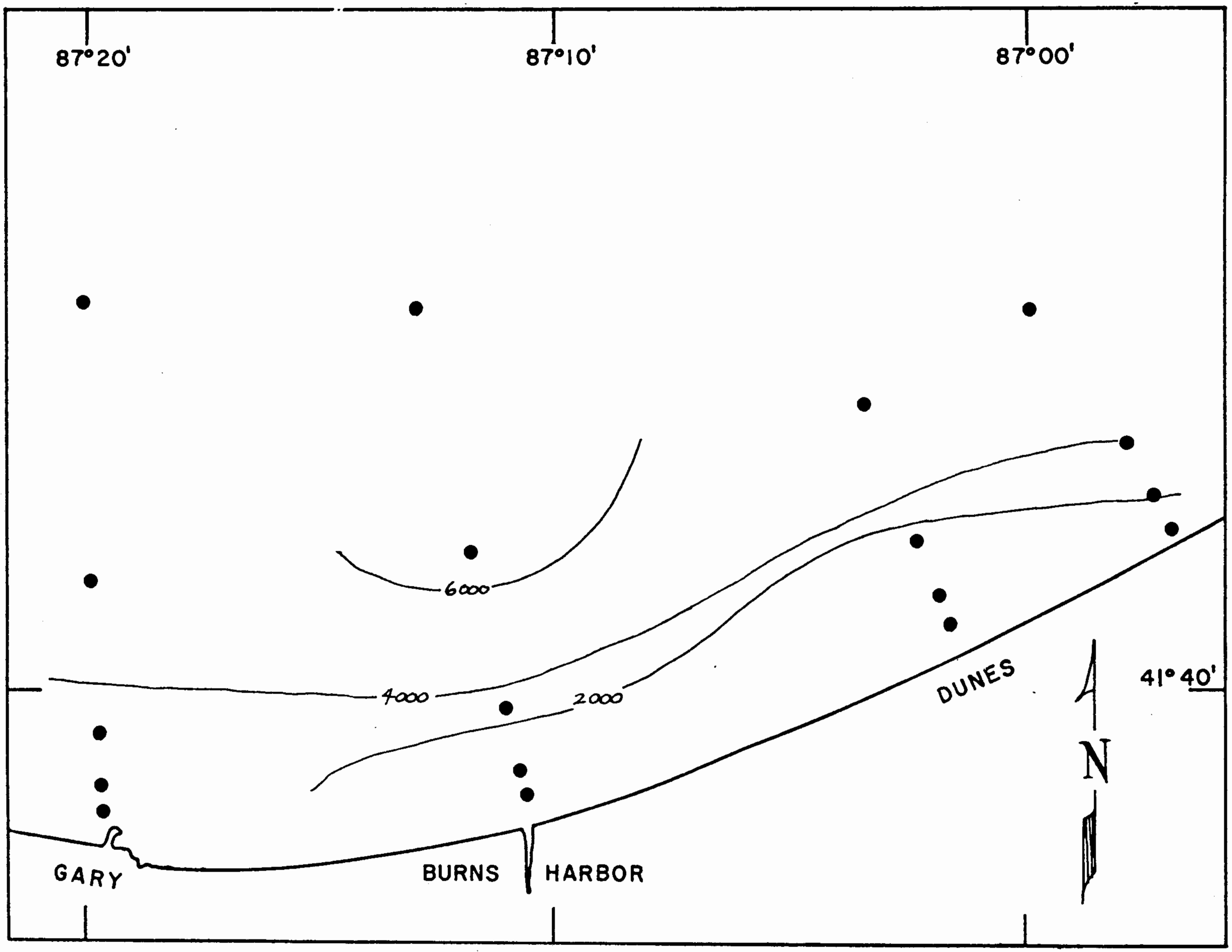

Figure 6. Distribution of total crustaceans, August.

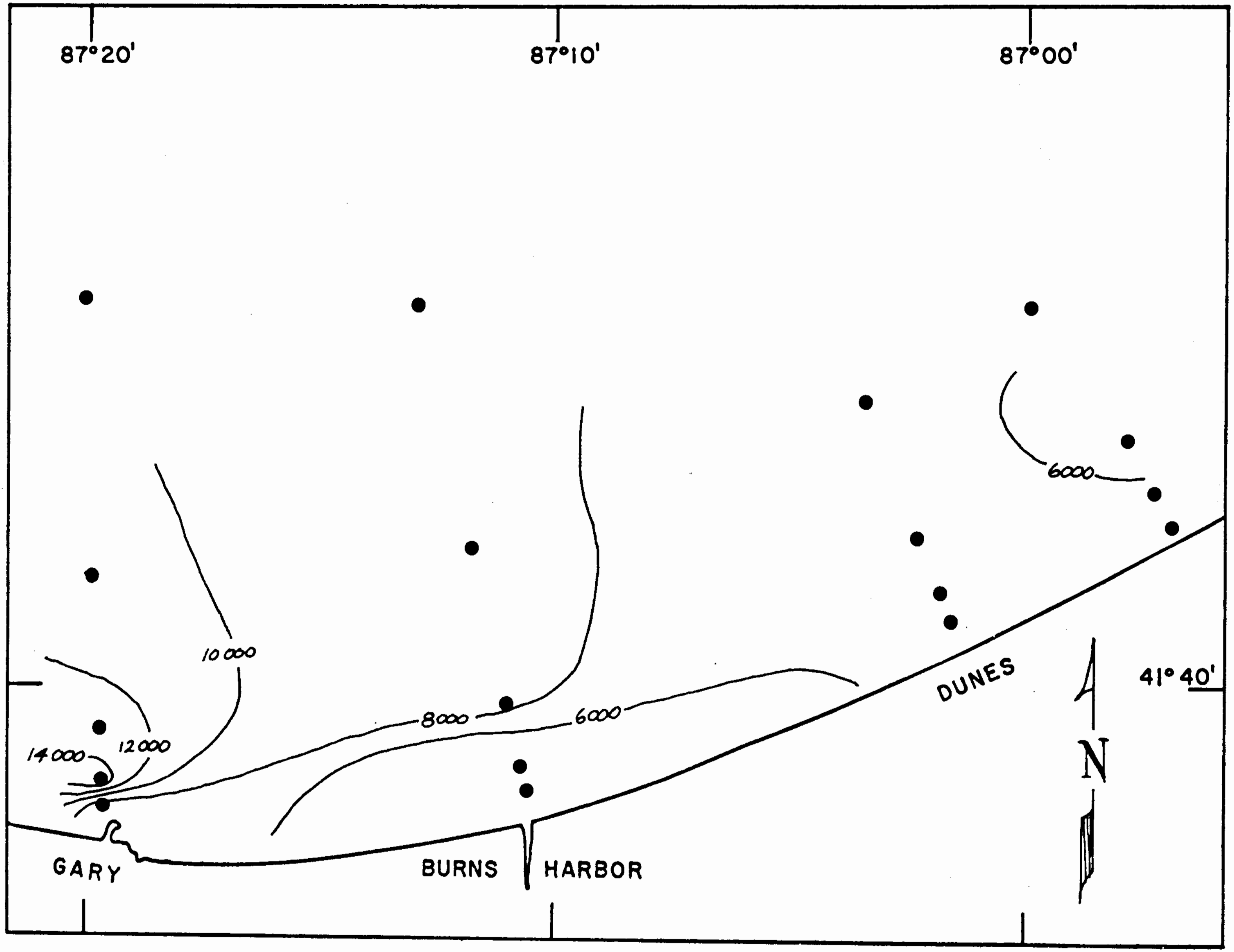

Figure 7. Distribution of total crustaceans, September.

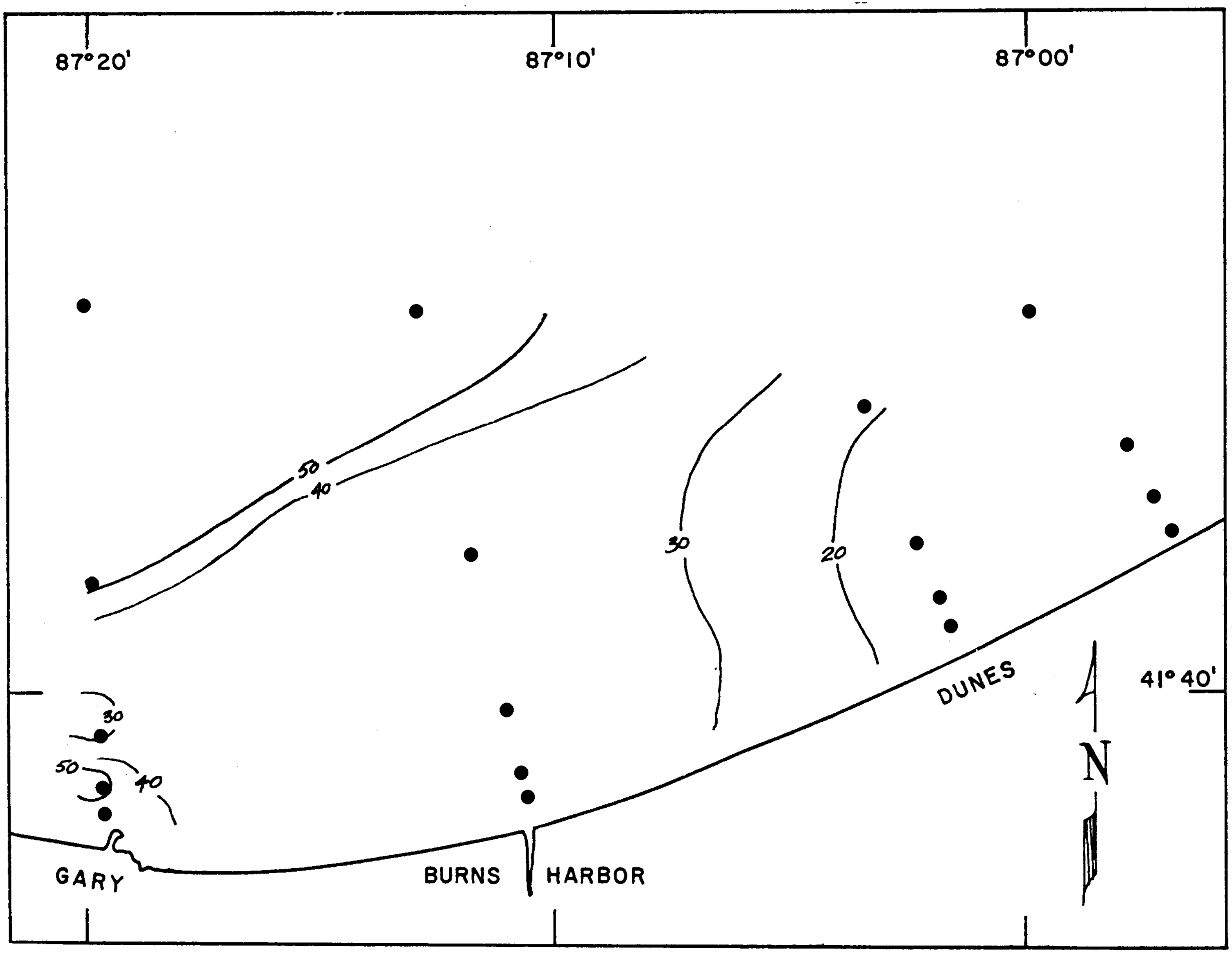

Figure 8. Distribution of total calanoid copepods, June.

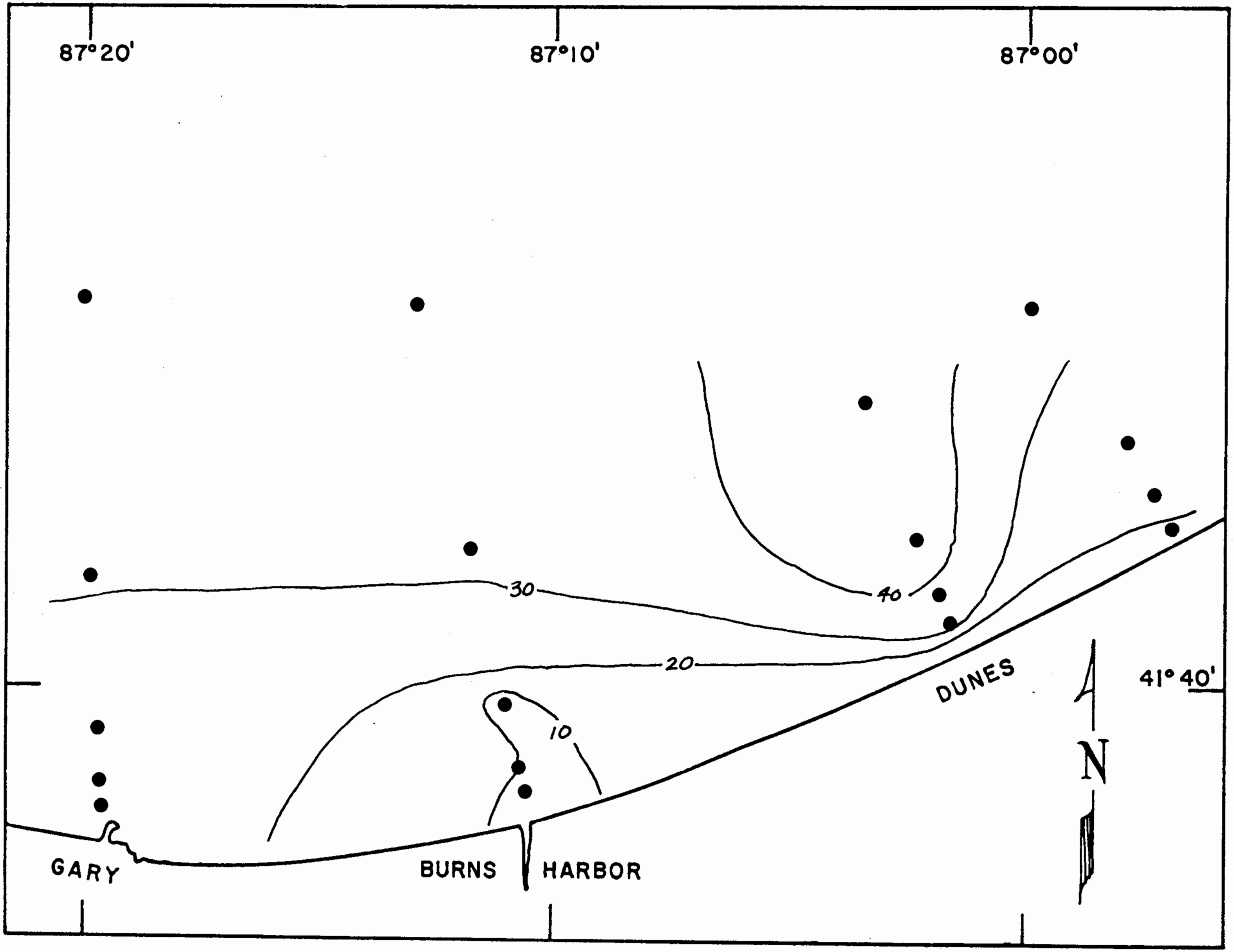

Figure 9. Distribution of total calanoid copepods, August.

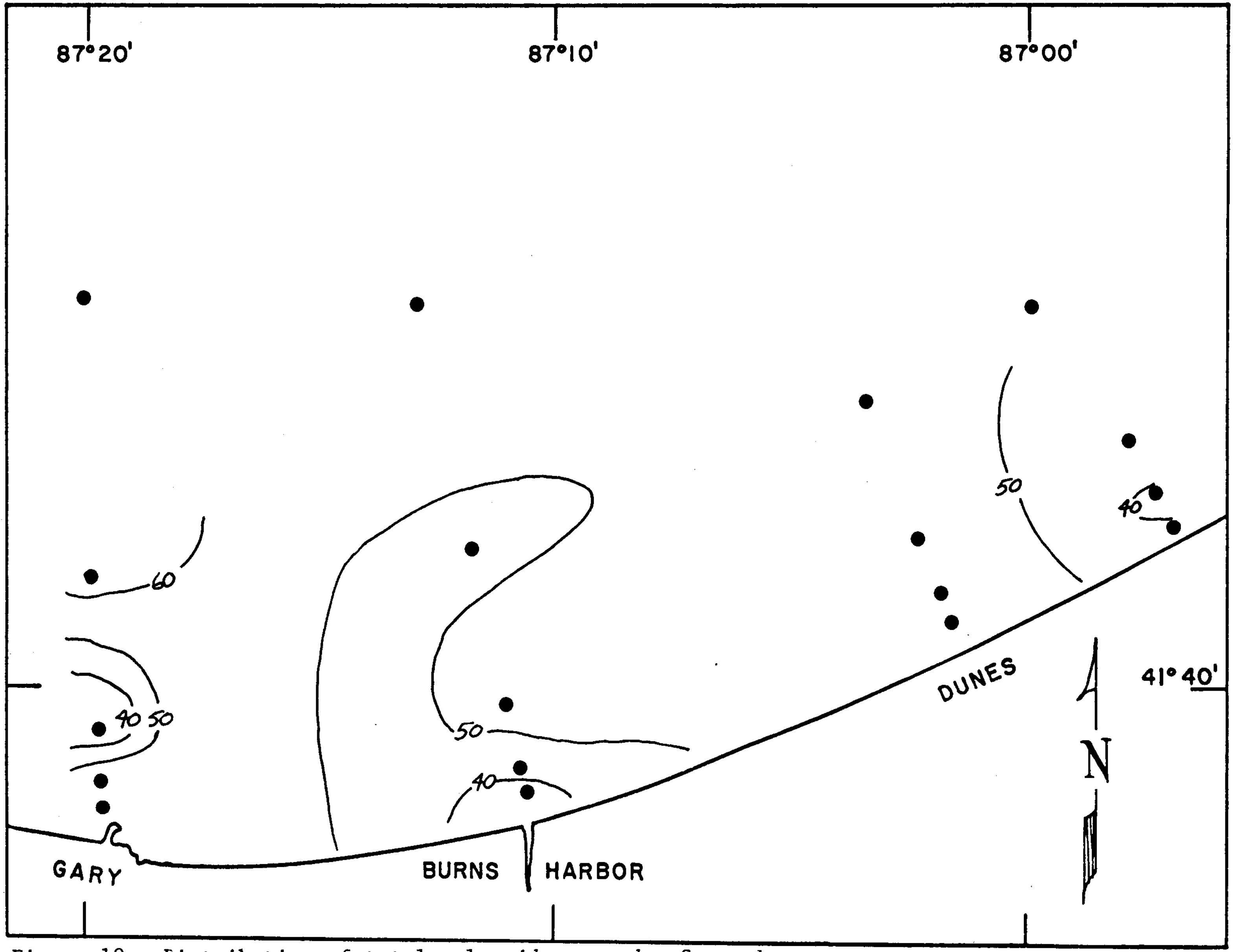

Figure 10. Distribution of total calanoid copepods, September.

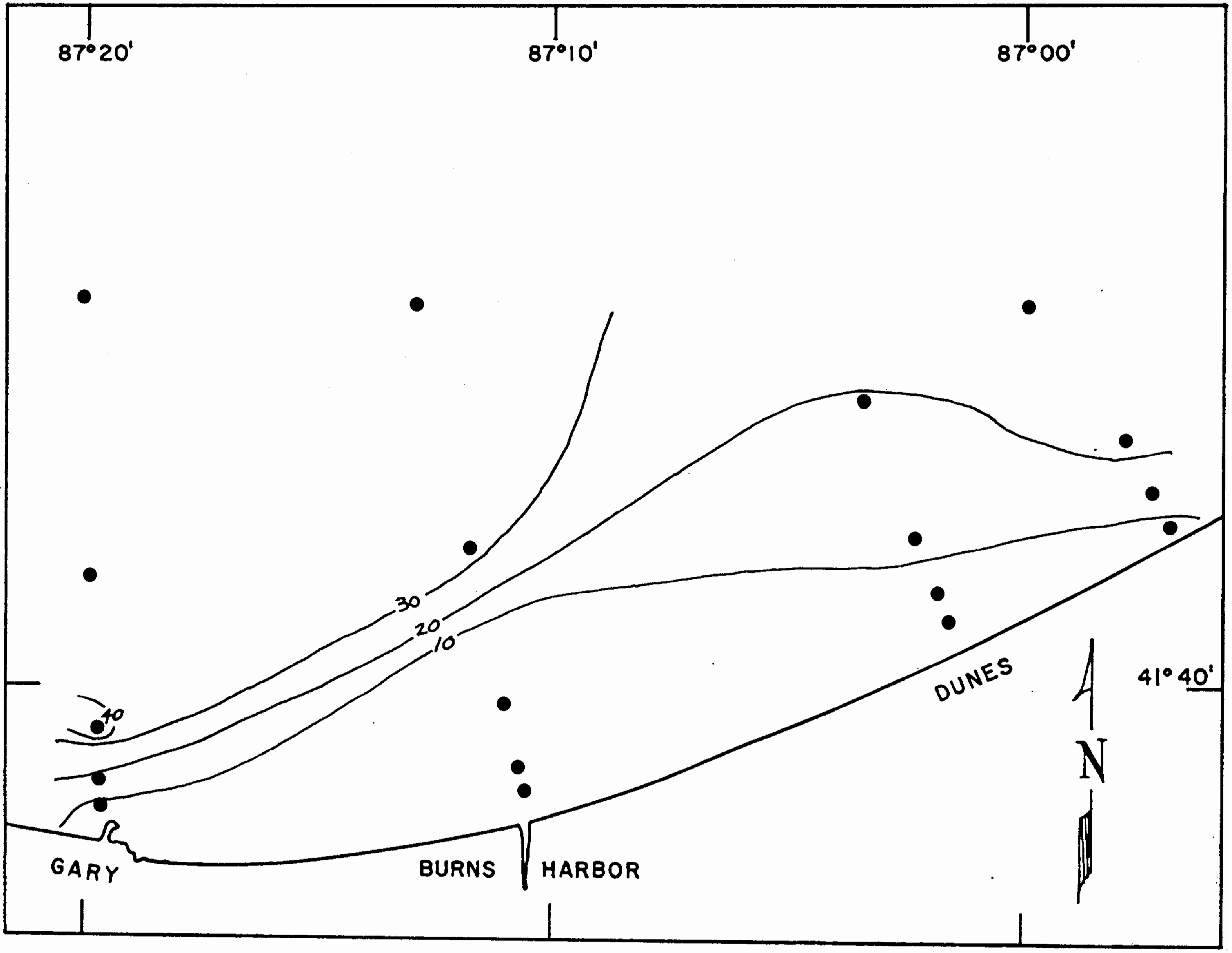

Figure 11. Distribution of total cyclopoid copepods, June.

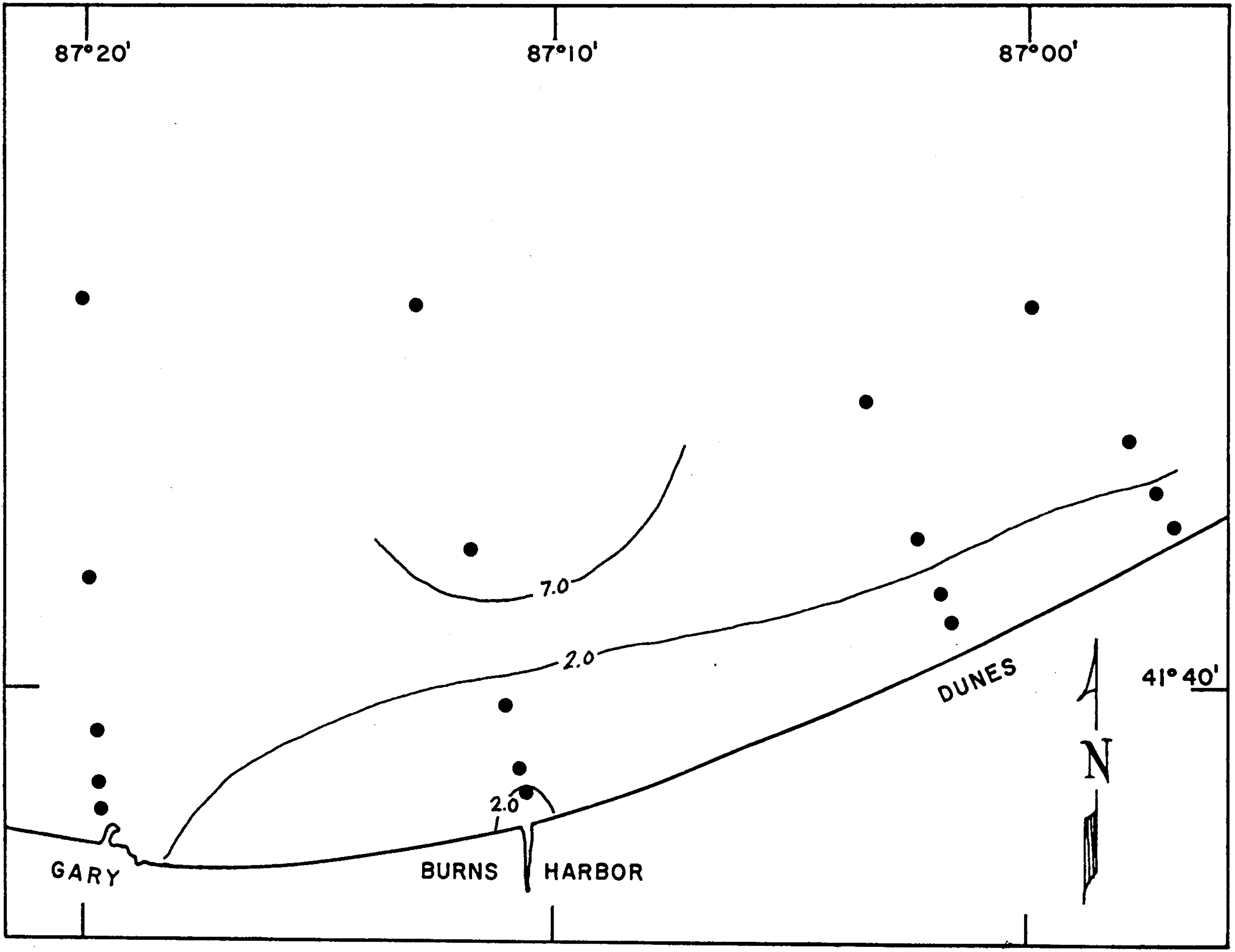

Figure 12. Distribution of total cyclopoid copepods, August.

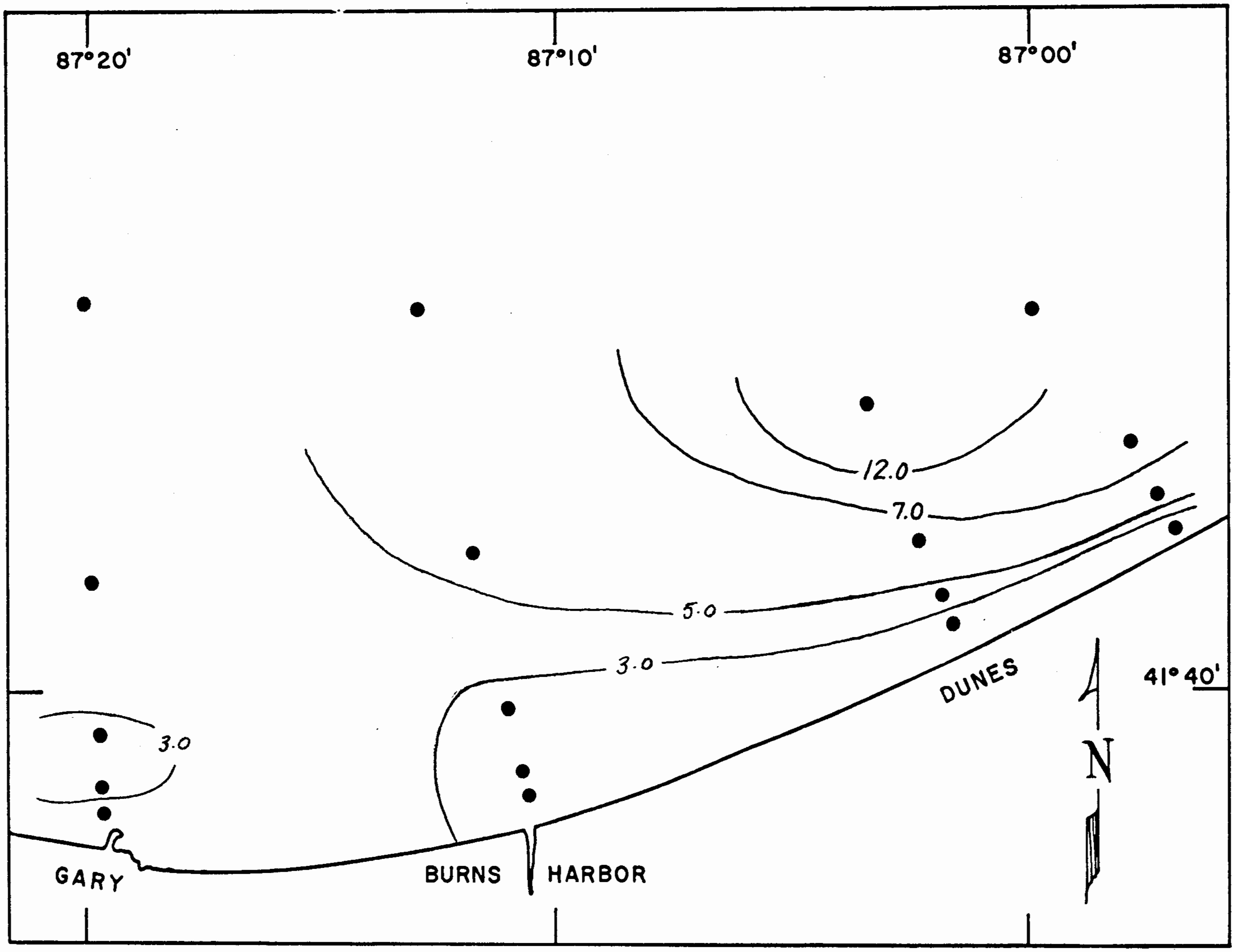

Figure 13. Distribution of total cyclopoid copepods, September.

in June and August and generally exhibited a reciprocal pattern in comparison with the copepods. Whereas copepods generally were most prevalent at offshore locations, cladocerans were predominant inshore. A distinct gradient from low relative abundance (<10% of total Crustacea) at outermost stations off Gary to high abundance (>80%) near Michigan City Harbor was discernible in June (Figure 14). In August, cladocerans were predominant, representing greater than 70 to 80% of all crustaceans at inshore stations in comparison with 50 to 60% at offshore locations (Figure 15). By September, cladocerans were less prevalent throughout the study area, especially in offshore waters where relative abundances of 30 to 40% were observed. Highest abundances (50 to 60%) were located near harbor mouths (Figure 16).

Gannon _et al_. (1976) and Gannon and Stemberger (1978) suggested that the ratio of calanoid copepods to cyclopoid copepods plus cladocerans may be useful in detecting summertime trends in zooplankton distribution as related to water quality. Calanoid copepods generally are most prevalent in oligotrophic conditions relative to the other major crustacean groups and, therefore, the ratio may be greater in areas of higher water quality. This trend was discernible in the Indiana waters of southern Lake Michigan. In June, the ratio was highest at the outermost stations off Gary where consistently higher water quality conditions were observed (Figure 17). The ratio was highest off Indiana Dunes in August and lowest in the vicinity of the mouths of Burns and Michigan City harbors (Figure 18). As cladocerans became less abundant relative to calanoid copepods in September, the ratio increased in absolute value throughout the study area (Figure 19). However, the absolute value carries little limnological significance. Only the relative differences in the ratio within a given data set may have interpretive value. The ratio was highest throughout the offshore waters and on the transect of stations off Indiana Dunes. As in August, lowest values were observed off Burns Harbor and Michigan City harbor (Figure 19).

A correlation coefficient matrix was examined to discern whether or not some of the observed trends in spatial distribution of zooplankton and physicochemical variables were statistically significant. Consistent trends did not exist across all sampling periods. Strongest correlations were observed in June when spatial gradients in physicochemistry and zooplankton densities were most distinct. Total rotifers exhibited significant positive correlations with temperature and specific conductance at the .01 level and a significant negative correlation with Secchi disc transparency at the .05 level in June. Total Crustacea exhibited significant (.01) positive correlations with temperature and specific conductance. Total Crustacea and Secchi disc correlations were not significant, undoubtedly because of differences in distributions of calanoid copepods and cladocerans relative to water transparency. Cladocerans showed significant (.05) positive correlation and calanoid copepods exhibited significant (.05) negative correlation to Secchi disc depths. Moreover, as a further reflection of this pattern, the ratio of calanoid copepods to cyclopoid copepods and cladocerans showed significant (.05) positive correlation to Secchi disc transparency. Cyclopoid copepods did not exhibit any significant correlations with physicochemical variables in June.

In August, total rotifers showed significant (.05) negative correlation

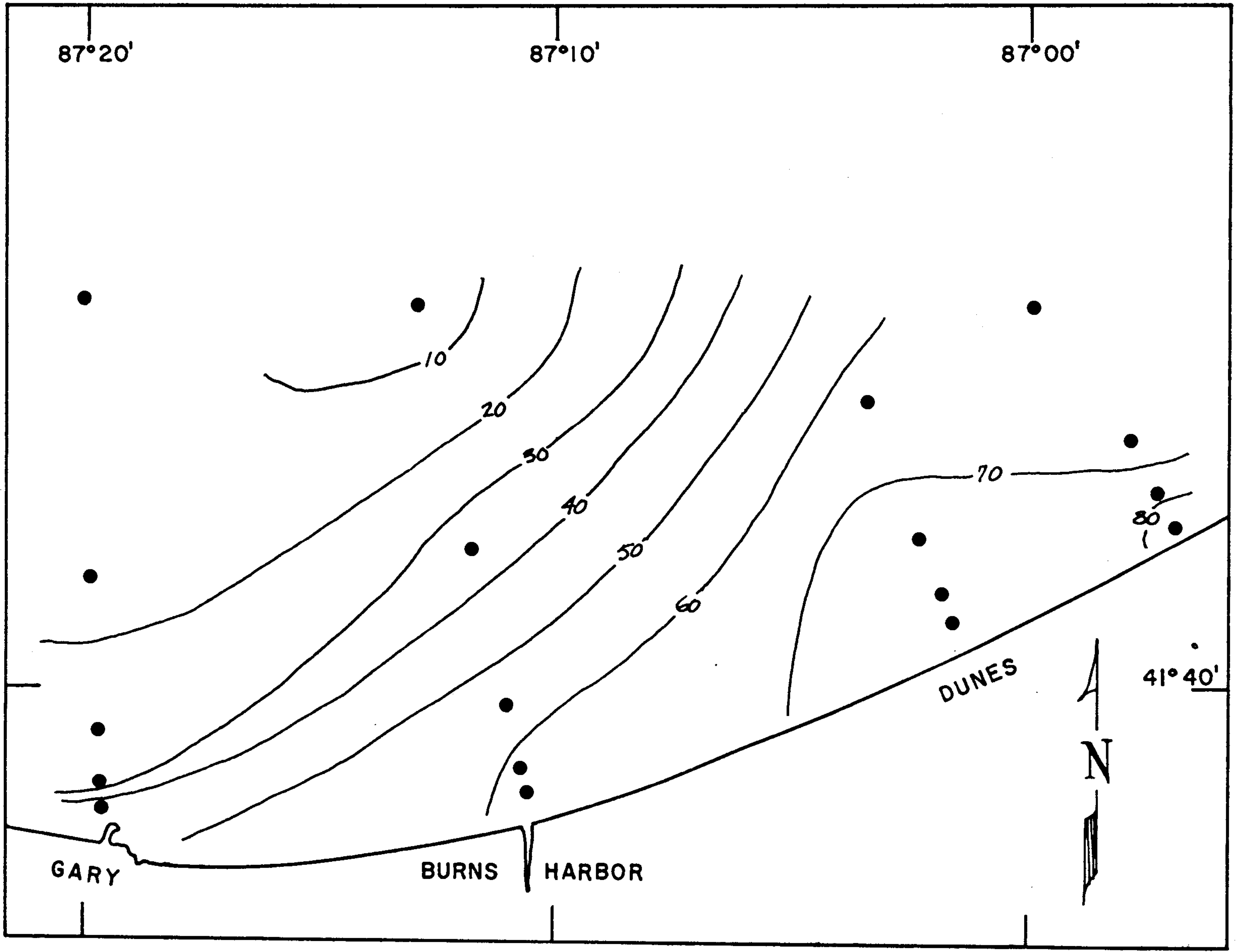

Figure 14. Distribution of total cladocerans, June.

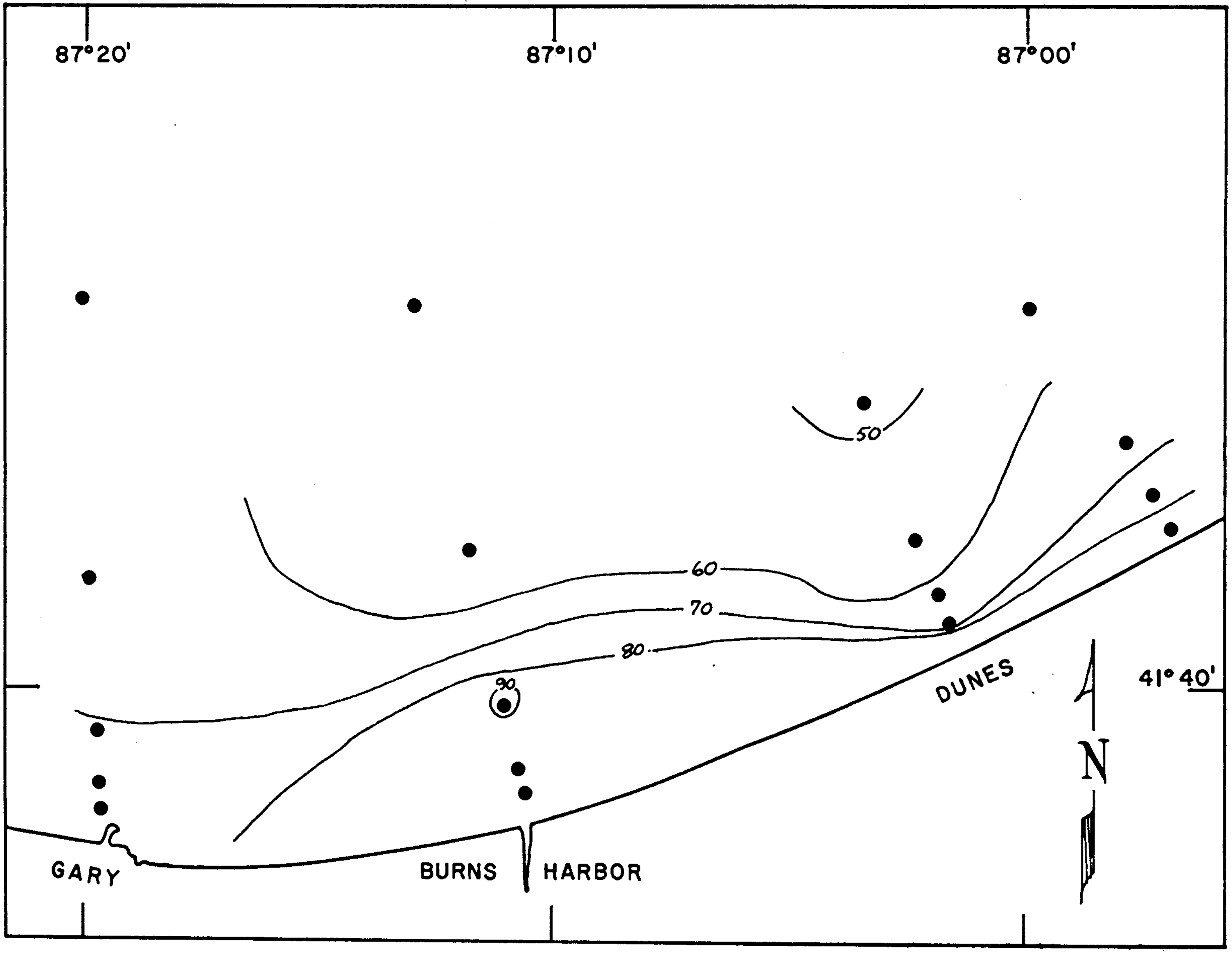

Figure 15. Distribution of total cladocerans, August.

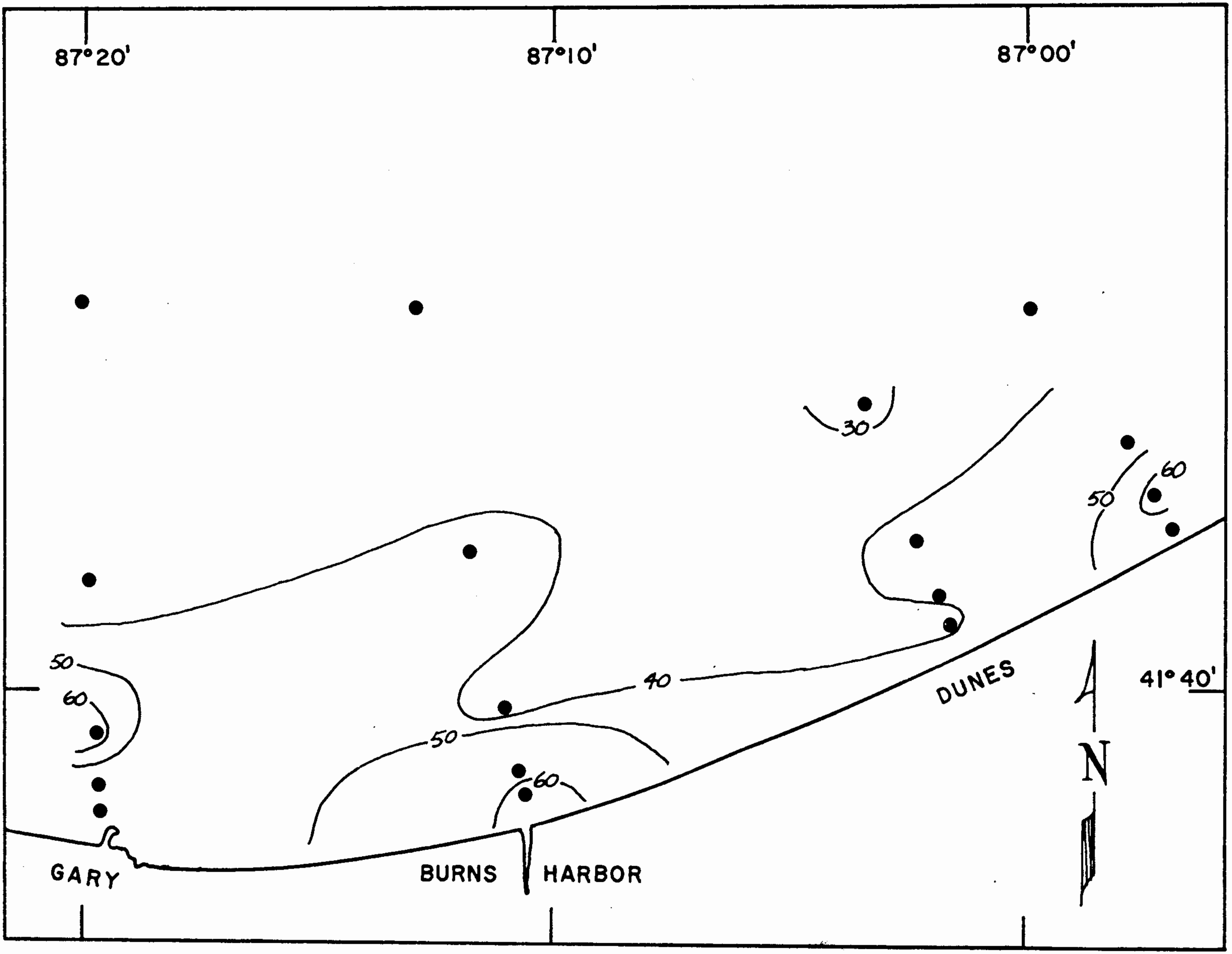

Figure 16. Distribution of total cladocerans, September.

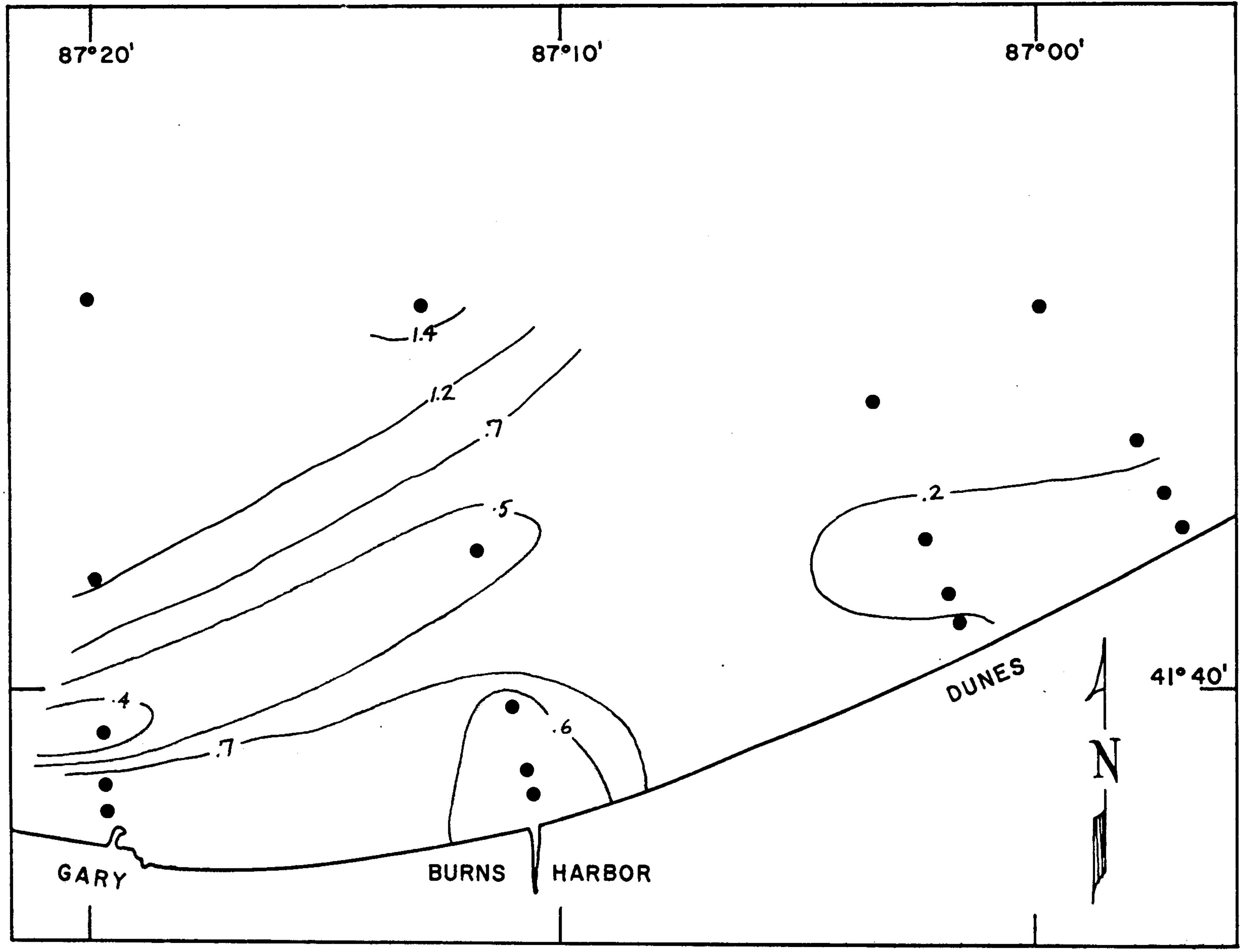

Figure 17. Distribution of calanoid/cyclopoid + cladoceran ratio, June.

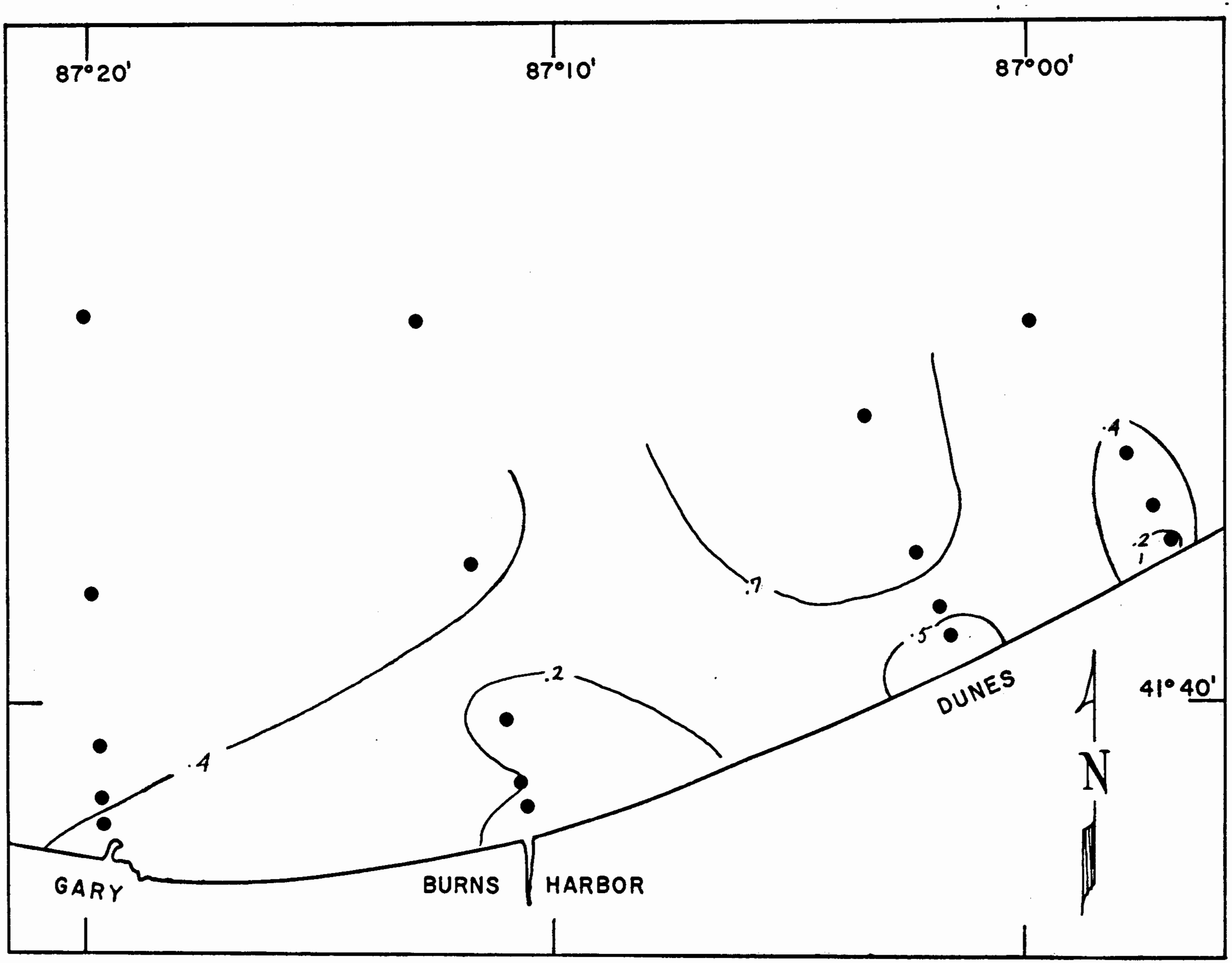

Figure 18. Distribution of calanoid/cyclopoid + cladoceran ratio, August.

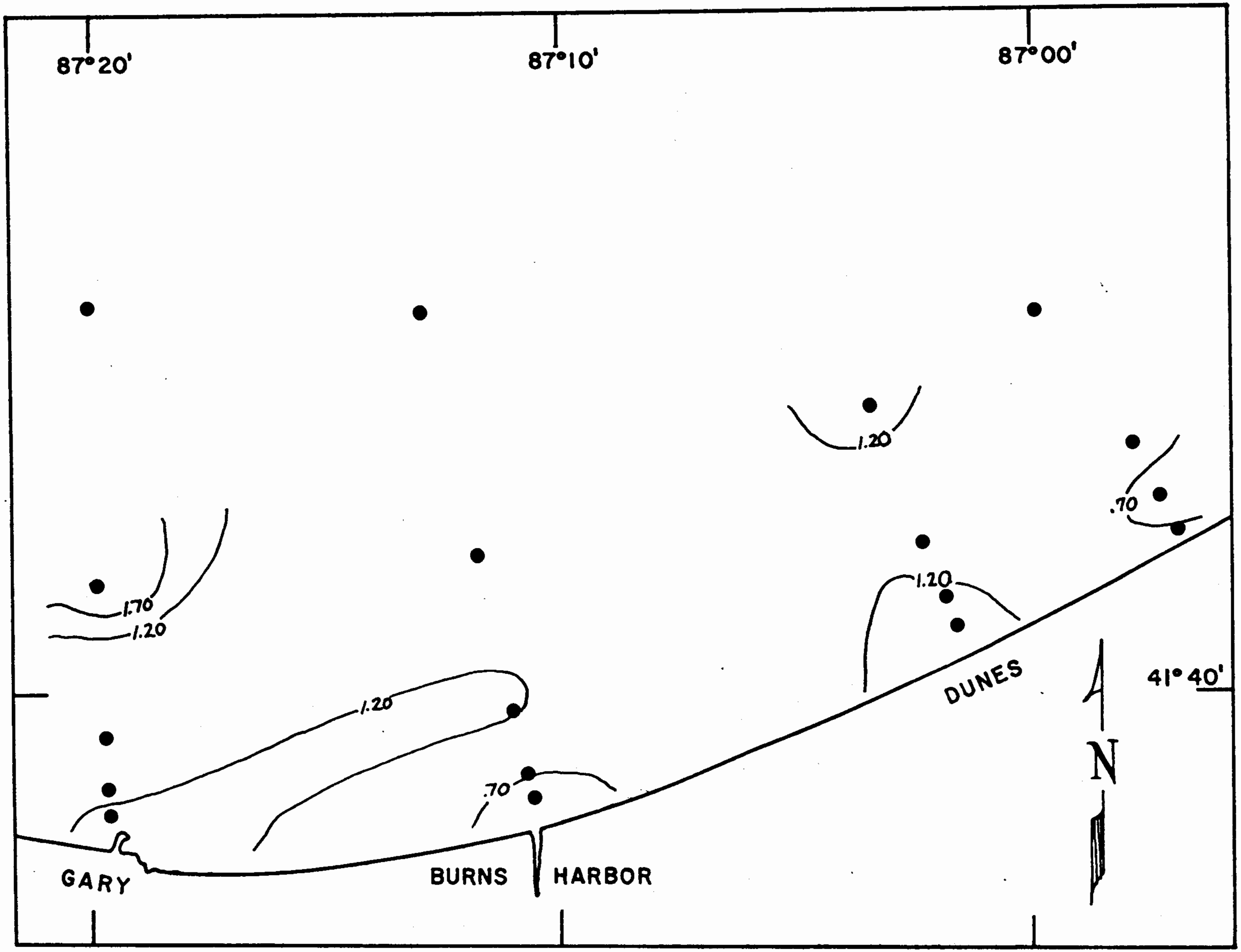

Figure 19. Distribution of calanoid/cyclopoid + cladoceran ratio, September.

with Secchi disc transparency, but no other correlations with physicochemistry were significant. Cladocerans exhibited a significant (.01) positive correlation, whereas calanoid copepods showed a significant (.01) negative correlation to temperature. In September, rotifers exhibited no significant physicochemical correlations, but total crustaceans showed a significant (.05) positive correlation to specific conductance. As in June, cladocerans had a significant (.05) negative correlation with Secchi disc transparency whereas calanoid copepods were positively correlated at the .01 level. No consistent trends in correlation of zooplankton with nutrient chemistry were observed during the study period.

SPECIES COMPOSITION

During the sampling period, 52 rotifer species were collected from the Indiana waters of southern Lake Michigan (Table 2). The predominant species were Keratella cochlearis, K. crassa, Kellicottia longispina, Polyarthra remata, P. vulgaris, and Conochilus unicornis. Congeneric occurrence of species in southern Lake Michigan waters was common. Nine genera were represented by two or more species, including a maximum of five species each in Keratella and Trichocerca. Approximately 40 species, including all of the predominant ones, are characteristic of limnetic waters of Lake Michigan. The remainder (e.g., Euclanis, Lophocaris, Stephanocercos) are primarily benthic and littoral forms that occasionally appear in the plankton in nearshore waters especially near river mouths.

Crustacean plankters included 35 species in the study area, including eight calanoid copepods, five cyclopoid copepods, one harpacticoid copepod, and 21 cladocerans (Table 3). As in the rotifers, congeneric occurrence of micro-crustaceans was recorded in southern Lake Michigan waters. Three species each of Leptodiaptomus, Daphnia, and Alona and two species each of Ceriodaphnia and Diaphanosoma were recorded. Approximately 22 species are characteristic of Lake Michigan limnetic waters, including predominant Epischura lacustris, Leptodiaptomus ashlandi, L. minutus, diaptomid copepodids, Diacyclops thomasi, Diaphanosoma spp., Daphnia retrocurva, D. galeata mendotae, Bosmina longirostris, and Eubosmina coregoni. The remainder (e.g., Eucyclops, Canthocamptus, Alona, Eurycercus, Leydigia, Pleuroxis, and Ilyocryptus) are littoral and benthic species which occasionally appear in the plankton of nearshore waters.

SEASONAL AND SPATIAL DISTRIBUTION OF MAJOR ROTIFERA

Keratella cochlearis cochlearis was the most abundant rotifer in the Indiana waters of southern Lake Michigan. This species had a mean abundance for all sampling periods of 77,200 individuals per m^3 (Appendix D, Table D-1). It was most abundant (mean of 160,700 per m^3) in June when it constituted over 40% of total rotifers. Its density was considerably less (about 40,000 per

TABLE 2. SPECIES COMPOSITION, MEAN ABUNDANCE (NUMBER x $10^3/M^3$), AND TROPHIC STATUS OF ROTIFERS IN SOUTHERN LAKE MICHIGAN. DATA ARE POOLED NEAR SURFACE AND BOTTOM SAMPLES FROM ALL STATIONS IN EACH SAMPLING PERIOD. THE ABUNDANCE OF SPECIES LESS THAN 100 INDIVIDUALS/M^3 IS REPRESENTED BY A PLUS SIGN (+)

Class Monogonata Order Ploima	June	Aug.	Sept.	Trophic Status*
Family Brachionidae				
Subfamily Brachioninae				
Brachionus angularis Gosse	+	+	0.0	E
B. caudatus Barrois and Daday	0.0	0.1	0.0	E
Euchlanis dilatata Ehrbg.	0.0	0.0	+	E
Kellicottia longispina (Kellicott)	16.2	2.4	1.3	O
Keratella cochlearis cochlearis (Gosse)	160.7	40.1	36.2	ET
K. cochlearis f. *hispida* (Lauterborn)	0.0	0.1	0.0	ET
K. cochlearis f. *robusta* (Lauterborn)	1.6	2.3	1.2	ET
K. cochlearis f. *tecta* (Gosse)	0.0	0.2	0.0	E
K. crassa Ahlstrom	12.5	15.2	2.5	ET?
K. earlinae Ahlstrom	0.5	0.2	0.3	ET?
K. quadrata (O. F. Müller)	0.5	0.2	0.4	ET
K. valga f. *brevispina*	0.0	0.0	+	I
Lophocaris salpina (Ehrbg.)	0.0	+	0.0	E
Notholca foliacea (Ehrbg.)	0.1	0.1	0.1	O
N. labis Gosse	0.0	0.0	+	O
N. laurentiae Stemberger	0.0	0.1	1.0	O
N. squamula (O. F. Müller)	0.1	0.1	0.1	O
Platyias patulus (O. F. Müller)	0.0	+	+	E
Trichotria tectractis (Ehrbg.)	+	0.0	0.0	I
Subfamily Colurinae				
Lepadella patella (O. F. Müller)	+	0.0	0.0	I
Family Lecanidae				
Lecane mira (Murray)	0.0	0.0	+	E
Monostyla closterocerca (Schmarda)	0.0	0.0	+	E
Family Trichocercidae				
Trichocerca cylindrica (Imhof)	0.0	0.1	+	E
T. multicrinis (Kellicott)	0.0	0.6	0.0	E
T. porcellus (Gosse)	+	2.9	4.1	E
T. pusilla (Jennings)	0.0	+	0.0	E
T. rousseleti (Voigt)	+	0.8	0.2	E

(continued).

TABLE 2. (continued).

Class Monogonata Order Ploima	June	Aug.	Sept.	Trophic Status*
Family Gastropidae				
Ascomorpha ecaudis Perty	0.5	0.1	+	M
Ascomorpha ovalis (Bergendal)	0.1	1.6	0.2	M
Gastropus stylifer Imhof	0.8	6.4	1.2	ET
Family Tylotrochidae				
Tylotrocha monopus (Jennings)	0.7	0.6	+	M?
Family Asplanchnidae				
Asplanchna priodonta Gosse	4.8	1.1	0.1	ET
Family Synchaetidae				
Ploesoma hudsoni (Imhof)	0.1	0.1	0.1	ET
P. lenticulare Herrick	0.0	1.8	0.0	ET
P. truncatum (Levander)	0.2	2.6	1.0	ET
Polyarthra dolichoptera Idelson	0.3	0.0	0.0	O
P. euryptera Wierzejski	0.0	0.0	+	M?
P. major Burckhardt	0.2	3.3	2.8	M?
P. remata Skorikov	62.8	19.8	6.5	ET
P. vulgaris Carlin	17.4	61.2	32.2	ET
Synchaeta kitina Rousselet	0.6	0.2	+	I
S. lakowitziana Lucks	+	0.0	0.0	O
S. oblonga Ehrbg.	0.1	0.0	0.0	M?
S. pectinata Ehrbg.	0.0	0.1	0.0	M?
S. stylata Wierzejski	1.2	10.4	2.6	M?
Family Testudinellidae				
Filinia longiseta (Ehrbg.)	0.0	0.0	+	E
F. terminalis (Plate)	0.0	0.2	+	O?
Pompholyx sulcata Hudson	+	+	0.0	E
Family Conochilidae				
Conochilus unicornis (Rousselet)	102.1	9.8	1.2	ET
Family Collothecidae				
Collotheca mutabilis (Hudson)	3.1	6.2	2.2	M?
C. pelagica (Rousselet)	0.0	0.1	0.0	M?
Stephanocercos fimbriatus (Goldfuss)	0.0	0.0	+	I
Total Rotifers	386.7	190.8	97.7	

* Trophic Status: ET = eurytopic; E = eutrophic; M = mesotrophic; O = oligotrophic; I = insufficient information. Compiled from Gannon and Stemberger (1978), Stemberger (1979), and other sources.

TABLE 3. SPECIES COMPOSITION, MEAN ABUNDANCE (NUMBER/M^3), AND TROPHIC STATUS OF CRUSTACEANS FROM STANDARDIZED NET TOWS IN SOUTHERN LAKE MICHIGAN. DATA ARE FROM ALL STATIONS IN EACH SAMPLING PERIOD. PRESENCE OF A SPECIES IN NUMBERS LOWER THAN 10 INDIVIDUALS/M^3 IS INDICATED BY A PLUS SIGN (+)

	June	Aug.	Sept.	Trophic Status*
Subclass Copepoda				
Order Calanoida	2,980	870	4,010	
Senecella calanoides Juday	0	0	+	O
Limnocalanus macrurus Sars	10	+	+	O
Eurytemora affinis (Poppe)	80	+	20	I
Epischura lacustris Forbes	30	70	420	M
Leptodiaptomus sicilis Forbes	10	+	10	O
L. ashlandi Marsh	450	90	140	M
L. minutus Lilljeborg	310	290	160	M
Skistodiaptomus oregonensis Lilljeborg	40	70	60	ET
Diaptomid copepodids	2,060	340	3,210	
Order Cyclopoida	1,780	130	360	
Acanthocyclops vernalis Fisher	40	10	+	E
Diacyclops thomasi Forbes	1,720	120	320	ET
Mesocyclops edax (Forbes)	0	+	+	ET
Tropocyclops prasinus mexicanus Kiefer	0	0	+	ET
Eucyclops agilis (Koch)	0	0	+	I
Cyclopoid copepodids	20	10	30	
Order Harpacticoida	+	0	0	
Canthocamptus staphylinoides Pearse	+	0	0	I
Subclass Branchipoda				
Order Cladocera	6,620	2,010	3,670	
Family Leptodoridae				
Leptodora kindtii (Focke)	+	20	50	ET
Family Polyphemidae				
Polyphemus pediculus (L.)	30	10	+	ET
Family Sididae				
Diaphanosoma spp.	+	430	260	ET?
Family Macrothricidae				
Ilyocryptus spinifer Herrick	0	+	0	I

(continued).

TABLE 3. (continued).

	June	Aug.	Sept.	Trophic Status*
Family Holopedidae				
Holopedium gibberum Zaddach	0	20	+	ET
Family Daphnidae				
Ceriodaphnia lacustris Birge	+	20	0	E
C. quadrangula Müller	+	10	+	E
Daphnia galeata mendotae Birge	+	180	250	ET
D. retrocurva Forbes	30	930	1,170	ET
D. ambigua Scourfield	+	0	0	E
Family Bosminidae				
Bosmina longirostris (Müller)	6,530	310	1,630	E
Eubosmina coregoni (Baird)	10	80	310	I
Family Chydoridae				
Alona affinis (Leydig)	0	0	+	ET
A. quadrangularis (Müller)	0	0	+	ET
A. setulosa Megard	+	0	0	I
Camptocercus rectirostris Schodler	0	0	+	I
Chydorus sphaericus (Müller)	10	+	+	I
Eurycercus lamellatus (Müller)	+	+	0	ET?
Leydigia quadrangularis (Leydig)	0	0	+	I
Pleuroxus procurvus Birge	0	+	0	I
Total Crustacea	11,390	3,010	8,040	

* Trophic Status: ET = eurytopic; E = eutrophic; M = mesotrophic; O = oligotrophic; I = insufficient information. Compiled from Gannon and Stemberger (1978), and other sources.

m^3) in August and September, although it still represented over 25% of total rotifers (Table 3).

In June, *K. cochlearis* was most abundant (222,600 to 384,400 per m^3) at nearshore stations off Burns Harbor and Indiana Dunes (Figure 20). This region was most turbid (<3 m Secchi disc readings) and, indeed, the distribution of this species exhibited a significant (.05) negative correlation with Secchi disc transparency. In waters with highest (>5 m) Secchi disc readings, i.e., outermost stations off Gary and Burns Harbor, *K. cochlearis* numbers were less than 50,000 per m^3 (Figure 20).

Keratella cochlearis densities in August were highest (>400,000 per m^3) off Burns Harbor and Indiana Dunes. As in June, numbers were highest in turbid waters and this species had a significant (.05) negative correlation with Secchi disc transparency and a significant (.05) positive correlation with turbidity. It was least abundant (254,000 per m^3) at the outermost station off Indiana Dunes (Figure 21).

This species exhibited a west to east decrease in density during September. It was most prevalent (>100,000 per m^3) at nearshore locations off Gary and was about ten times less abundant off Indiana Dunes and Michigan City (Figure 22). The waters off Gary had higher specific conductance and nutrients than elsewhere in the study area during September (Appendix C).

The second most abundant species in the genus *Keratella* was *K. crassa*. Its average abundance during the study period was 10,000 per m^3 (Appendix D, Table D-1) and it was most prevalent in August (15,000 per m^3) (Table 2).

Seasonal patterns of distribution for *K. cochlearis* and *K. crassa* were similar. In June, *K. crassa* was least abundant (2,000 to 6,000 per m^3) at offshore locations on westernmost transects and increased in numbers eastward to a maximum (45,000 per m^3) at the 1/2 mile station off Indiana Dunes (Figure 23). This pattern continued in August with numbers ranging from 2,500 to 11,700 per m^3 offshore to near 30,000 per m^3 at the 1/2 mile stations of Indiana Dunes and Michigan City (Figure 24). The distribution of *K. crassa* in August appeared to be related to water chemistry since this species showed significant (.05) positive correlation with alkalinity and specific conductance and a significant (.01) negative correlation with Secchi disc transparency. The pattern of west to east decrease in density was evident in September with highest numbers (6,300 per m^3) noted nearest Gary (Figure 25). *Keratella crassa*, although considerably reduced in density in comparison with June and August, exhibited a significant (.05) correlation with specific conductance in September.

In contrast to the distribution pattern for *Keratella*, *Kellicottia longispina* generally was more abundant offshore than nearshore. *Kellicottia* was most abundant in June with a mean density of 16,200 per m^3 (Table 2). It had an overall mean density of 6,400 per m^3 (Appendix D, Table D-1). Its density was consistently low at 1/2 mile stations (Figures 26-28). The pattern does not appear to be specifically related to harbor outfalls since densities also were low at the 1/2 mile station off Indiana Dunes. Moreover, its distribution did not correlate well with physicochemical variables. For

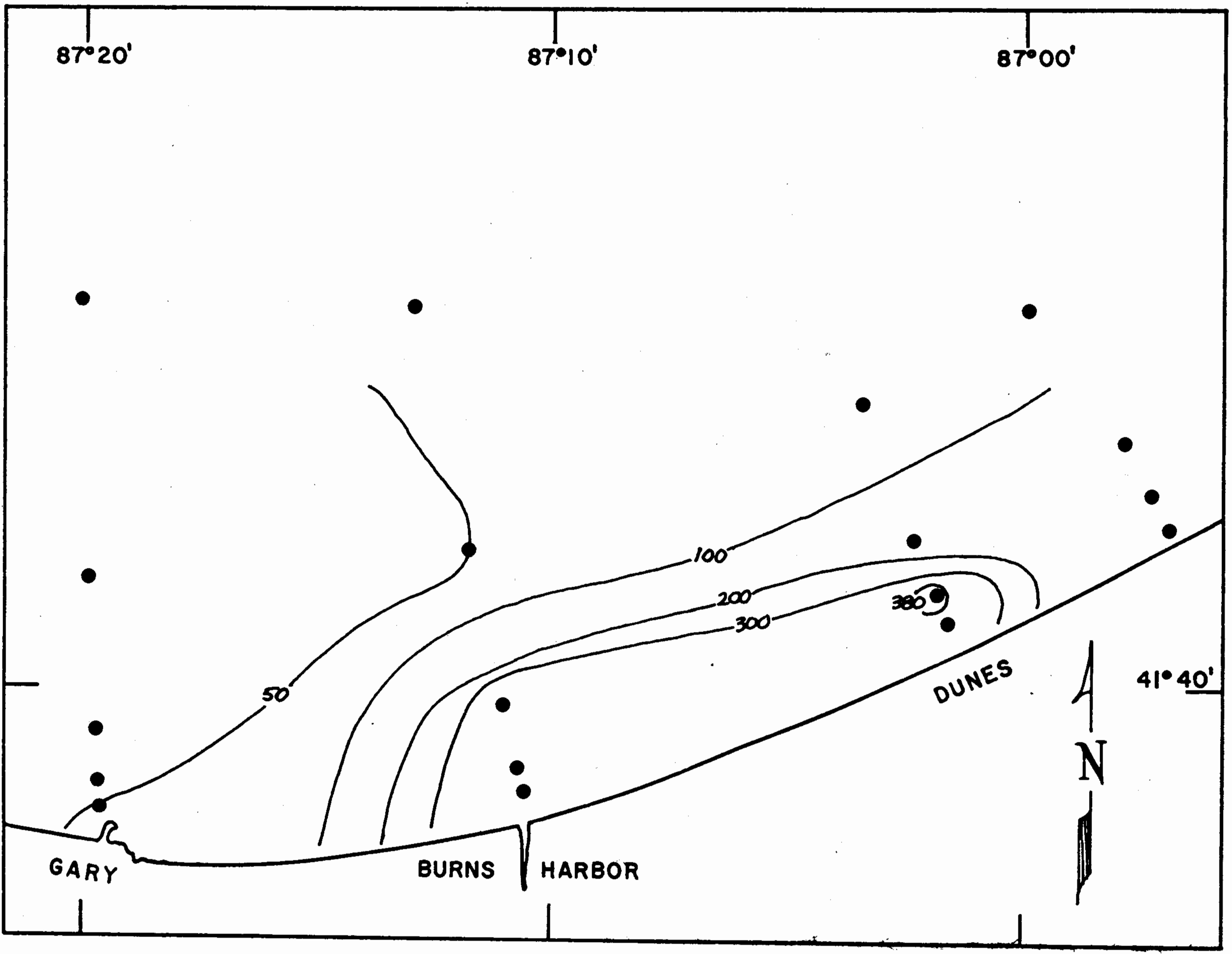

Figure 20. Distribution of *Keratella cochlearis cochlearis*, June.

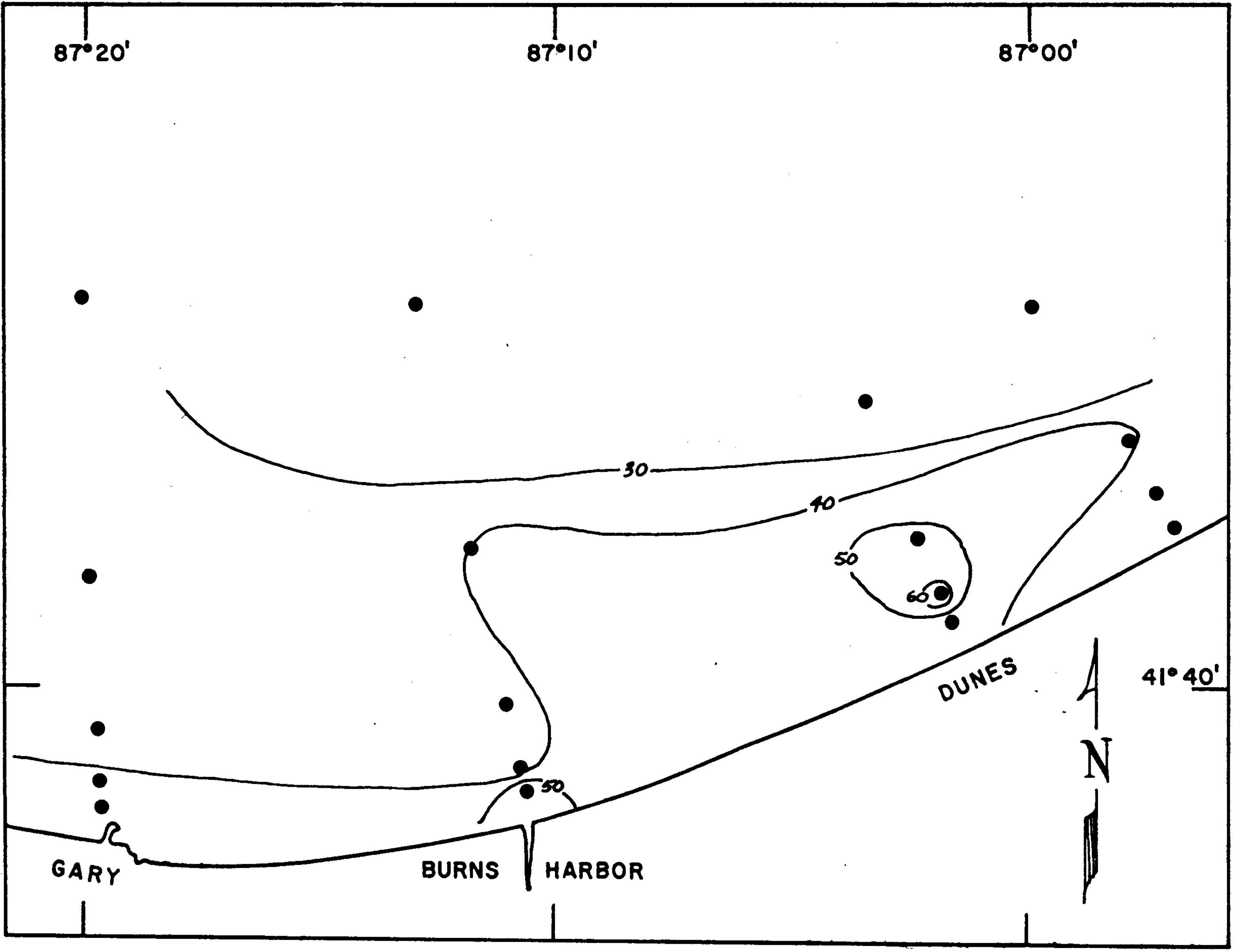

Figure 21. Distribution of Keratella cochlearis cochlearis, August.

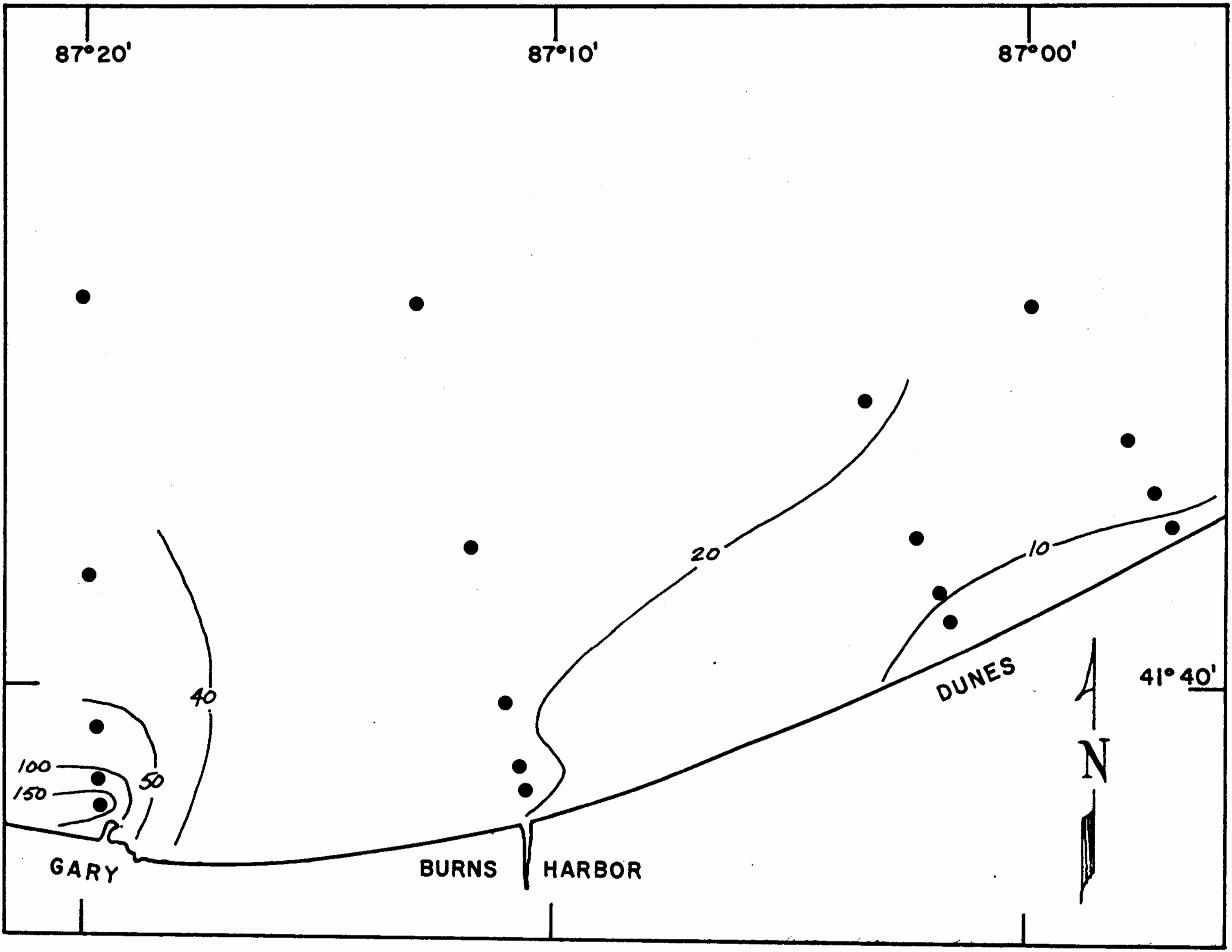

Figure 22. Distribution of <u>Keratella cochlearis cochlearis</u>, September.

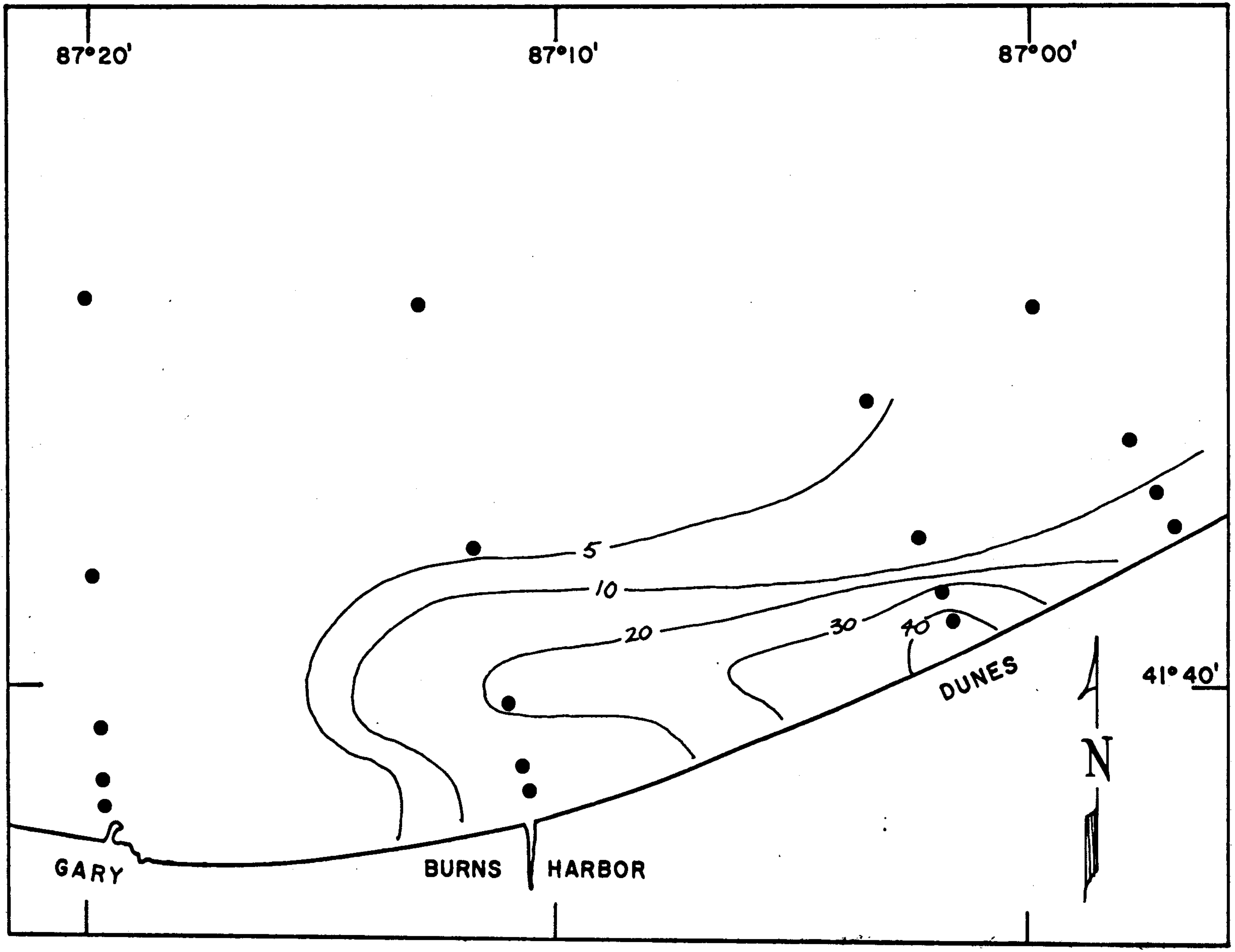

Figure 23. Distribution of *Keratella crassa*, June.

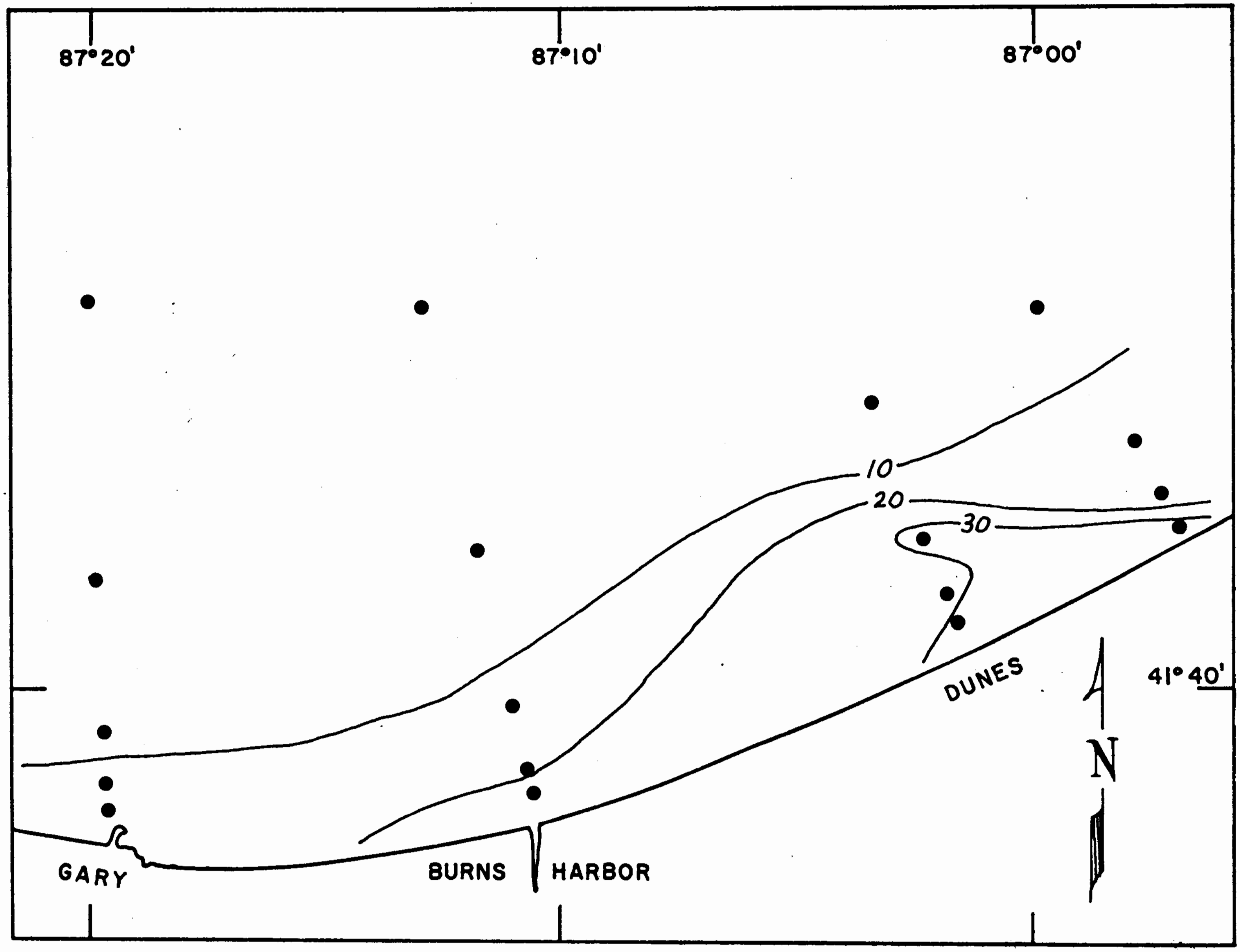

Figure 24. Distribution of Keratella crassa, August.

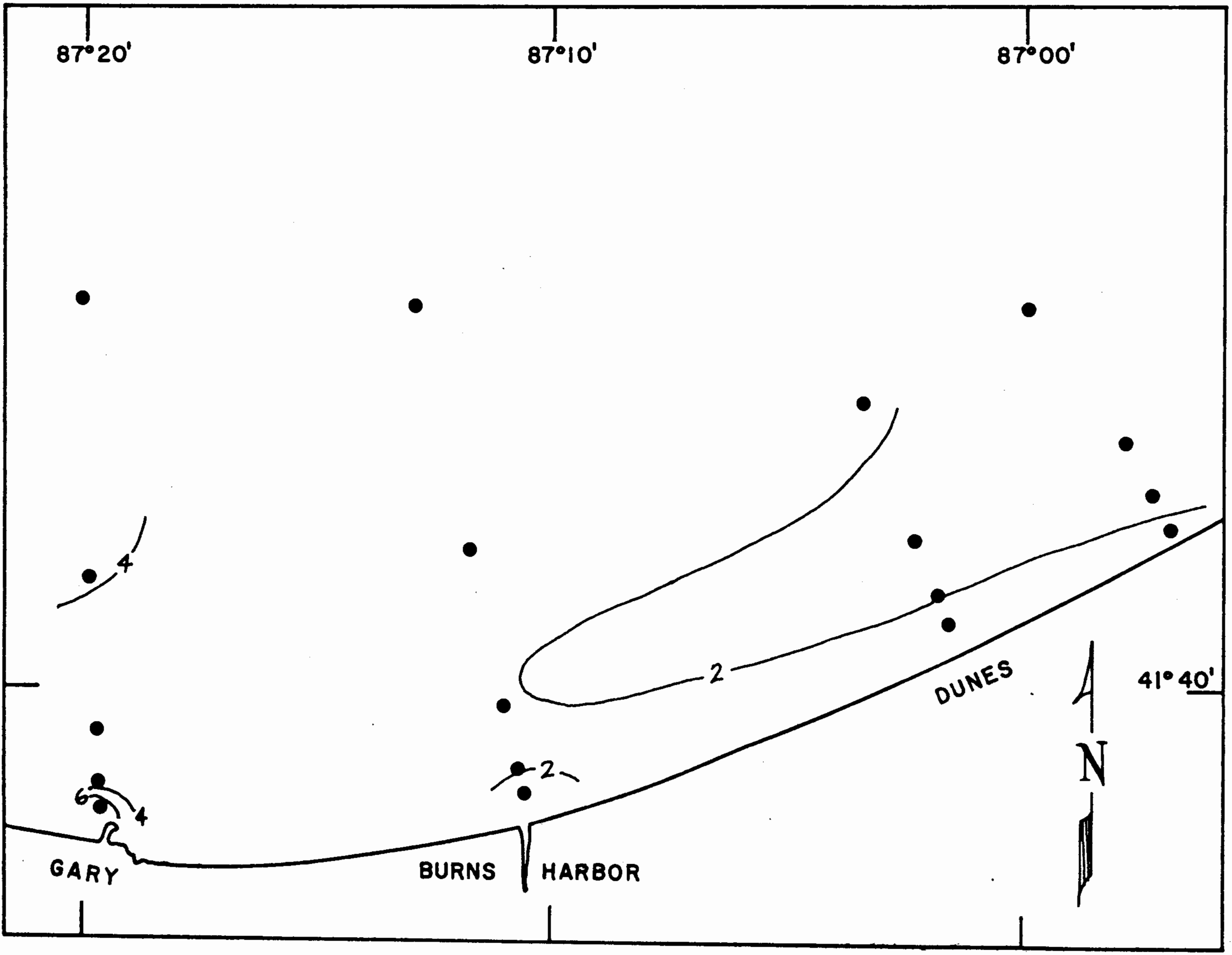

Figure 25. Distribution of *Keratella crassa*, September.

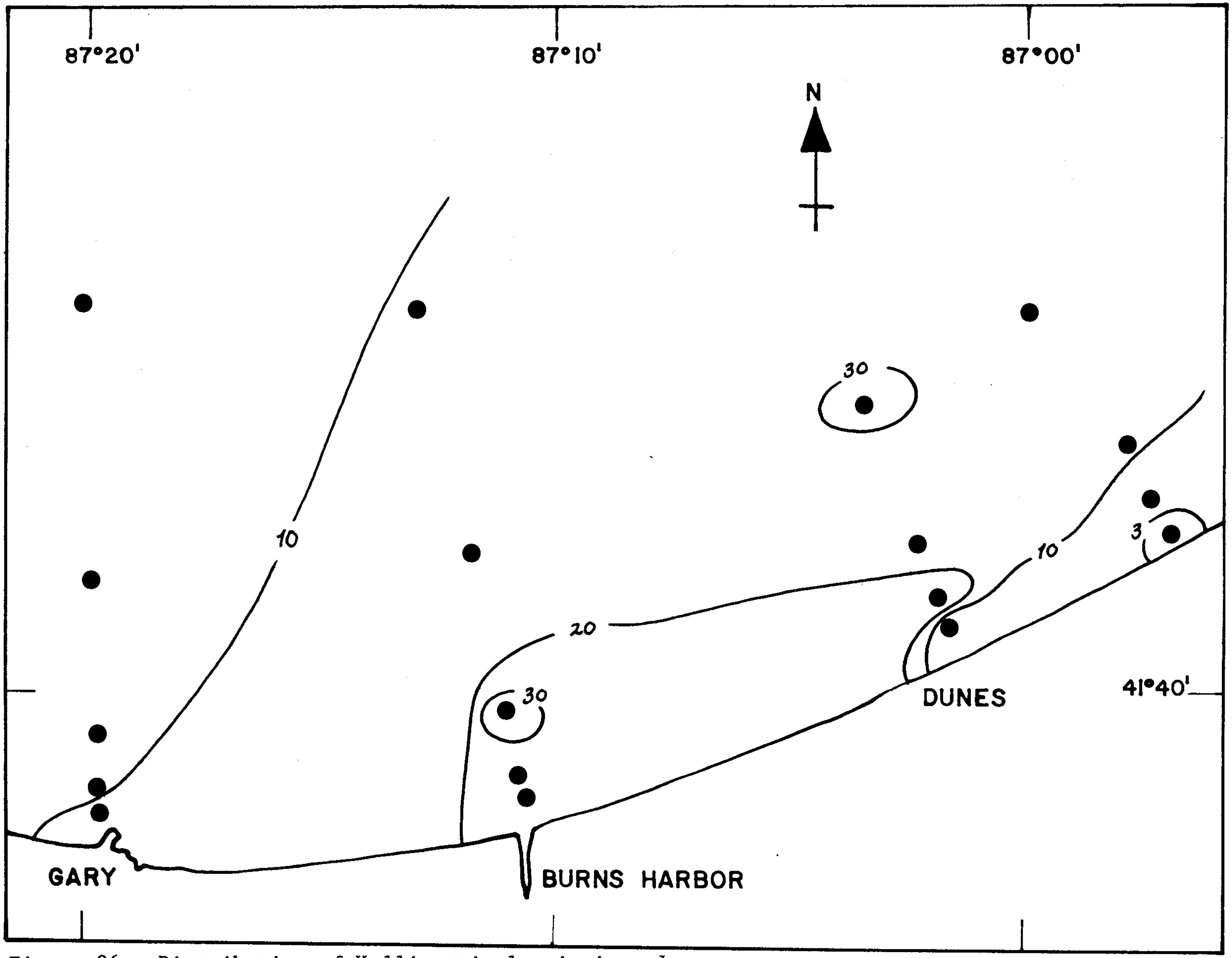

Figure 26. Distribution of *Kellicottia longispina*, June.

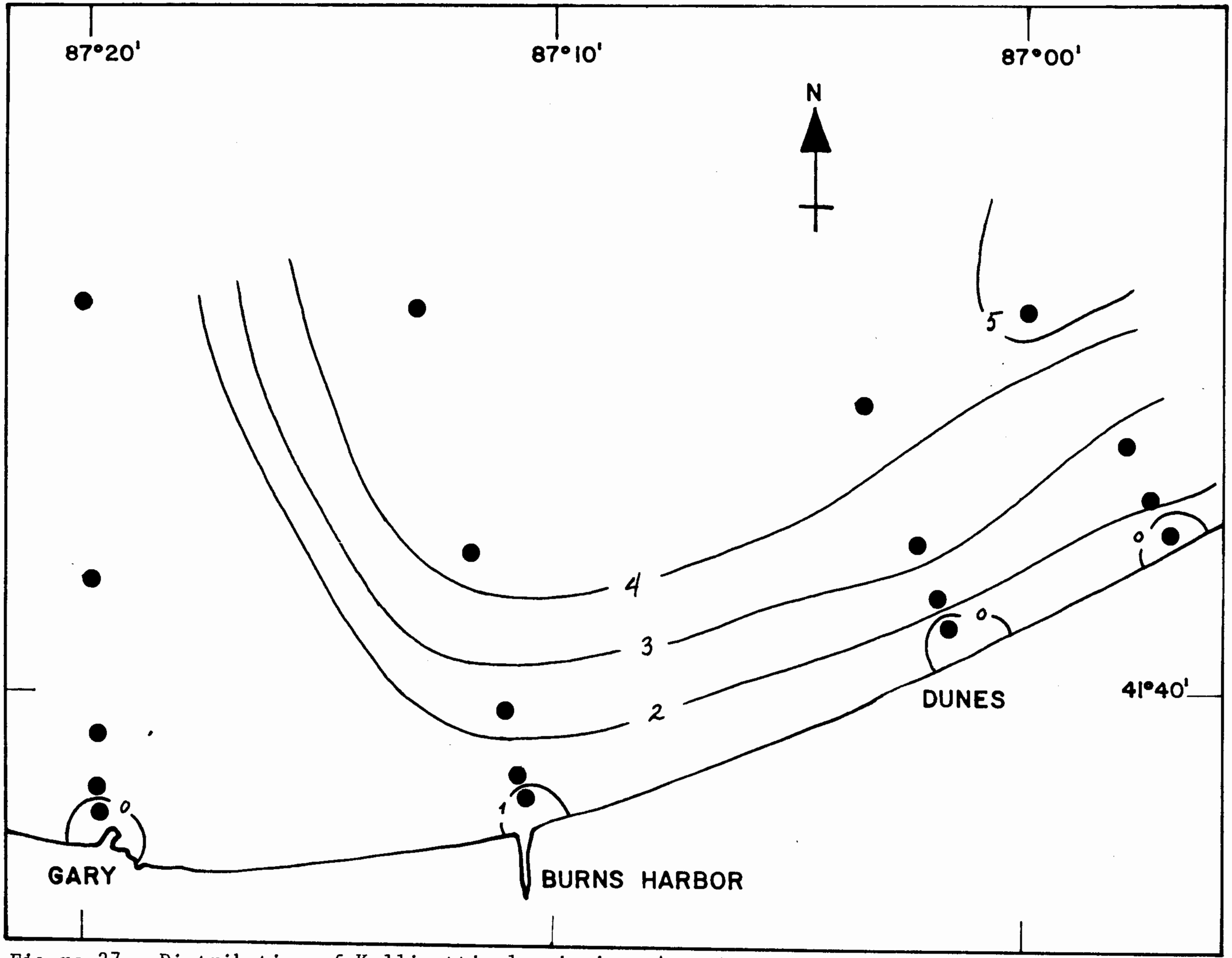

Figure 27. Distribution of Kellicottia longispina, August.

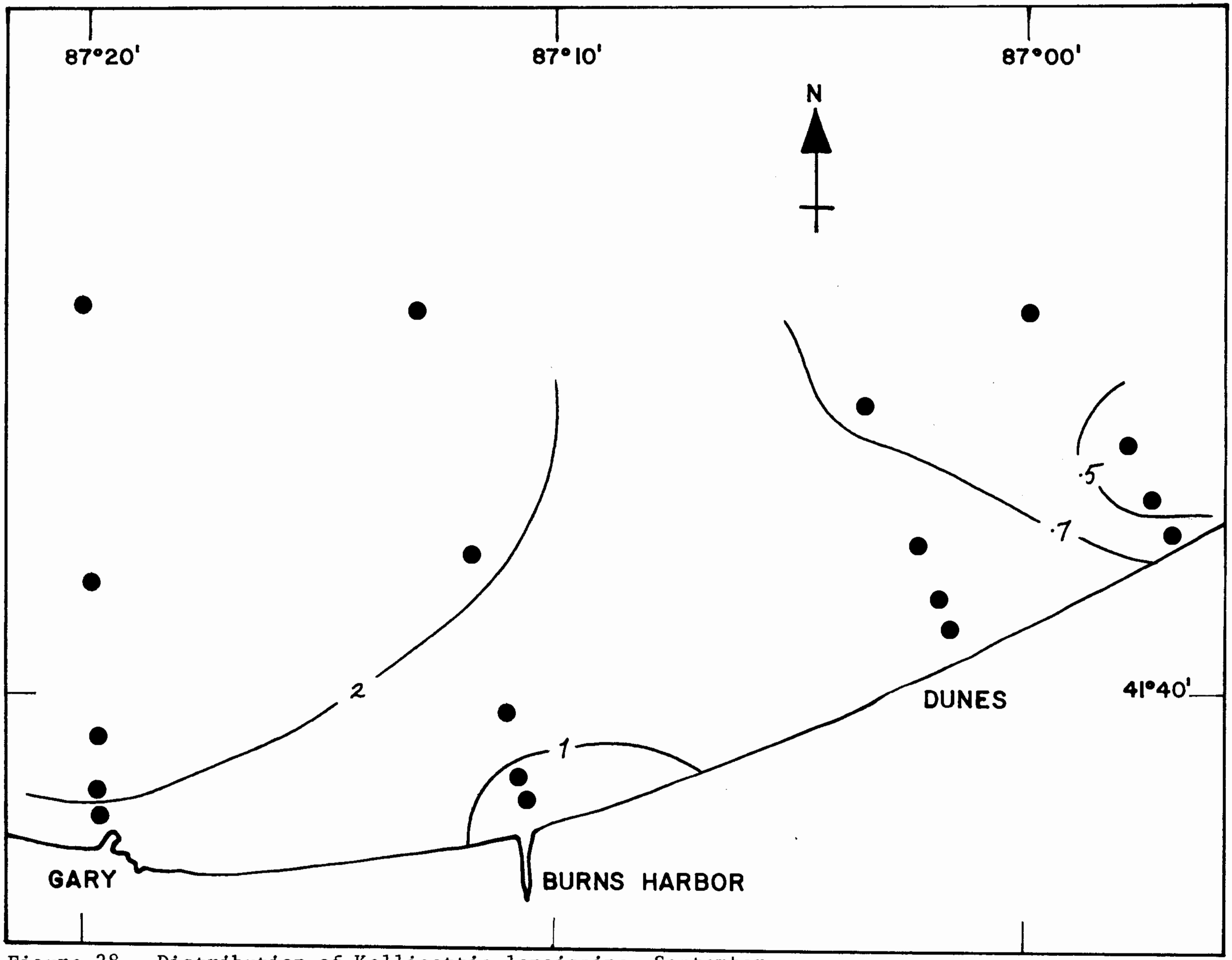

Figure 28. Distribution of *Kellicottia longispina*, September.

example, it exhibited significant (.01) positive correlation with temperature in June and significant (.01) negative correlation in August. Either no correlations or inconsistent ones were obtained.

Five species of *Polyarthra* were recorded in the study area, but only *P. vulgaris* and *P. remata* were relatively abundant. Respectively, they were the second and fourth most abundant species during the sampling period. *Polyarthra vulgaris* densities were highest (61,200 per m^3) in August and averaged 37,400 per m^3 for all cruises. *Polyarthra remata* was most prevalent in June (62,800 per m^3) and averaged 29,000 per m^3 for all cruises (Table 2; Appendix D, Table D-1).

Polyarthra remata exhibited a similar spatial distribution pattern to *P. vulgaris*. Consequently, only *P. vulgaris* is illustrated (Figures 29-31).

Polyarthra vulgaris exhibited a distinct inshore-offshore gradient in distribution in June (Figure 29). It ranged from 600 per m^3 at the 5 mile station to 49,000 per m^3 at the 1/2 mile station off Burns Harbor. It was most abundant at nearshore stations off Burns Harbor and Indiana Dunes and exhibited significant (.05) negative correlation with Secchi disc transparency. In August, it was most prevalent (70,000 to 80,000 per m^3) near Gary and Burns Harbor and at mid-transect stations off Indiana Dunes (Figure 30). No consistent distribution pattern was discernible in September but highest densities (71,600 per m^3) were recorded at the 1/2 mile station off Gary (Figure 31).

Conochilus unicornis was overwhelmingly most abundant (mean of 102,100 per m^3) in June when it comprised about one-third of total rotifers (Table 2). Its population dropped to 10% and 1% of June numbers in August and September, respectively. It was the third most abundant (mean of 36,200 per m^3) rotifer during the sampling period (Appendix D, Table D-1). In June, the distribution of *Conochilus* was similar to that observed for *Keratella* and *Polyarthra* (Figure 32). Densities ranged from less than 1,000 per m^3 at westernmost offshore stations to more than 300,000 per m^3 at nearshore locations off Indiana Dunes. High densities (98,300 to 226,300 per m^3) also were recorded nearest Burns Harbor and Michigan City harbor. It exhibited significant (.01) positive correlations with temperature and specific conductance in June. Patterns of distribution in August and September were less distinct and no significant correlations with physicochemical variables were obtained. In general, *Conochilus* was more prevalent offshore than nearshore on the two westernmost transects whereas its distribution eastward was irregular with respect to distance from shore (Figures 33-34).

NOTES ON SELECTED MINOR ROTIFER TAXA

Besides *Kellicottia*, the only rotifers encountered in the Indiana waters of southern Lake Michigan that appear to prefer colder waters were four species of *Notholca* (Table 2). *Notholca labis* was collected only at one station off Michigan City in September, but *N. foliacea*, *N. laurentiae*, and

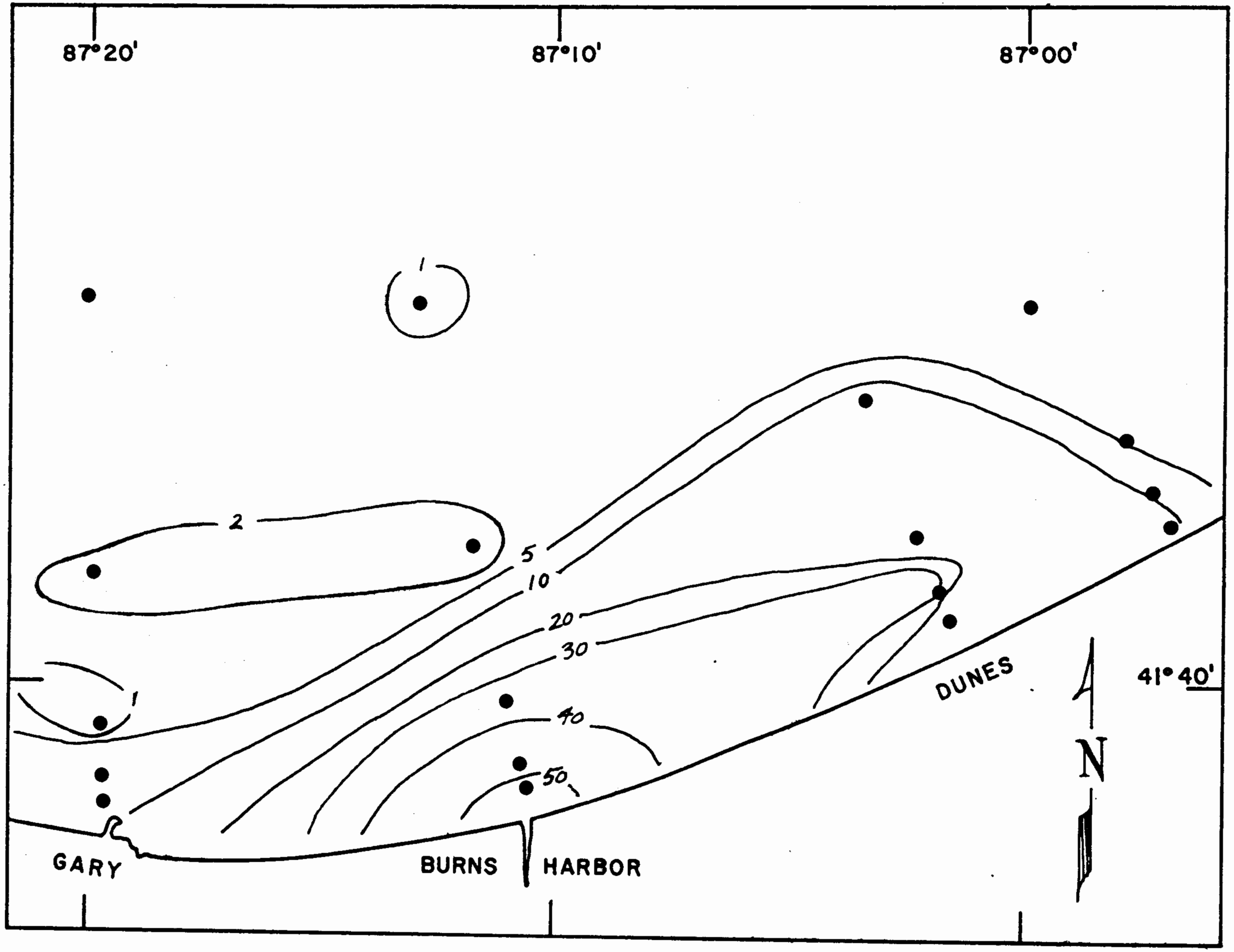

Figure 29. Distribution of Polyarthra vulgaris, June.

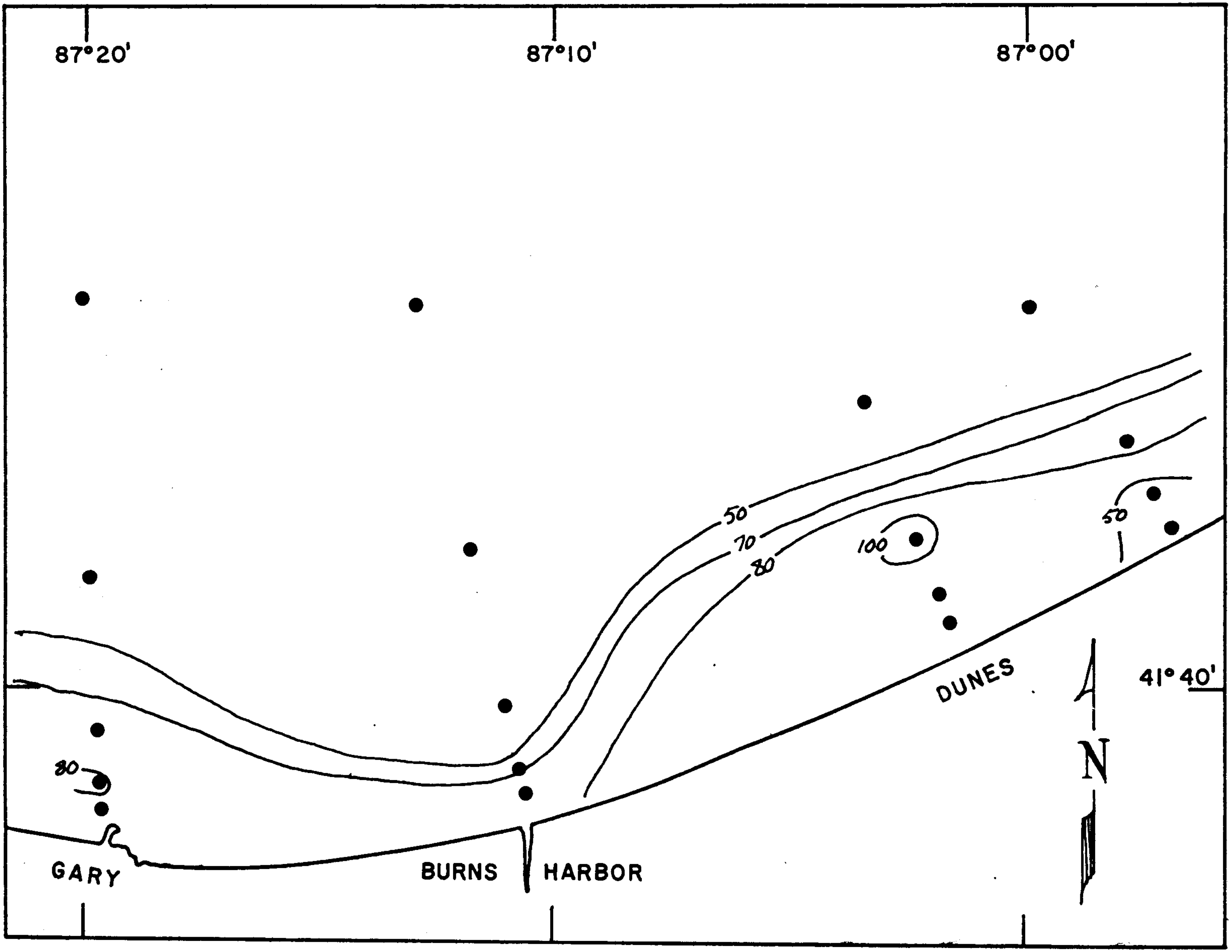

Figure 30. Distribution of Polyarthra vulgaris, August.

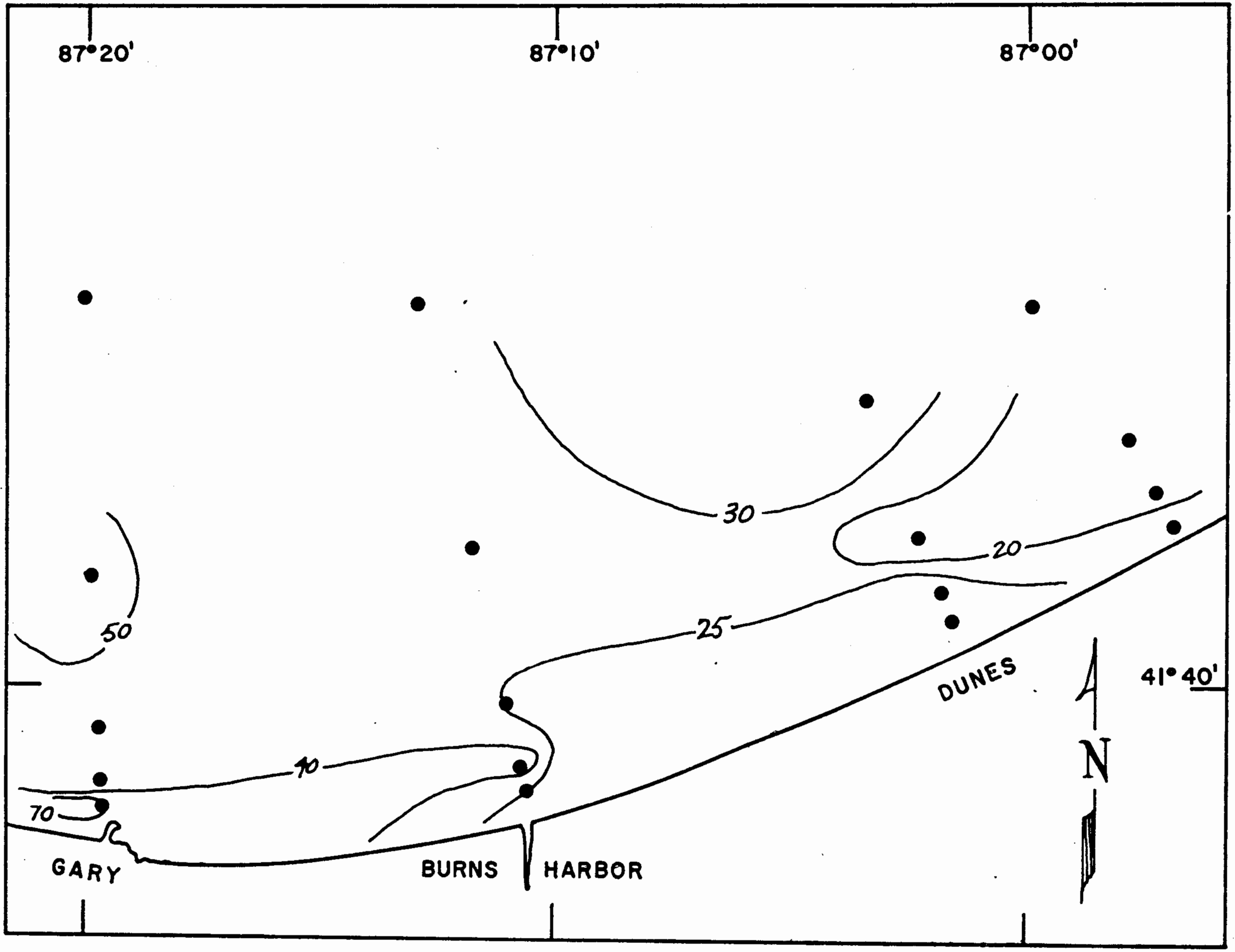

Figure 31. Distribution of Polyarthra vulgaris, September.

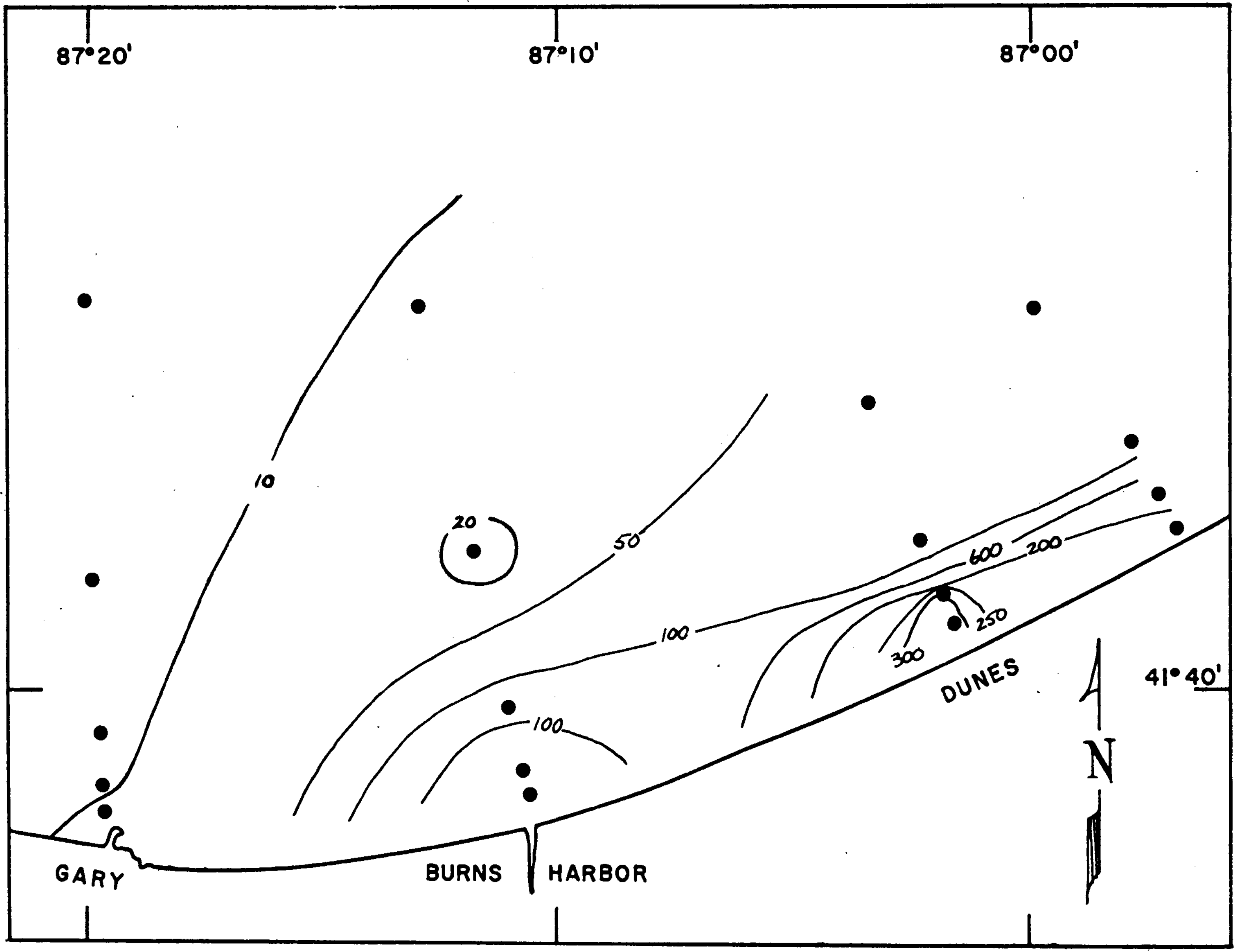

Figure 32. Distribution of Conochilus unicornis, June.

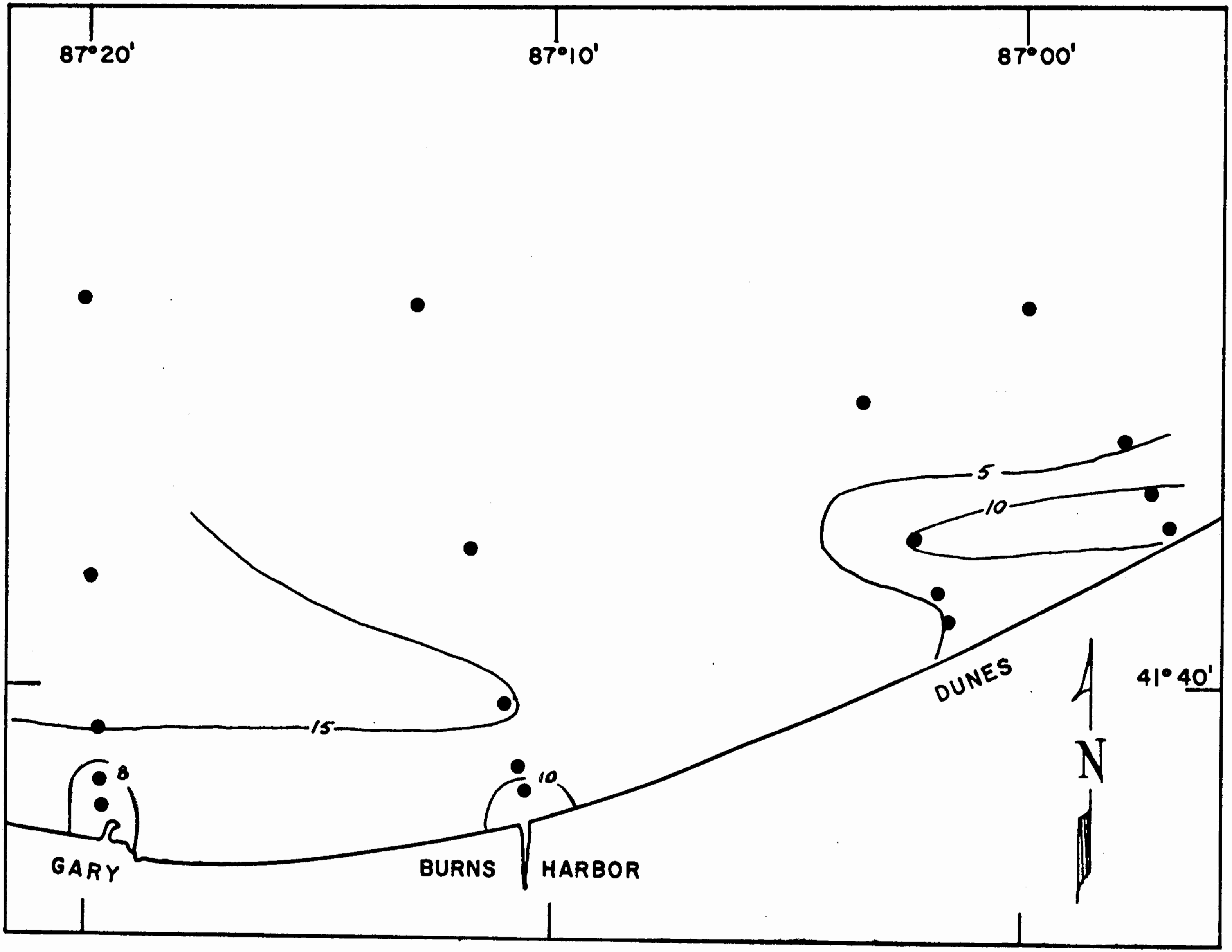

Figure 33. Distribution of *Conochilus unicornis*, August.

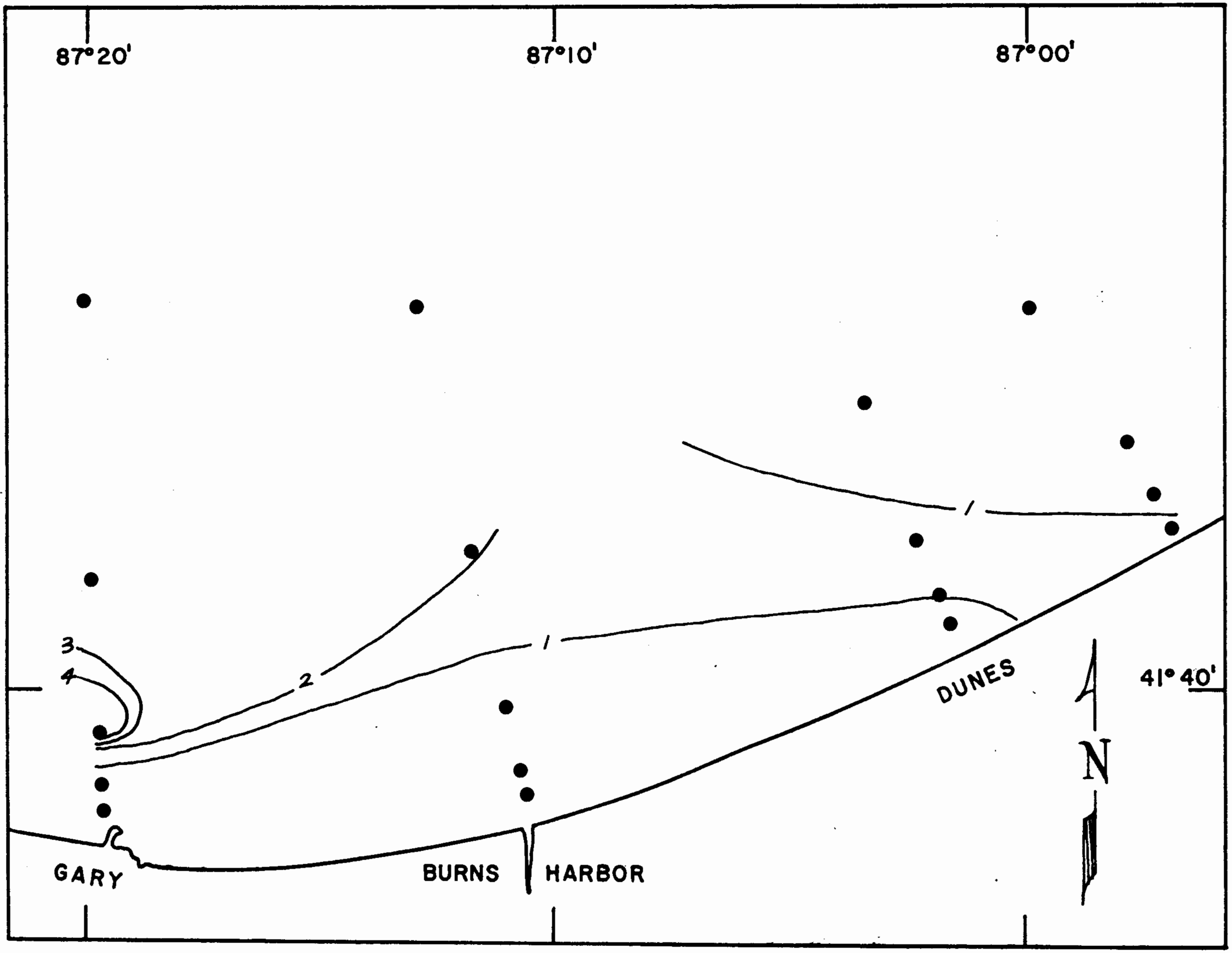

Figure 34. Distribution of Conochilus unicornis, September.

N. squamula were obtained in low numbers throughout the sampling period. They were observed only at westernmost outer stations in June where coldest waters prevailed (Appendix A). The highest density (2,700 per m^3) was recorded at the 5 mile station off Burns Harbor for *N. squamula*. All three species were rare (400 to 1,700 per m^3) only at outermost stations in August. *Notholca foliacea* and *N. squamula* were rare (100 to 400 per m^3) only at offshore stations in September but *N. laurentiae* was more widespread, occurring at most stations with a maximum of 3,400 per m^3 at the outermost station off Indiana Dunes.

A few limnetic species, such as *Filinia longiseta*, *Keratella cochlearis* f. *tecta*, *Pompholyx sulcata*, and *Polyarthra euryptera*, have apparent value as eutrophic indicators in the Great Lakes (Gannon and Stemberger 1978). These species were rare in the Indiana waters of southern Lake Michigan. Only a few individuals of *Pompholyx* were observed near Indiana (Gary) and Burns Harbor mouths in August and September. Similarly, a few *Filinia longiseta* were collected near Burns Harbor in September and a few *Polyarthra euryptera* were observed nearest Indiana Dunes in September. *Keratella cochlearis* f. *tecta* was found in low numbers (400 to 800 per m^3) near Burns Harbor, Indiana Dunes, and Michigan City in August.

The comparatively long species list of rotifers in southern Lake Michigan (Table 2) is primarily because of the presence of many littoral and benthic species in the plankton. Collection of occasional littoral specimens in the plankton is to be expected in turbulent nearshore waters. However, limnetic appearance of large numbers of littoral species (e.g., *Brachionus*, *Euchlanis*, *Trichocerca*) is an apparent response to eutrophication in the Great Lakes (Gannon and Stemberger 1978). None of the littoral species were observed in high densities during the sampling period.

Two species of *Brachionus* were observed. A few *B. angularis* were collected near Gary in June and near Michigan City in August and a few *B. caudatus* were observed near Burns Harbor in August. A single specimen of *Euchlanis dilatata* was collected nearest Burns Harbor in September. Five species of *Trichocerca* were collected with *T. porcellus* (overall mean abundance of 2,400 per m^3) being most abundant (Appendix D, Table D-1). *Trichocerca multicrinis*, the species of *Trichocerca* most often observed as an eutrophic indicator (Gannon and Stemberger 1978), was observed only in August with a mean abundance of 600 per m^3 (Table 2). It was collected only from stations near Gary and Burns Harbor mouths with a maximum of 2,900 per m^3 observed nearest Burns Harbor. *Trichocerca porcellus* and *T. rousseleti* were present during all sampling periods. They were rare in June; the former was collected near Gary and Burns Harbor and the latter only near Gary. They were widely distributed in August and September but highest densities occurred inshore. Maximum densities for *T. porcellus* were 7,300 per m^3 near Burns Harbor in August and 10,400 per m^3 near Gary in September. For *T. rousseleti*, maximum numbers were 2,500 per m^3 in August and 800 per m^3 in September near Indiana Dunes. *Trichocerca cylindrica* was found in low numbers (300 to 1,200 per m^3) near Gary, Burns Harbor, and Indiana Dunes in August and only near Gary (300 per m^3) in September. A few specimens of *T. pusilla* were collected off Indiana Dunes in August.

Other littoral and benthic rotifers (e.g., Lecane, Lepadella, Lophocaris, Monostyla, Platyias, Stephanocercos, Testudinella, Trichotria, and Tylotrocha) were collected as single individuals or a few specimens in nearshore waters, primarily near harbor mouths.

Other rotifers (e.g., Ascomorpha, Asplanchna, Collotheca, Gastropus, Keratella, Ploesoma, Polyarthra, and Synchaeta) are limnetic forms that were observed in comparatively low numbers in southern Lake Michigan. Only the prevalent species (mean overall abundance of >1,000 per m^3) will be discussed here (Appendix D, Table D-1).

Seven species had mean densities of greater than 1,000 per m^3 during the sampling period (Appendix D, Table D-1). In general, Synchaeta stylata, Gastropus stylifer, and Keratella cochlearis f. robusta tended to be most prevalent offshore whereas Asplanchna priodonta, Collotheca mutabilis, Ploesoma truncatum, and Polyarthra major exhibited a tendency toward greater densities near shore.

Synchaeta stylata had a total mean abundance of 4,800 per m^3 and was most prevalent (mean of 10,400 per m^3) in August when it comprised 5.5% of total rotifers (Table 2; Appendix D, Table D-1). In June, it had a maximum density of 12,800 per m^3 at the outermost station off Burns Harbor. Densities were low (1,300 to 1,600 per m^3) nearest Gary and Michigan City and none were collected nearest Burns Harbor. Its distribution was discontinuous in August with no individuals reported for the Burns Harbor and Indiana Dunes transects. This species was found only near Gary and Michigan City harbors with maximum abundance of 34,600 and 27,900 per m^3, respectively. In September, maximum numbers (8,100 per m^3) were obtained at the outermost station off Indiana Dunes. Densities tended to be slightly higher offshore (mean of 3,200 per m^3 at outermost stations) than inshore (mean of 2,900 per m^3 at innermost stations).

Gastropus stylifer had a mean overall abundance of 2,900 per m^3 and also was most prevalent during August (mean of 6,400 per m^3) (Table 2; Appendix D, Table D-1). Gastropus was relatively high (mean of 1,900 per m^3) at outermost stations in June but maximum numbers (4,200 per m^3) were recorded nearest Indiana Dunes. Its density nearest Gary and Burns Harbor was low (300 and 1,200 per m^3, respectively) and it was not collected on the Michigan City transect. Densities were higher at mid-depth locations in August with a maximum abundance of 15,100 per m^3 recorded at the 1 mile station off Burns Harbor. Relatively high densities also were recorded at 1 mile stations off Gary and Michigan City (9,200 and 7,100 per m^3). Numbers nearest harbors (mean of 4,800 per m^3) and farthest offshore (mean of 5,100 per m^3) were similar. In September, densities were highest offshore with the maximum abundance (3,700 per m^3) recorded off Gary. Numbers were especially low (<500 per m^3) near Burns Harbor and Michigan City harbor.

Keratella cochlearis f. robusta had an overall mean abundance of 1,700 per m^3 and was most prevalent (mean of 2,300 per m^3) in August (Table 2; Appendix D, Table D-2). In June, it was low in abundance (mean of 1,600 per m^3) at outermost stations and was most prevalent (15,400 to 17,200 per m^3) near Burns Harbor. Numbers in August were high (3,700 to 5,400 per m^3) at all outermost stations except off Gary. Numbers on the Gary transect were consistently low (300 to 400 per m^3). Densities were low (mean of 1,400 per m^3) at harbor mouths but relatively high (7,100 per m^3) nearest Indiana Dunes. Numbers in September were highest (mean of 1,900 per m^3) at outermost stations and the peak abundance was 2,500 per m^3 2 miles off Burns Harbor. Low densities (mean of 600 per m^3) were recorded at all 1/2 mile stations.

Asplanchna priodonta had an overall mean abundance of 2,000 per m^3 and was most prevalent in June (mean of 4,800 per m^3) (Table 2; Appendix D, Table D-1). It was infrequent (0 to 2,100 per m^3) at outermost stations in June and was most abundant (17,200 per m^3) at the Burns Harbor mouth. It also was prevalent nearest Indiana Dunes (9,300 per m^3). A similar pattern was observed in August but at much reduced densities. Highest numbers (2,100 per m^3) were recorded nearshore at Indiana Dunes and Michigan City. Densities also were relatively high (1,700 per m^3) at the Burns Harbor mouth. It was low in abundance (800 per m^3) or absent from outermost stations. Asplanchna was collected from about one-half of the stations in low abundance during September. Highest numbers (700 per m^3) were observed at the outermost station off Indiana Dunes.

Ploesoma truncatum also exhibited its highest mean abundance (2,600 per m^3) in August and had an overall mean density of 1,300 per m^3 (Table 2; Appendix D, Table D-2). It was found only inshore near Gary, Burns Harbor, and Indiana Dunes in June, ranging from 300 per m^3 near Gary to 1,300 per m^3 off Burns Harbor. Relatively high densities were obtained off Indiana Dunes (11,900 per m^3) and nearest Burns Harbor (7,900 per m^3) in August whereas outermost stations averaged 1,600 per m^3. The same trend for higher densities nearshore was apparent in September. Numbers were especially high (2,700-3,700 per m^3) near Gary. Outermost stations averaged 600 per m^3.

Polyarthra major was rare in June (mean of 200 per m^3) but was prevalent in August and September (means of 3,300 and 2,800 per m^3). Its overall mean abundance during the sampling period was 2,100 per m^3. It was collected at three scattered stations in June with highest numbers observed nearest Indiana Dunes. It was most abundant nearshore in August, especially nearest Burns Harbor (12,100 per m^3). Outermost stations averaged 1,000 per m^3. Densities were similar inshore (mean of 2,500 per m^3 at 1/2 mile stations) and offshore (mean 2,300 per m^3 at outermost stations) on harbor transects in September. However, numbers were considerably higher offshore (8,800 per m^3) than nearest shore (2,700 per m^3) on the Indiana Dunes transect.

Collotheca mutabilis had an overall abundance of 3,800 per m^3 and was most abundant in August with a mean of 6,200 per m^3. Except off Gary, densities of Collotheca were higher inshore. In June, the lowest numbers (200 to 600 per m^3) were observed at mid-depth stations off Gary. Maximum densities were obtained near Indiana Dunes (11,800 per m^3). Stations nearest harbors averaged 3,300 per m^3 while outermost stations were 1,100 per m^3. In August, there was a slight trend for increasing numbers shoreward to a maximum at 1 mile stations and then numbers decreased nearest shore. The highest density (8,700 per m^3) was recorded at the 2 mile station off Indiana Dunes and the mean of all 2 mile stations was 7,400 per m^3. In contrast, means at outermost and innermost stations were 6,700 and 5,900 per m^3, respectively.

Densities were more uniformly distributed in September but the trend for increasing numbers shoreward was still evident. The highest (6,600 per m^3) was at the 2 mile station off Gary.

SEASONAL AND SPATIAL DISTRIBUTION OF MAJOR CRUSTACEA

An examination of the crustacean plankton data revealed that patterns of distribution are more readily discernible using percentage composition rather than numbers per unit volume. A similar conclusion was reached in processing micro-crustacean data from the Straits of Mackinac and northern Lake Michigan (Gannon *et al*. 1976). Consequently, distribution of micro-crustaceans will be discussed primarily in terms of percentage composition in this section.

Bosmina longirostris was the most abundant micro-crustacean in the Indiana waters of southern Lake Michigan. It had a total mean abundance for all cruises of 3,000 per m^3 (Appendix D, Table D-2), representing 70.6% of all Cladocera and 38.5% of total Crustacea. It was most prevalent (mean of 6,530 per m^3) in June and represented 57.3% of cladocerans and 58.1% of total micro-crustaceans. Densities were considerably less in August and September (means of 310 and 1,630 per m^3, respectively) but *B. longirostris* still comprised 15.4% and 38.4% of total Cladocera, respectively.

In June, *Bosmina longirostris* exhibited a northwest to southeast gradient in abundance, with southeastern stations nearest Indiana Dunes and Michigan City recording the highest densities (4,900 to 15,200 per m^3). In contrast, outermost stations on western transects were comparatively low in abundance (430 to 1,070 per m^3). This species comprised less than 10% of total Crustacea offshore on western transects and over 70% near Indiana Dunes and Michigan City (Figure 35).

Bosmina longirostris densities in August were highest (530 per m^3) off the Gary Harbor mouth but, in terms of percentage composition, it was relatively most abundant near Indiana Dunes (Figure 36). It comprised less than 10% of total Crustacea at offshore locations and over 50% nearest Indiana Dunes. In September, densities (2,450 to 5,890 per m^3) and relative abundance (30-40% of total Crustacea) were highest near Gary (Figure 37).

The spatial distribution of *Bosmina longirostris* throughout the sampling period strongly resembled the distribution of predominate rotifers, such as *Keratella cochlearis* (Figures 20-22) and physicochemical variables (Appendices A-C). *Bosmina* densities were consistently highest in waters with high turbidity and specific conductance. This species exhibited a significant (.05) positive correlation with specific conductance and alkalinity and a significant (.05) negative correlation with Secchi disc transparency in August. Moreover, a significant (.01) positive correlation was obtained with specific conductance and temperature in September.

The other representative of the cladoceran family Bosminidae, *Eubosmina coregoni*, was considerably less abundant than *Bosmina longirostris*. *Eubosmina*

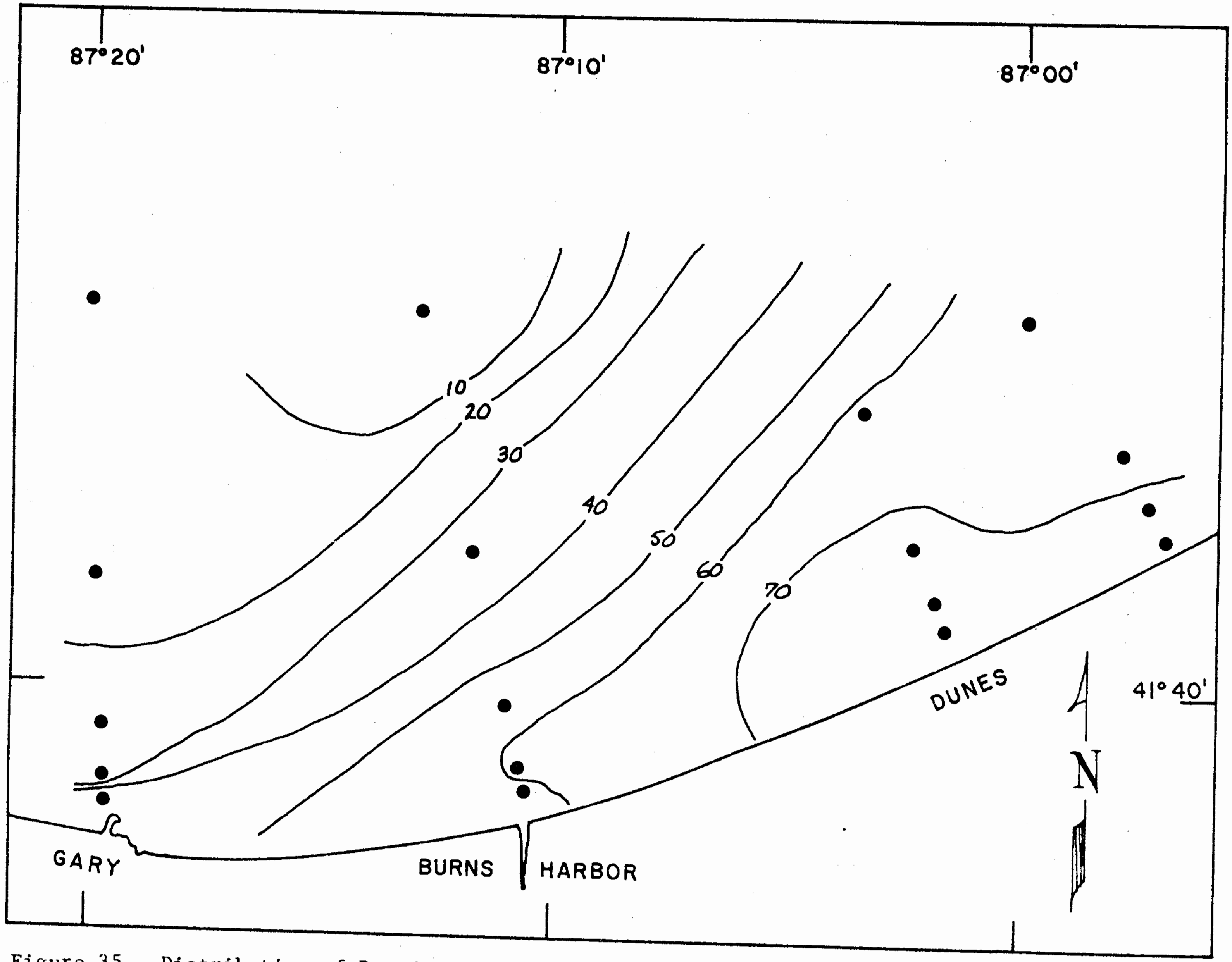

Figure 35. Distribution of Bosmina longirostris, June.

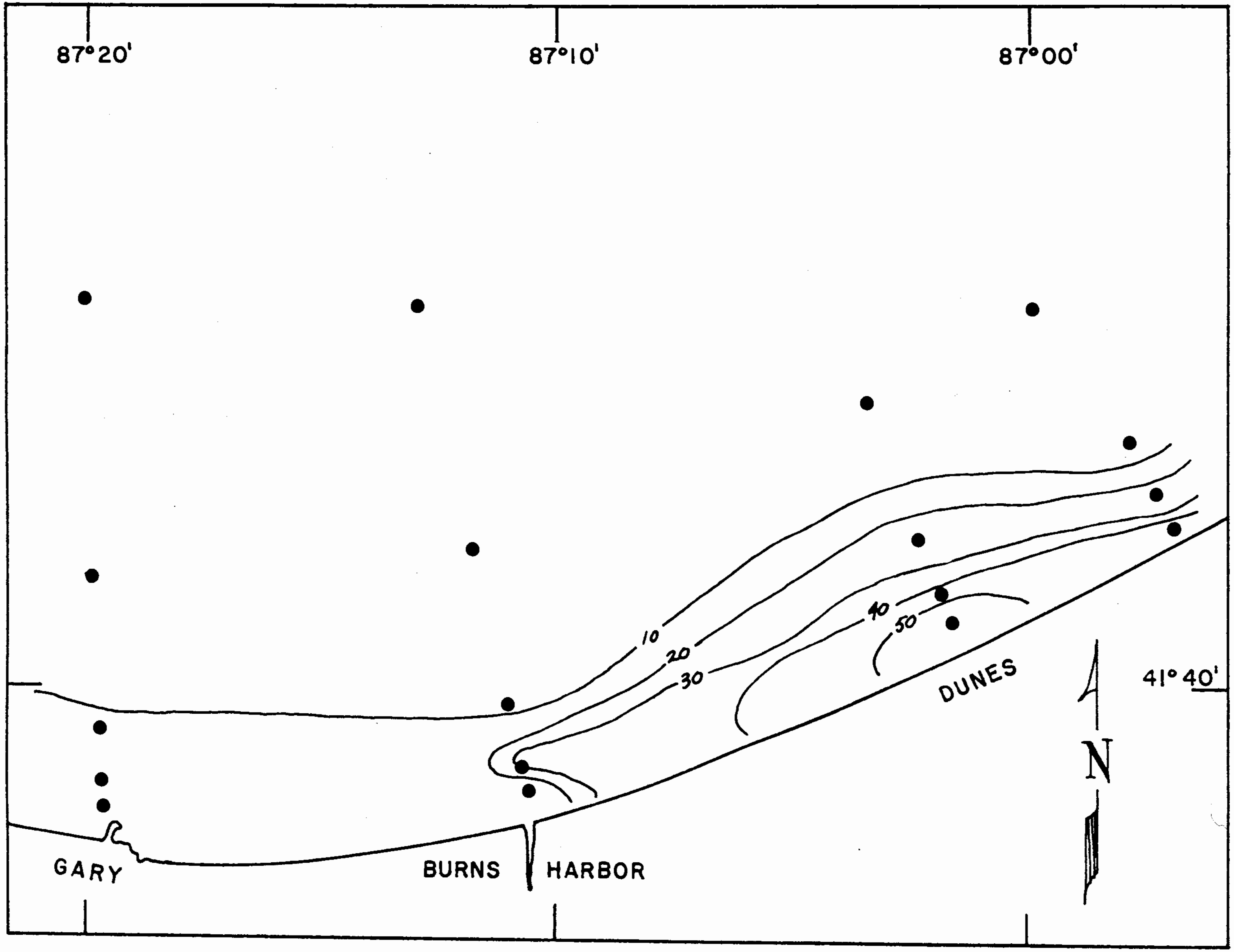

Figure 36. Distribution of Bosmina longirostris, August.

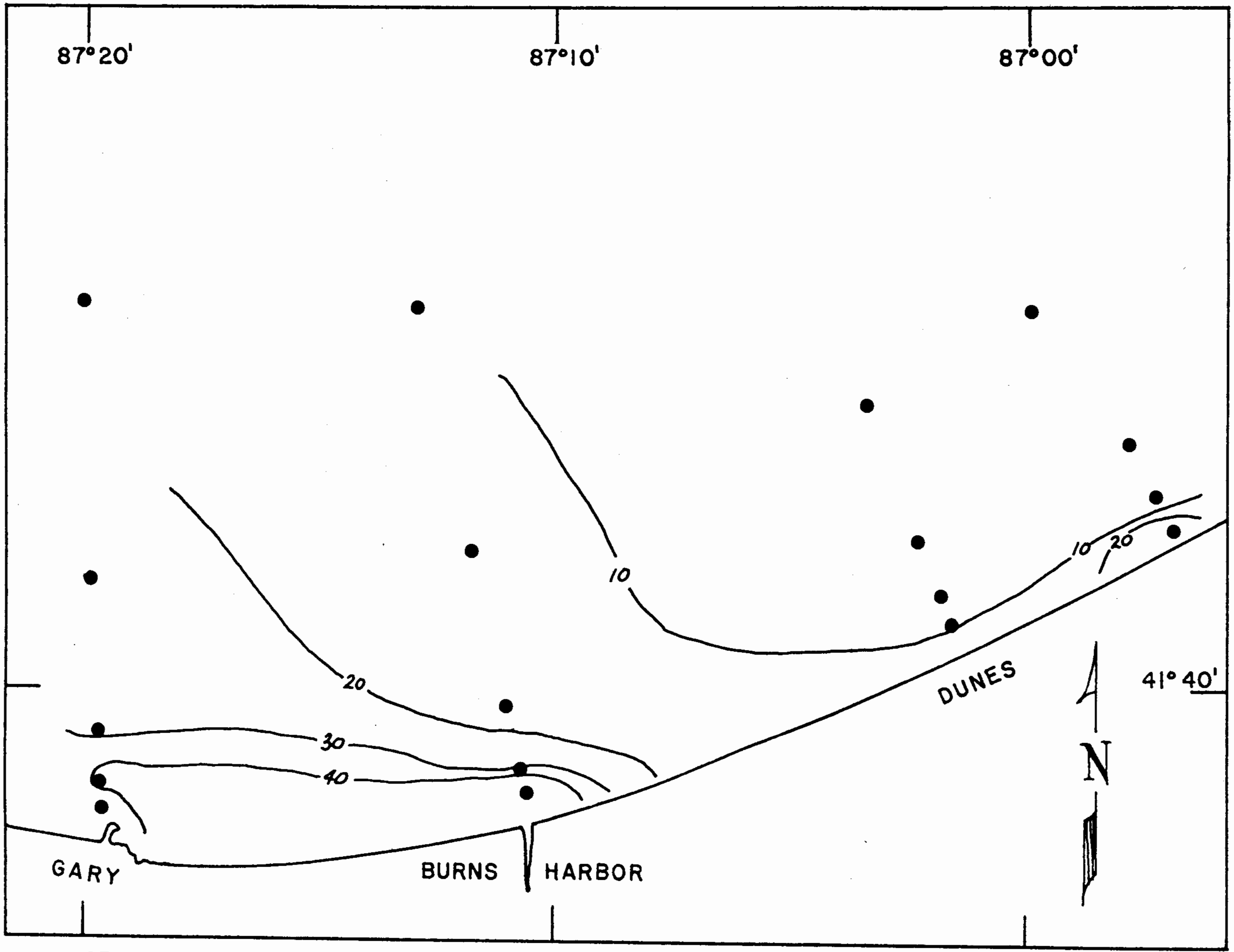

Figure 37. Distribution of Bosmina longirostris, September.

coregoni had a total mean abundance of 140 per m^3 during the study period (Appendix D, Table D-2). Its density increased as the season progressed from a mean of 10 per m^3 in June to a mean of 310 per m^3 in September (Table 3). In contrast to B. longirostris, the distribution of E. coregoni was sufficiently discontinuous from station to station that it was not possible to contour these data. Nevertheless, some trends in spatial distribution of this species are noteworthy.

In June, it seems that the Eubosmina population was just beginning to appear in plankton. This species was found in low numbers (10 to 30 per m^3) at most nearshore locations in warmer water. It was absent from all cooler offshore stations. In contrast, Eubosmina was more prevalent offshore in August. A maximum of 310 per m^3 was recorded at the outermost stations off Gary. Relative abundance offshore ranged from 3 to 6% of total Crustacea while nearshore values ranged from 2.8% nearest Gary to none near Indiana Dunes and Michigan City. Distribution of Eubosmina was especially discontinuous in September with two density peaks, one (940 per m^3) 1 mile off Gary and the other (600 per m^3) 1/2 mile off Michigan City. It tended to be slightly more prevalent at middle stations on the transects than nearshore or offshore. Its relative abundance averaged 3.6% at the outermost stations, 3.5% nearest shore, and 4.2% at middle locations.

No consistent statistically significant correlations between the distribution of E. coregoni and physicochemical variables were obtained. Moreover, no consistently significant correlations were obtained with any other crustacean plankter except B. longirostris.

Daphnia retrocurva was the second most abundant cladoceran in the study area. It had a total mean abundance of 690 per m^3 for all cruises (Appendix D, Table D-2). Similar to E. coregoni, D. retrocurva was apparently just beginning to appear in the plankton during June (mean of 30 per m^3) and became common in August (mean of 930 per m^3) and September (mean of 1,170 per m^3), representing 0.5, 46.3, and 31.9%, respectively, of total Cladocera (Table 3).

The spatial distribution of D. retrocurva was similar to Eubosmina. In June, D. retrocurva was found only at warmer nearshore stations and was most prevalent (10 to 150 per m^3) on the two easternmost transects. It comprised from 0 to 0.6% of total Crustacea at various stations (Figure 38). In August, its distribution was discontinuous, ranging from 10 per m^3 nearshore at Indiana Dunes to 2,040 per m^3 2 miles off Burns Harbor (Figure 39). In spite of the anomolous high density at this Burns Harbor station, it was relatively more abundant on the outer transects (35.3%) than on the inner ones (28.3%). Daphnia retrocurva was most prevalent at middle locations on each transect in September. It ranged from 240 per m^3 nearest Gary to 2,910 per m^3 at the 1 mile station on the same transect. Harbor mouth stations (mean of 570 per m^3) were lower in density than the station nearest Indiana Dunes (1,140 per m^3). This species averaged 10.7% of total Crustacea at outermost stations, 18.9% at middle stations, and 14.9% nearest shore (Figure 40).

Daphnia galeata mendotae was considerably less abundant than D. retrocurva. It had an overall mean abundance of 140 per m^3 (Appendix D,

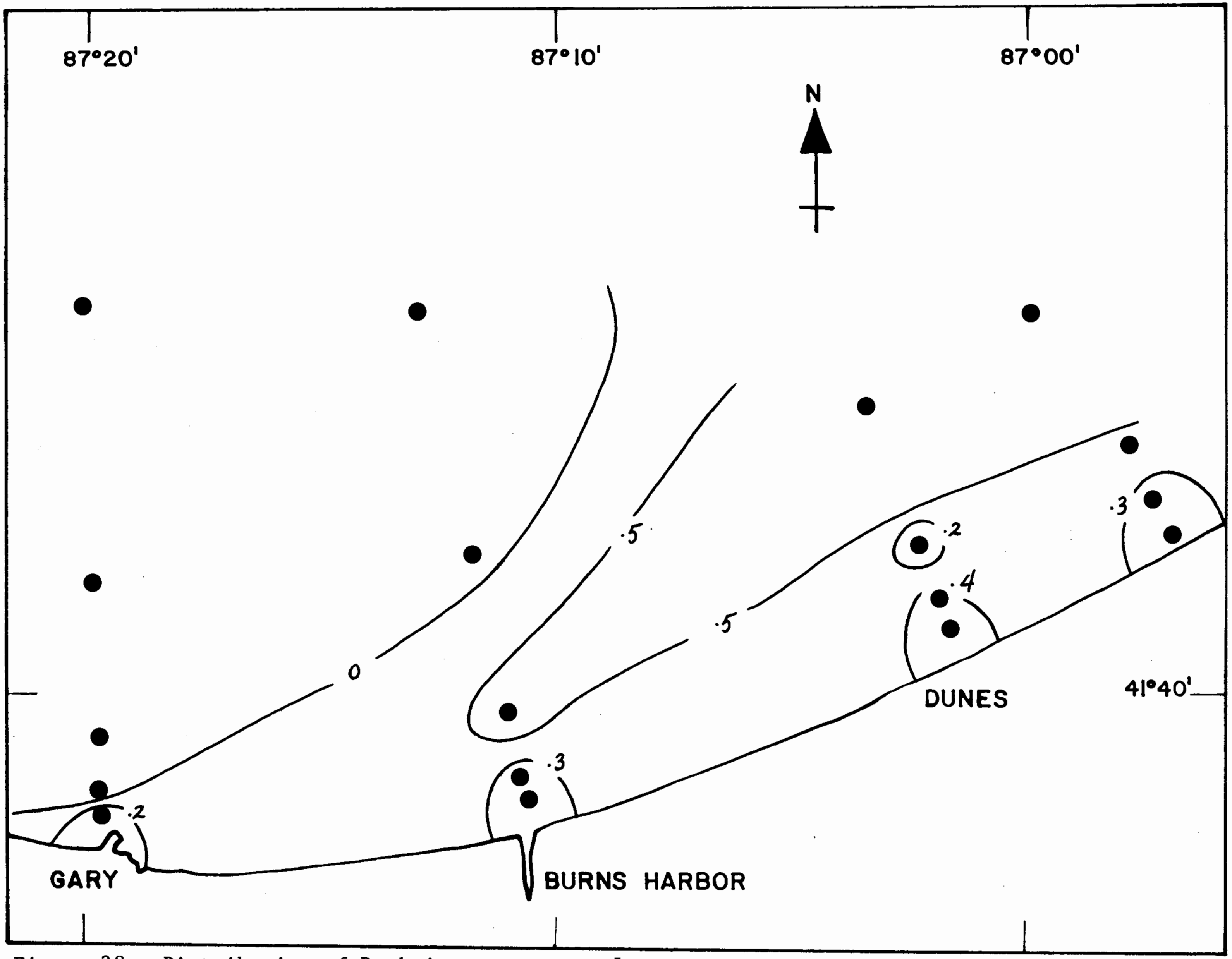

Figure 38. Distribution of *Daphnia retrocurva*, June.

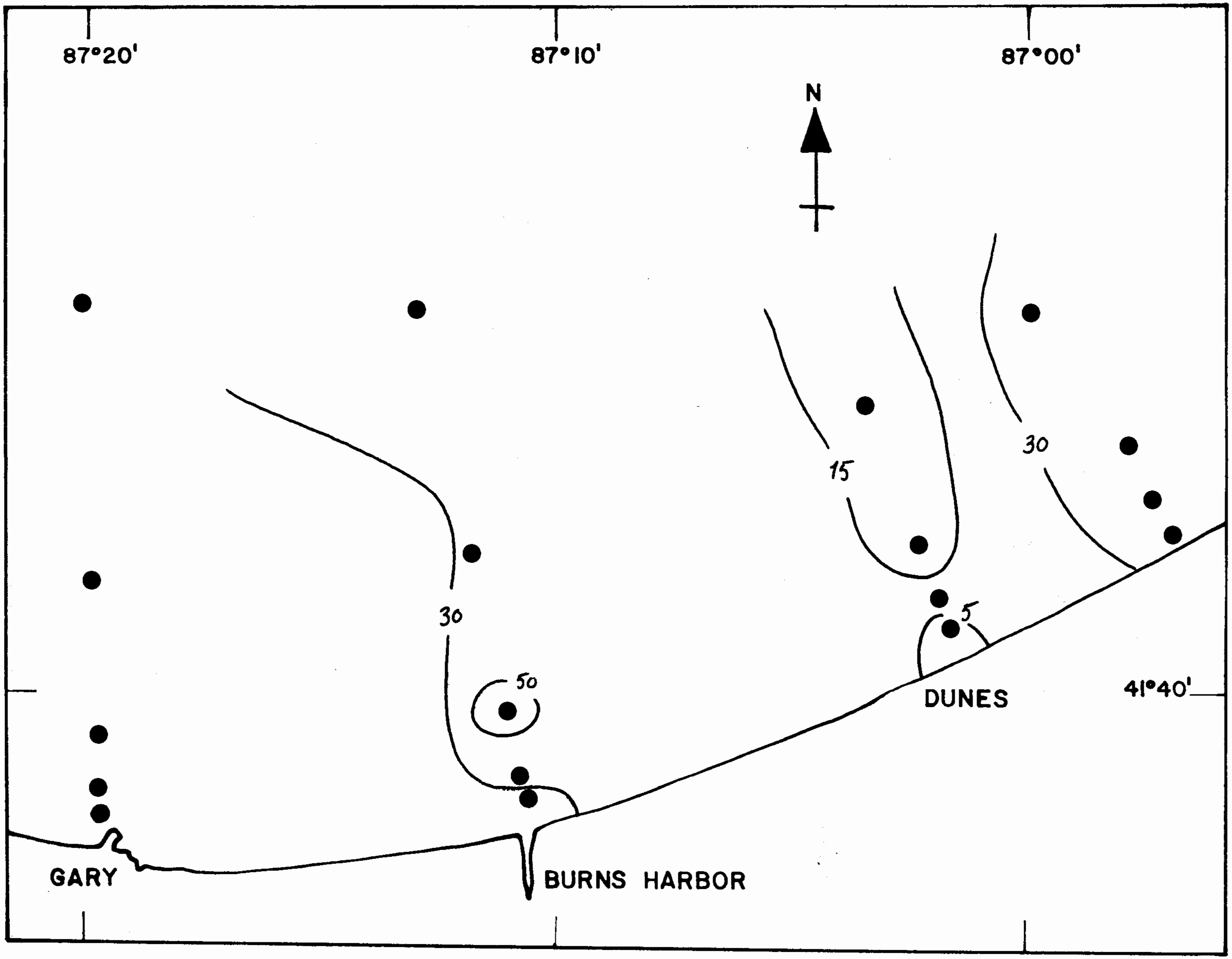

Figure 39. Distribution of *Daphnia retrocurva*, August.

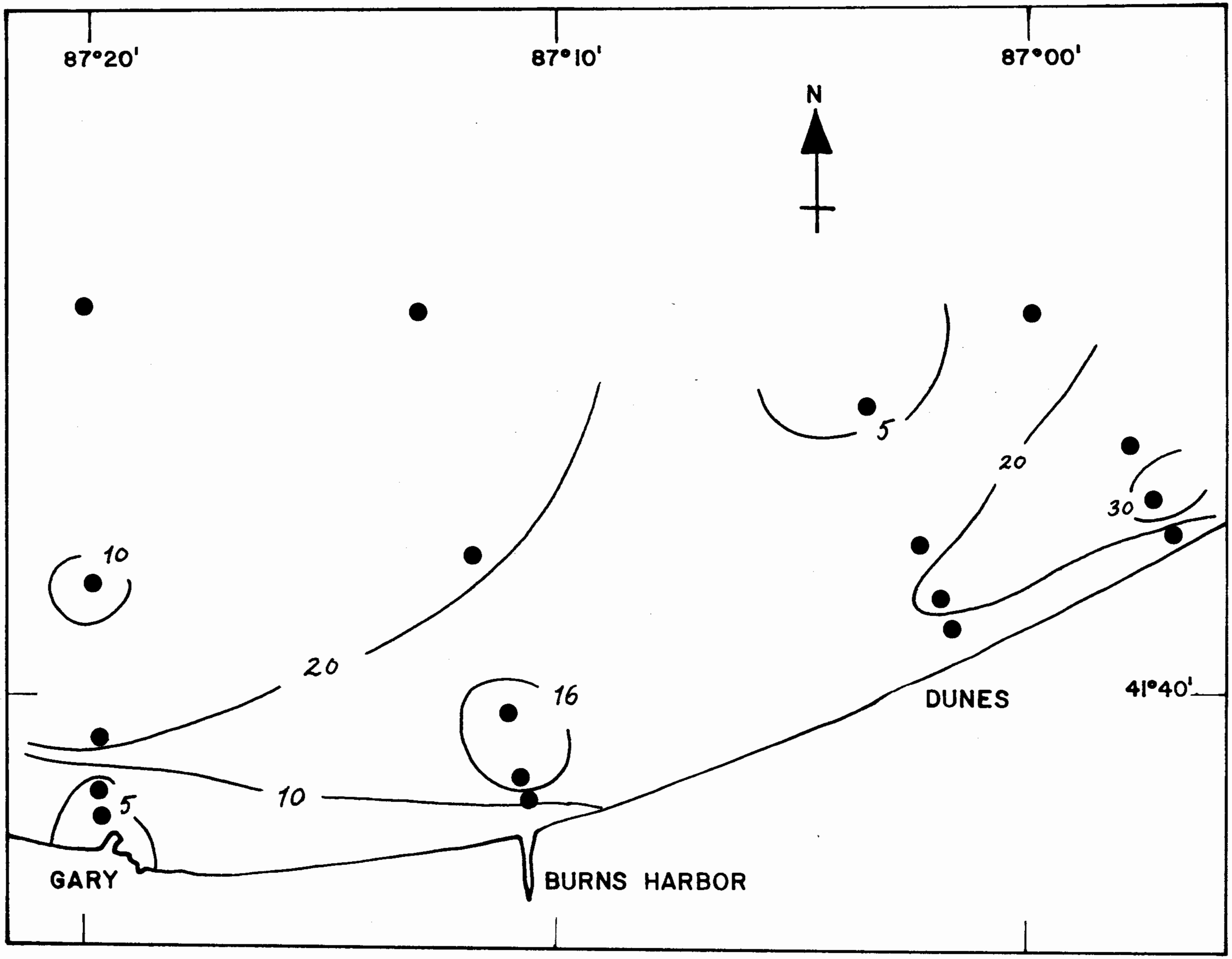

Figure 40. Distribution of <u>Daphnia</u> <u>retrocurva</u>, September.

Table D-2). Only a few individuals were collected in June near Gary and Indiana Dunes and the population became progressively larger in August (mean of 930 per m^3) and September (mean of 1,170 per m^3) (Table 3).

In contrast to D. retrocurva, D. galeata mendotae was more abundant offshore. In August, it was collected at every station except the 1/2 mile station off Indiana Dunes. Densities at stations nearest shore ranged from 30 to 60 per m^3 (mean of 2.6% of total Crustacea) while outermost stations were from 410 to 490 per m^3 (mean of 7.6%). In general, there was a trend of decreasing densities shoreward from northwest to southeast in the study area (Figure 41). In September, numbers also were greater offshore but the trend of decreasing densities shoreward was from northeast to southwest. Concentrations were highest (920 per m^3) at outer stations on the Indiana Dunes transect and lowest (0, 30 and 80 per m^3) near the mouths of Gary harbor, Burns Harbor, and Michigan City harbor, respectively. Relative abundance ranged from over 12% of total Crustacea at the easternmost outer station to zero near Gary (Figure 42).

Diaphanosoma spp. (primarily D. leuchtenbergianum) was the only other relatively abundant cladoceran in the study area. It had a total mean abundance for all cruises of 200 per m^3 (Appendix D, Table 2). As with most other cladocerans, individuals were just beginning to appear in the plankton during June; a few specimens were collected only at one station, 1 mile off Indiana Dunes. Mean abundance was 430 per m^3 in August and 260 per m^3 in September (Table 3).

The distribution of Diaphanosoma resembled that of Eubosmina and Daphnia retrocurva, with highest densities recorded at stations 1 to 2 miles from shore during August and September. Low densities nearest shore did not appear to be influenced overtly by harbors since numbers nearest Indiana Dunes (mean of 145 per m^3) and nearest harbors (mean of 197.7 per m^3) were appreciably similar in August and September. In August, highest densities (850 to 1,330 per m^3) were observed at offshore stations on the two inner transects where Diaphanosoma represented over 20% of total Crustacea (Figure 43). Densities nearest shore ranged from 10 to 450 per m^3 (mean of 13.6%). In September, Diaphanosoma distribution was more discontinuous but the tendency for higher numbers at mid-depth locations still was evident. Highest densities (near 500 per m^3) were recorded 1 mile off Burns Harbor and 5 miles off Indiana Dunes. Lowest numbers (30 to 60 per m^3) were obtained nearest Gary and Burns Harbor and at the outermost station off Gary. Densities nearest shore ranged from 40 to 280 per m^3 (mean of 3.5%) (Figure 44).

Diacyclops thomasi was the only relatively abundant cyclopoid copepod in the plankton of southern Lake Michigan. Its total mean abundance for all cruises was 760 per m^3 (Appendix D, Table D-2). It was most prevalent (mean of 1,720 per m^3) in June when it comprised 6.7% of total Crustacea and 36.1% of all Copepoda (Table 3). Diacyclops consistently was more prevalent offshore during all sampling periods. In June, it was most abundant (7,170 per m^3) 1 mile off Gary and least prevalent (140 per m^3) nearest Indiana Dunes. A general decreasing trend in relative abundance from northwest (30.9 to 45.8% of total Crustacea) to southeast (4.5 to 10.0%) was evident in June (Figure 45). Diacyclops was a minor constituent of the plankton in August,

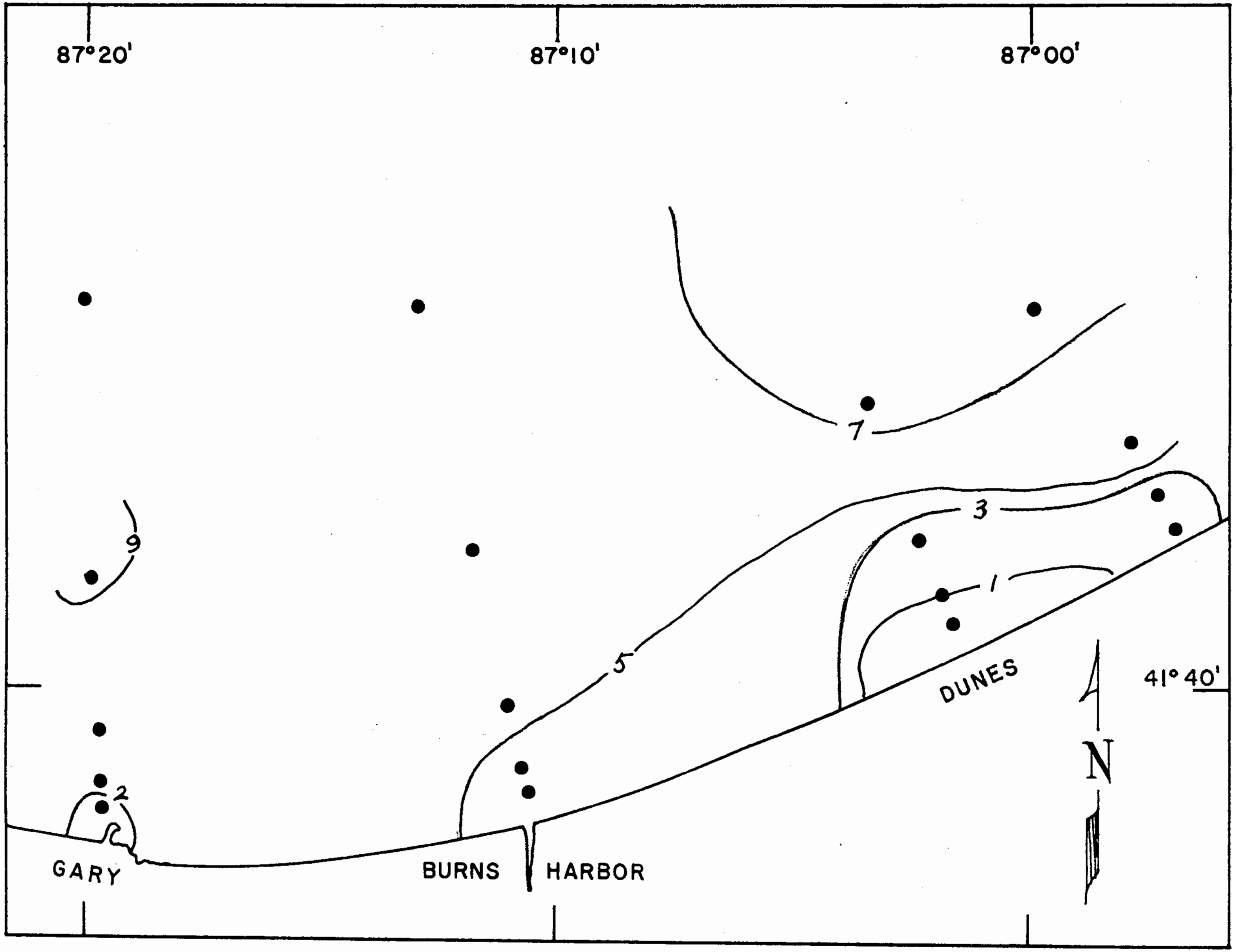

Figure 41. Distribution of Daphnia galeata mendotae, August.

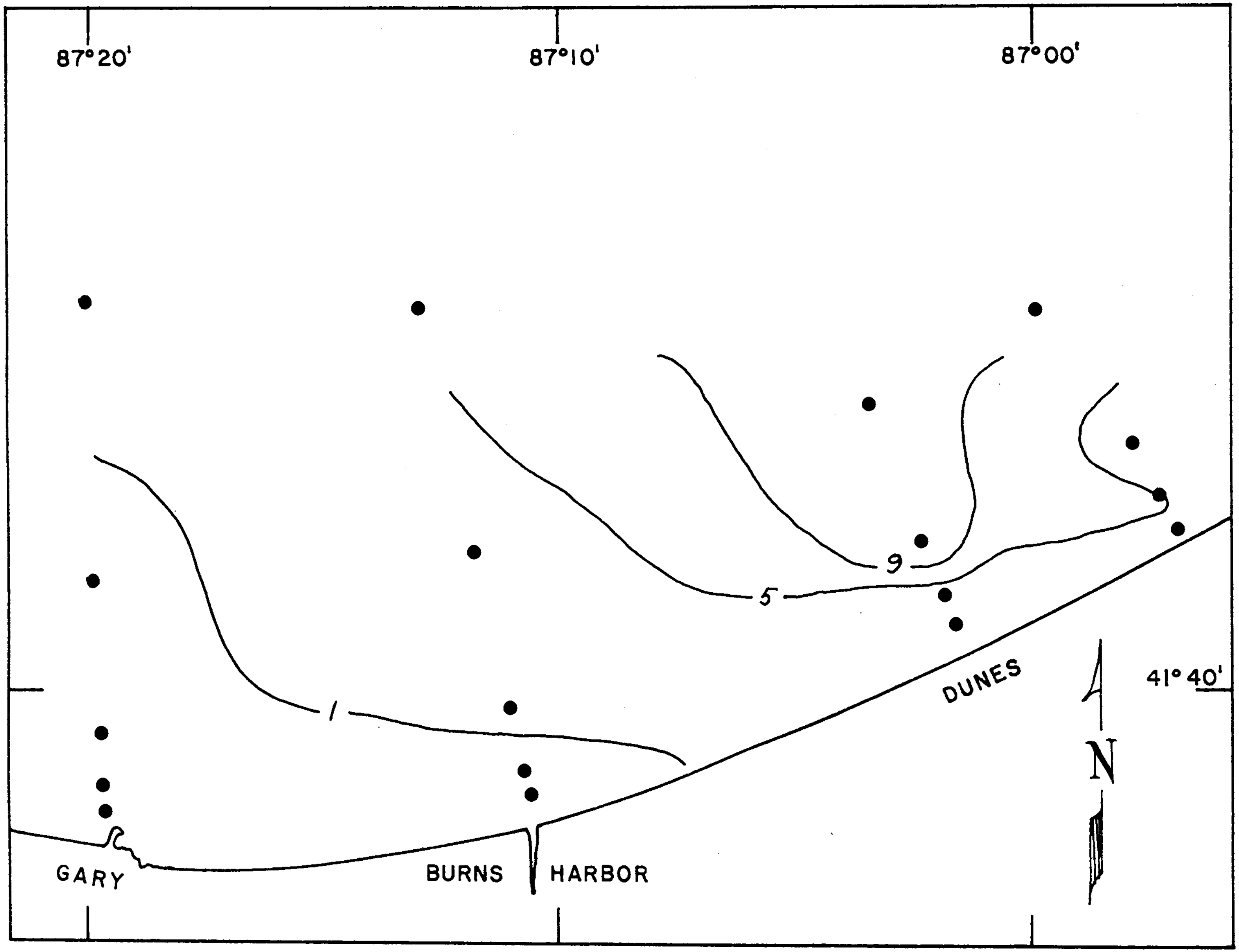

Figure 42. Distribution of *Daphnia galeata mendotae*, September.

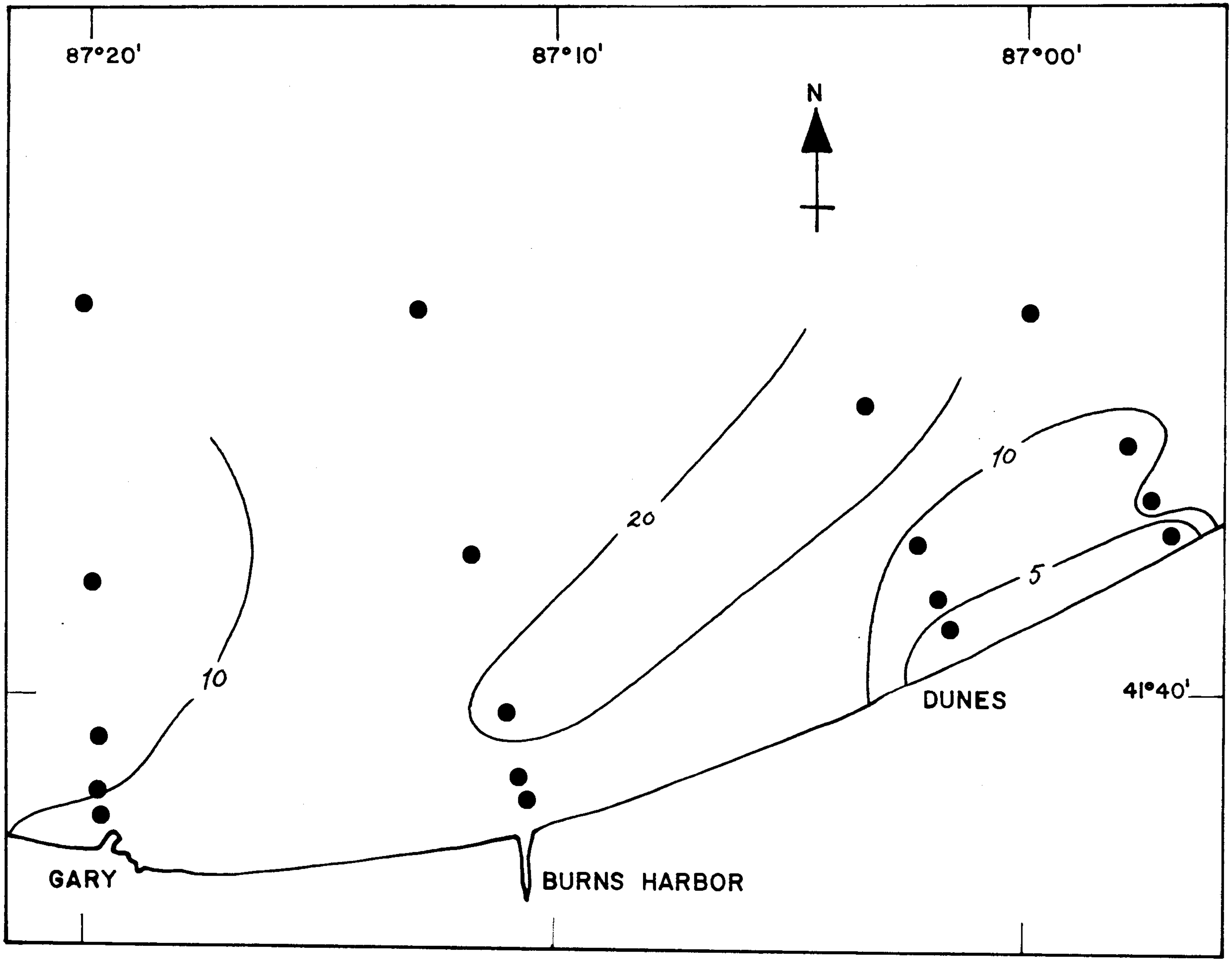

Figure 43. Distribution of Diaphanosoma, August.

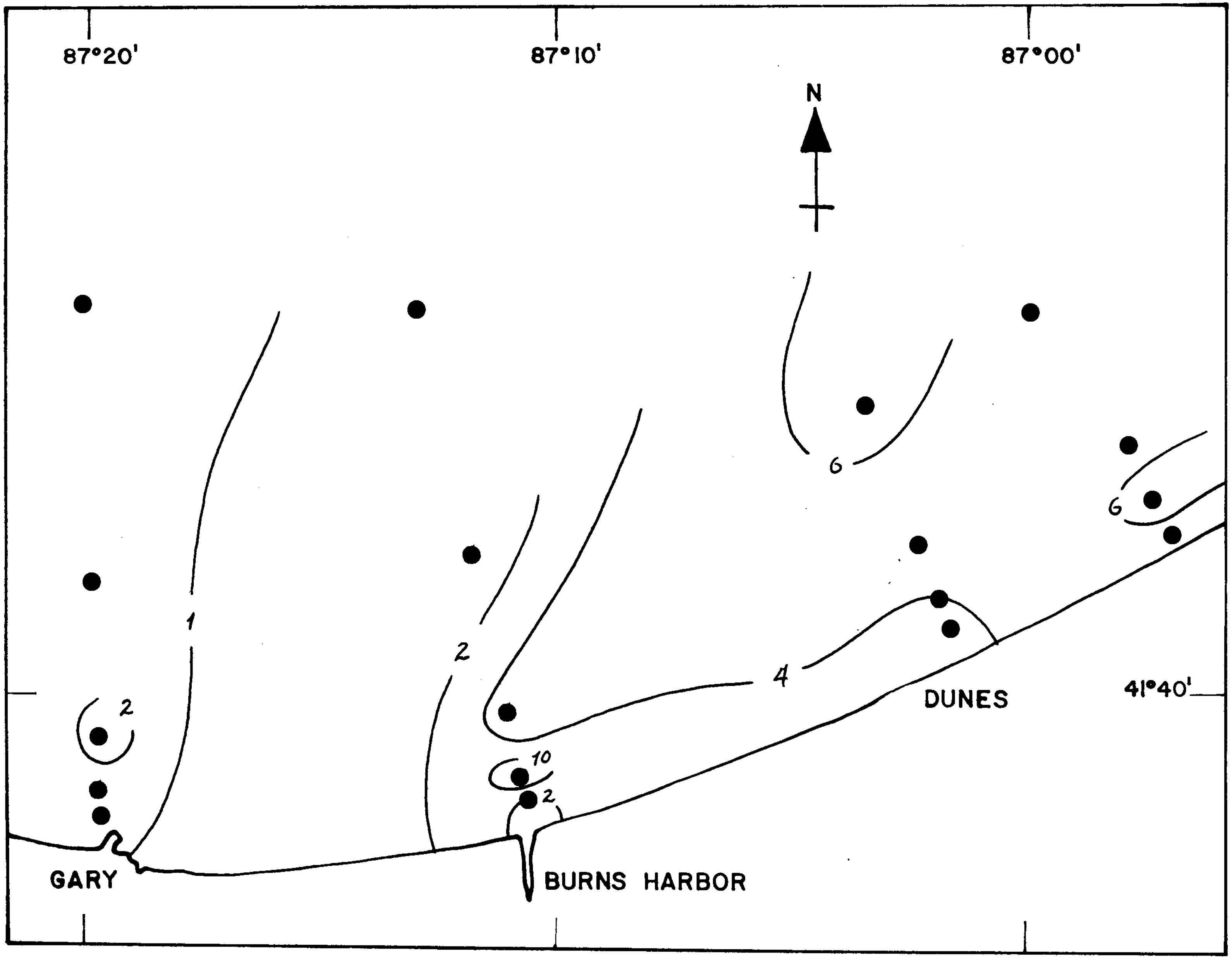

Figure 44. Distribution of Diaphanosoma, September.

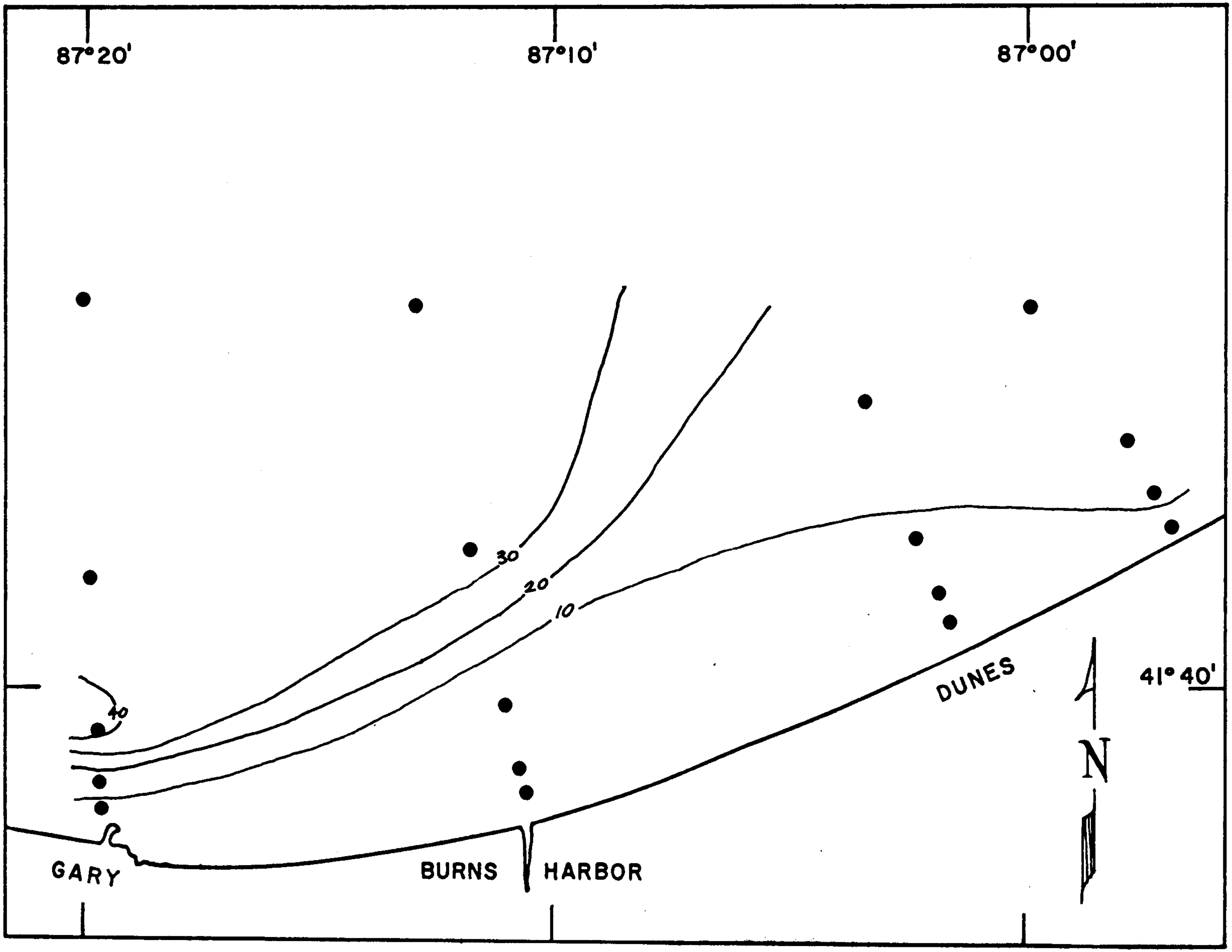

Figure 45. Distribution of Diacyclops thomasi, June.

comprising only 4.0% of total Crustacea, but it was still most prevalent offshore. Its mean abundance at outermost stations was 315 per m^3 in comparison with a mean of 16.7 per m^3 at all other stations. It was absent nearest shore at Indiana Dunes and Michigan City. This species was relatively most abundant (8.7%) at the outermost station off Gary and ranged from 0-2% nearshore (Figure 46). Although the mean abundance of Diacyclops increased to 320 per m^3 in September, it remained at 4.0% of total Crustacea (Table 3). It was most abundant (1,150 per m^3) at the outermost station off Indiana Dunes and least prevalent (50 per m^3) nearest Burns Harbor. This species was relatively most abundant (5.0 to 15.5%) at outer stations northeastward and was considerably less frequent (1.0 to 4.6%) elsewhere (Figure 47). As with all the Cladocera exept Bosmina longirostris, no consistently significant correlations between Diacyclops distribution and physicochemical variables were observed.

Immature diaptomid copepodids were the most abundant calanoid copepods, averaging 1,980 per m^3 during the sampling period and comprising 72.2% of total calanoids, 55.9% of total copepods, and 24.8% of total Crustacea (Appendix D, Table D-2). The copepodids were not identified to species, but based on relative abundance of adults, it is assumed that the majority of the immature diaptomids were Leptodiaptomus ashlandi and L. minutus. Average density of copepodids varied considerably; it was highest (3,210 per m^3) in September and was approximately 1.5 and 10 times lower in June and August, respectively. Even though density was so low in August, abundance remained relatively high at 11.3% of total Crustacea as compared to 18.1% and 39.9% in June and September, respectively (Table 3).

Diaptomid copepodids exhibited a marked decrease in density eastward in the study area in June and a decrease southward in August (Figures 48, 49). In June, highest numbers (7,450 per m^3) were recorded at the outermost station off Burns Harbor and lowest (50 per m^3) were near Michigan City. Relative abundance ranged from over 40% of total Crustacea near Gary to less than 1% near Michigan City (Figure 48). They were slightly less abundant (19.3%) less than 1 mile from shore in comparison with offshore stations (mean of 22.5%). The copepodids also were relatively more abundant nearest harbor mouths (mean of 22.4%) in comparison with the 1/2 mile station off Indiana Dunes (12.1%). In August, numbers ranged from 920 per m^3 at the outermost station off Burns Harbor to 60 per m^3 nearest Michigan City. Relative abundance was slightly less (mean of 12.2%) nearshore (1/2 and 1 mile stations) than offshore (mean of 11.1%) (Figure 49). In September, the spatial distribution of diaptomid copepodids was more discontinuous. Highest numbers (6,950 per m^3) were recorded near Gary and lowest (1,480 per m^3) near Michigan City. Abundance (range of 21.8 to 52.9%) was relatively high at all stations. No consistent east-west or north-south trends in abundance were observed. Relative abundance was slightly higher (mean of 45.3%) on Gary and Indiana Dunes transects than off Burns Harbor and Michigan City (32.8%) (Figure 50).

Adults of Leptodiaptomus ashlandi and L. minutus were similar in overall mean abundance (240 and 250 per m^3, respectively). Both species were most prevalent (450 and 310 per m^3, respectively) in June. Leptodiaptomus minutus (mean of 290 per m^3) was about three times more abundant than L. ashlandi in

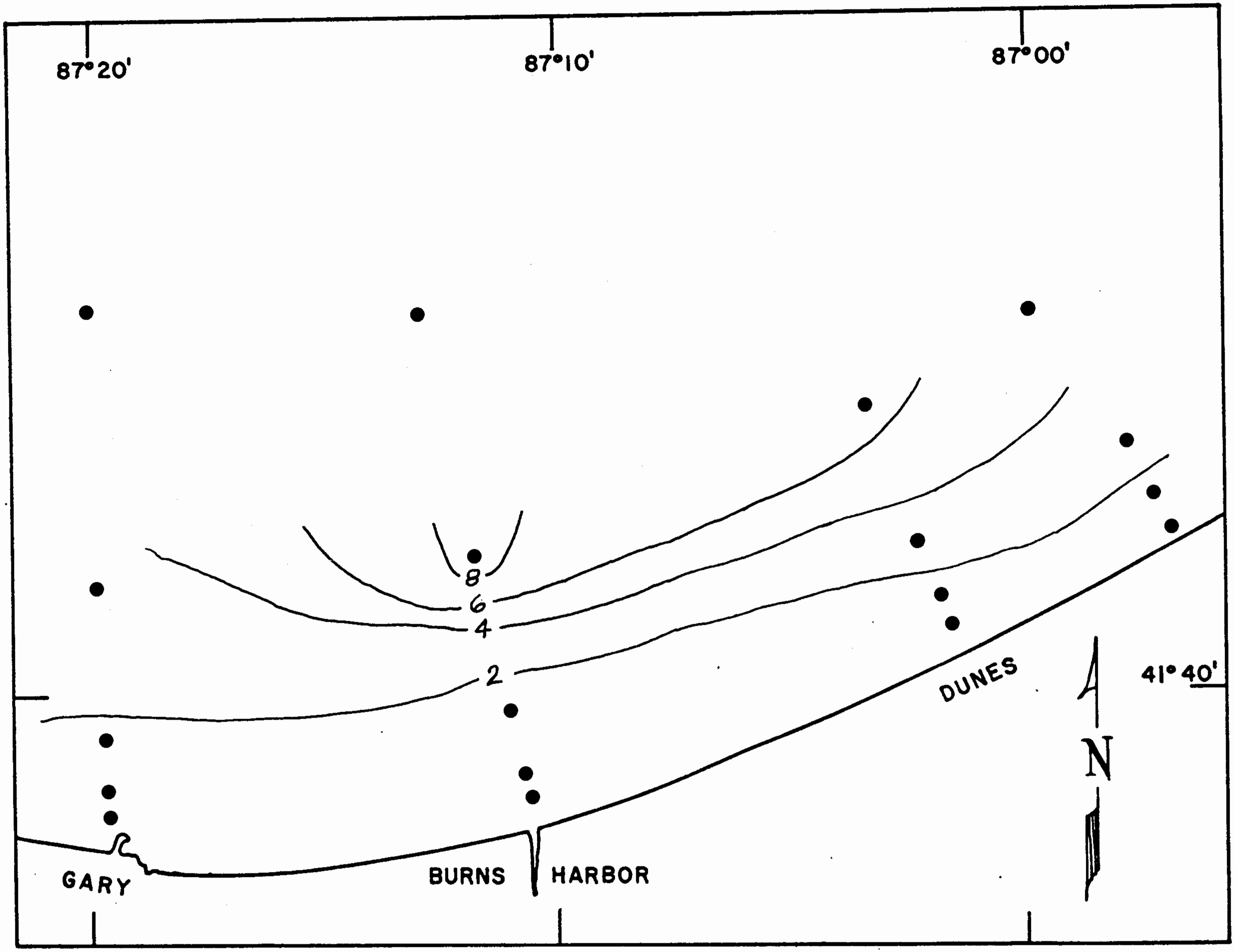

Figure 46. Distribution of Diacyclops thomasi, August.

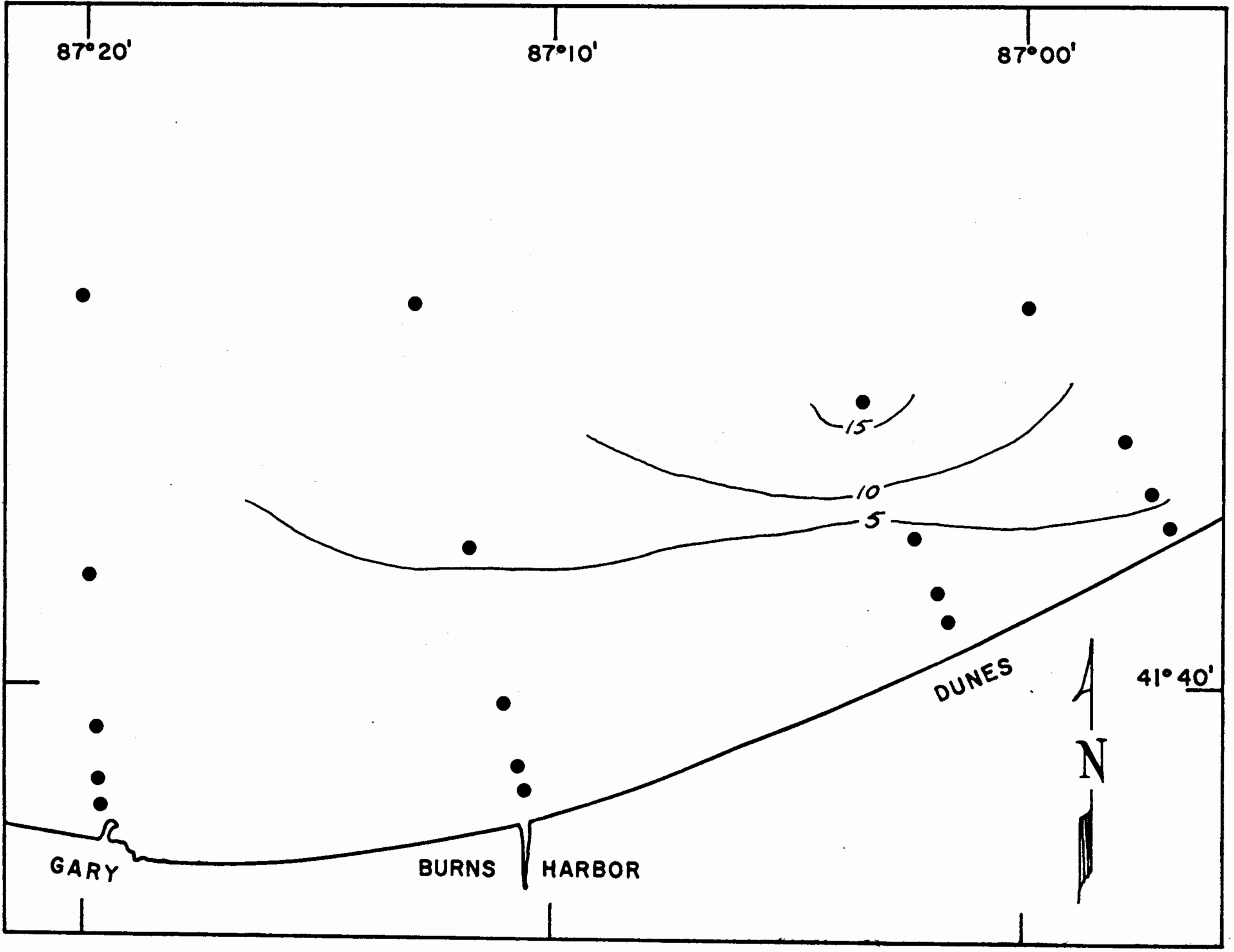

Figure 47. Distribution of Diacyclops thomasi, September.

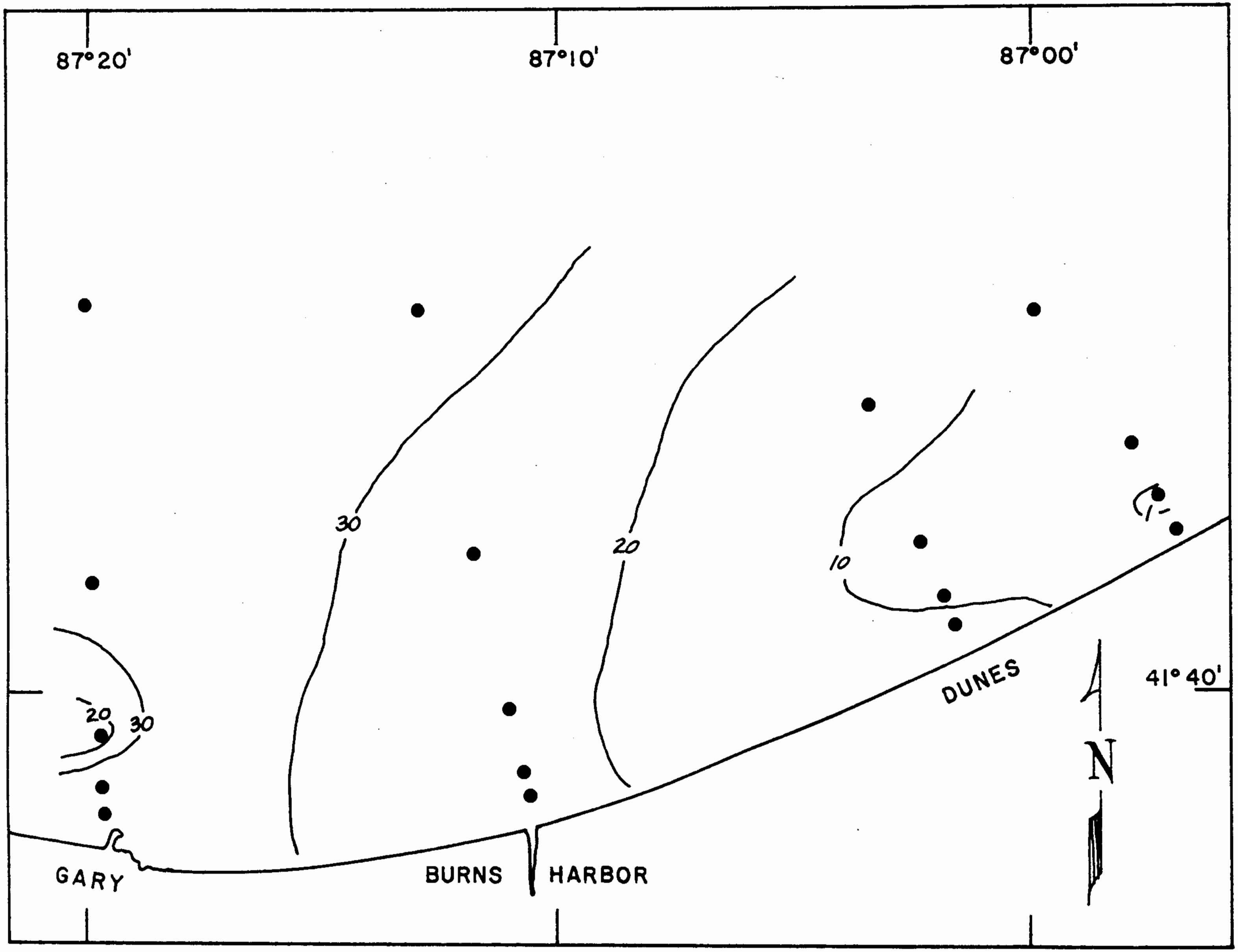

Figure 48. Distribution of diaptomid copepodids, June.

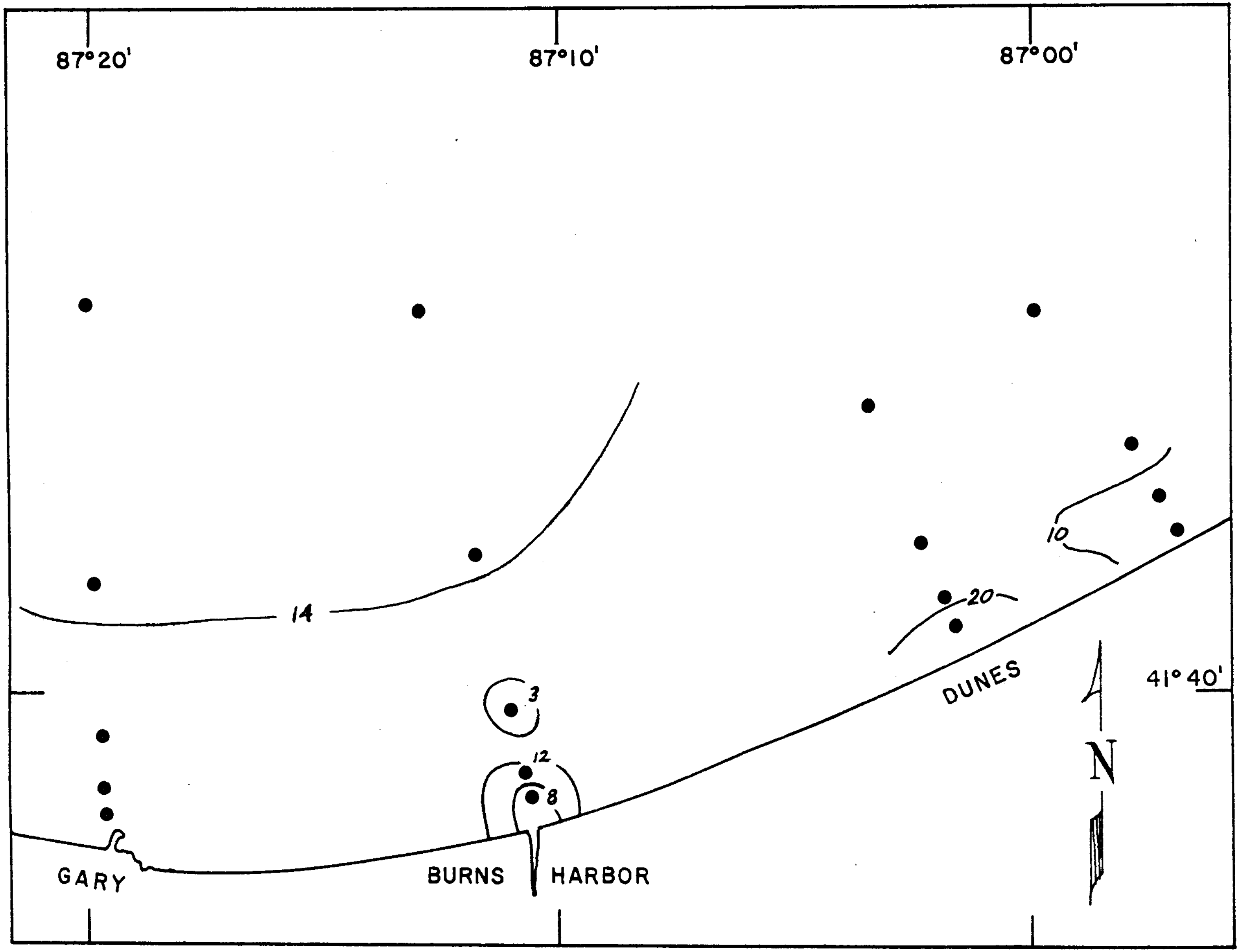

Figure 49. Distribution of diaptomid copepodids, August.

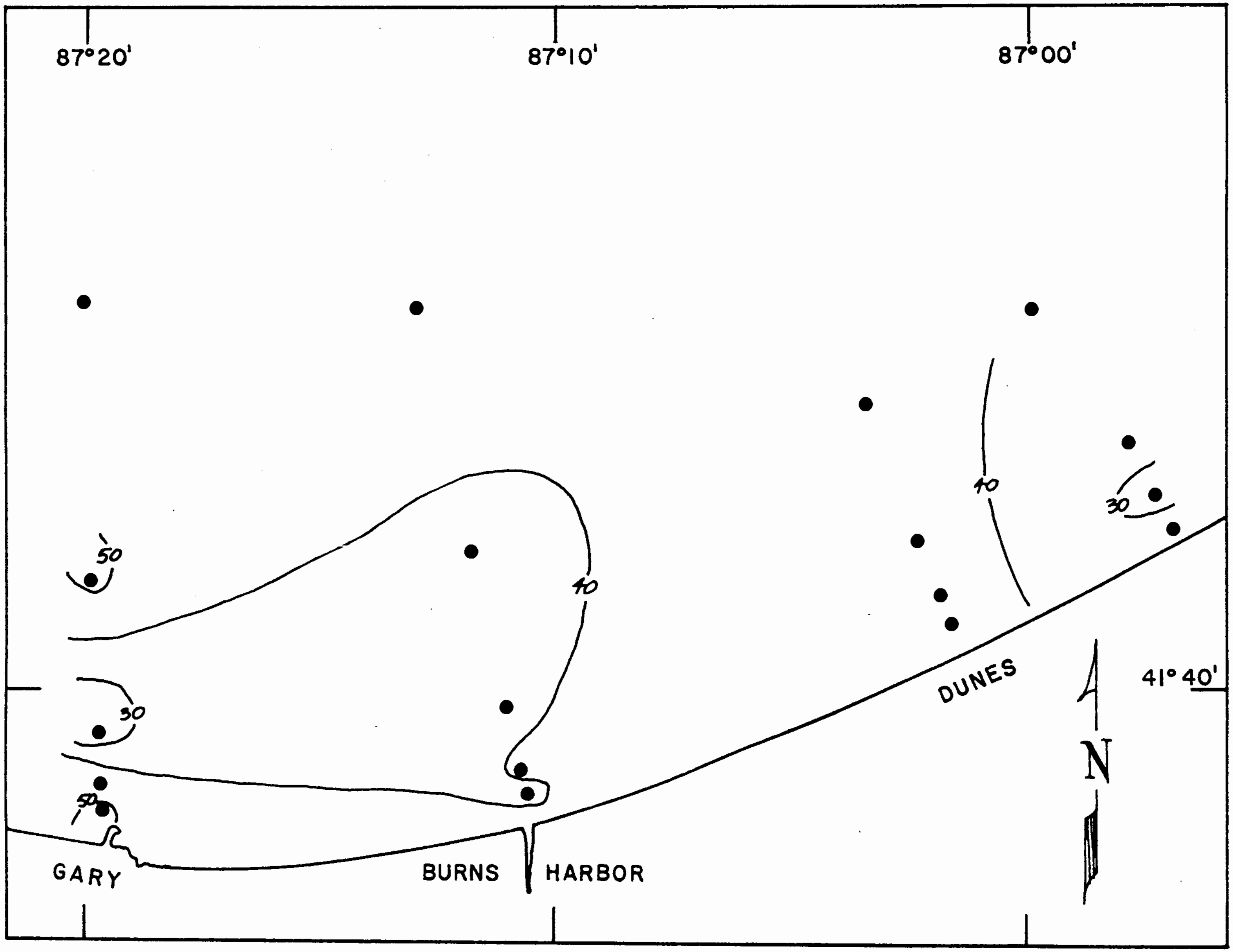

Figure 50. Distribution of diaptomid copepodids, September.

August and the two species were nearly equal in mean abundance (140 and 160 per m^3, respectively) in September (Table 3).

Both L. ashlandi and L. minutus generally were more abundant at offshore stations throughout the study period. Leptodiaptomus minutus exhibited a northeast to southwest decreasing trend in relative abundance on all three sampling dates (Figures 51-53). In June, densities ranged from near 500 per m^3 at outer stations on easternmost transects to near 200 per m^3 at inner stations on westernmost transects. Densities in August ranged from 1,430 per m^3 at the outermost station off Indiana Dunes to 20-40 per m^3 at innermost stations off Indiana Dunes, Burns Harbor, and Michigan City harbor. Densities were most disjunct from station to station in September with maximum numbers (>300 per m^3) recorded offshore at Gary and Indiana Dunes. Lowest densities (0-50 per m^3) were near Gary and Burns Harbor.

In contrast to L. minutus, the distribution of L. ashlandi was discontinuous from station to station but the general trend for greater abundance offshore still was evident. In June, L. ashlandi was most abundant (2,400 per m^3) at the outermost station off Burns Harbor and was least abundant (40 per m^3) nearest Indiana Dunes. Relative abundance offshore (mean of 5.8%) was slightly higher than at 1/2 and 1 mile stations (mean of 4.3%) (Figure 54). Numbers were highest (400 per m^3) at the 2 mile station off Indiana Dunes in August. This species was not collected nearest Michigan City; only a few individuals were obtained nearest Burns Harbor and Indiana Dunes. Relative abundance was higher offshore (mean of 7.1%) in comparison with stations less than one mile from shore (1.5%) (Figure 55). In September, densities were highest (mean of 290 per m^3) on the Gary transect and lowest (mean of 37 per m^3) on the Michigan City transect. Besides relatively high abundance (3.8%) nearest Indiana Dunes, abundances elsewhere ranged from 0.4 to 2.4% (Figure 56).

NOTES ON MINOR CRUSTACEA TAXA

Limnocalanus macrurus, Senecella calanoides, and Leptodiaptomus sicilis are cold stenothermic species that likely would be rare in the nearshore waters of southern Lake Michigan during summer and early fall. Indeed, they were rare in standardized tows and in tows from the bottom to the surface at deeper stations throughout the study period. Limnocalanus was present at outermost stations on all transects in June and was most prevalent (50 per m^3) at the 5 mile station off Gary. A few individuals were observed at nearshore stations off Gary and Burns Harbor, but none were found near Indiana Dunes and Michigan City harbor. A few individuals were observed only at outermost stations in August and September. The distribution of Leptodiaptomus sicilis was similar to Limnocalanus. In June, L. sicilis occurred mostly at outermost stations, reaching a maximum of 50 per m^3 at the 2 mile station off Gary. It was absent from innermost stations except off Gary. This species was rare (maximum of 30 per m^3) in August with most individuals occurring at outer stations. It was more prevalent (maximum of 300 per m^3) at outermost

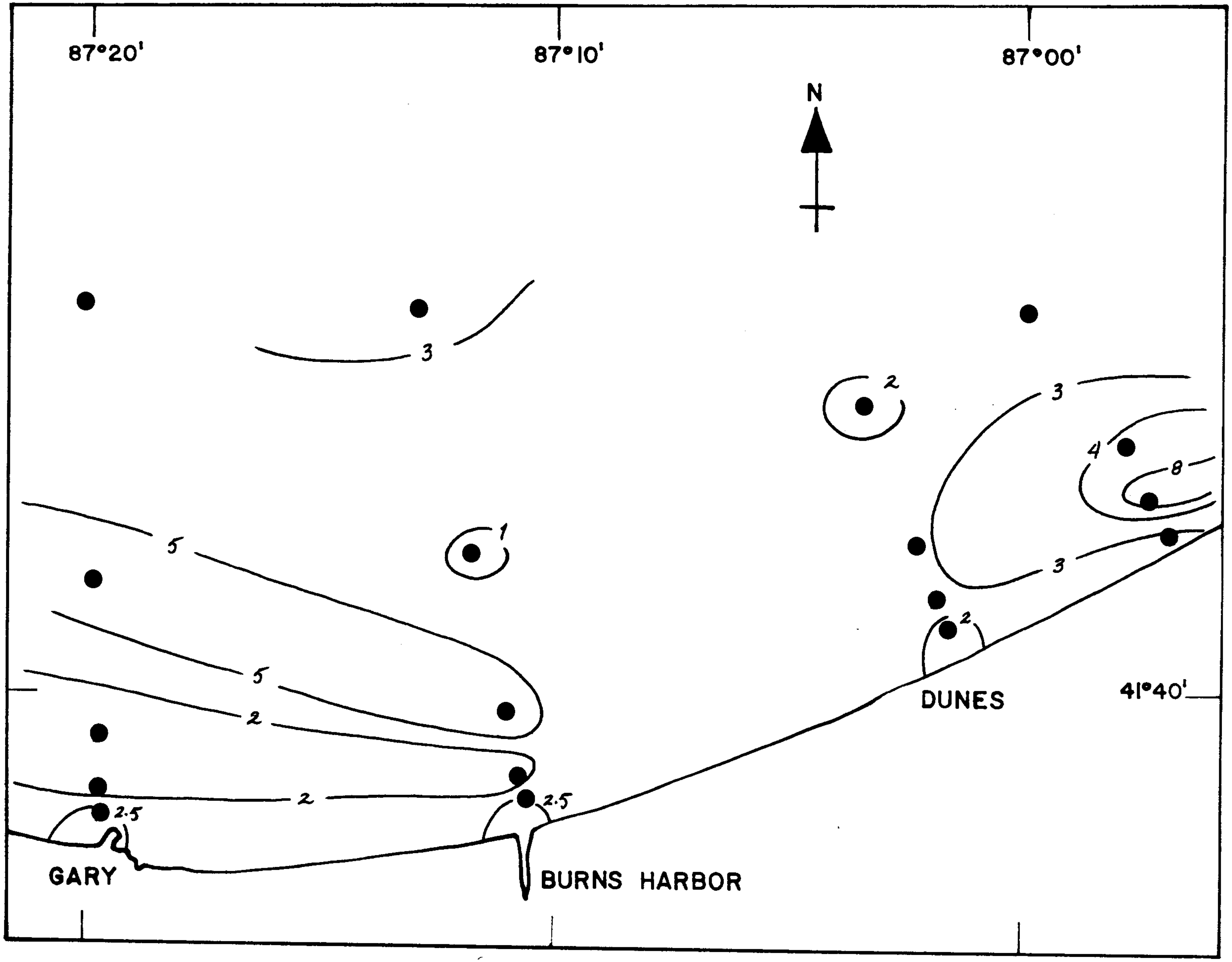

Figure 51. Distribution of Leptodiaptomus minutus, June.

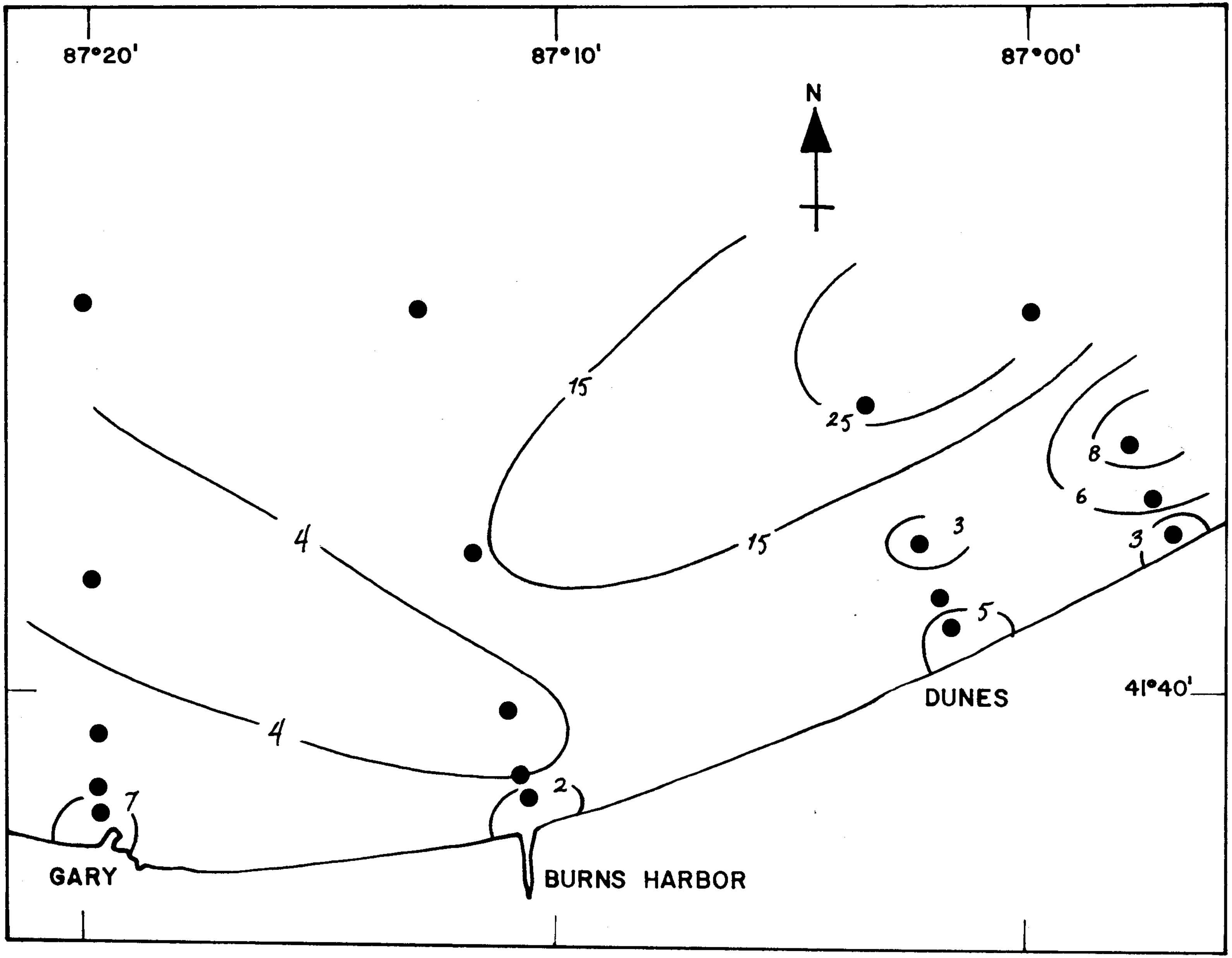

Figure 52. Distribution of *Leptodiaptomus minutus*, August.

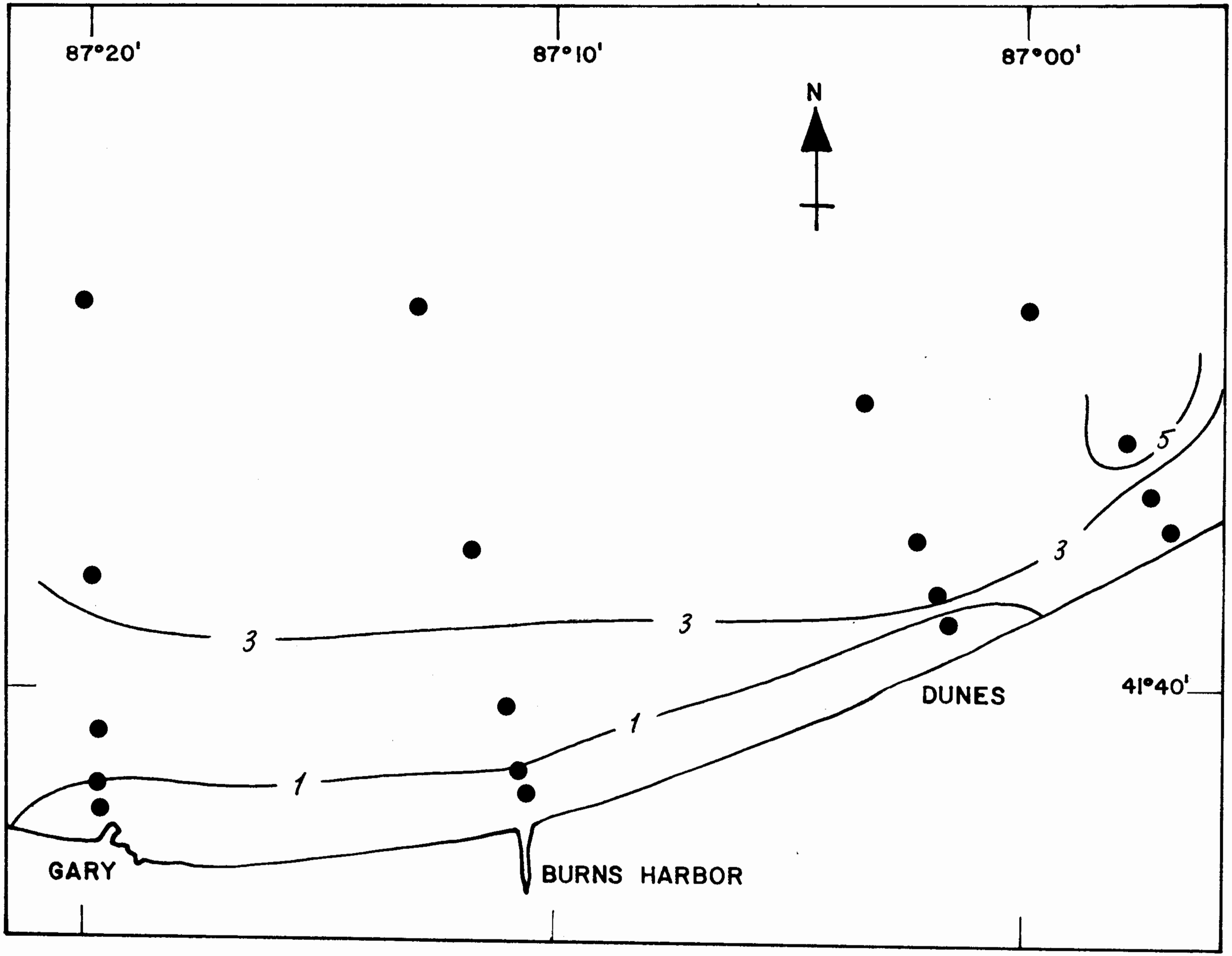

Figure 53. Distribution of *Leptodiaptomus minutus*, September.

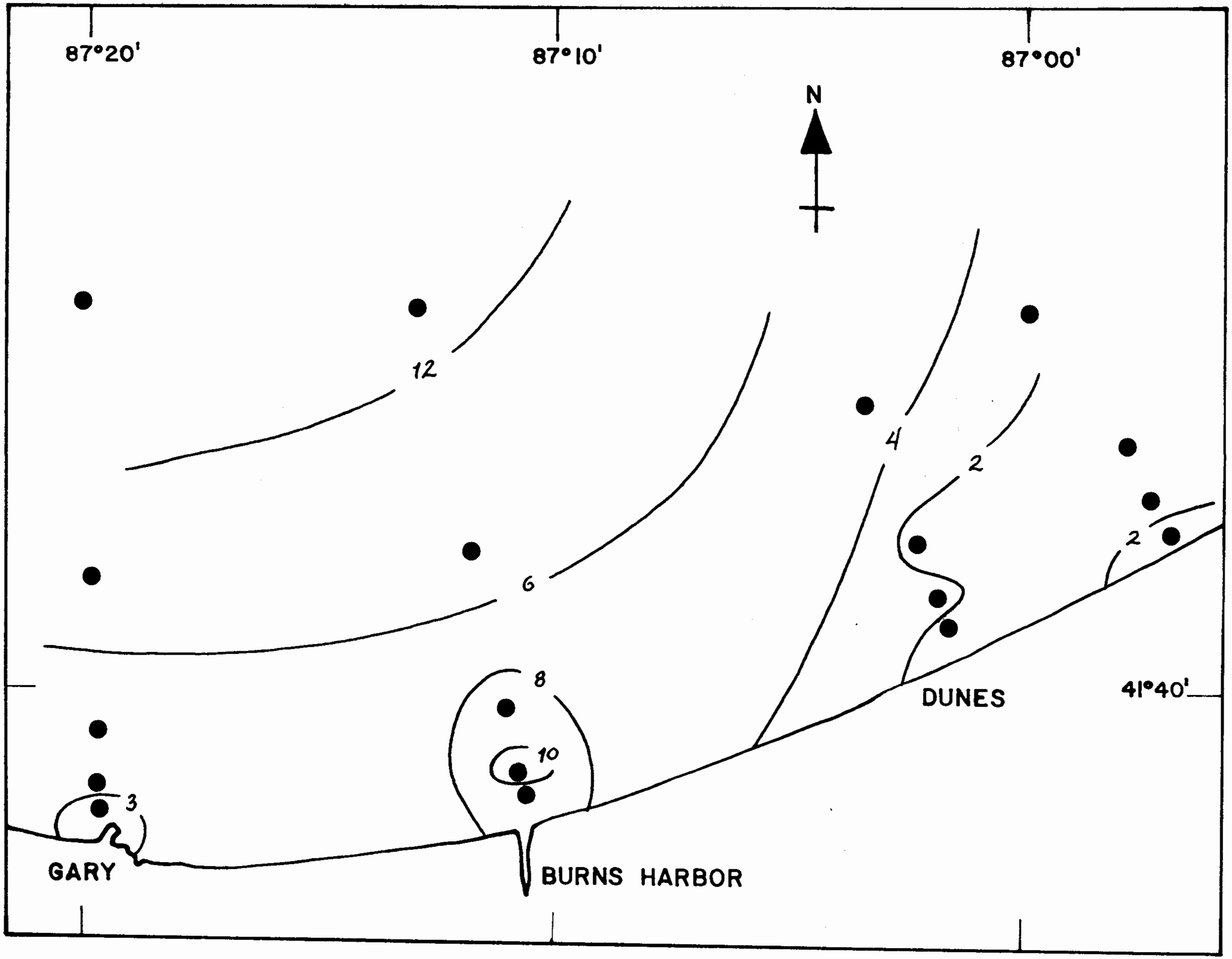

Figure 54. Distribution of *Leptodiaptomus ashlandi*, June.

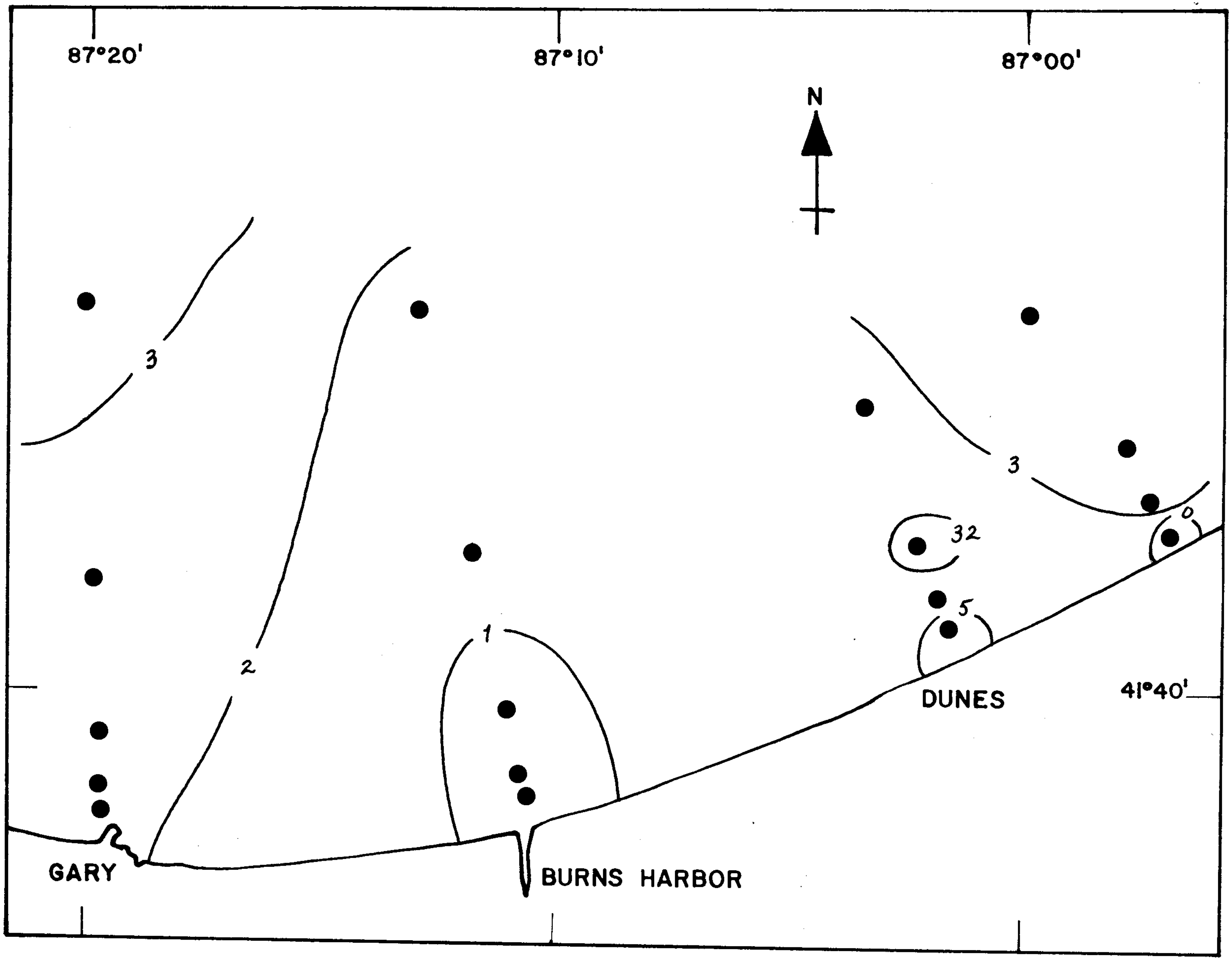

Figure 55. Distribution of Leptodiaptomus ashlandi, August.

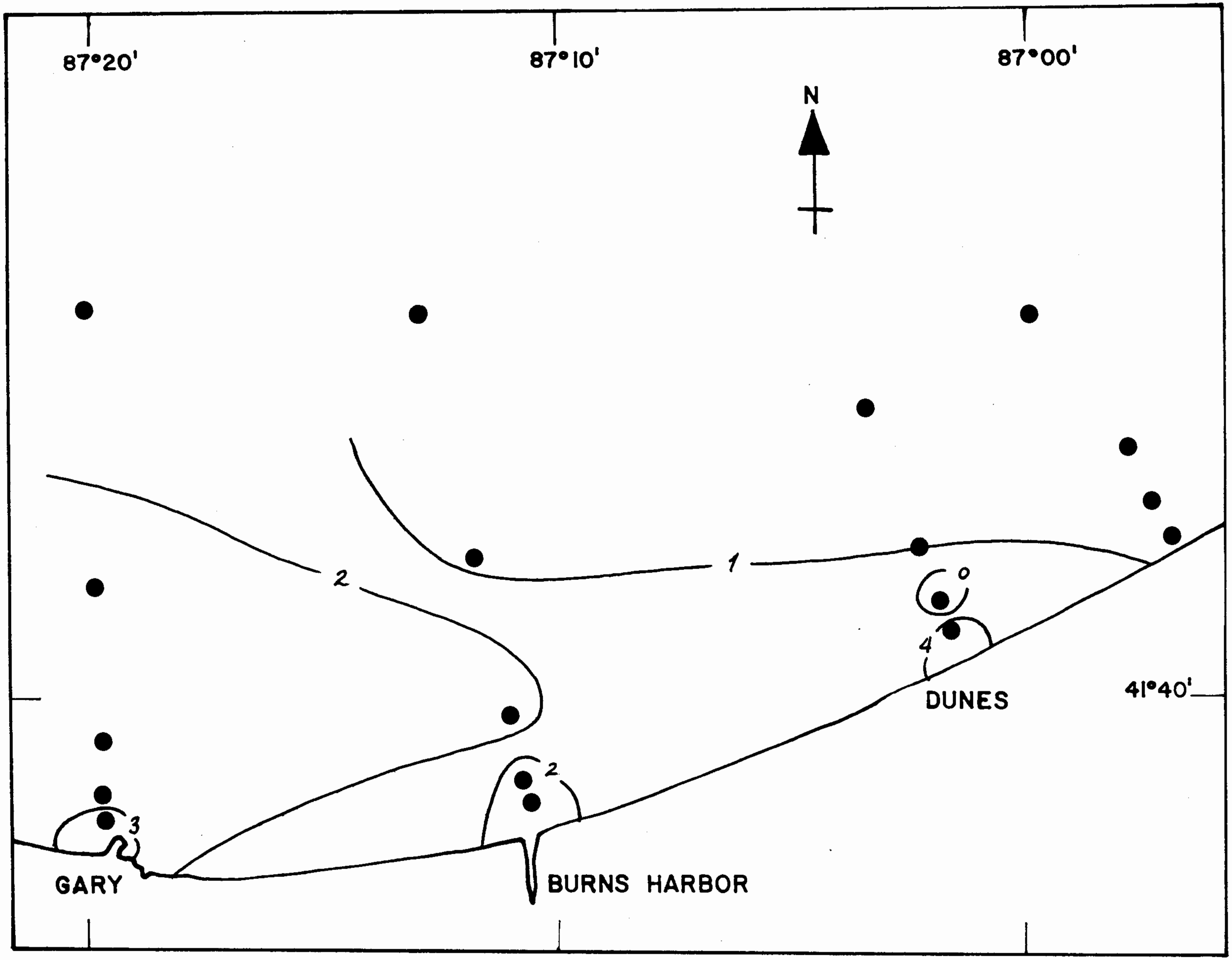

Figure 56. Distribution of *Leptodiaptomus ashlandi*, September.

stations, especially on western transects, in September. This species was absent from 1/2 mile stations in August and September.

The other calanoid copepods occurring in low numbers were *Skistodiaptomus oregonensis*, *Epischura lacustris*, and *Eurytemora affinis*. In June, *S. oregonensis* was present at most stations with a maximum of 90 per m^3 at the 2 mile station off Burns Harbor. Only a few individuals were observed at nearshore stations in August, and maximum numbers (>300 per m^3) were found at 2 mile locations. The same pattern was observed in September with maximum numbers (>200 per m^3) recorded at 5 mile stations off Burns Harbor and Indiana Dunes. *Epischura* was consistently more prevalent offshore during June and August. A northeast to southwest decreasing trend in abundance was evident in June, with numbers of 50 to 90 per m^3 offshore on the eastern two transects of 0 to 40 per m^3 nearshore on the western two transects. A similar northwest to southeast decreasing trend was apparent in September, with a maximum of 360 per m^3 at nearshore stations off Gary, Indiana Dunes, and Michigan City. Numbers of *Epischura* were considerably higher in September (mean of 420 per m^3). Densities ranged from 1,490 per m^3 1 mile off Burns Harbor to 30 per m^3 nearest Gary, but no spatial distribution pattern was discernible. In contrast to *Skistodiaptomus* and *Epischura*, *Eurytemora affinis* was more prevalent at nearshore locations. In June, it was absent from outer westernmost stations and was most abundant (150 to 190 per m^3) at 1 mile stations off Indiana Dunes and Michigan City harbor. It was rare (about 10 per m^3) at scattered locations in August, with the stations on the two westernmost transects most sparsely populated. This species was absent from outermost stations in September; it was rare at inshore locations except near Burns Harbor (130 to 140 per m^3).

Acanthocyclops vernalis was low (20 per m^3) in overall abundance (Appendix D, Table D-2) but exhibited a noteworthy distributional pattern. In June, it was absent from the westernmost transect off Gary where highest water quality conditions were observed (Appendix A). It was most prevalent eastward off Indiana Dunes (430 per m^3) and Michigan City harbor (450 per m^3). Its distribution was restricted to harbor mouths in August and September. This species was found in low numbers in August nearest Gary and Burns Harbor (maximum of 110 per m^3) in September. Other cyclopoid copepods, *Mesocyclops edax* and *Tropocyclops prasinus mexicanus*, were extremely rare in southern Lake Michigan. Single individuals of *M. edax* were seen in August (1 mile station off Burns Harbor) and in September (2 mile station off Gary). The small copepod, *T. prasinus mexicanus*, was observed only in September at all stations nearest shore except off Gary.

Minor cladoceran taxa were extremely rare, usually comprising a mean average abundance of less than 10 per m^3 (Appendix D, Table D-2). Only *Leptodora kindtii* was relatively more abundant (total mean abundance of 20 per m^3 for all cruises). This species was found at all stations throughout the study period. It was slightly more prevalent (maximum of 60 to 100 per m^3) nearshore, especially off Indiana Dunes.

Chydorus sphaericus was represented by a few individuals mostly at locations nearest shore. This species was most frequent at 1/2 and 1 mile stations off the harbor mouths. It reached a maximum abundance of 120 per m^3

nearest Burns Harbor in June. Similarly, *Ceriodaphnia quadrangula* and *C. lacustris* were rare but relatively most frequent near harbor mouths. Only *C. quadrangula* was observed in June, but in low numbers (10 to 20 per m^3), at 1/2 and 1 mile stations. Both species were present in August but in low densities (maximum near 100 per m^3). Most individuals of both species were observed near Burns Harbor. In September, only a single individual of *C. quadrangula* was found nearest Burns Harbor.

Polyphemus pediculus was most frequent (mean of 30 per m^3) in June. It was most abundant (maximum of 200 per m^3) nearshore off Indiana Dunes and Michigan City. A few individuals (maximum about 25 per m^3) were scattered throughout the study area in August and September. It was found at most stations in August but was more frequent at outermost stations on western transects, reaching a maximum abundance of 110 per m^3 at the 5 mile station off Gary. Only a few individuals were observed in September on Burns Harbor and Indiana Dunes transects. Only a single individual of *Daphnia ambigua* was collected at the 2 mile station off Burns Harbor in June.

The remaining micro-crustaceans are primarily benthic species that infrequently appeared as single individuals at some stations. *Eurycercus lamellatus* was observed most frequently. It was collected at all nearshore locations in June and August. Three species of *Alona* were observed nearest harbor mouths in June and August (Table 3). A single individual of *Ilyocryptus spinifer* was observed nearest Michigan City harbor and a single specimen of *Leydigia quadrangularis* was seen nearest Gary in August. One *Pleuroxis procurvus* was collected in August and several *Camptocercus rectirostris* were observed in September near Burns Harbor. The harpacticoid copepod, *Canthocamptus staphylinoides*, was seen nearest shore at Indiana Dunes and the cyclopoid, *Eucyclops agilis*, was observed nearest Burns Harbor in June.

DISCUSSION

The species composition of zooplankton in a lake, with few exceptions, usually remains constant for many decades, perhaps for centuries, because these species have adapted to the physicochemical environment and have been successful in competing with other species. A species which newly disperses to that lake rarely can become established unless some environmental disturbance occurs. Perturbations which change the physicochemical milieu or alter the balance of competition between species can cause extermination of some species and allow the appearance of others. At the present state of our knowledge, eutrophication, size-selective predation by planktivorous fishes, and toxic substances are the major factors that may cause changes in zooplankton species composition and abundance. Although monitoring and surveillance programs primarily have been designed to assess eutrophication trends, caution must be exercised in establishing one-to-one causal relationships between changes in zooplankton community composition and eutrophication (Gannon and Stemberger 1978).

The importance of this investigation is to provide a benchmark on zooplankton community composition for comparison with future studies. Ideally, we would also like to compare results of this study with previous investigations. Unfortunately, it is difficult to assess the impact of past changes in water quality and lake ecology on zooplankton because of the lack of comparable historical data for the Indiana waters of southern Lake Michigan.

Eddy (1927) reported on southern Lake Michigan plankton from qualitative collections obtained near Chicago in 1887-1888 and quantitative samples gathered near Gary, Indiana Dunes, and Michigan City in 1926-1927. The collections were from surface tows evidently made off breakwaters and jetties and, therefore, these data are not strictly comparable to the present study because of the different methods and sampling locations employed. Nevertheless, it is readily apparent that many of the predominant zooplankton genera (e.g., *Keratella*, *Kellicottia*, *Bosmina*, *Letodiaptomus*, and *Diacyclops*) present in 1977 were reported as common in 1887-1888.

One of the most interesting results of the present study is the overwhelming predominance of rotifers in comparison with crustacean plankton in southern Lake Michigan in 1977. Again, comparisons must be made with caution but it is interesting to note some obvious differences in the relative abundance of rotifers and crustacean plankters between 1926-1927 and 1977. Rotifers comprised an average of 95% of total zooplankton at stations nearest shore off Gary, Indiana Dunes, and Michigan City in June and September, 1977, and an average of 59.8% at similar locations in October, 1926, and May, 1927 (Eddy 1927).

Increase in density of zooplankton without any appreciable shifts in species composition is apparently an initial response by zooplankton to nutrient enrichment (Fuller *et al*. 1977, Gannon and Stemberger 1978). Density of rotifers and crustacean plankters was approximately 16 times higher in June, 1977, than in May, 1927, at nearshore locations off Michigan City and Indiana Dunes. Even considering that Eddy sampled somewhat earlier in the growing season, an increase in zooplankton density probably has occurred in southern Lake Michigan. Indeed, counts of total plankton (primarily phytoplankton) have increased in samples from water intakes in southern Lake Michigan (Damann 1945, 1960) and such trends have been used as indications of the response of the plankton community to eutrophication (Beeton 1969).

The predominant rotifer species in 1926-1927 were *Keratella cochlearis*, *Polyarthra vulgaris* (= *P. trigla*), *Kellicottia longispina* (= *Notholca longispina*), *Synchaeta stylata*, and *S. tremula* (Eddy 1927). *Synchaeta* was relatively less abundant in 1977 but, otherwise, most of the predominant species in 1926-1927 still were the prevalent ones in the present investigation. The most abundant crustacean plankters in 1926-1927 were *Bosmina* sp., *Diacyclops thomasi* (= *Cyclops bicuspidatus*), *Tropocyclops prasinus mexicanus* (= *Cyclops prasinus*), *Daphnia retrocurva*, *Leptodiaptomus minutus* (= *Diaptomus minutus*), and *L. ashlandi* (= *D. ashlandi*). As with the rotifers, most of the predominant micro-crustacean species were the same in 1926-1927 and 1977.

The identity of the bosminid cladocerans in Eddy's (1927) plankton collections has caused considerable confusion in the interpretation of zooplankton response to water quality changes in Lake Michigan. Certain bosminid cladocerans have been used as indicators of trophic conditions. The classical species shift during eutrophication, as determined primarily from paleolimnological studies, is from the oligotrophic "species," *Bosmina longispina*, to the eutrophic species *B. longirostris*. Eddy (1927) listed both "species" in Lake Michigan during 1887-1888 and 1926-1927. Wells (1960) found only *B. longirostris* in the lake during 1954-1955. Based on the results of these two studies, Beeton (1965) and Brooks (1969) suggested that *B. longispina* was replaced by *B. longirostris* in Lake Michigan, and used this species shift as an indicator of advancing eutrophication. This alleged species shift cannot be verified because the exact identity of Eddy's *B. longispina* cannot be determined.

Williams (1966) presented quantitative 1961-1962 data on abundance and composition of rotifers (predominant genera) from five water intakes around the Great Lakes, including one station at Gary. Because of different sampling methods, this study cannot be compared directly to the 1977 data. However, it is noteworthy that the Gary station had the highest mean density of rotifers in the Great Lakes and these data were correlated with relatively high phytoplankton counts. As in the present study, *Keratella* and *Polyarthra* were the predominant genera in 1961-1962.

More substantive information on zooplankton community composition as influenced by water quality can be obtained by comparing recent quantitative studies in regions of different water quality in Lake Michigan. Most pertinent is the study of zooplankton species composition, inshore distribution, and abundance in southern Lake Michigan in 1970 by Johnson (1972), who used nearly the same sampling locations as in this investigation. He used a 1/4 m diameter, no. 20 mesh (76 µm) Wisconsin plankton net to collect zooplankton on transects of stations off Gary, Burns Harbor, and Michigan City during June through October, 1970. Both rotifer and crustacean data were procured but data analysis and interpretation were more thorough for crustacean plankton.

Johnson (1972) recorded 10 species of Copepoda, and 14 species each of Cladocera and Rotifera. Species lists, although more comprehensive for rotifers in 1977, were basically similar in the two studies. *Bosmina longirostris*, *Daphnia retrocurva*, and *Diacyclops thomasi* were the most abundant crustacean plankters in 1970. Johnson did not observe any consistent patterns in zooplankton abundance and distribution between the three transects; however, biomass of crustacean plankton was generally higher at Michigan City and Gary stations than at Burns Harbor.

In contrast with the 1977 study, crustacean plankters were relatively more abundant in 1970. Johnson (1972) recorded mean numbers of over 100,000 per m^3 for total crustaceans with ranges of 25,000 per m^3 in June to 375,000 per m^3 in July. These values are approximately ten times higher than density figures reported in this study and in the offshore waters of Lake Michigan (Wells 1960, Gannon 1972). Moreover, Johnson's values are two to three times higher than Eddy's (1927) historical data. Comparable high numbers have been reported only in Milwaukee Harbor (Gannon 1972), near the Fox River mouth in

Green Bay (Gannon 1974b), and near the southwestern shore of Lake Michigan (Roth and Stewart 1973). Higher numbers of total Crustacea only have been observed in the concurrent study of Green Bay in 1977 (Gannon *et al.* in press).

Contrasts in rotifer data betwen 1970 and 1977 in southern Lake Michigan are interesting also. Johnson (1972) noted the same predominant species (especially *Keratella cochlearis* and *Polyarthra vulgaris*) as in 1977. However, density of total rotifers (mean of 120,000 per m^3) was about seven times higher than values reported by Eddy (1927) but only about one-half of mean total numbers in this investigation. Total rotifer densities were much higher (>1,000,000 per m^3) in Milwaukee Harbor (Stemberger 1974) but similar (100,000 to 360,000 per m^3) off Ludington in eastern Lake Michigan (Duffy and Liston 1978) and in Green Bay (230,000 per m^3) during 1977 (Gannon *et al.* in press).

Because of the infrequency of zooplankton collections in southern Lake Michigan, it is difficult to interpret the apparent differences in zooplankton densities between investigations. The increasing trend in both rotifer and crustacean plankton abundance since 1926-1927 is probably real. Differences between 1970 and 1977 may be within yearly variation, but long-term seasonal or annual zooplankton data are lacking for Lake Michigan.

The sampling program in 1977 did not include stations at river mouths and, therefore, it is difficult to resolve apparent impacts of harbor water discharges on nearshore zooplankton community composition. However, trends in spatial distribution and abundance of zooplankton appeared to be related to existing water quality conditions.

Water quality patterns in the nearshore waters of southern Lake Michigan are largely dependent on current and seiche regimes that mix relatively high quality offshore waters with variously polluted harbor effluents from steel mills, refineries, and municipal sewage plants (Snow 1974). An offshore to inshore decreasing gradient in water quality* was present during each sampling period in 1977. The gradient was most distinct in June, with highest water quality offshore in the northwestern portion of the study area and decreasing southeastward. A similar but less distinct pattern was evident in August, with a northeast to southwest decreasing trend. Waters were more thoroughly mixed in September, but slightly poorer water quality was present toward the southeastern portion of the study area. Similarly, patterns in zooplankton (especially rotifers) abundance and distribution were most evident in June and exhibited statistically significant correlations with physicochemical variables. Patterns were not as distinct in August and September, but consistent trends were discernible.

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*Poorer water quality is defined here as having relatively high specific conductance, alkalinity, nutrient chemistry, and turbidity and low Secchi disc transparency.

Total rotifers and predominant species (e.g., *Keratella cochlearis*, *K. crassa*, *Polyarthra vulgaris*, and *Conochilus unicornis*) were distinctly most abundant in nearshore waters of poorer water quality. Statistically significant correlations between high rotifer densities and high specific conductance and alkalinity and low turbidity and Secchi disc transparency often were observed. Of predominant species, only *Kellicottia longispina* was more abundant in higher quality waters. This pattern may be related to temperature as *K. longispina* is most abundant in deeper, cool waters in summer (Stemberger 1979).

The predominant rotifers found in areas of poorer water quality are all eurytopic species. Eutrophic indicator species, such as *Brachionus*, *Euchlanis*, and *Trichocerca*, were rare in southern Lake Michigan but were confined or most prevalent nearest harbor mouths. Because of the apparent high rate of exchange between offshore and nearshore waters, it appears that the major response to nutrient loading of the rotifer community is an increase in density of predominant, eurytopic species rather than species shifts toward more eutrophic forms (Tables 2 and 3). Fuller *et al*. (1977) noted that the initial response of rotifers to eutrophication is an increase in density of indigenous species. Williams (1966) made a similar observation in examining rotifers in water intake samples from throughout the United States. Only in more persistently eutrophic waters, such as in lower Saginaw Bay of Lake Huron (Stemberger *et al*. 1979), do eutrophic indicator species become numerically important constituents of the rotifer community.

The overwhelming abundance of rotifers in southern Lake Michigan simply may be a response to the greater availability of food in more nutrient enriched waters. Rotifers have inherently high intrinsic rates of increase under favorable environmental conditions and, therefore, appear to be more sensitive indicators of water quality than crustacean plankters (Gannon and Stemberger 1978). However, size-selective predation by fishes also may be a prominent factor in southern Lake Michigan. Indeed, Webb (1973) reported that alewives, *Alosa pseudoharengus*, were extremely abundant in southern Lake Michigan during June and July. They were less prevalent in August and September as they moved offshore following spawning. Crustacean zooplankters, especially *Diacyclops thomasi*, were the predominant food of alewives. Alewives are well known to be size-selective in their food habits and to considerably influence size structure and composition of crustacean zooplankton populations (Brooks and Dodson 1965, Wells 1970, Gannon 1976). The low relative abundance of crustacean zooplankters and the predominance of smaller species suggest that size-selective predation by planktivorous fish, principally alewives, influenced crustacean zooplankton density and composition in southern Lake Michigan in 1977.

Bosmina longirostris was the predominant crustacean plankter in southern Lake Michigan in 1977. It is a eurytopic species but becomes overwhelmingly abundant in eutrophic waters, such as Milwaukee Harbor and lower Green Bay (Gannon 1972, 1974b). Its abundance and distribution in southern Lake Michigan were similar to predominant rotifers such as *Keratella cochlearis*. It was the only crustacean plankter to exhibit consistent statistically significant correlations with physicochemical variables. Webb (1973) reported that *B. longirostris* was predominant food for alewives in southern Lake

Michigan. Evidently, this parthenogenetic species reproduces rapidly in nutrient-enriched nearshore waters and is able to offset potentially high predation rates.

As in the rotifers, the primary response by the crustacean community to water quality conditions was population increases of eurytopic, indigenous species, such as *B. longirostris*, in nutrient-enriched waters. No significant shifts in species composition were evident from the available historical record. Oligotrophic indicator species, such as *Limnocalanus* and *Senecella*, were rare in southern Lake Michigan and were confined to outermost stations. The eutrophic indicator, *Acanthocyclops vernalis*, was rare but confined nearest shore, especially off harbor mouths.

Besides *Bosmina longirostris*, no consistent statistically significant trends were noted between distribution of crustacean species and physicochemical variables. This indicates that their abundance and distribution are not controlled principally by water quality conditions and that biotic factors, such as size-selective predation, may play a more prominent role. Nevertheless, there were consistent and statistically significant trends between physicochemical variables and the distribution and abundance of crustacean plankton by major groups. There still was a tendency for calanoid copepods to be more prevalent in more oligotrophic offshore waters in comparison with cyclopoid copepods and cladocerans as observed elsewhere in Lake Michigan (Gannon 1974b, Gannon *et al*. 1976).

Another distributional trend that often was evident in southern Lake Michigan was low abundance of zooplankton nearest harbor mouths and highest abundance slightly farther offshore. Similar trends have been observed elsewhere in Lake Michigan (Gannon 1972, 1974b; Stemberger 1974). Perhaps flushing times are sufficiently high near harbor mouths to provide a less favorable environment for planktonic species, or toxic substances may be amply concentrated nearest harbor mouths to inhibit zooplankters. A combination of lower flushing times, abundance of nutrients and suitable food, and adequately diluted toxicants may allow high densities of zooplankton to develop nearby (Gannon and Stemberger 1978).

Stoermer and Tuchman (1980), in the concurrent phytoplankton study, noted the increase of halophilic algae in southern Lake Michigan concomitant with increased chloride concentrations. A brackish water calanoid copepod, *Eurytemora affinis*, is a comparatively recent addition to the Lake Michigan zooplankton community. It was first reported in Lake Michigan in 1964 (Robertson 1966) and apparently entered the Great Lakes in the bilge water of ships passing through the St. Lawrence River or Erie Canal from the Atlantic coast (Faber and Jermolajev 1966). It was not a prevalent species in southern Lake Michigan and the distribution of this euryhaline species elsewhere in the Lake Michigan basin does not appear to be influenced by chloride concentrations (Gannon 1972, 1974b).

No discernible patterns (positive or negative) were observed in correlation coefficients between phytoplankton and zooplankton species abundances at particular stations in southern Lake Michigan. Perhaps more rigorous statistical scrutiny would have revealed more relationships between the two data sets but any such patterns would undoubtedly be subtle. Similarly, correlation coefficients between zooplankton and physicochemical variables exhibit a few statistically significant and limnologically interpretable correlations. Consequently, it is not possible to quantitatively define the trophic conditions (i.e., levels of physicochemical variables and phytoplankton assemblages) maintaining the zooplankton composition and spatial patterns observed in southern Lake Michigan.

This lack of quantification does not distract from the utility of zooplankton in water quality monitoring. The most prominent and consistent feature of the zooplankton community in southern Lake Michigan during 1977 was the overwhelming abundance of eurytopic species in contrast with the rarity of eutrophic and oligotrophic indicator species. This pattern has been observed elsewhere in the Great Lakes (Gannon and Stemberger 1978) and in inland lakes as well (Fuller _et_ _al_. 1977).

Increases in biomass of eurytopic species without shifts in species composition appear to be the initial response by the zooplankton community to advancing eutrophication. Predominance of eurytopic zooplankton species is a mesotrophic feature and, indeed, the eutrophic waters from rivers in this portion of the lake dynamically mix with more oligotrophic offshore waters resulting in the observed physicochemical and biotic mesotrophic character of southern Lake Michigan waters in 1977. Detecting future changes in the abundance and distribution of eurytopic species relative to the rest of the zooplankton community and detecting shifts in composition, abundance, and areal distribution of eutrophic and oligotrphic indicator species can be useful in determining the biotic response to eutrophication control management strategies in Lake Michigan.

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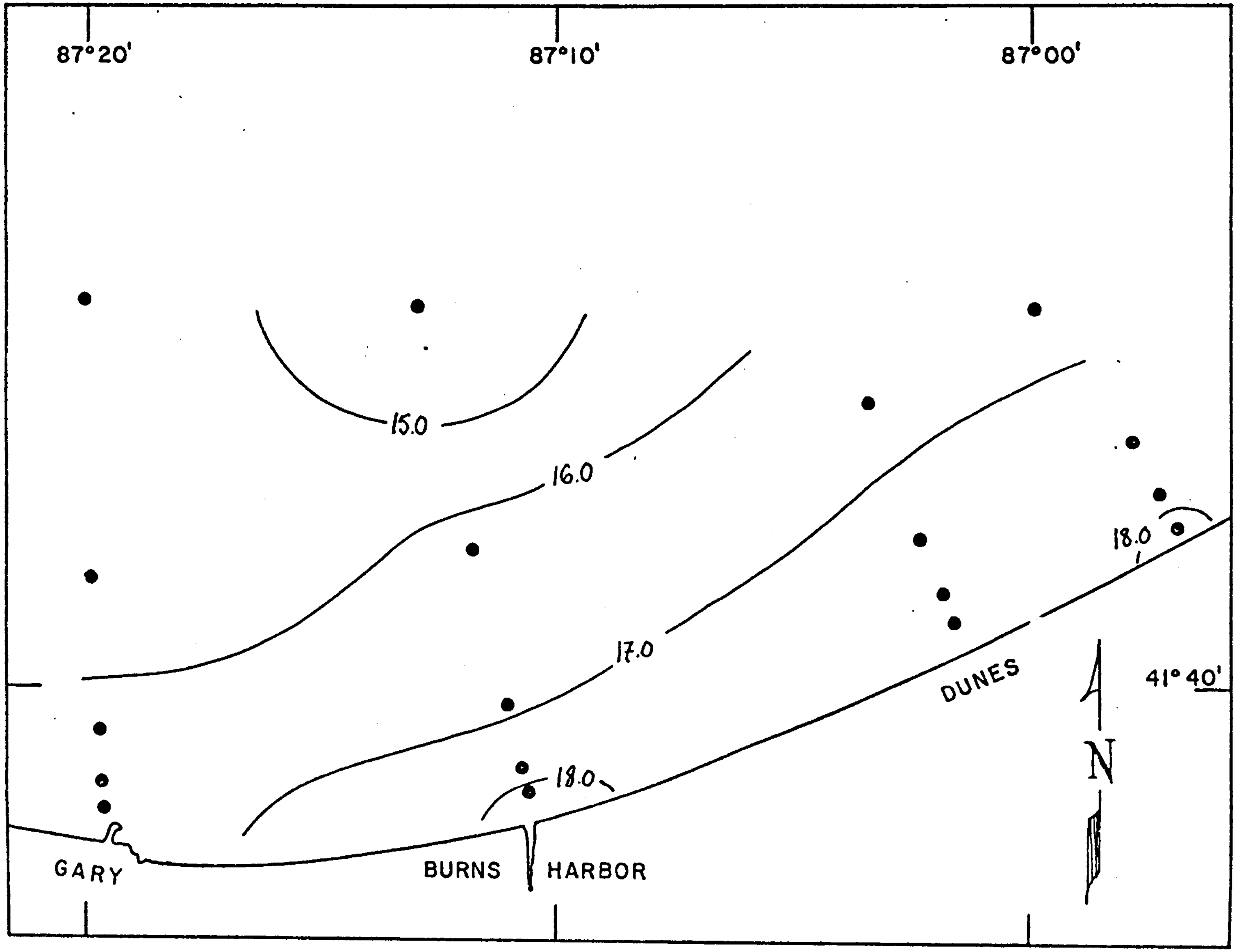
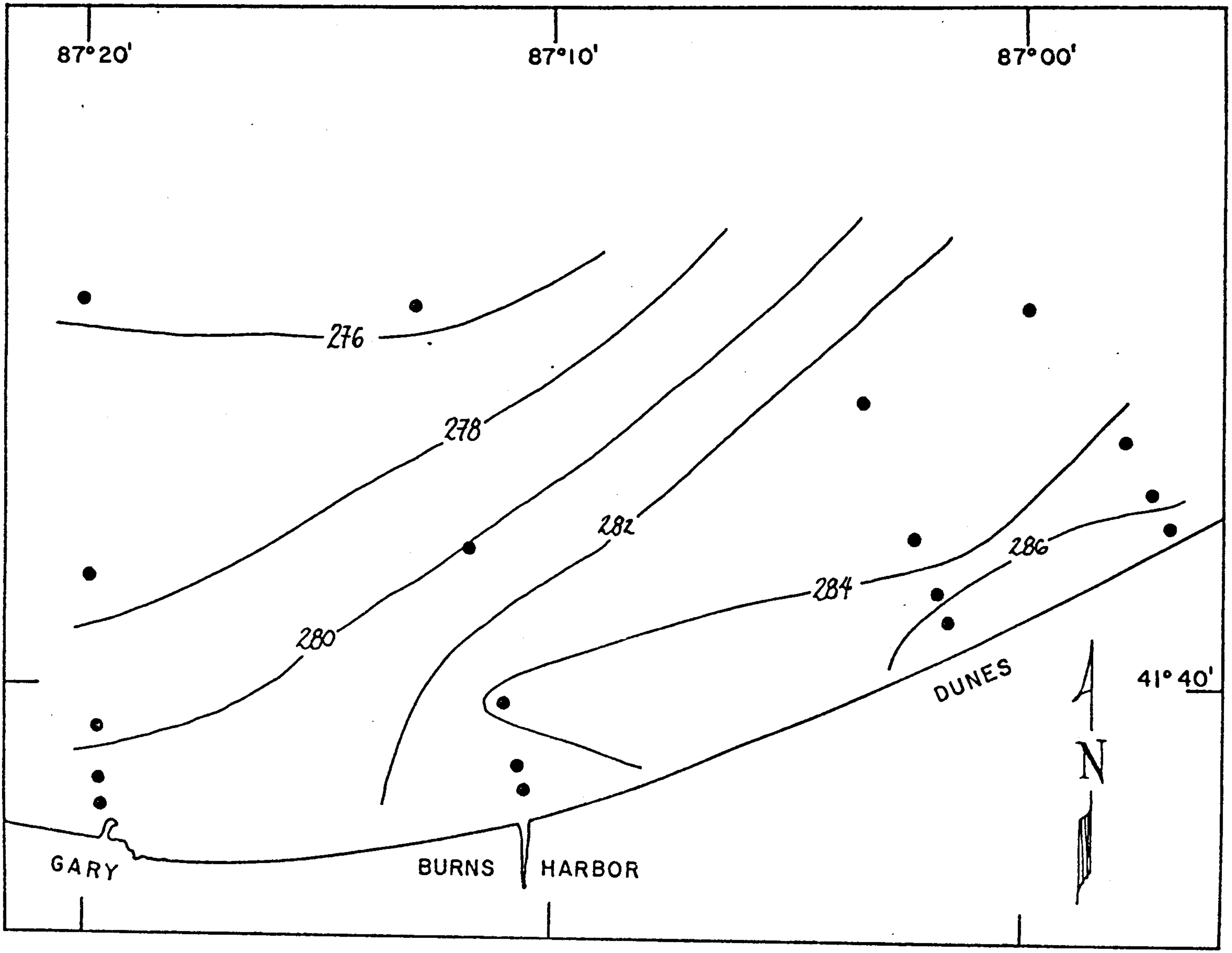
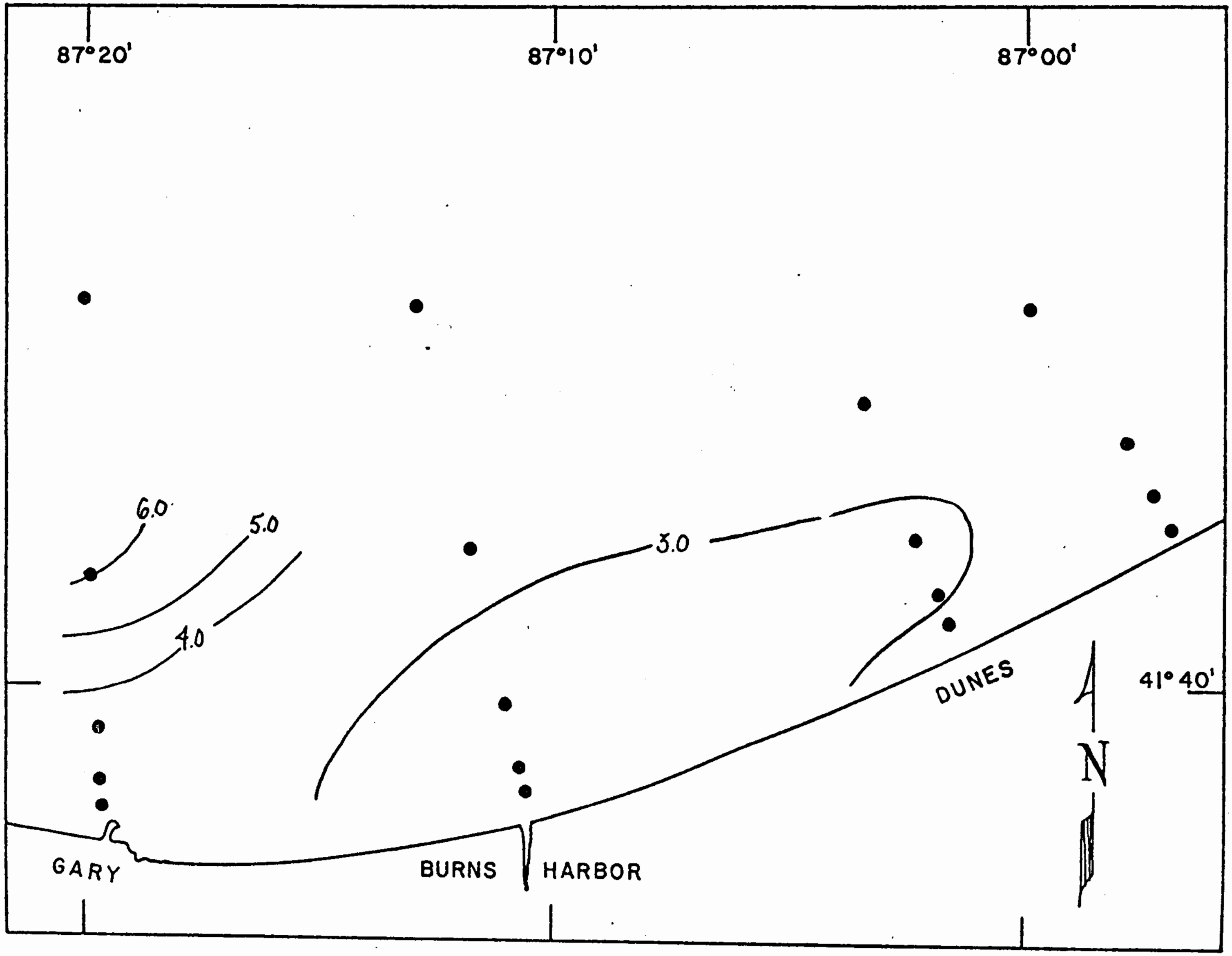


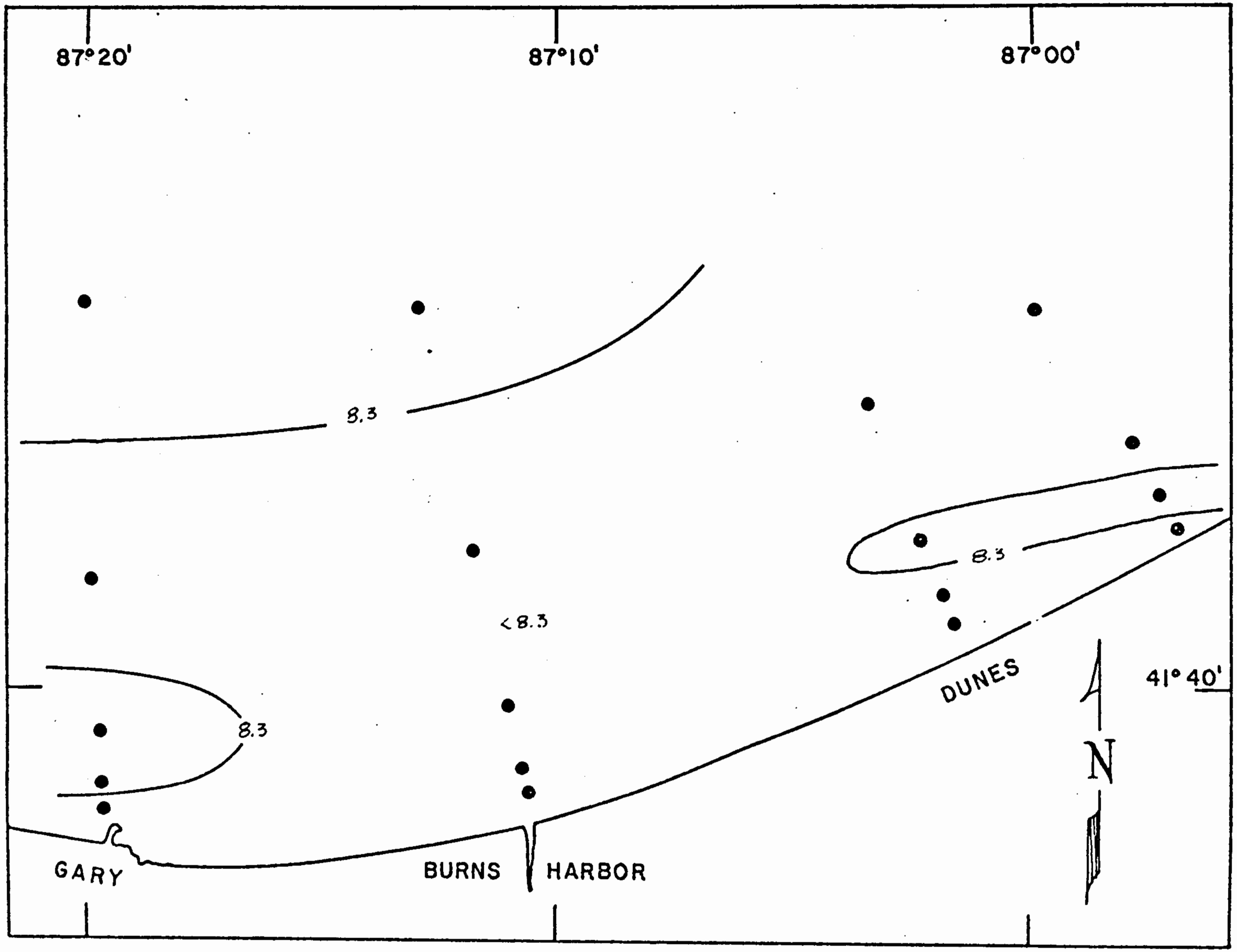
Appendix Figure A-1. Temperature contours, southern Lake Michigan; 11 June, 1977.



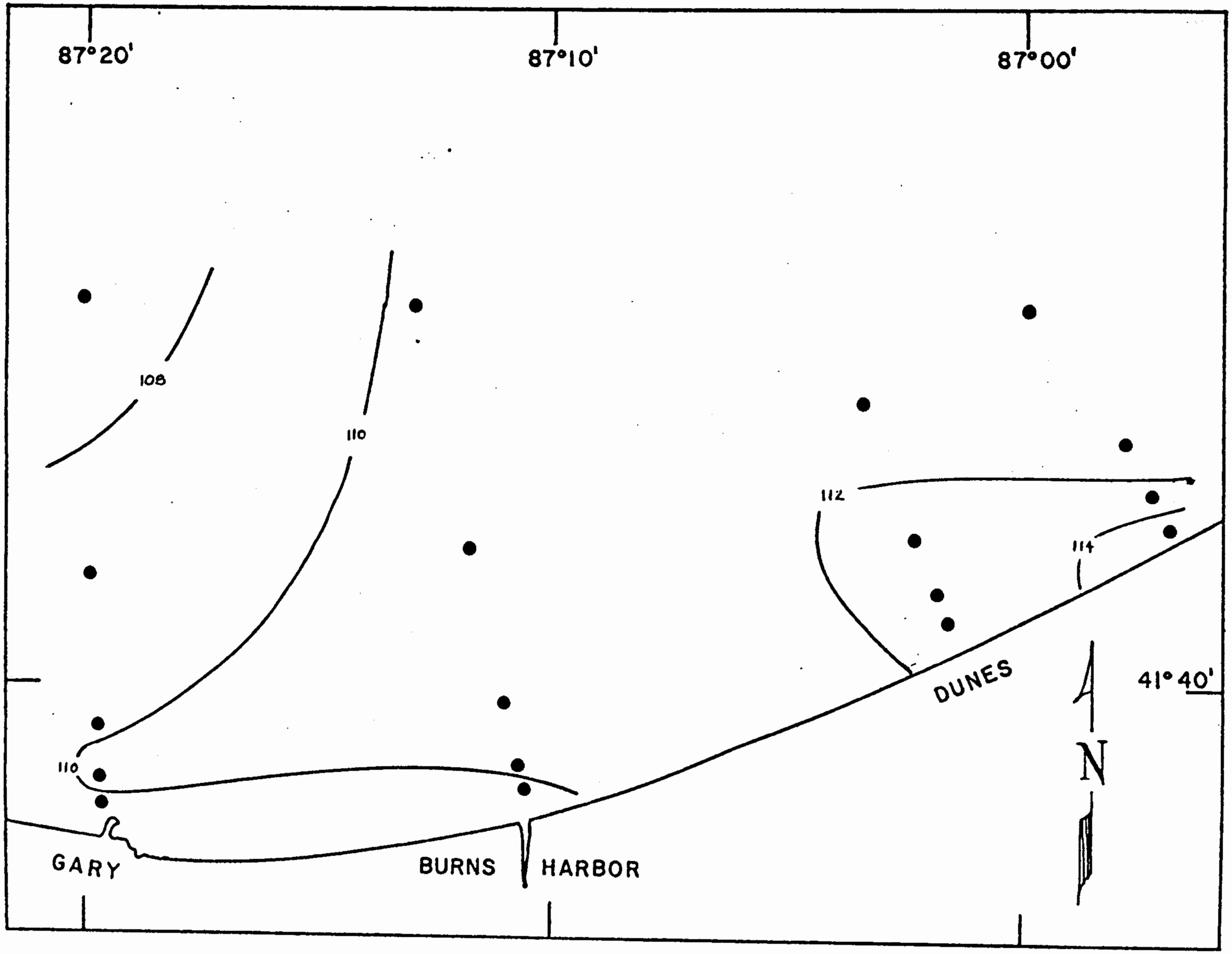
Appendix Figure A-2. Conductivity contours, southern Lake Michigan; 11 June, 1977.



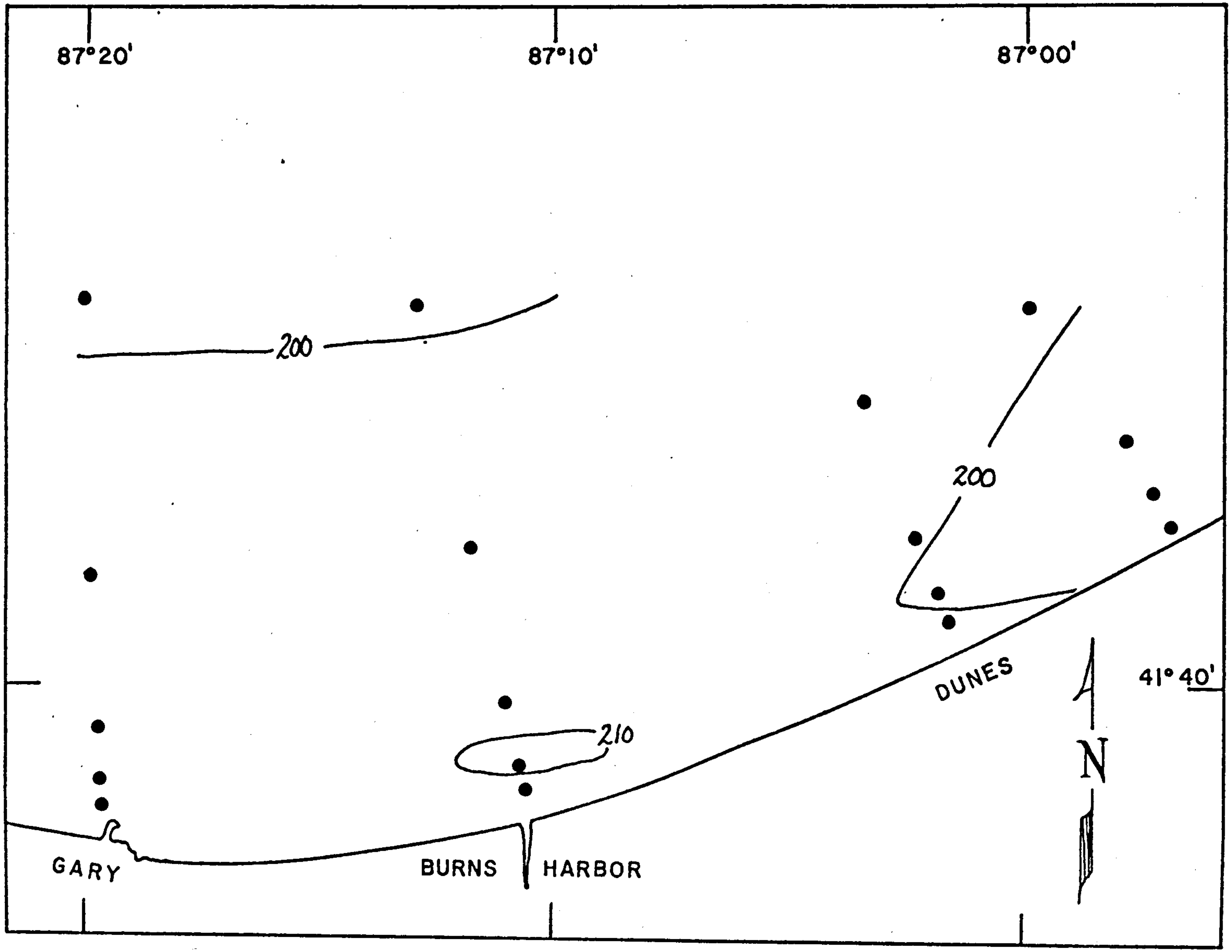
Appendix Figure A-3. Secchi disc contours, southern Lake Michigan; 11 June, 1977.



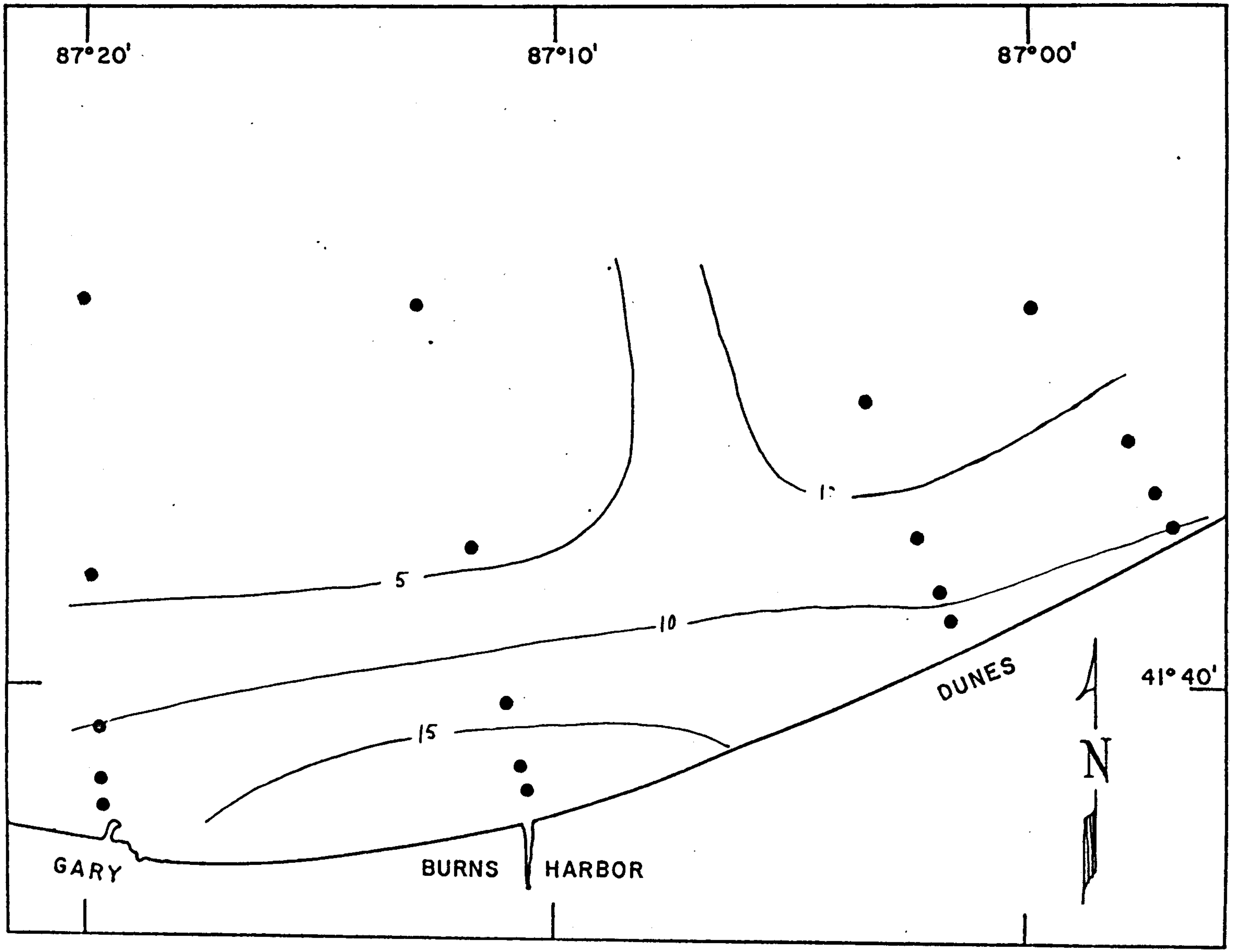
Appendix Figure A-4. Contours for pH, southern Lake Michigan; 11 June, 1977.



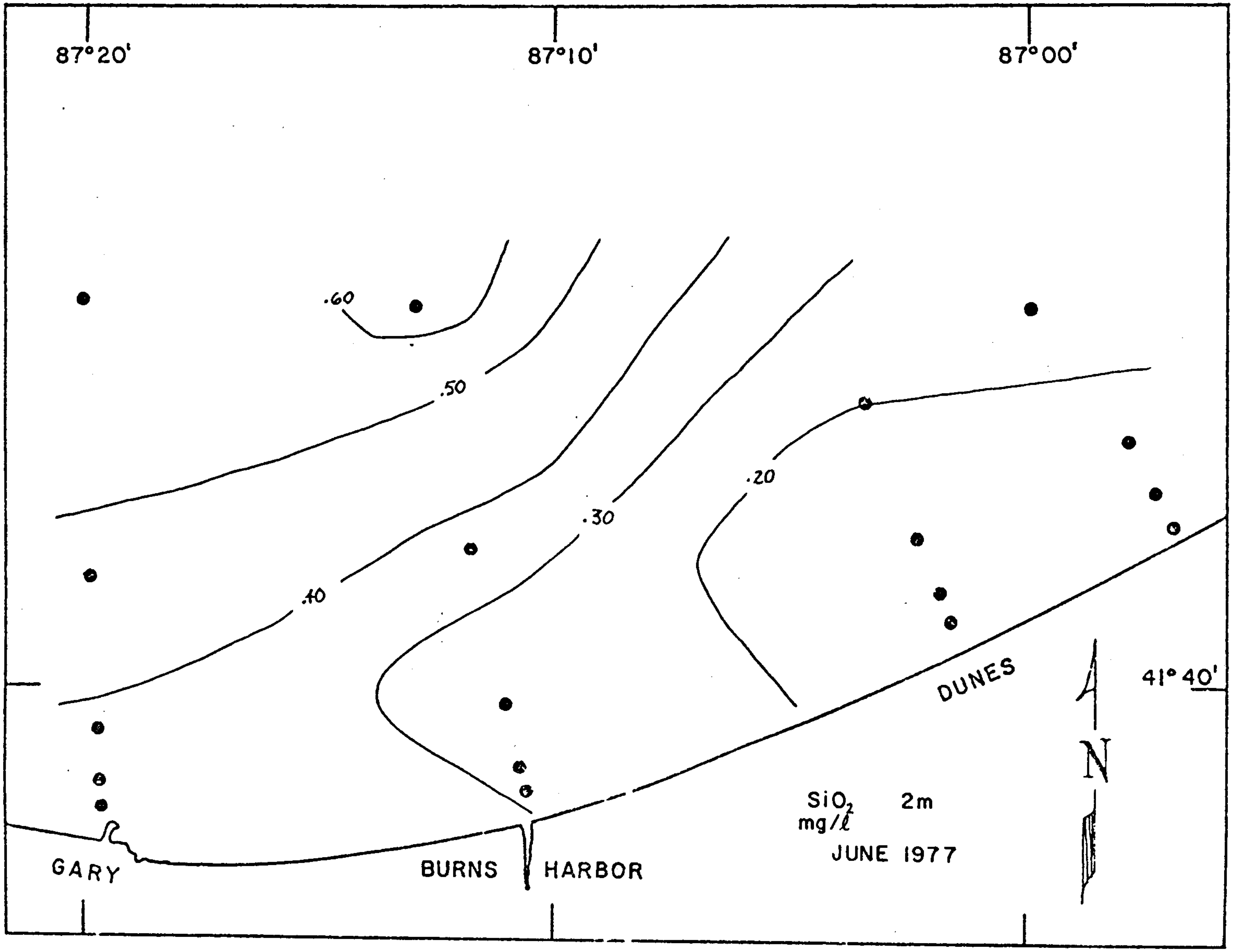
Appendix Figure A-5. Alkalinity contours, southern Lake Michigan; 11 June, 1977.



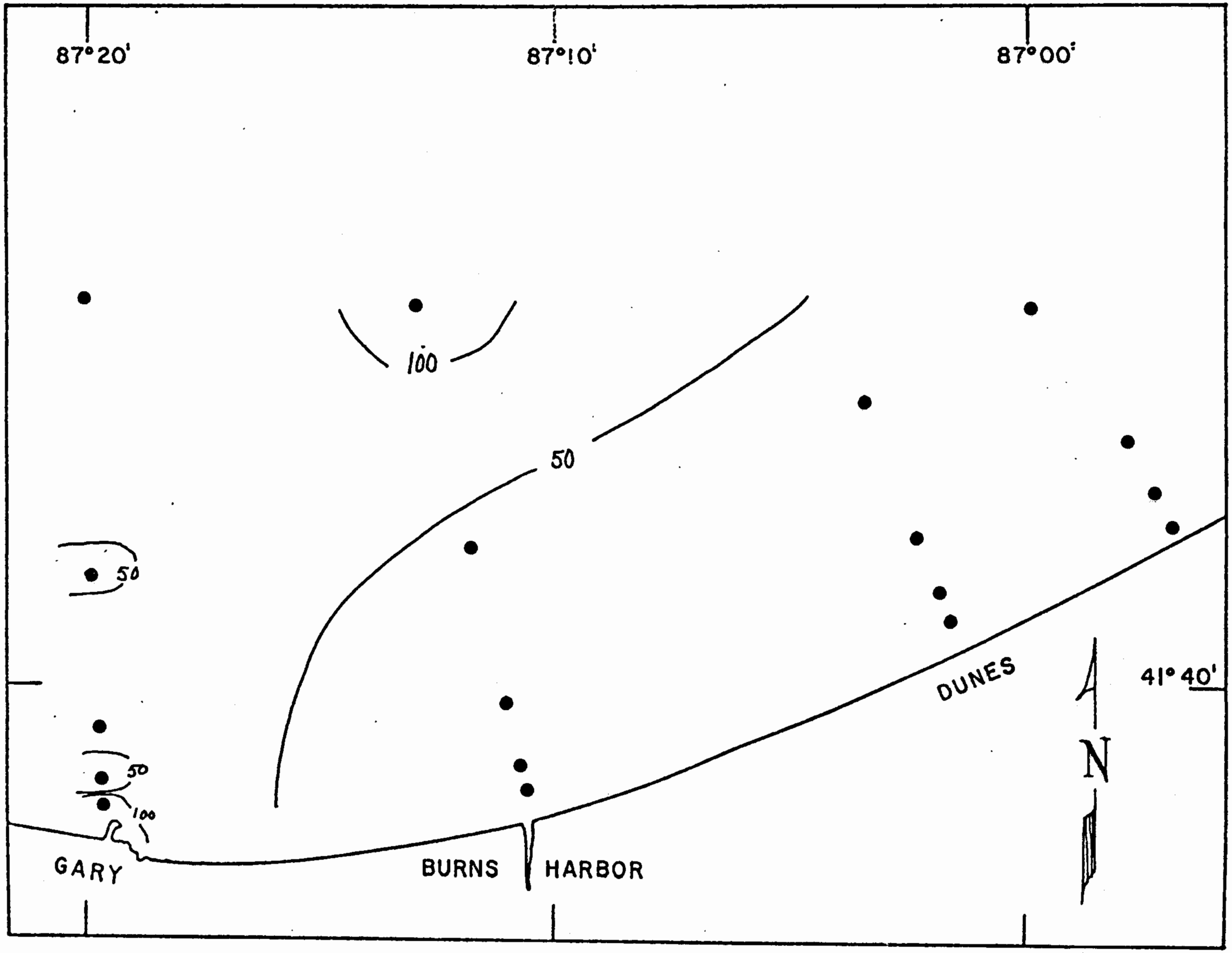
Appendix Figure A-6. NO_3-N contours, southern Lake Michigan; 11 June, 1977.



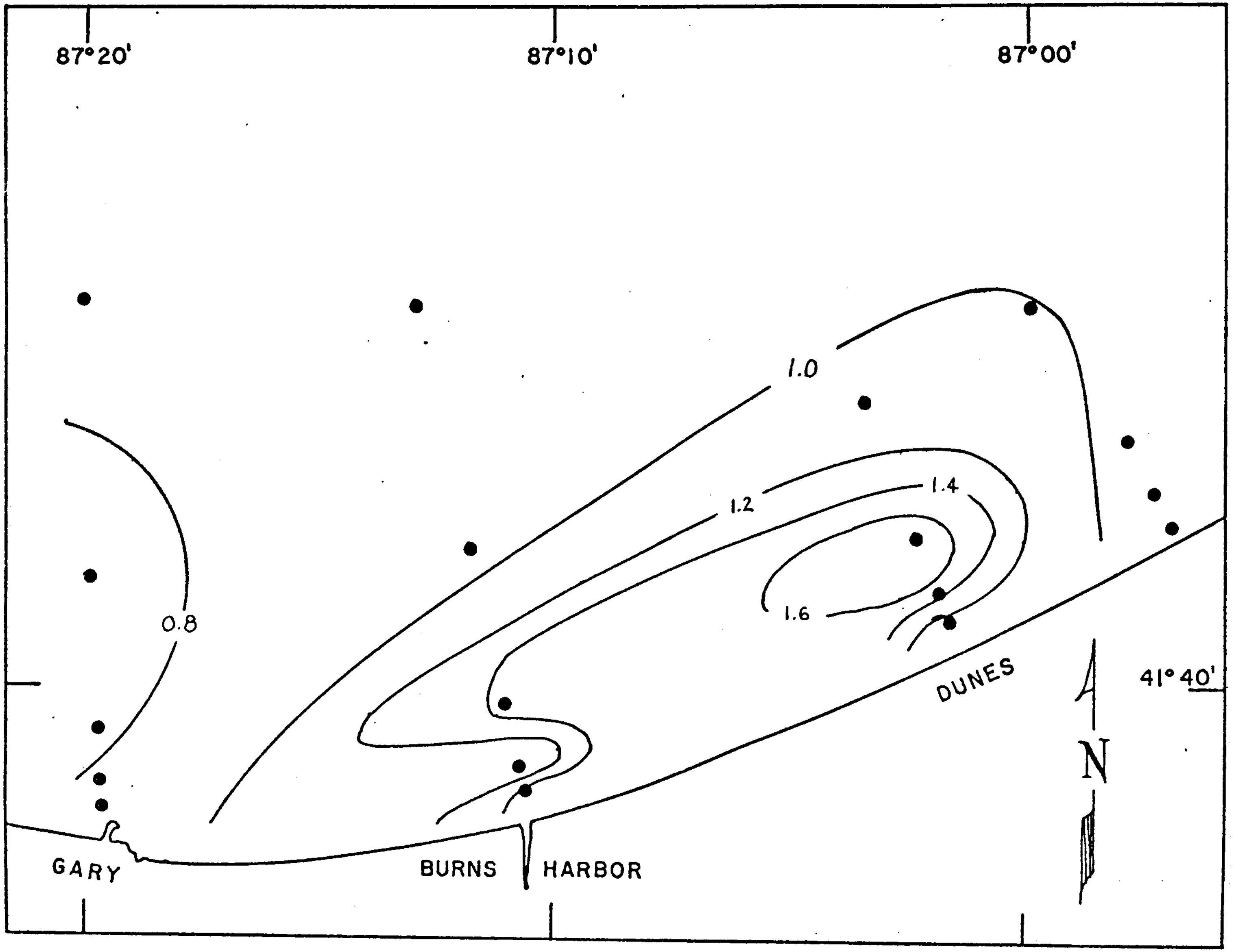
Appendix Figure A-7. Ammonia contours, southern Lake Michigan; 11 June, 1977.



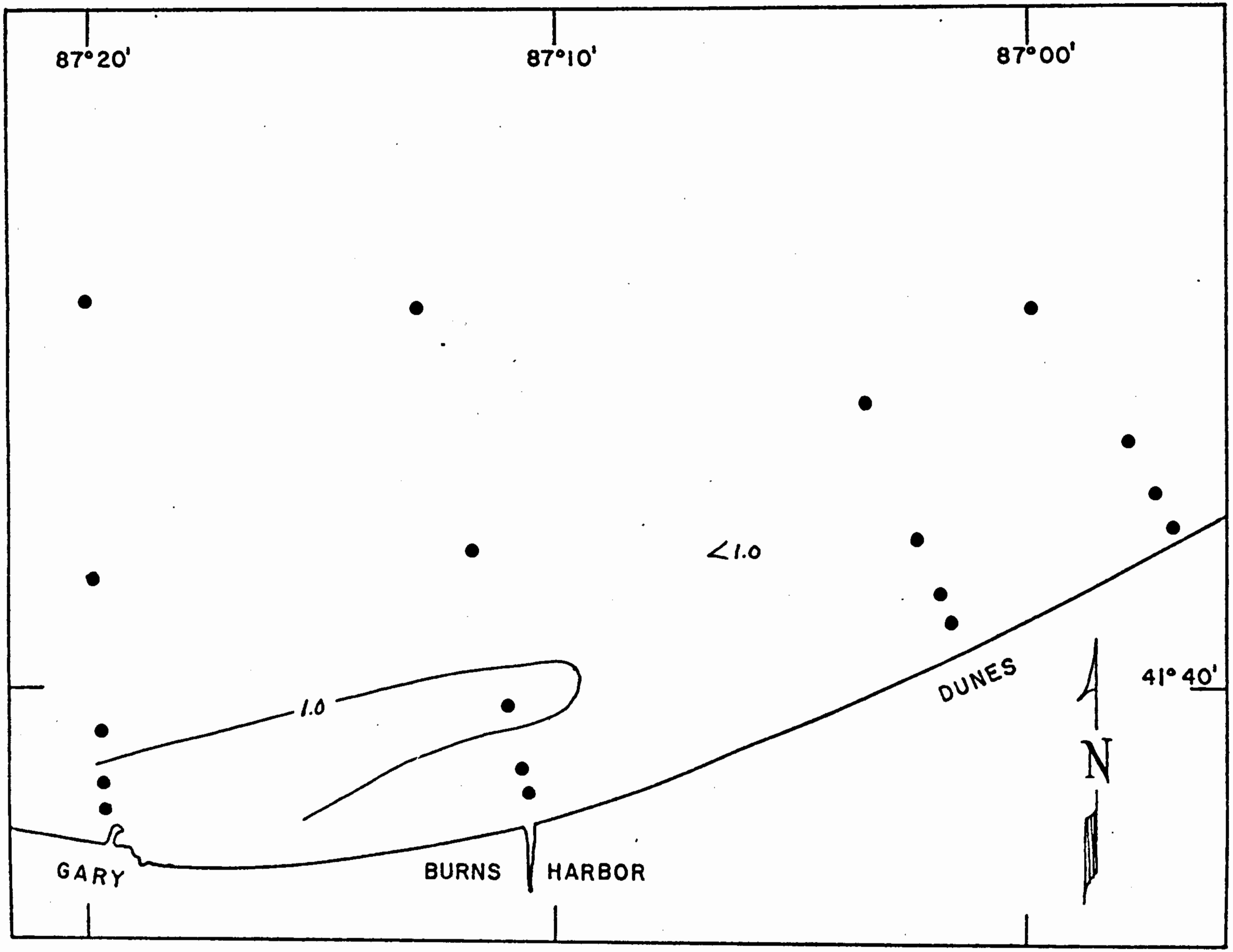
Appendix Figure A-8. Silica contours, southern Lake Michigan; 11 June, 1977.



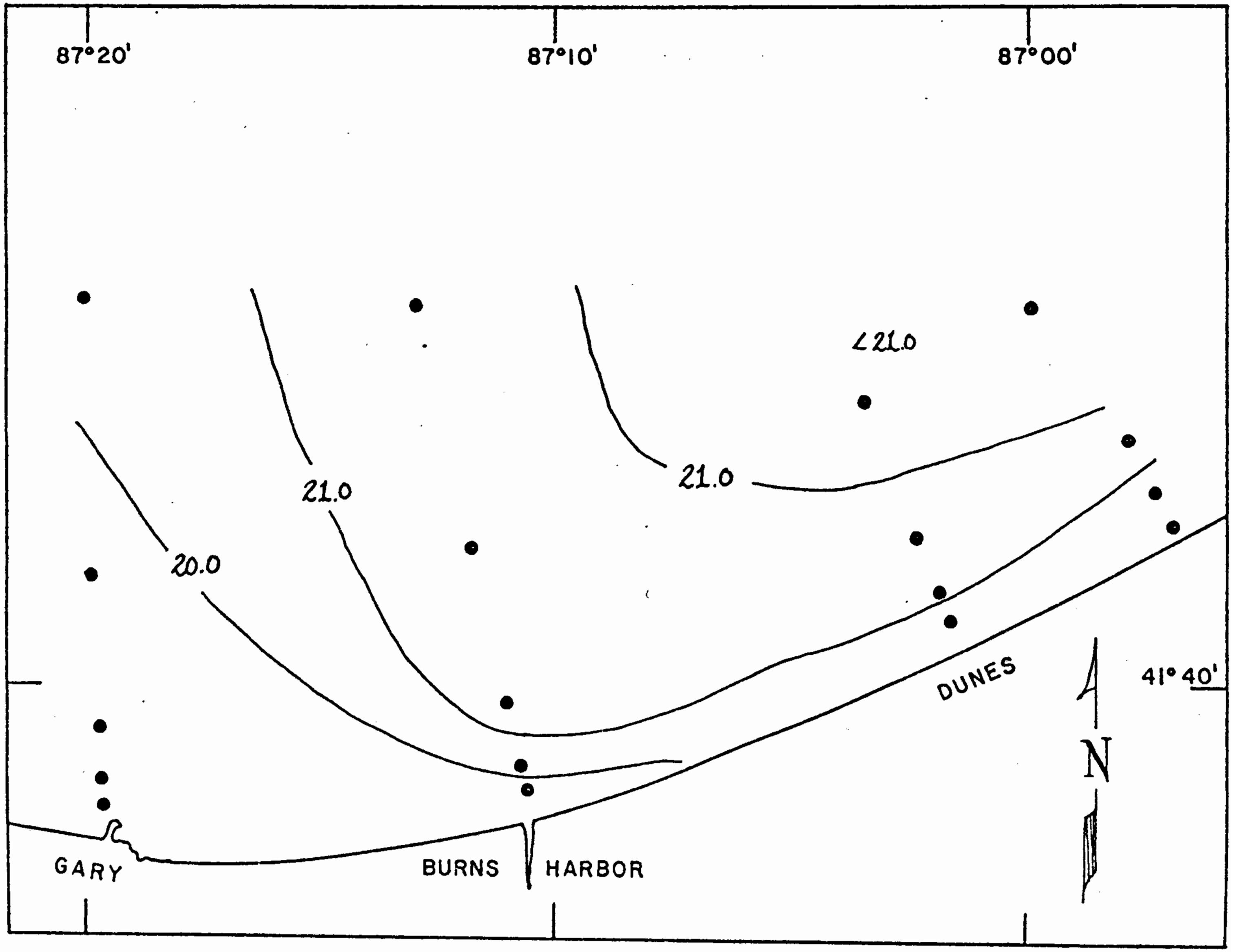
Appendix Figure A-9. Anaerobic heterotroph contours, southern Lake Michigan; 11 June, 1977.



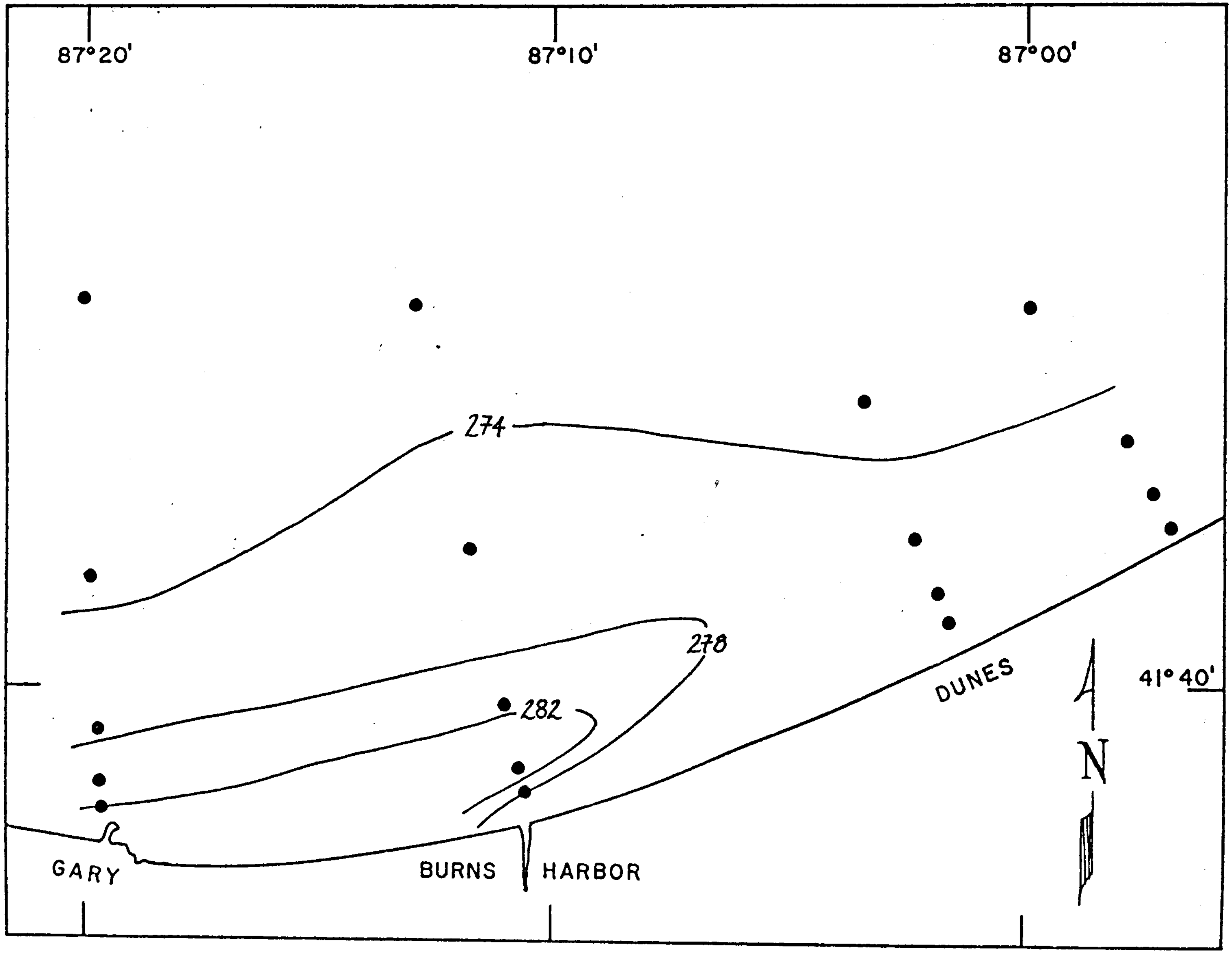
Appendix Figure A-10. Turbidity contours, southern Lake Michigan; 11 June, 1977.



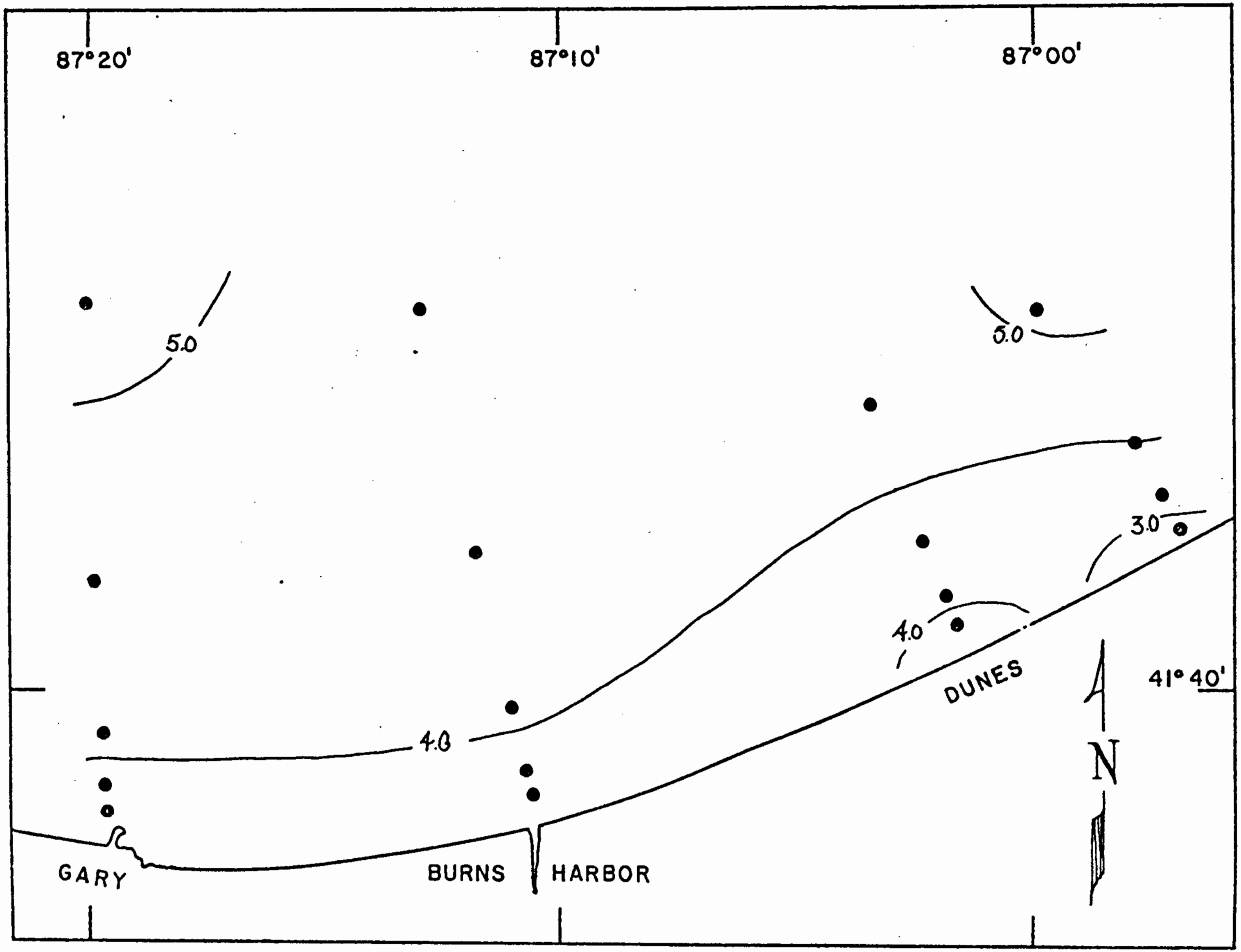
Appendix Figure A-11. Fecal coliform contours, southern Lake Michigan; 11 June, 1977.



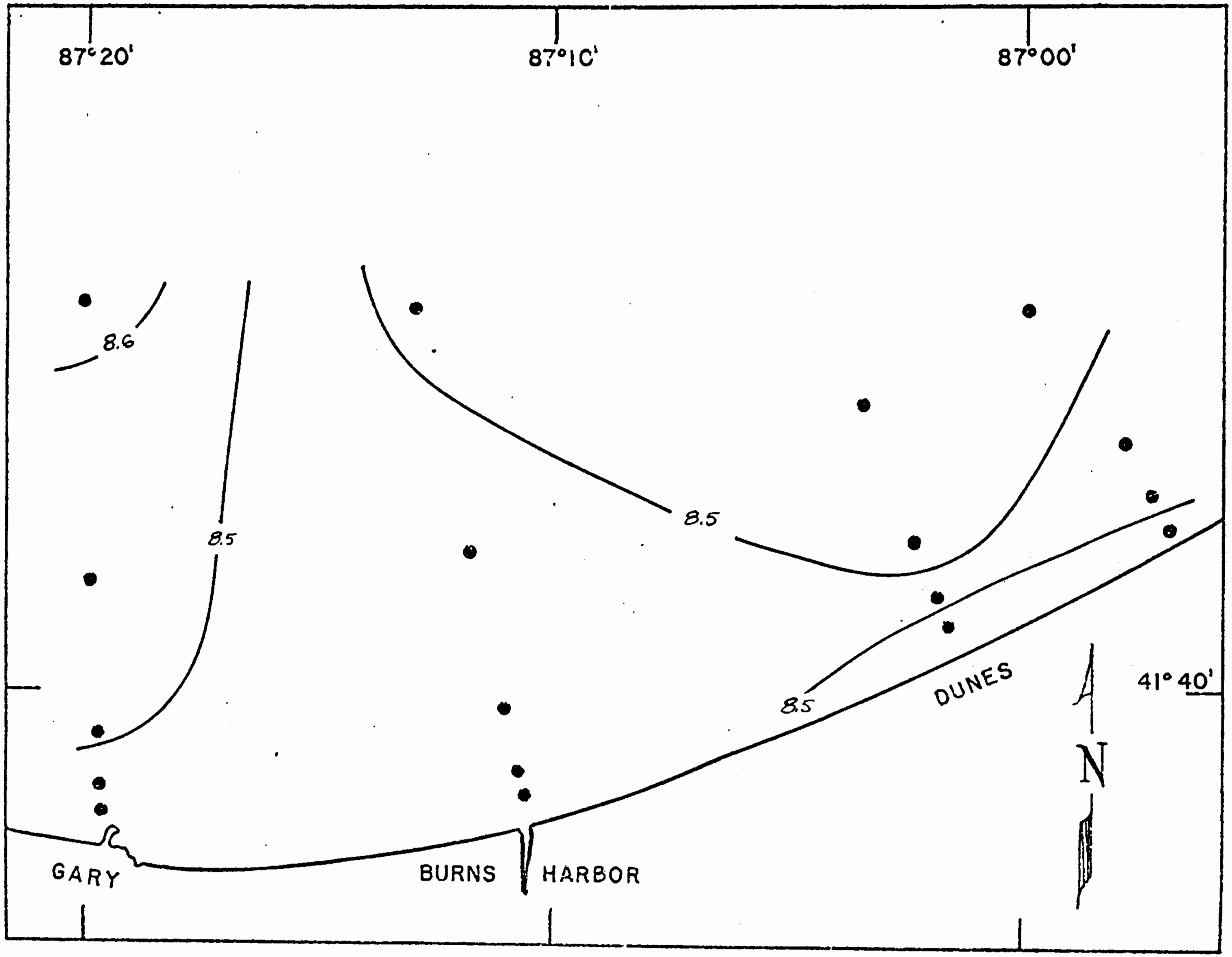
Appendix Figure B-1. Temperature contours, southern Lake Michigan; 20 August, 1977.



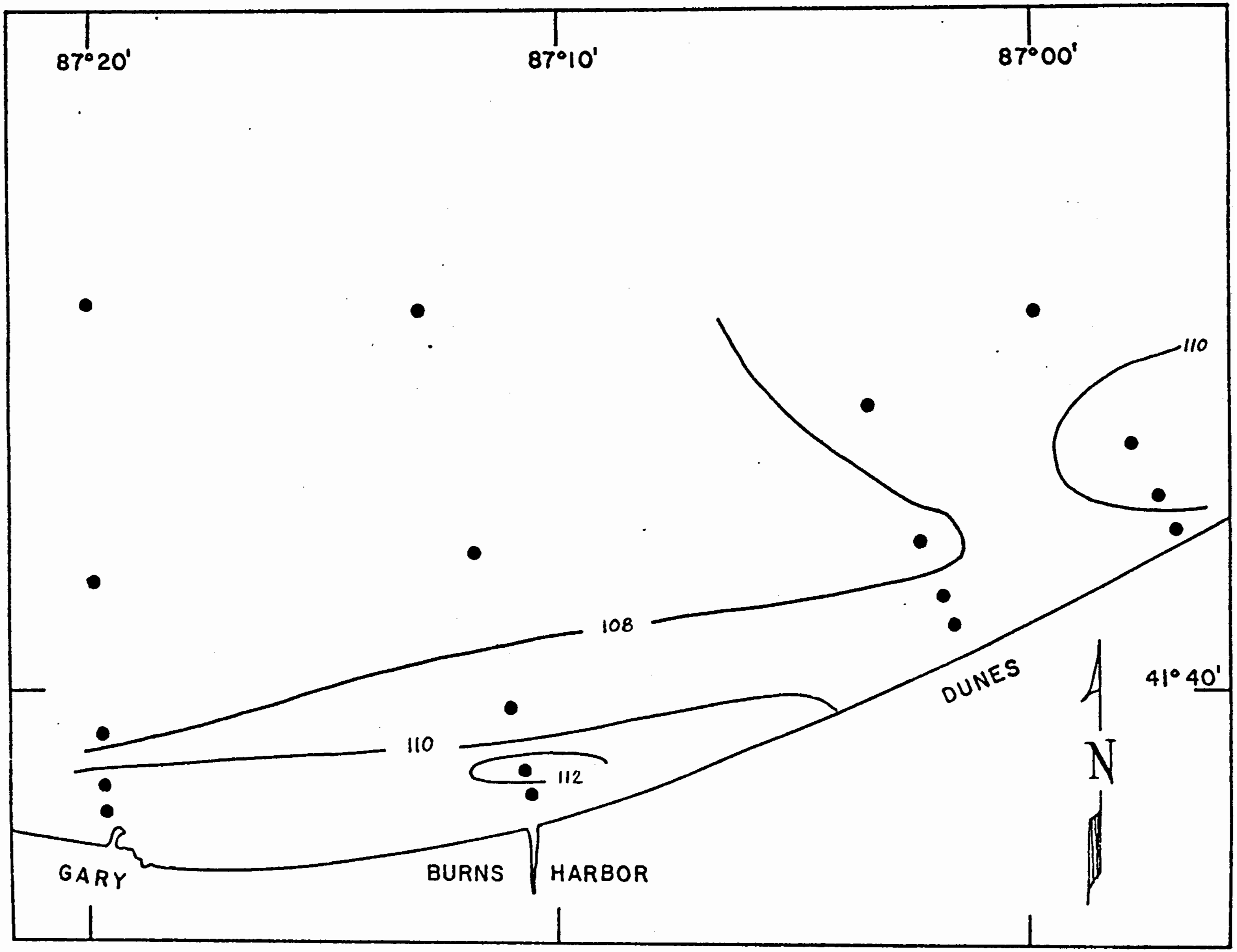
Appendix Figure B-2. Conductivity contours, southern Lake Michigan; 20 August, 1977.



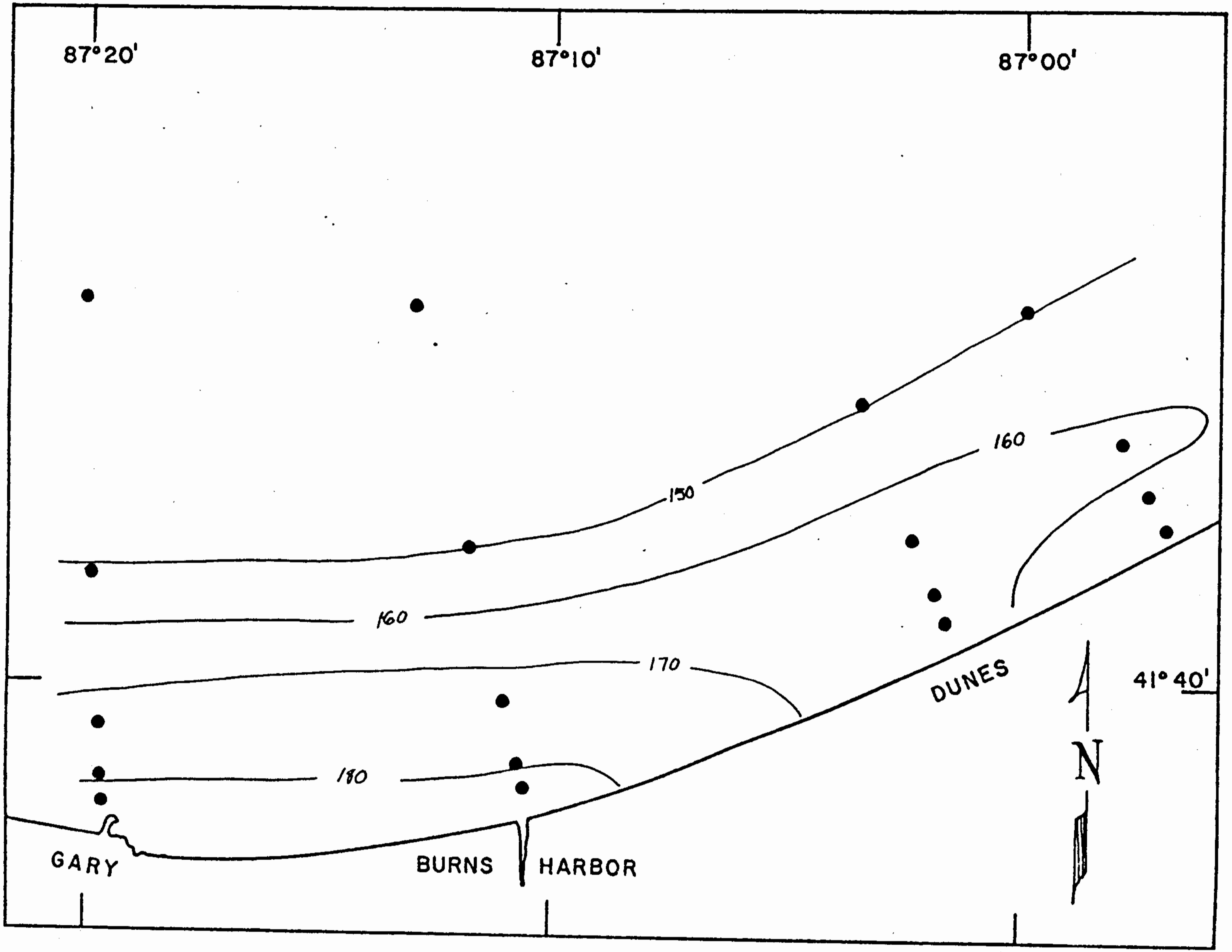
Appendix Figure B-3. Secchi disc contours, southern Lake Michigan; 20 August, 1977.



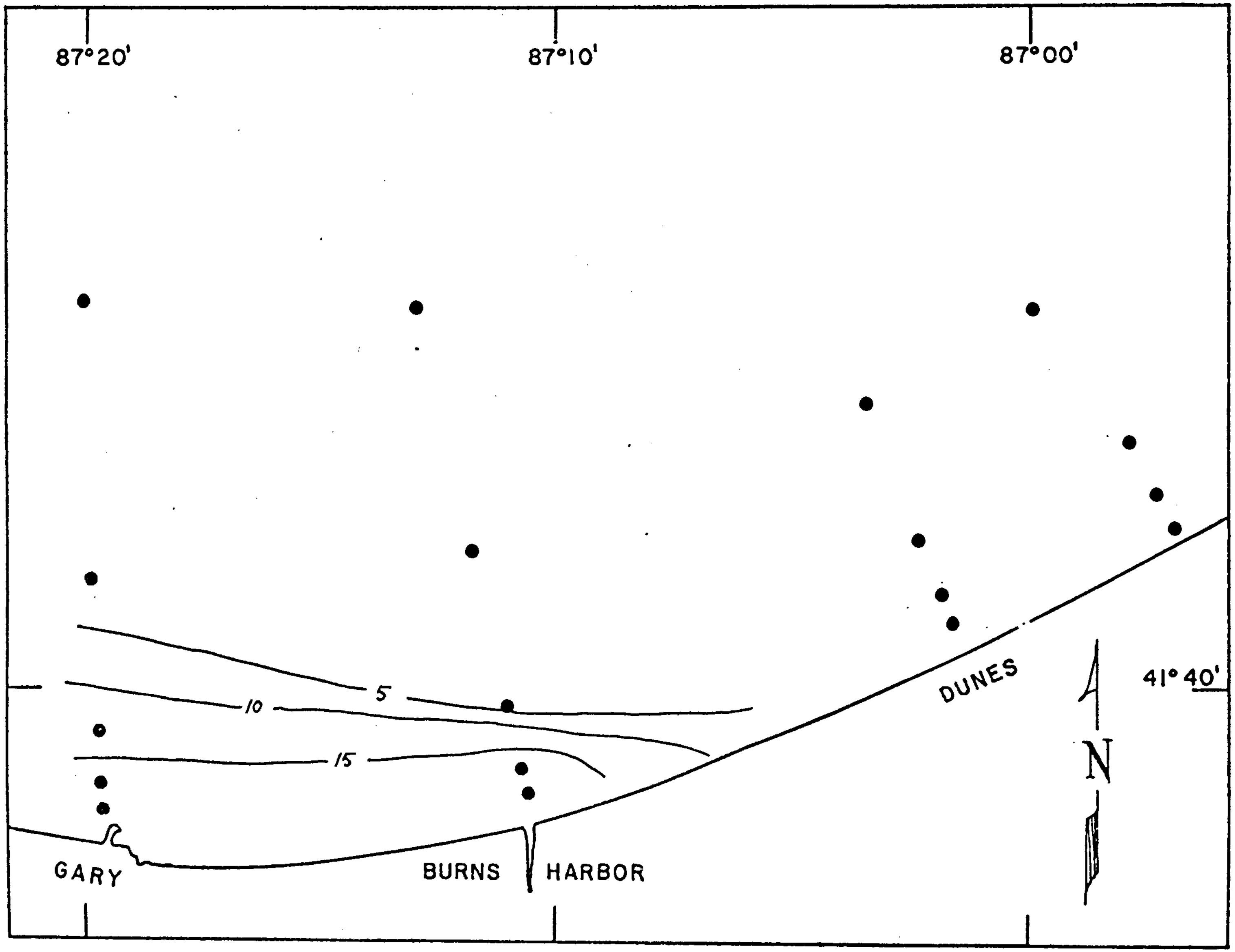
Appendix Figure B-4. Contours for pH, southern Lake Michigan; 20 August, 1977.



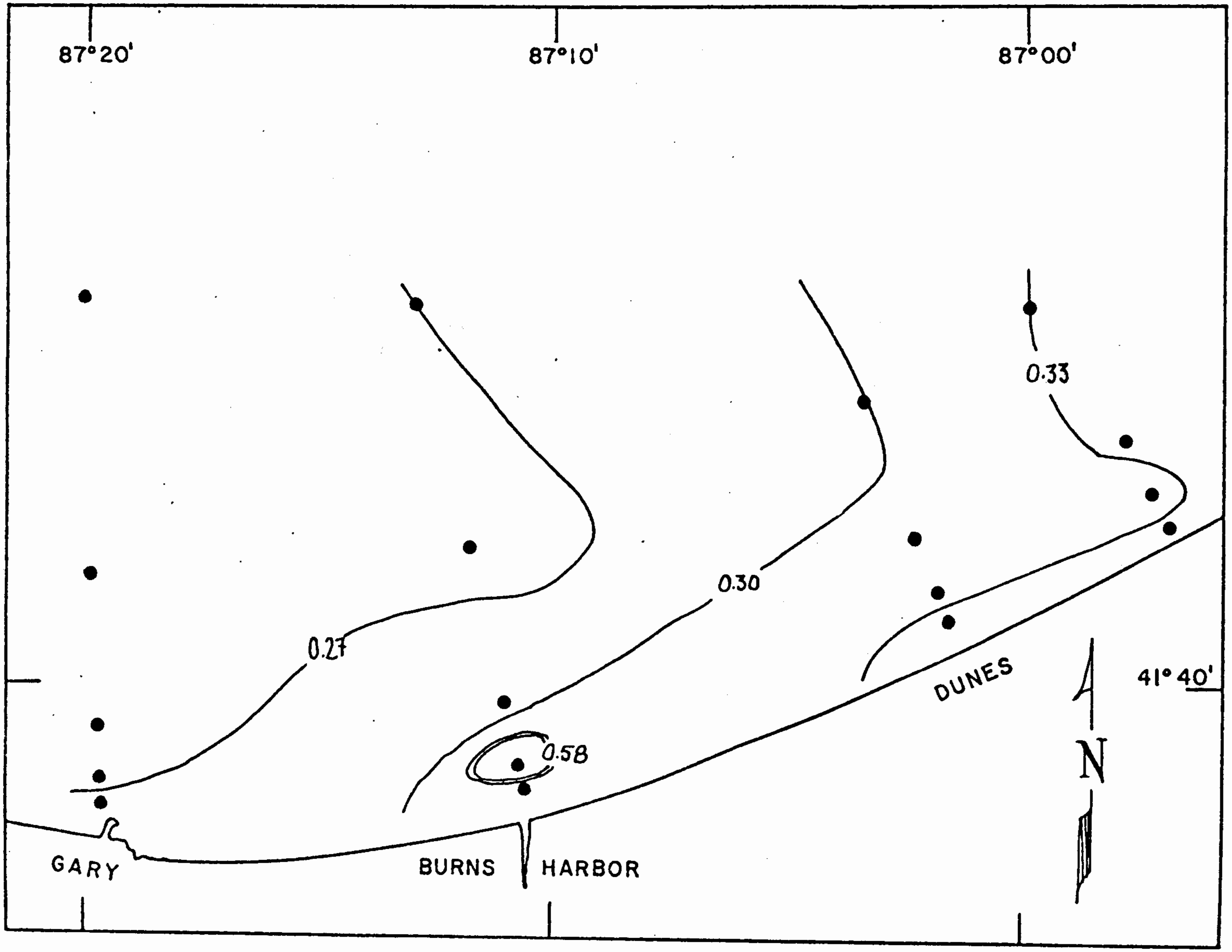
Appendix Figure B-5. Alkalinity contours, southern Lake Michigan; 20 August, 1977.



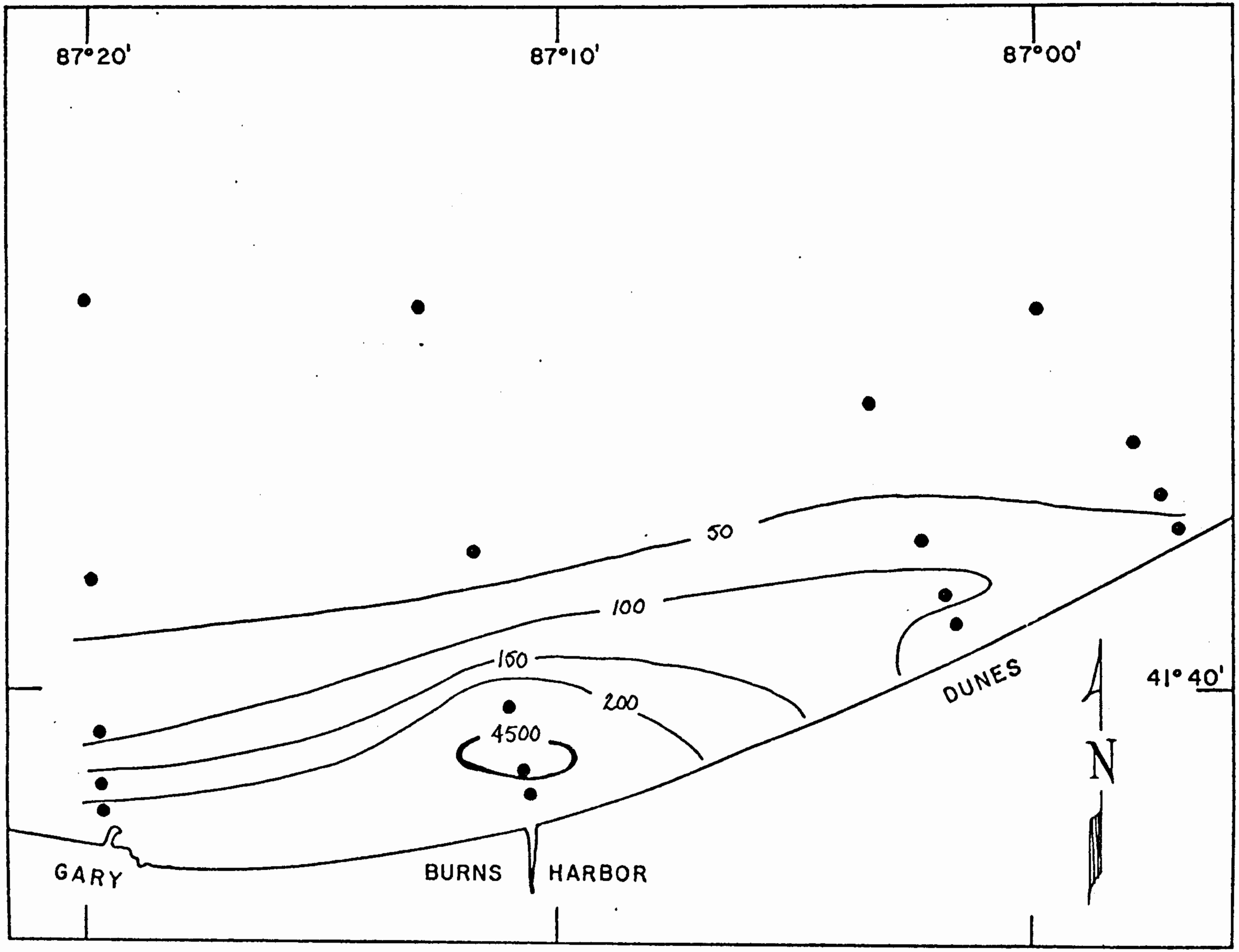
Appendix Figure B-6. NO3-N contours, southern Lake Michigan; 20 August, 1977.



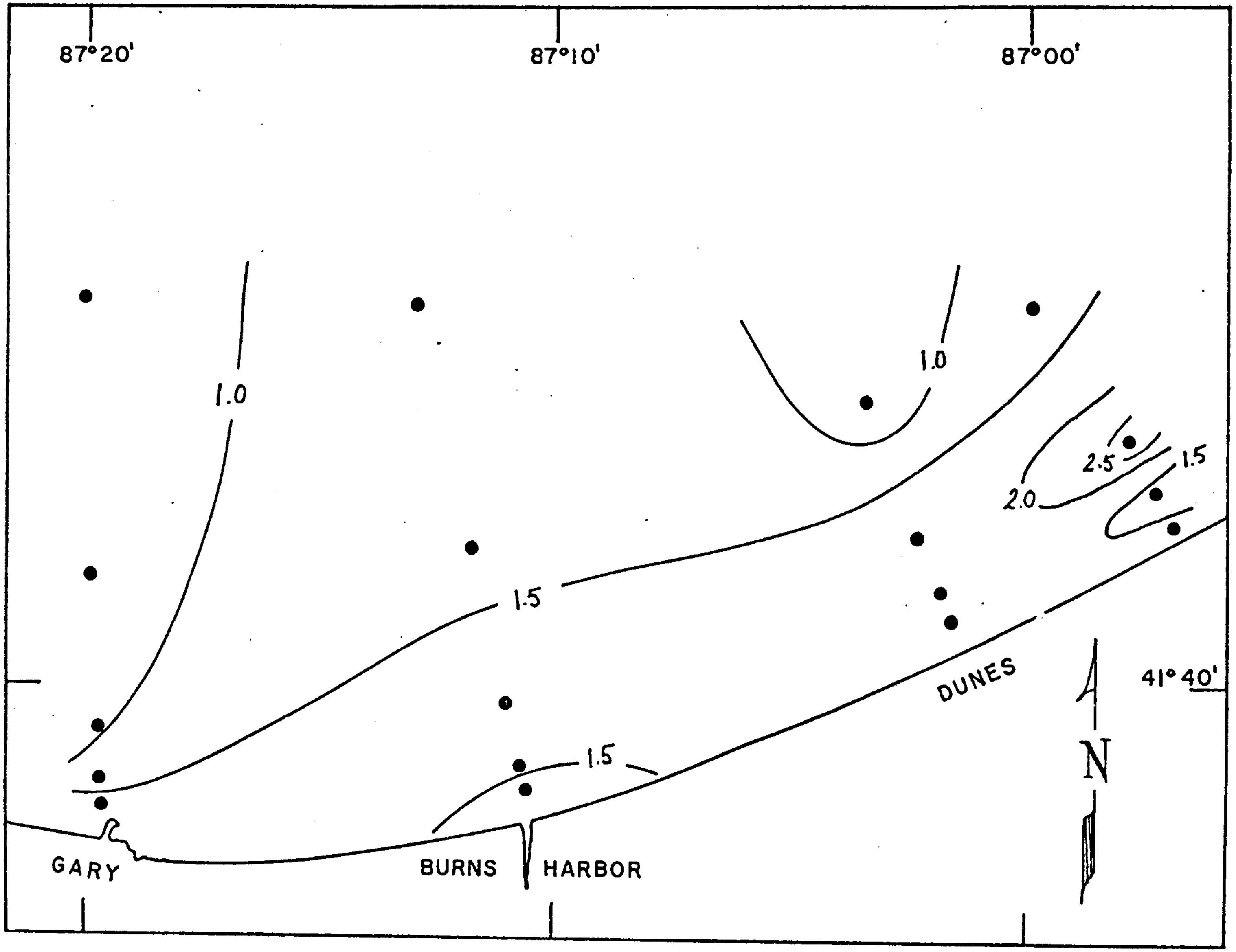
Appendix Figure B-7. Ammonia contours, southern Lake Michigan; 20 August, 1977.



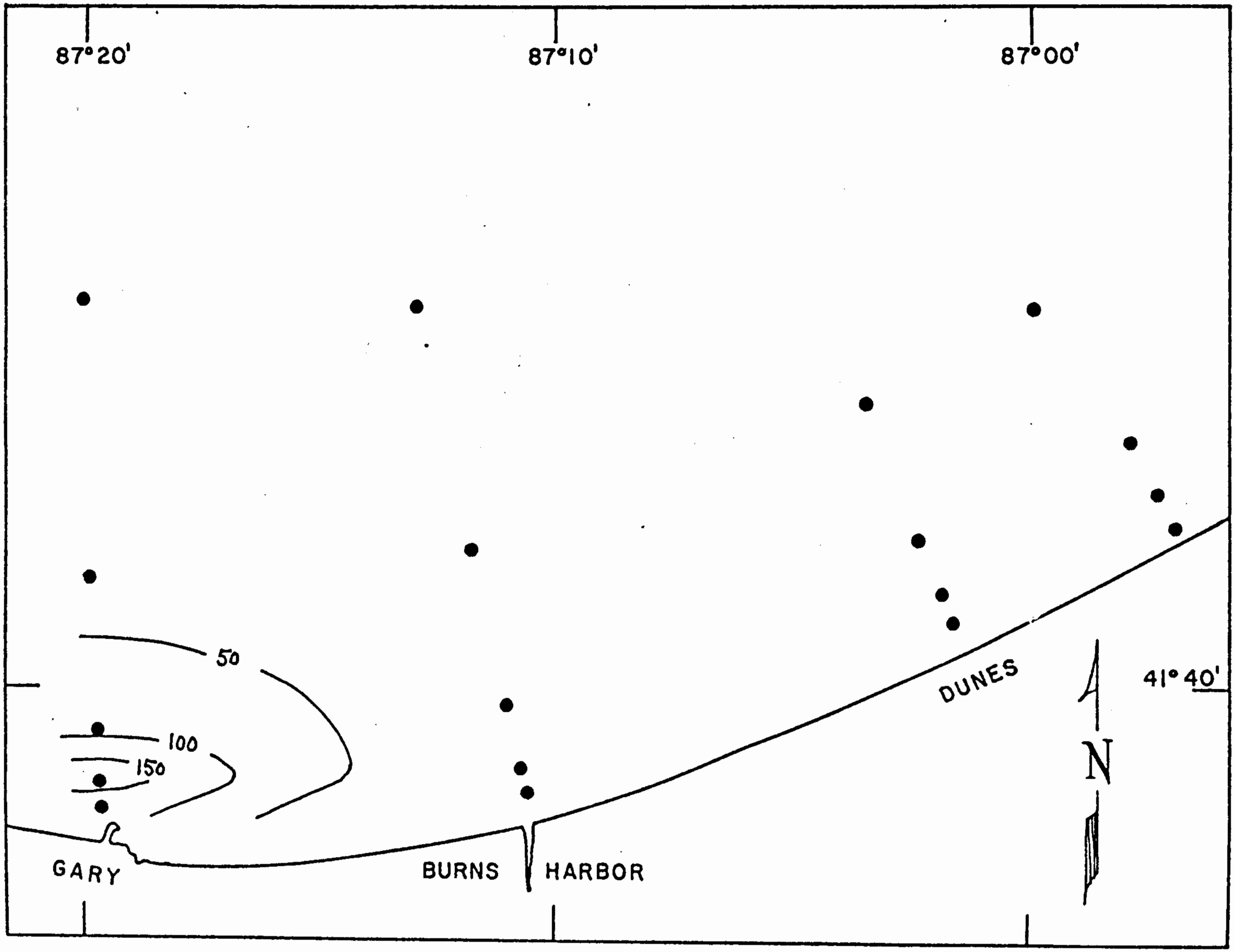
Appendix Figure B-8. Silica contours, southern Lake Michigan; 20 August, 1977.



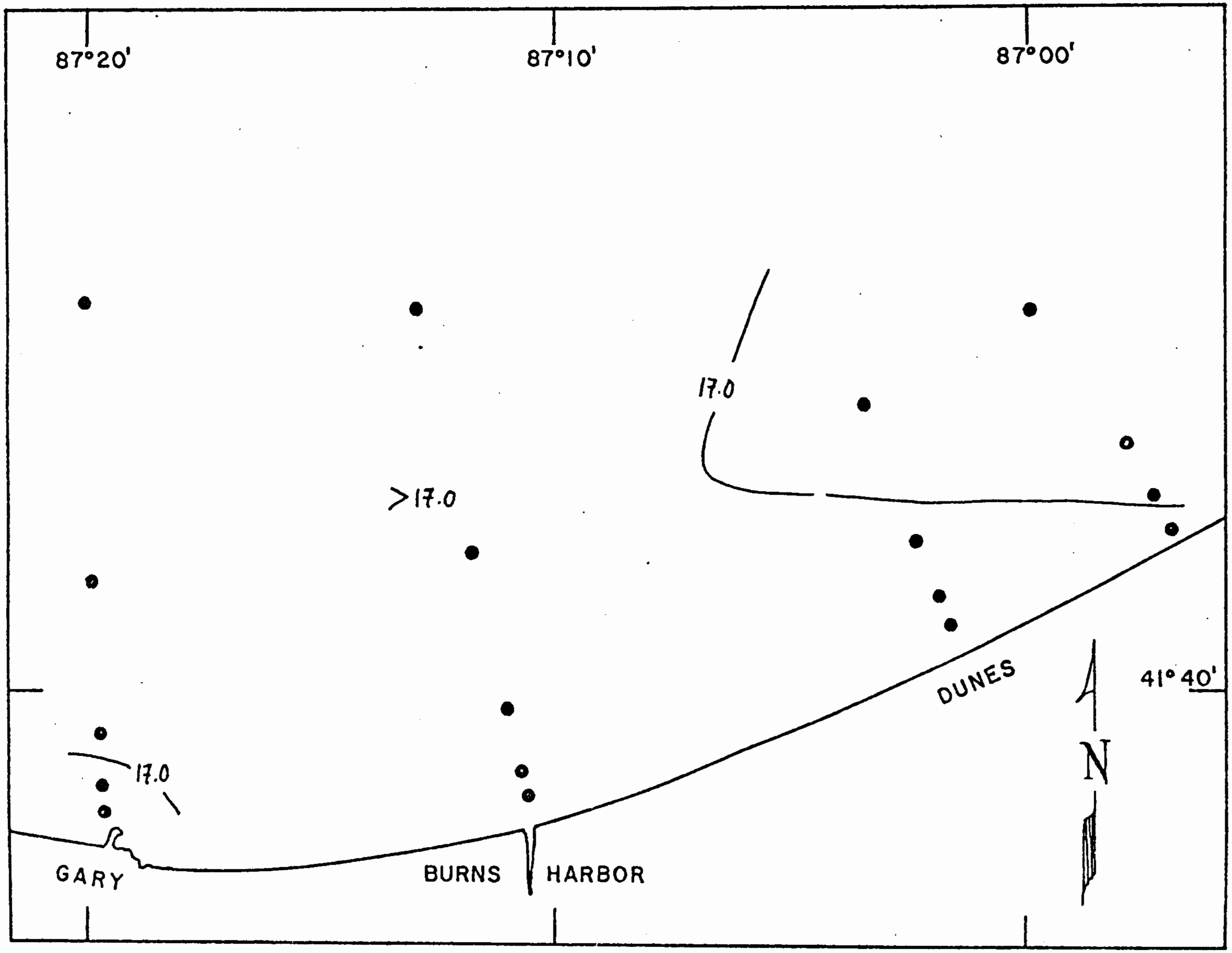
Appendix Figure B-9. Anaerobic heterotroph contours, southern Lake Michigan; 20 August, 1977.



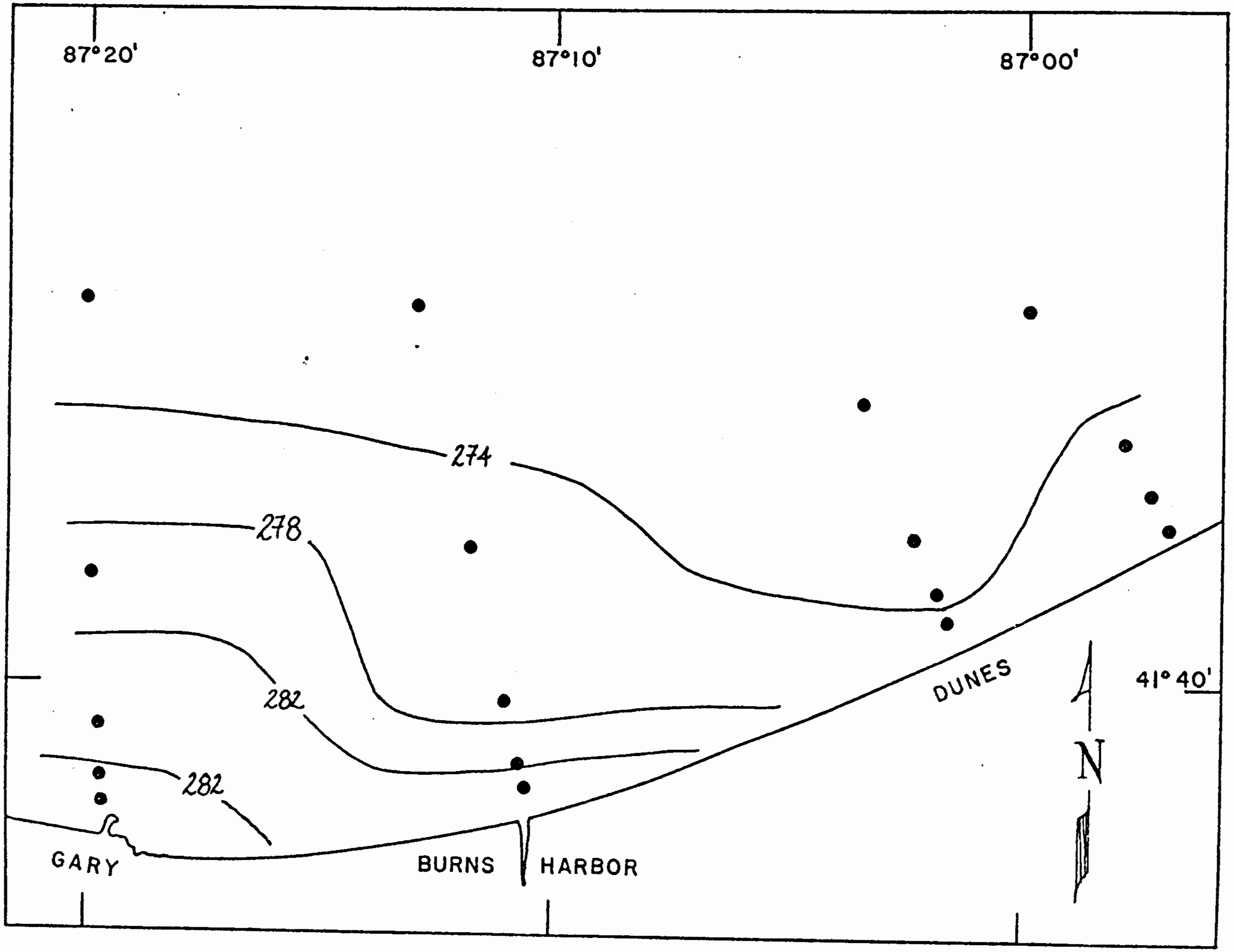
Appendix Figure B-10. Turbidity contours, southern Lake Michigan; 20 August, 1977.



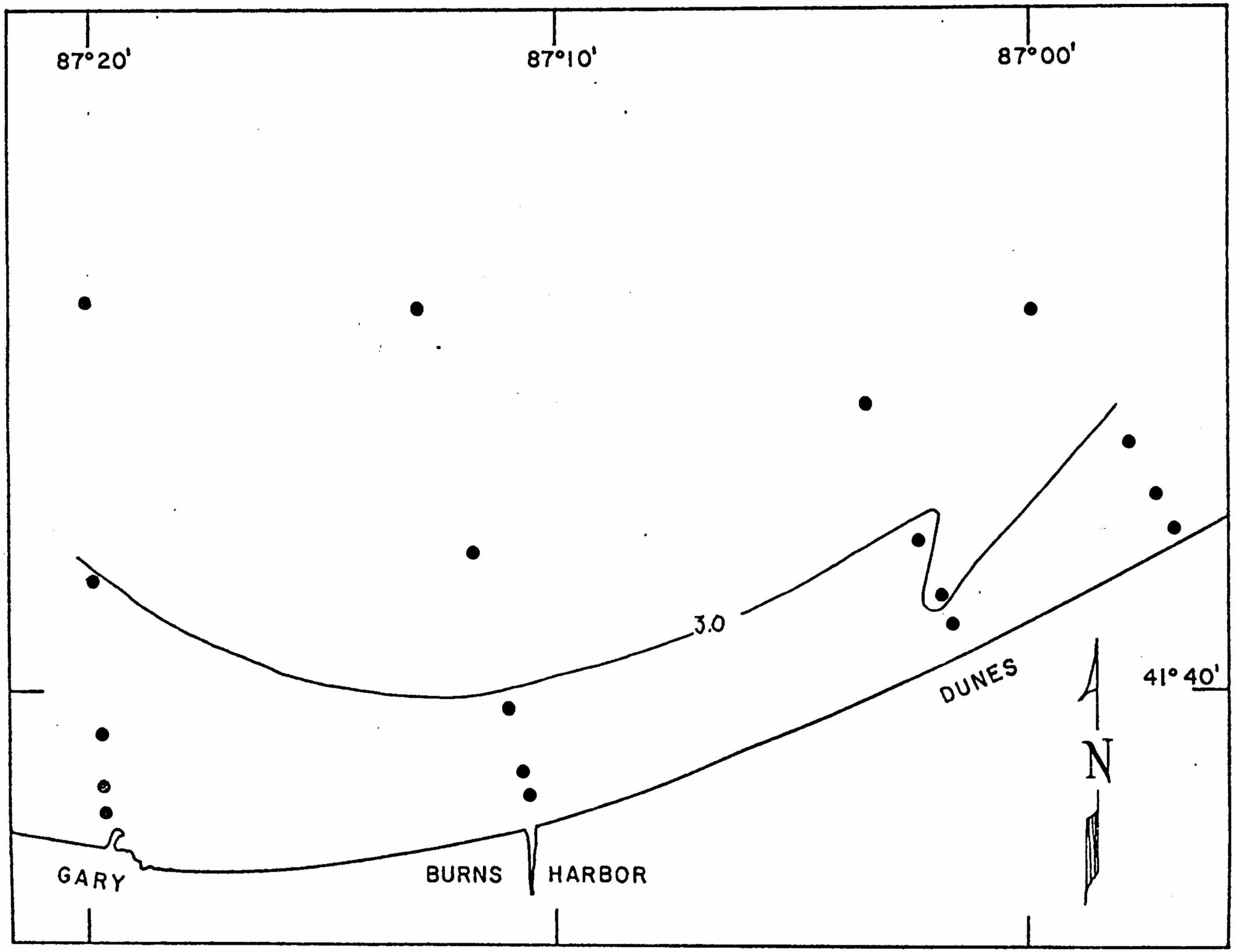
Appendix Figure B-11. Fecal coliform contours, southern Lake Michigan; 20 August, 1977.



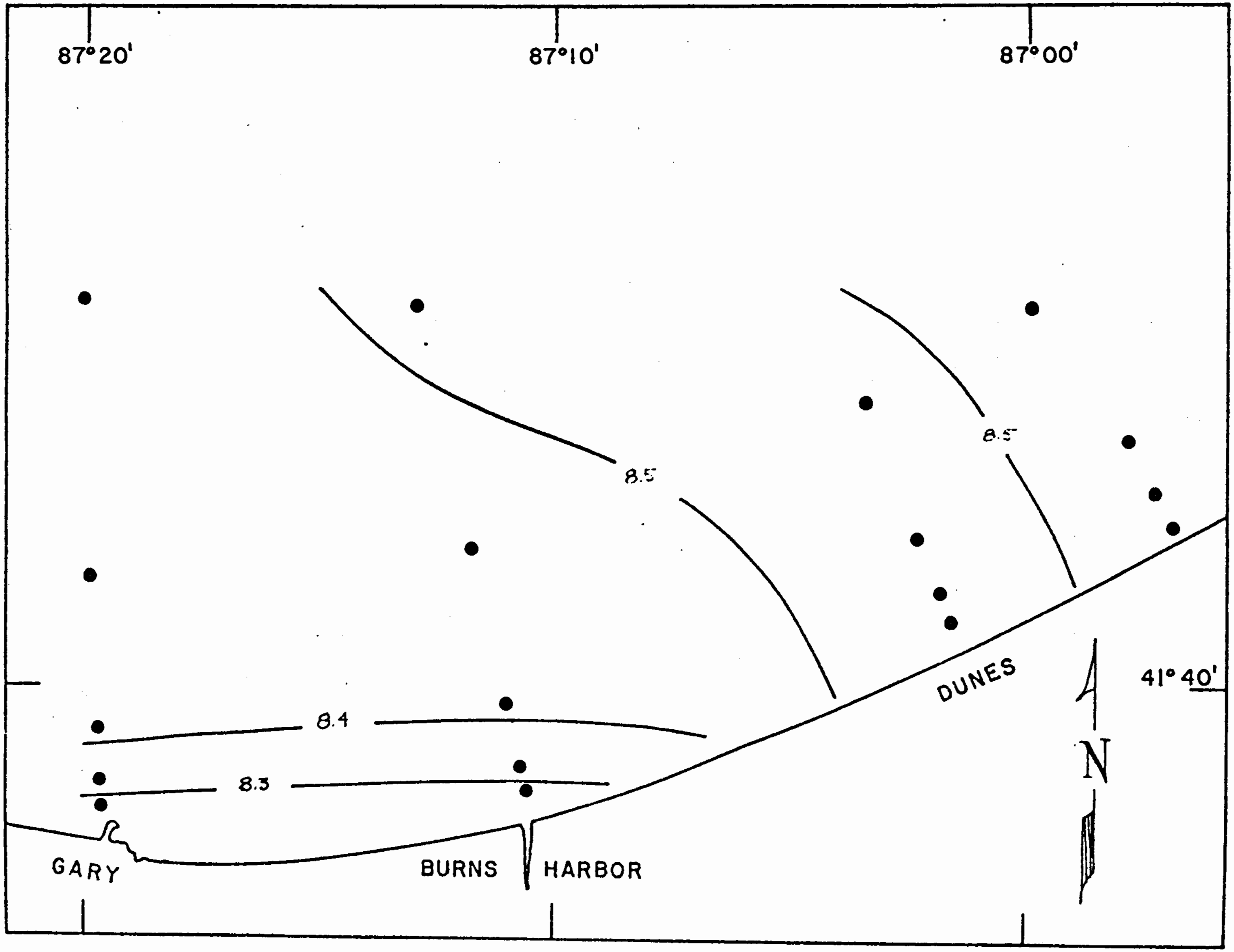
Appendix Figure C-1. Temperature contours, southern Lake Michigan; 24 September, 1977.



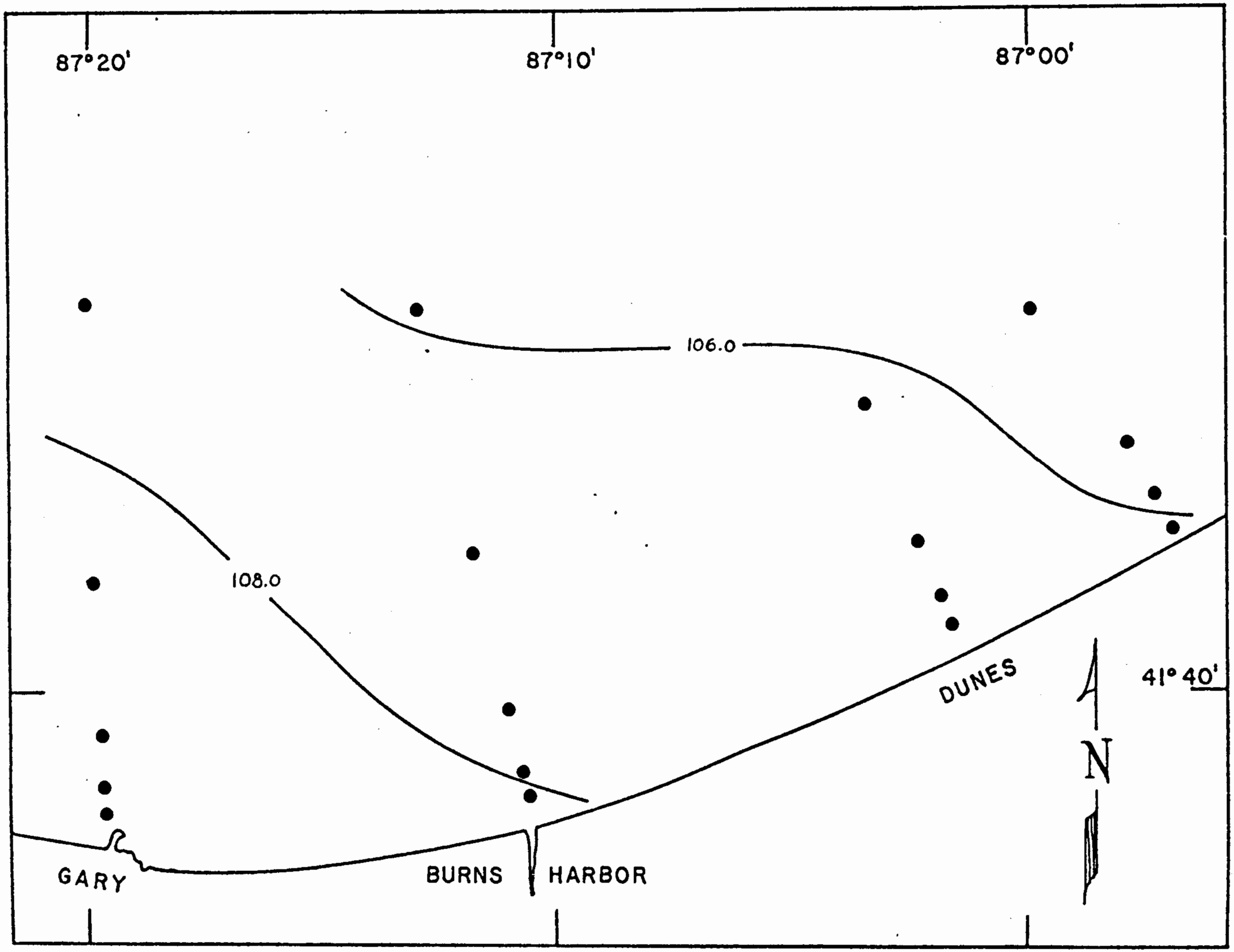
Appendix Figure C-2. Conductivity contours, southern Lake Michigan; 24 September, 1977.



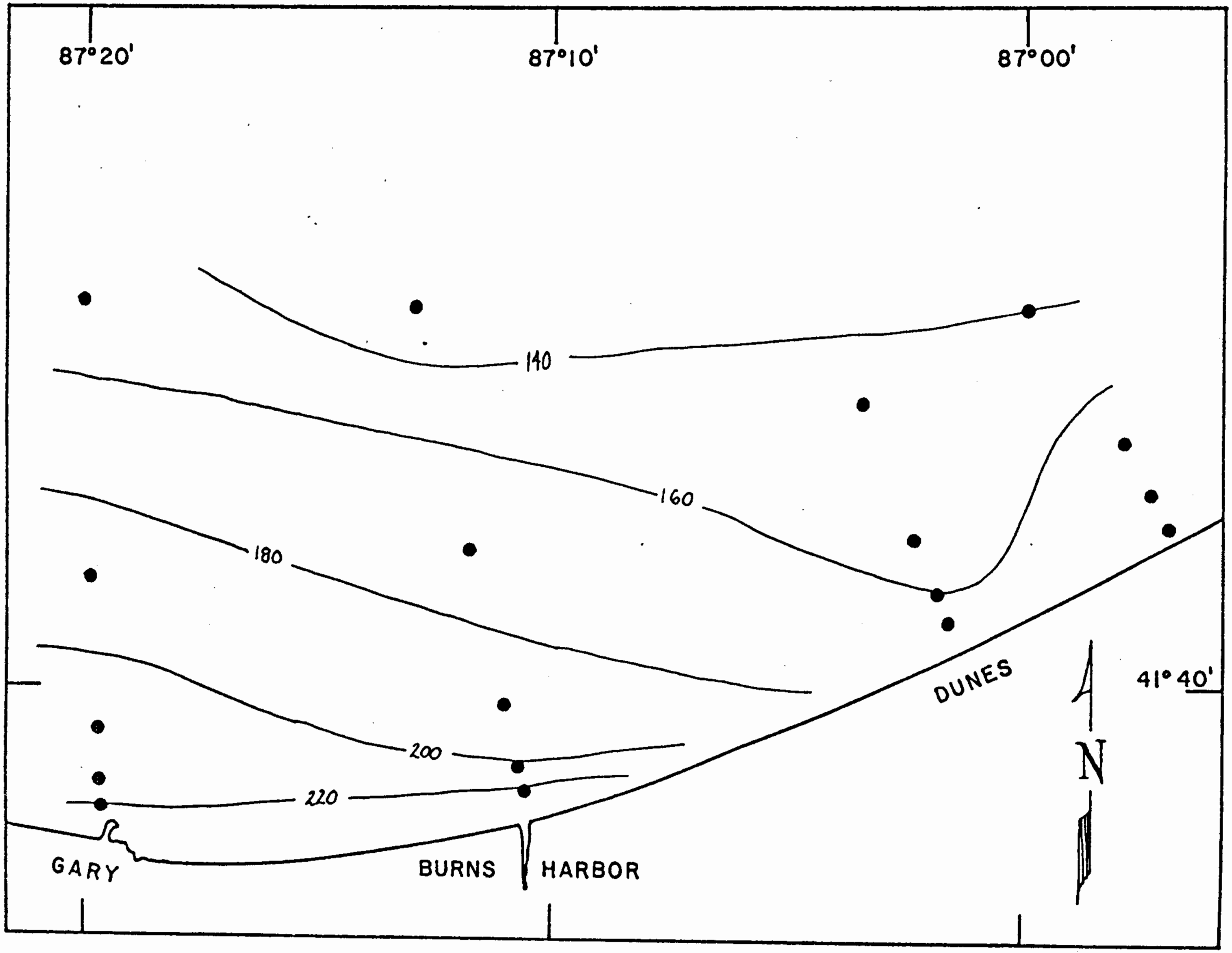
Appendix Figure C-3. Secchi disc contours, southern Lake Michigan; 24 September, 1977.



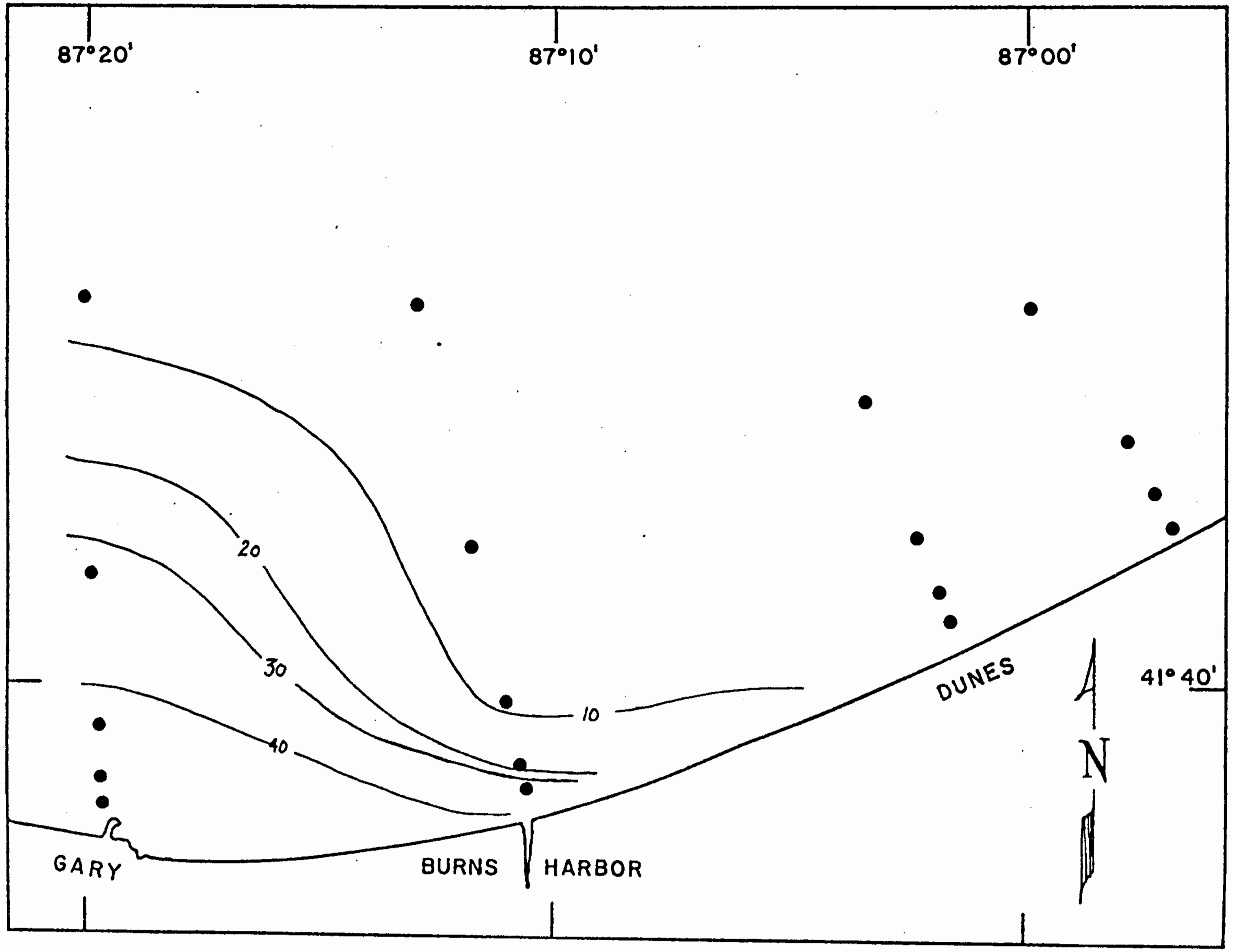
Appendix Figure C-4. Contours for pH, southern Lake Michigan; 24 September, 1977.



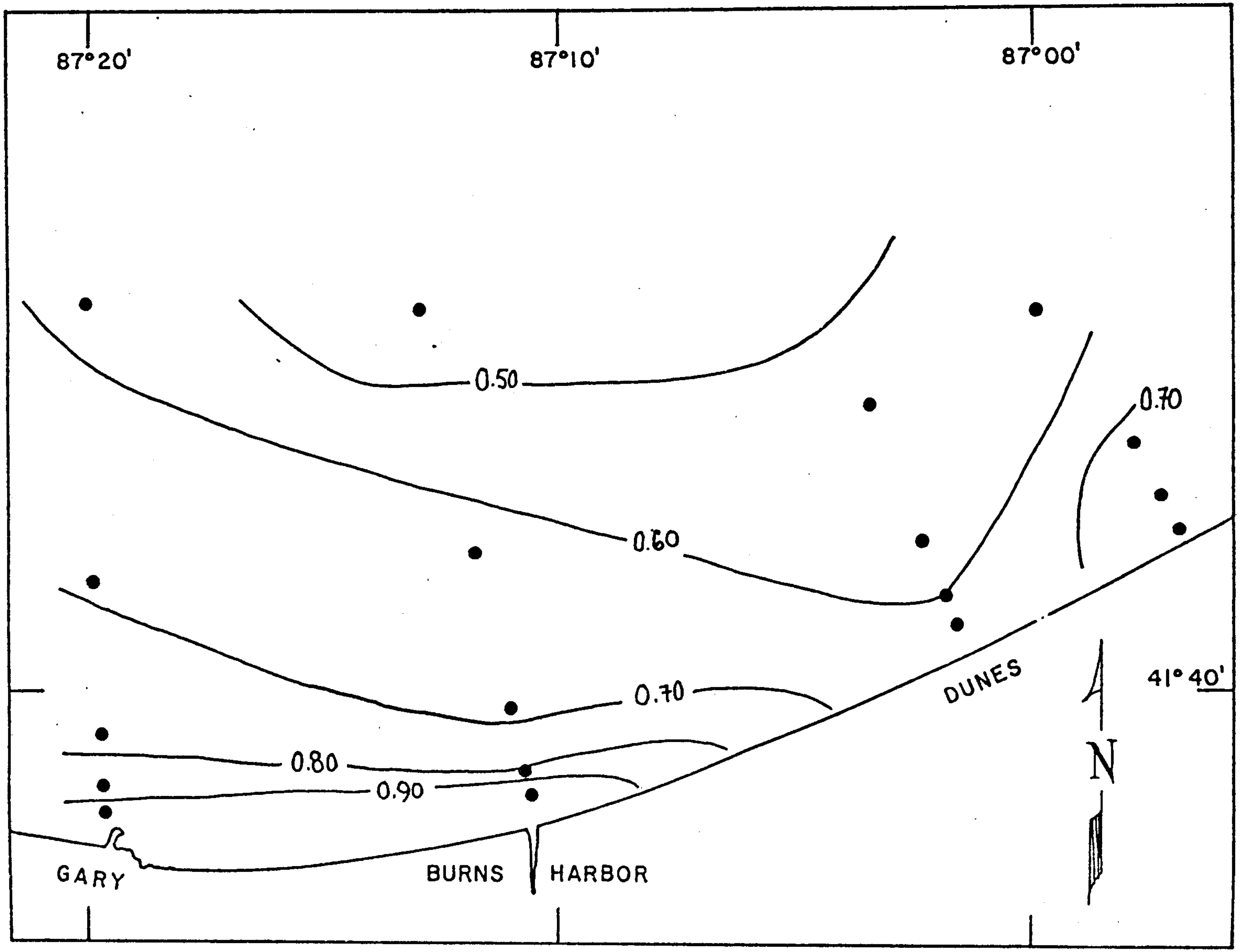
Appendix Figure C-5. Alkalinity contours, southern Lake Michigan; 24 September, 1977.



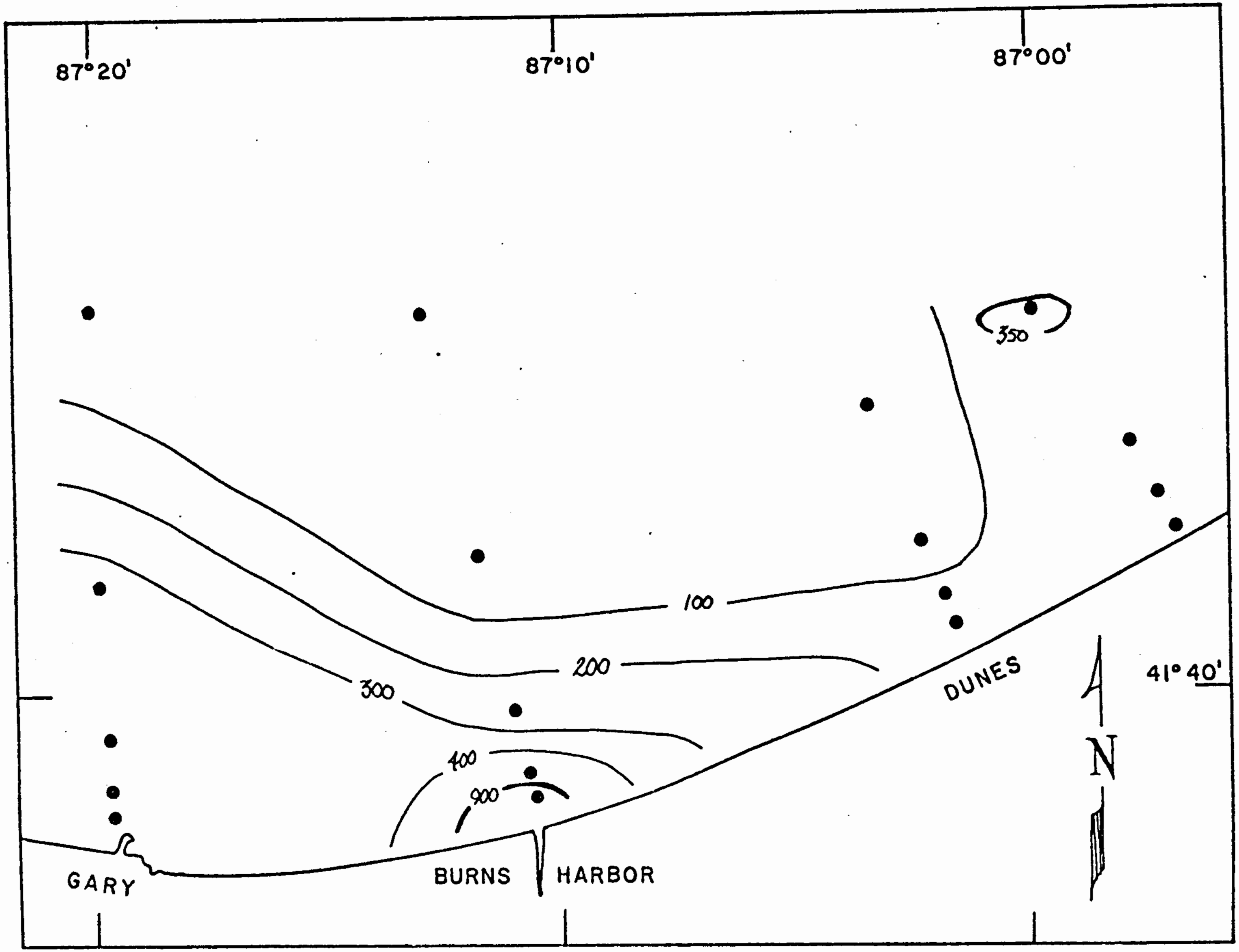
Appendix Figure C-6. NO_3-N contours, southern Lake Michigan; 24 September, 1977.



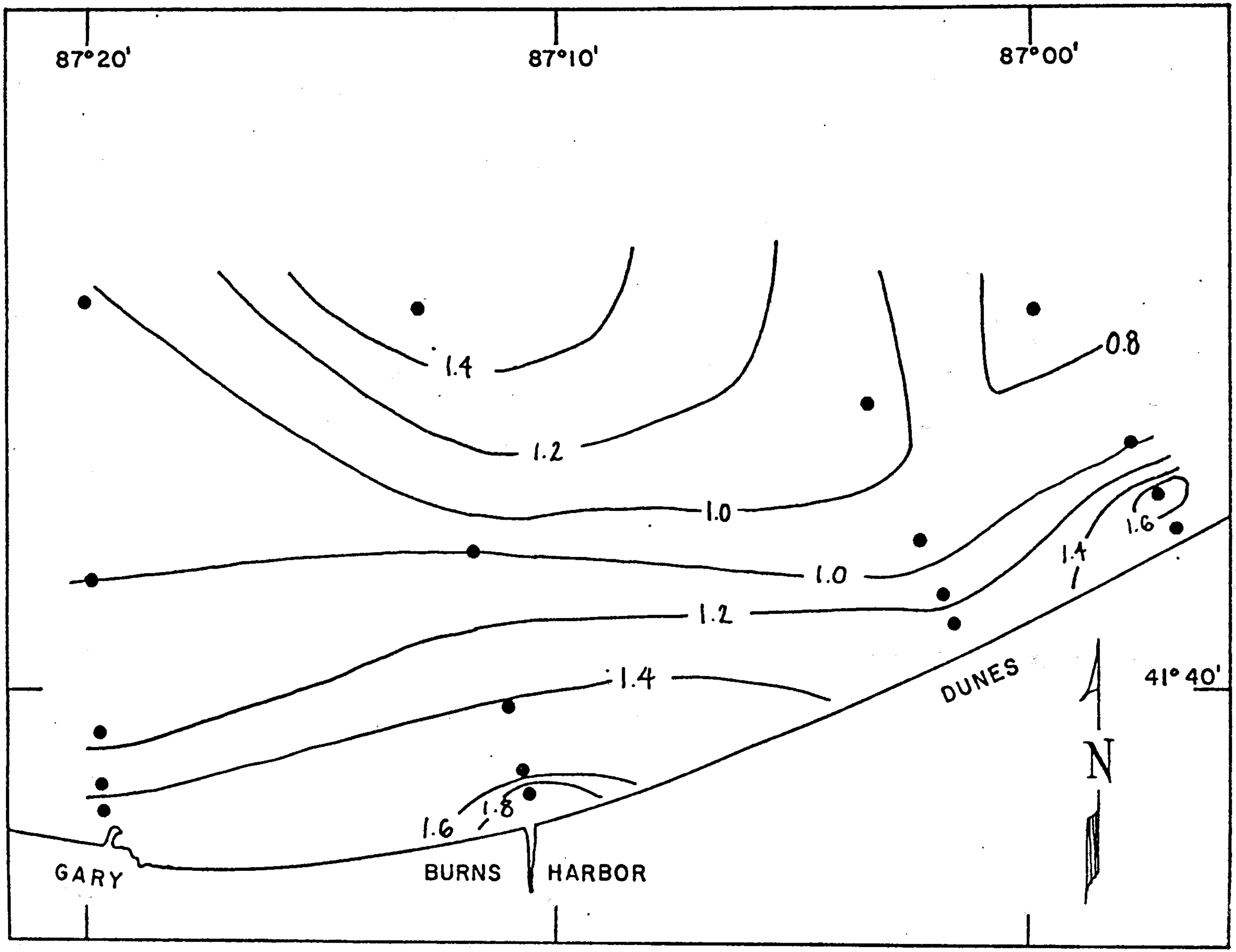
Appendix Figure C-7. Ammonia contours, southern Lake Michigan; 24 September, 1977.



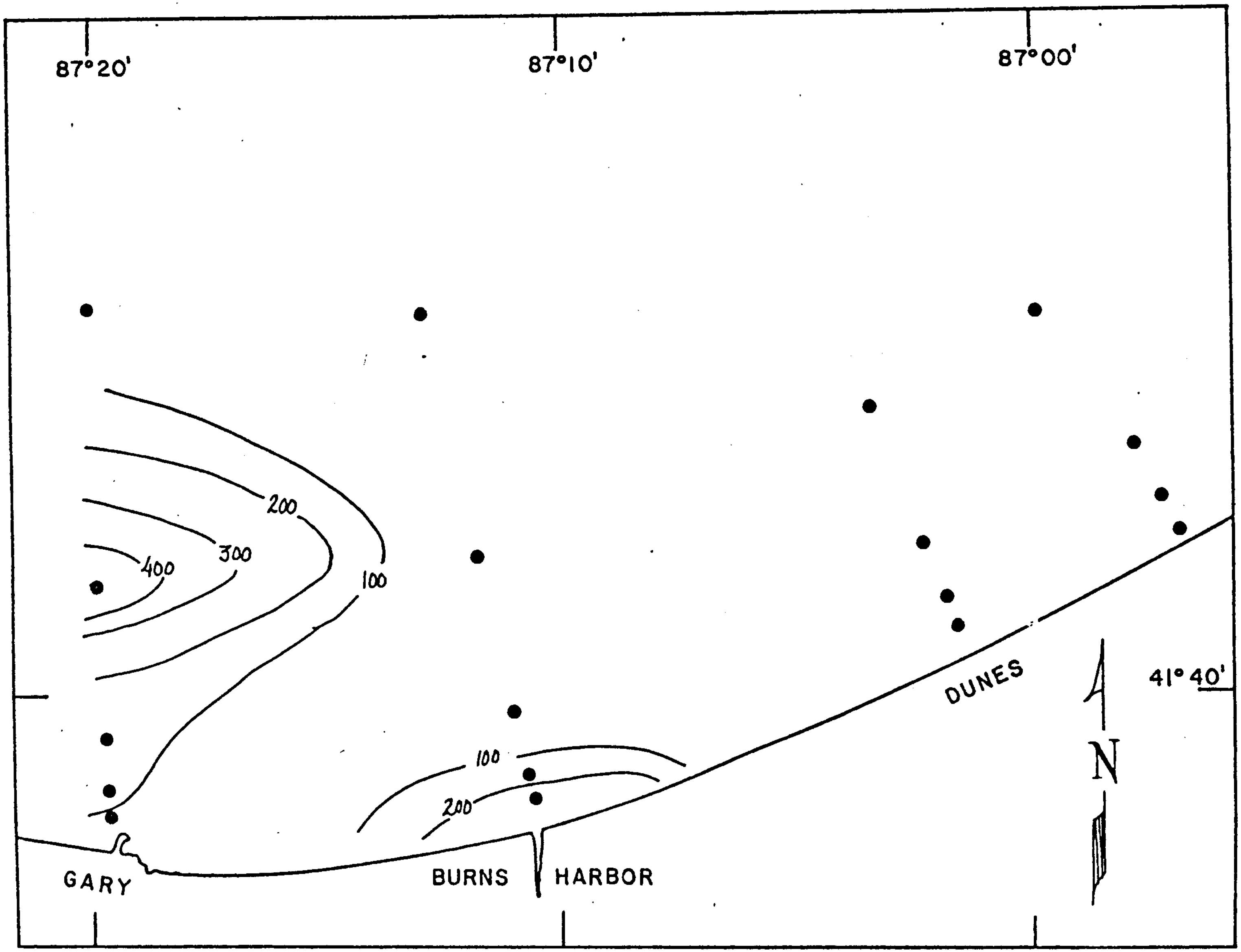
Appendix Figure C-8. Silica contours, southern Lake Michigan; 24 September, 1977.



Appendix Figure C-9. Anaerobic heterotroph contours, southern Lake Michigan; 24 September, 1977.



Appendix Figure C-10. Turbidity contours, southern Lake Michigan; 24 September, 1977.



Appendix Figure C-11. Fecal coliform contours, southern Lake Michigan; 24 September, 1977.

TABLE D-1. SPECIES COMPOSITION AND MEAN AND MAXIMUM ABUNDANCE (NUMBERS x $10^3/M^3$) OF ROTIFERS IN THE INDIANA WATERS OF SOUTHERN LAKE MICHIGAN. SUMMARY IS BASED ON POOLED NEAR SURFACE AND BOTTOM SAMPLES FROM ALL STATIONS AND SAMPLING DATES COMBINED. PRESENCE OF A SPECIES IN NUMBERS LESS THAN $100/M^3$ IS INDICATED BY A PLUS SIGN (+)

Class Monogonata Order Ploima	Mean	Maximum
Family Brachionidae		
Subfamily Brachioninae		
Brachionus angularis Gosse	+	0.4
B. caudatus Barrois and Daday	+	1.0
Euchlanis dilatata Ehrbg.	+	+
Kellicottia longispina (Kellicott)	6.4	35.8
Keratella cochlearis cochlearis (Gosse)	77.2	384.4
K. cochlearis f. *hispida* (Lauterborn)	+	0.4
K. cochlearis f. *robusta* (Lauterborn)	1.7	7.1
K. cochlearis f. *tecta* (Gosse)	0.1	0.8
K. crassa Ahlstrom	10.0	45.0
K. earlinae Ahlstrom	0.3	2.0
K. quadrata (O. F. Müller)	0.4	2.0
K. valga f. *brevispina*	+	+
Lophocaris salpina (Ehrbg.)	+	0.4
Notholca foliacea (Ehrbg.)	0.1	0.4
N. labis Gosse	+	+
N. laurentiae Stemberger	0.4	3.4
N. squamula (O. F. Müller)	0.1	2.7
Platyias patulus (O. F. Müller)	+	+
Trichotria tectractis (Ehrbg.)	+	+
Subfamily Colurinae		
Lepadella patella (O. F. Müller)	+	+
Family Lecanidae		
Lecane mira (Murray)	+	+
Monostyla closterocerca (Schmarda)	+	+
Family Trichocercidae		
Trichocerca cylindrica (Imhof)	+	0.4
T. multicrinis (Kellicott)	0.2	2.9
T. porcellus (Gosse)	2.4	10.4
T. pusilla (Jennings)	+	+
T. rousseleti (Voigt)	0.4	2.5

(continued).

TABLE D-1. (continued).

Class Monogonata Order Ploima	Mean	Maximum
Family Gastropidae		
Ascomorpha ecaudis Perty	+	+
Ascomorpha ovalis (Bergendal)	0.7	3.5
Gastropus stylifer Imhof	2.9	15.1
Family Tylotrochidae		
Tylotrocha monopus (Jennings)	0.4	3.7
Family Asplanchnidae		
Asplanchna priodonta Gosse	2.0	17.2
Family Synchaetidae		
Ploesoma hudsoni (Imhof)	0.1	0.7
P. lenticulare Herrick	0.6	11.9
P. truncatum (Levander)	1.3	7.9
Polyarthra dolichoptera Idelson	0.1	2.6
P. euryptera Wierzejski	+	0.2
P. major Burckhardt	2.1	12.1
P. remata Skorikov	29.0	164.2
P. vulgaris Carlin	37.4	113.7
Synchaeta kitina Rousselet	0.3	2.0
S. lakowitziana Lucks	+	+
S. oblonga Ehrbg.	+	0.2
S. pectinata Ehrbg.	+	0.5
S. stylata Wierzejski	4.8	34.6
Family Testudinellidae		
Filinia longiseta (Ehrbg.)	+	+
F. terminalis (Plate)	0.1	1.2
Pompholyx sulcata Hudson	+	0.4
Family Conochilidae		
Conochilus unicornis (Rousselet)	36.2	322.1
Family Collothecidae		
Collotheca mutabilis (Hudson)	3.8	11.8
C. pelagica (Rousselet)	+	1.2
Stephanocercos fimbriatus (Goldfuss)	+	+
Total Rotifers	221.4	

TABLE D-2. SPECIES COMPOSITION AND MEAN AND MAXIMUM ABUNDANCE (NUMBER/M^3) OF CRUSTACEAN PLANKTON IN THE INDIANA WATERS OF SOUTHERN LAKE MICHIGAN DURING THE 1977 SAMPLING PERIOD.

SUMMARY IS BASED ON STANDARDIZED NET TOWS FROM ALL STATIONS AND ALL SAMPLING DATES COMBINED.

PRESENCE OF A SPECIES IN NUMBERS LESS THAN $10/M^3$ IS INDICATED BY A PLUS SIGN (+)

	Mean	Maximum
Subclass Copepoda		
Order Calanoida	2,740	7,580
Senecella calanoides Juday	+	+
Limnocalanus macrurus Sars	+	30
Eurytemora affinis (Poppe)	40	410
Epischura lacustris Forbes	180	1,480
Leptodiaptomus sicilis Forbes	+	50
L. ashlandi Marsh	240	870
L. minutus Lilljeborg	250	1,430
Skistodiaptomus oregonensis Lilljeborg	60	340
Diaptomid copepodids	1,980	6,950
Order Cyclopoida	800	7,170
Acanthocyclops vernalis Fisher	20	140
Diacyclops thomasi Forbes	760	7,170
Mesocyclops edax (Forbes)	+	+
Tropocyclops prasinus mexicanus Kiefer	+	20
Eucyclops agilis (Koch)	+	+
Cyclopoid copepodids	20	100
Order Harpacticoida		
Canthocamptus staphylinoides Pearse	+	+
Subclass Branchipoda		
Order Cladocera	4,250	15,750
Family Leptodoridae		
Leptodora kindtii (Focke)	20	100
Family Polyphemidae		
Polyphemus pediculus (L.)	10	200
Family Sididae		
Diaphanosoma spp.	220	1,330
Family Macrothricidae		
Ilyocryptus spinifer Herrick	+	+

(continued).

TABLE D-2. (continued).

	Mean	Maximum
Family Holopedidae		
Holopedium gibberum Zaddach	10	110
Family Daphnidae		
Ceriodaphnia lacustris Birge	10	110
C. quadrangula Müller	+	40
Daphnia galeata mendotae Birge	140	920
D. retrocurva Forbes	690	2,910
D. ambigua Scourfield	+	+
Family Bosminidae		
Bosmina longirostris (Müller)	3,000	15,610
Eubosmina coregoni (Baird)	140	940
Family Chydoridae		
Alona affinis (Leydig)	+	+
A. quadrangularis (Müller)	+	+
A. setulosa Megard	+	+
Camptocercus rectirostris Schødler	+	+
Chydorus sphaericus (Müller)	+	+
Eurycercus lamellatus (Müller)	+	10
Leydigia quadrangularis (Leydig)	+	+
Pleuroxus procurvus Birge	+	+
Total Crustacea	7,800	23,980

☆ U.S. GOVERNMENT PRINTING OFFICE: 1983—655-121.