

in Dat 12/2003

NRBIB # ISRO-2118

Bibkey ID # 547357

duplicate # 558606

Zooplankton Assemblages of Inland Lakes in Isle Royale National Park, Michigan USA

Gary L. Larson
C. David McIntire
Robert Truitt
Robert Hoffman

Technical Report NPS/CCSOOSU/NRTR 2000/02

April 2000



United States Department of Interior - National Park Service

The National Park Service disseminates results of biological, physical, or social science research through the Natural Resources Technical Report Series. Natural resources inventories and monitoring activities, scientific literature reviews, bibliographies, and proceedings of technical workshops or conferences are also disseminated through this series. Documents in this series usually contain information of a preliminary nature and are prepared primarily for internal use within the National Park Service. This information is not intended for use in open literature.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the National Park Service.

Copies are available from the following:

Denver Service Center (303) 969-2130
Technical Information Center
P.O. Box 25287
Denver, Colorado 80225-0287

National Technical Information Service (703) 487-4785
U.S. Department of Commerce
5285 Port Royal
Springfield, Virginia 22161

Gary L. Larson
@usgs.gov

Zooplankton Assemblages of Inland Lakes in Isle Royale National Park, Michigan USA

Gary L. Larson
USGS-Forest and Rangeland Ecosystem Science Center
3200 S.W. Jefferson Way, Corvallis, Oregon 97331

C. David McIntire
Department of Botany and Plant Pathology
Oregon State University, Corvallis, Oregon 97331

Robert Truitt
Department of Forest Resources
College of Forestry, Oregon State University
Corvallis, Oregon 97331

Robert Hoffman
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 97331

Abstract

The objective of this study was to document the zooplankton assemblages of lakes across the landscape of Isle Royale National Park. The results suggest that the crustacean and rotifer assemblages were very similar among park lakes, with *Bosmina longirostris*, *Keratella cochlearis*, *Conochilus unicornis*, *Polyarthra dolichoptera*, and *Ploesoma hudsoni* having the highest relative abundances. The few exceptions were not clearly linked with basin morphology and environmental variables. In comparison, the frequency of occurrence of *Bosmina longirostris* also was high in lakes in nearby Ontario, Canada, with the other taxa varying in occurrence. However, the dominant crustacean taxa of inland park lakes were different from those in Lake Superior. Rotifer taxa with the highest frequency of occurrence in inland park lakes were similar to those in northern Michigan lakes. For park lakes sampled more than once, the structure of the zooplankton assemblages showed limited temporal changes in most cases. The potential effects

of fish predation on the species composition and density of zooplankton were unresolved. A long-term monitoring program was recommended to assess interannual variation of water quality and the taxonomic structures of zooplankton assemblages in lakes across the landscape of the park.

Keywords: Zooplankton, Isle Royale National Park, Crustacea, Rotifera

Introduction

Larson et al. (1994, 1999) reported how differences in the limnological characteristics of lakes in mountainous areas were associated with climate gradients, forest type, and basin morphology. In contrast, the present study focused on the relatively flat landscape of Isle Royale National Park (ISRO). Although limited in vertical topography, the park contained a range of environmental conditions. The west-end of the park had deep soils, forest cover was predominantly northern hardwoods, and inland areas were warmer due to less influence from Lake Superior. The east-end had shallow soils, forest cover was predominantly boreal conifers, and Lake Superior provided a strong cool air influence (J. Oelfke, personal communication). Given these environmental differences, plus differences in lake morphology (see below), the objective of this study was to document the characteristics of zooplankton assemblages in selected lakes across the landscape of Isle Royale National Park.

Study Area

The study lakes are located in Isle Royale National Park, MI, a remote archipelago in Lake Superior. The park includes Isle Royale (72 km long and 14 km wide) and about 400 small islands. The highest point on Isle Royale (Mt. Desor) is 242 m above Lake Superior. Isle Royale is characterized by a series of ridges and valleys with glacial drift deposits. The landscape is

almost completely forested and includes boreal coniferous (Linn 1966) and northern hardwood forests (Shelton 1975).

Lake Superior influences the climate of the park by moderating temperatures year-round. Average annual precipitation at the park is thought to be similar to that of nearby northeastern Minnesota where the average is about 700 mm per year. Inland lakes typically are capped by snow and ice from November to April (J. Oelfke, Isle Royale National Park, personal communication).

The thirty six lakes included in this study were distributed throughout Isle Royale (Fig. 1; Table 1). Collectively, these lakes represented the range of lake sizes, depths, and elevations typical of lakes on Isle Royale (Table 2). Contemporaneous studies by Kallemeyn (1999) included 32 of these lakes.

Methods

An inland lake fish inventory of Isle Royale was conducted in 1995 and 1996 (Kallemeyn 1999). In addition to fish collections, the field crews collected physical, chemical, and zooplankton samples between June 16 and September 9 in 1995, and June 5 and September 6 in 1996 (Table 3). All of the lakes were located on Isle Royale, except for Amygdaloid Lake, which was located on Amygdaloid Island. All sampling was done from an unmotorized canoe over the deepest point in each lake. Vertical zooplankton samples (55) from near lake bottom to surface were collected using a new Wisconsin-style plankton net with a 63 μm mesh. Net efficiency was assumed to be 100%. Samples were preserved in 4% formalin. In the laboratory, the zooplankton samples were processed following the procedures outlined by Larson et al. (1994). Limnological field measurements and laboratory techniques for water samples were described by Kallemeyn

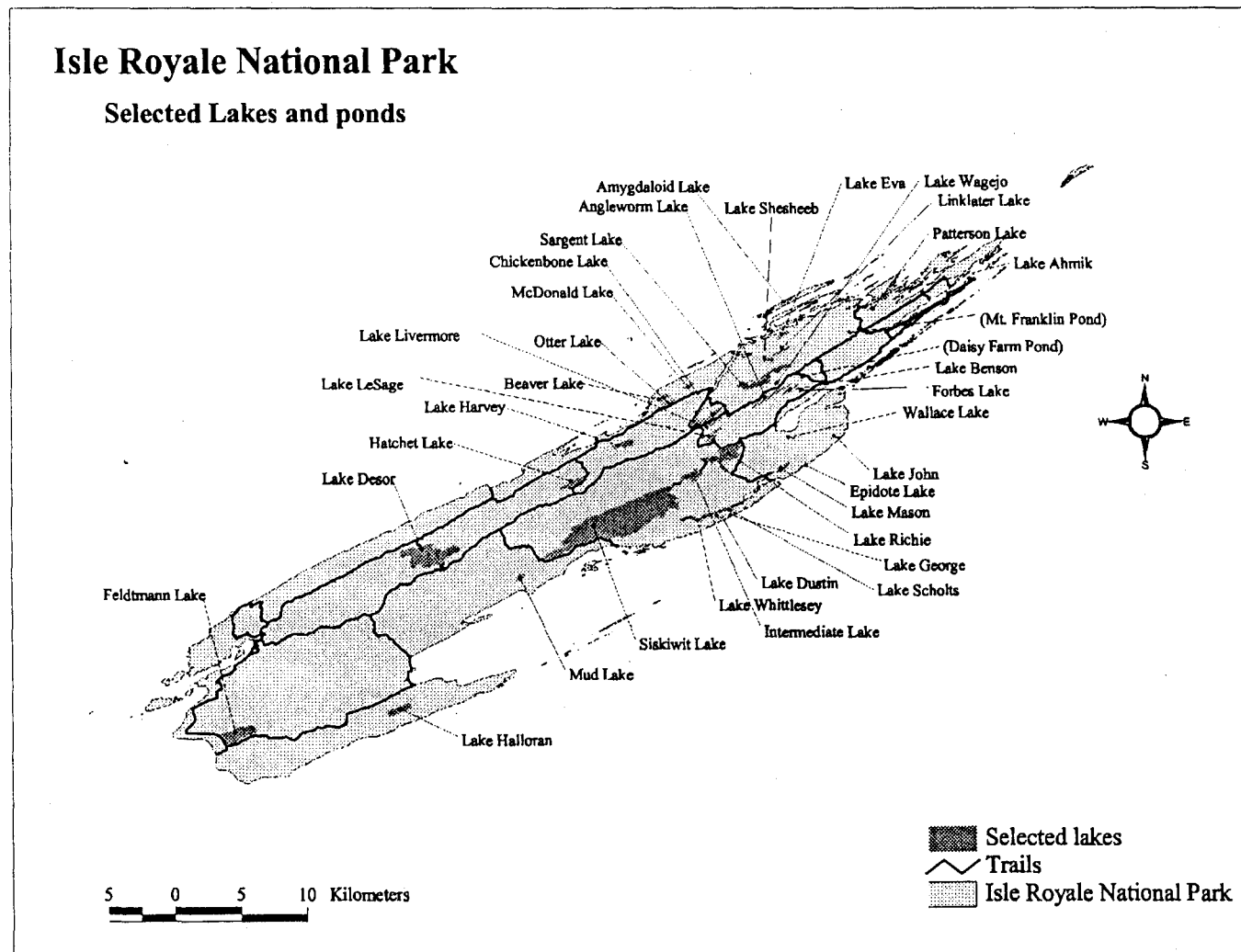


Figure 1. Locations of the 36 study lakes, Isle Royale National Park.

Table 1. Names and acronyms of ISRO study lakes.

Lake	Acronym
Ahmik	AHMIK
Amygdaloid	AMYGDA
Angleworm	ANGLE
Beaver	BEAVER
Benson	BENSON
Chickenbone	CHICKE
Daisyfarm	DAISYF
Desor	DESOR
Dustin	DUSTIN
Epidote	EPIDOT
Eva	EVA
Feldtmann	FELDT
Forbes	FORBES
George	GEORGE
Halloran	HALLOR
Harvey	HARVEY
Hatchet	HATCH
Intermediate	INTERM
John	JOHN
Lesage	LESAGE
Linklater	LINKLA
Livermore	LIVERM
Mason	MASON
McDonald	MCDON
Mount Franklin	MTFRAN
Mud	MUD
Otter	OTTER
Patterson	PATTER
Richie	RICHIE
Sargent	SARGE
Scholtz	SCHOLT
Shesheeb	SHESHE
Siskiwit	SISKI
Wagejo	WAGEJO
Wallace	WALLAC
Whittlesey	WHITTL

Table 2. Watershed areas (ha), surface areas (ha), elevations (m), maximum depths (m), and shoreline development of the ISRO study lakes. Note that maximum depths and shoreline developments were not available data for Mud Lake, Daisyfarm Pond, Mount Franklin Pond, and Wallace Lake.

Lake	Watershed	Elevation	Area	Zmax	Shoredev
Ahmik	35.26	192.73	10.3	3.35	2.1
Amygdaloid	26.12	186.95	10.8	8.84	2.7
Angleworm	495.62	240.49	50.4	8.40	3.0
Beaver	258.31	206.95	20.1	5.18	1.9
Benson	82.95	239.94	24.1	3.80	1.8
Chickenbone	1556.42	201.17	92.6	6.40	2.6
Daisyfarm Pond	35.40	271.00	0.7	< 3.00	--
Desor	1436.67	260.30	427.8	14.02	1.8
Dustin	497.82	197.95	4.4	6.10	1.7
Epidote	55.82	188.95	1.3	3.96	1.2
Eva	231.13	187.15	17.6	6.40	1.6
Feldtmann	886.57	201.17	185.8	2.74	1.4
Forbes	40.80	235.94	6.8	5.80	3.0
George	18.13	203.91	3.8	2.70	2.0
Halloran	230.68	199.95	77.4	2.70	1.4
Harvey	292.76	232.26	55.4	4.00	1.7
Hatchet	502.15	229.94	49.6	5.20	1.7
Intermediate	481.68	205.95	70.8	6.70	2.2
John	126.43	195.95	3.3	5.49	1.8
Lesage	932.98	223.42	45.0	6.40	2.4
Linklater	99.37	222.20	17.3	6.00	2.4
Livermore	168.78	213.06	30.1	5.50	2.0
Mason	492.82	185.95	22.8	8.50	2.3
McDonald	104.90	212.95	14.8	4.00	1.8
Mt. Franklin Pond	215.80	292.00	0.2	< 3.00	--
Mud	4594.00	202.00	20.8	< 3.00	--
Otter	96.28	212.95	20.2	4.27	1.8
Patterson	43.31	189.95	10.1	3.60	1.8
Richie	2080.23	191.42	216.2	10.67	2.4
Sargent	1089.31	211.95	143.4	13.72	3.6
Scholtz	469.27	203.95	2.3	1.52	2.1
Shesheeb	155.14	221.95	11.5	5.49	1.9
Siskiwit	7287.10	200.95	1635.2	46.00	2.2
Wagejo	58.17	228.94	6.1	2.19	1.4
Wallace	365.90	199.10	3.8	< 3.00	--
Whittlesey	450.48	208.04	65.0	7.62	2.4

Table 3. Sample dates for each ISRO study lake.

Lake	Date
AHMIK 1	9/09/95
AHMIK 2	6/07/96
AHMIK 3	7/29/96
AHMIK 4	8/27/96
AMYGDALOID	7/18/96
ANGLEWORM 1	7/05/95
ANGLEWORM 2	6/05/96
ANGLEWORM 3	7/23/96
ANGLEWORM 4	9/06/96
BEAVER	6/26/96
BENSON	7/12/95
CHICKENBONE	8/27/95
DAISYFARM POND	7/30/96
DESOR 1	6/10/96
DESOR 2	7/25/96
DESOR 3	8/22/96
DESOR 4	8/25/96
DUSTIN	7/24/96
EPIDOTE	7/30/96
EVA	9/06/95
FELDTMANN 1	6/13/96
FELDTMANN 2	7/24/96
FELDTMANN 3	8/26/96
FORBES	8/02/95
GEORGE	7/25/96
HALLORAN	6/16/96
HARVEY	7/27/95
HATCHET	7/30/95
INTERMEDIATE	8/10/95
JOHN	7/31/96
LESAGE	8/23/95
LINKLATER	6/29/95
LIVERMORE	8/25/95
MASON	7/20/95
MCDONALD	7/01/96
MT. FRANKLIN	8/02/96

MUD 1	6/06/96
MUD 2	7/22/96
MUD 3	8/28/96
OTTER	6/28/96
PATTERSON	9/08/95
RICHIE	8/13/95
SARGENT 1	6/16/95
SARGENT 2	6/05/96
SARGENT 3	7/23/96
SARGENT 4	9/06/96
SCHOLTZ	7/26/96
SHESHEEB	6/28/95
SISKIWIT 1	6/06/96
SISKIWIT 2	7/22/96
SISKIWIT 3	8/10/96
SISKIWIT 4	8/28/96
WAGEJO	7/02/95
WALLACE	8/01/96
WHITTLESEY	7/18/95

(1999). Water quality samples were not collected from Wallace Lake, Mud Lake, Daisy Farm Pond, and Mount Franklin Pond. Watershed areas and lake elevations and surface areas were determined by Michael Hyslop using the geographic information system at Michigan Technological University. Maximum depths were either recorded in the field (Kallemeyn 1999) or in the case of the four systems not included in the water quality survey, estimated by eye (Jack Oelfke, personal communication). Students t-tests were performed using SYSTAT (Wilkinson 1987).

Correspondence analysis with detrending (DCA) provided ordinations of the 36 lakes relative to the taxonomic composition of the rotifer assemblages and crustacean zooplankton assemblages in the 55 samples (Jongman et al. 1987). For each analysis, densities of the taxa (rotifers or crustaceans) were relativized and expressed as a proportion of the total density in each sample. For interpretation, lakes represented by sample points in close approximation to one another had similar species compositions, whereas lakes with greater distances in ordination space were less similar in taxonomic composition. Species richness, diversity, and redundancy were calculated following the methods described by McIntire and Overton (1971).

Results

Lake Morphology and Water Quality

Watershed area and lake elevation, surface area, and depth averaged 722.1 ha, 213.9 m, 93.8 ha, and 6.8 m, respectively (Table 4). Except for elevation, there was considerable variation among the lakes for these variables. For example, surface area ranged from 0.2 to 1635 ha. Differences between the lowest elevation and high elevation lakes was only 106.0 m, however.

Collectively, the lakes were moderately warm and turbid (shallow Secchi disk clarity readings), slightly alkaline, moderate in conductivity and alkalinity, and low in total phosphorus,

Table 4. Average, minimum, and maximum watershed areas, elevations, surface areas, maximum depths, and water quality characteristics of the ISRO study lakes.

Variable	n	Average	Minimum	Maximum	SD
Watershed Area (ha)	36	722.1	18.1	7287.1	1407.1
Elevation (m)	36	213.9	186.0	292.0	24.4
Surface Area (ha)	36	93.8	0.2	1635.0	276.7
Z max (m)	35	6.8	1.5	46.0	7.4
Temperature (°C)	32	20.8	16.8	24.2	2.0
Secchi (m)	30	2.9	1.3	9.0	1.4
pH	32	7.7	7.3	8.4	—
Cond ($\mu\text{S}/\text{cm}$)	32	73.8	50.7	99.5	15.6
DOC (mg/L)	32	10.4	5.0	15.3	2.7
TP ($\mu\text{g}/\text{L}$)	32	11.0	5.0	18.0	3.0
$\text{PO}_4 - \text{P}$ ($\mu\text{g}/\text{L}$)	32	3.0	1.0	12.0	3.0
Total N ($\mu\text{g}/\text{L}$)	32	431.0	250.0	650.0	106.0
$\text{NO}_3 - \text{N}$ ($\mu\text{g}/\text{L}$)	29	8.0	2.0	27.0	7.0
$\text{NH}_4 - \text{N}$ ($\mu\text{g}/\text{L}$)	32	8.0	2.0	27.0	5.0

orthophosphate-P, nitrate-N, and ammonia-N (Table 4). Total nitrogen averaged 431 $\mu\text{g/L}$, ranging from 250.0 to 650.0 $\mu\text{g/L}$.

Zooplankton

The 55 samples contained 17 rotifer taxa, 9 cladocera taxa, a calanoid copepod taxon, and 4 cyclopoid copepod taxa (Tables 5 and 6). Collectively, species richness ranged from 3.0 - 15.0, species diversity ranged from 0.40 - 2.39, and redundancy from 0.08 - 0.807 (Table 7). On average, more rotifer taxa (6.0) were present per sample than were crustacean taxa (3.5; paired t-Test, $df = 54$, $t = 7.94$, $P < 0.01$). Collectively, KECO was the most ubiquitous species in that it was found in 54 samples, whereas COUN was found in 47 samples, BOLO in 46, PLHU in 44, PODO in 42, and ASPR and DIOR in 31. The other taxa were found in fewer than 23 samples (Table 5). KECO had the highest relative abundance at 39.0% and COUN the second highest at 30.8% (Table 5). The other taxa had relative abundances of $< 10.0\%$.

Among rotifer taxa, KECO, COUN, PODO, and PLHU had relative abundances of $> 10\%$ in 44 samples, 33 samples, 21 samples, and 19 samples, respectively (Table 8). Other taxa had relative abundances of $< 10\%$. For relative abundances of $\geq 50\%$, KECO occurred in 16 samples and the other taxa occurred in ≤ 6 samples each (Table 8).

Among crustacean taxa, BOLO, DIOR, TRPR, DAGA, and DIBI had relative abundances of $> 10\%$ in 46, 23, 15, 14, and 11 samples, respectively (Table 9). For instances where relative abundances were $\geq 50\%$, BOLO occurred in 22 samples and the rest of the taxa in less than five samples each.

For all samples, average rotifer densities ranged from 0.3 - 668.1/L, whereas crustacean densities ranged from 0.2 - 31.3/L (Tables 10 and 11). Average rotifers densities (210.6/L) were higher than those of crustacean taxa (15.3/L; $df=54$, paired t-Test, $t=7.942$, $p < 0.01$). Rotifer

Table 5. List of zooplankton species from 36 lakes in Isle Royale National Park. The table includes species acronyms (Acron), relative abundance in the entire data set (Abund) and the number of samples in which species occurred (Occur).

Species	Acron	Abund	Occur
Calanoid Copepods:			
<i>Diaptomus oregonensis</i>	DIOR	0.0055	31
Cladocerans:			
<i>Bosmina longirostris</i>	BOLO	0.0344	46
<i>Ceriodaphnia sp.</i>	CERI	0.0019	16
<i>Chydorus sp.</i>	CHYD	<0.0001	1
<i>Daphnia ambigua</i>	DAAM	0.0008	6
<i>Daphnia galeata mendotae</i>	DAGA	0.0036	21
<i>Daphnia pulex</i>	DAPU	0.0002	3
<i>Daphnia retrocurva</i>	DARE	0.0018	5
<i>Diaphanosoma birgei</i>	DIBI	0.0035	17
<i>Holopedium gibberum</i>	HOGI	0.0046	10
Cyclopoid Copepods:			
<i>Acanthocyclops vernalis</i>	ACVE	0.0005	5
<i>Diacyclops thomasi</i>	DITH	0.0012	4
<i>Mesocyclops edax</i>	MEED	0.0032	12
<i>Tropocyclops prasinus</i>	TRPR	0.0066	17
Rotifers:			
<i>Asplanchna priodonta</i>	ASPR	0.0143	31
<i>Conochilus unicornis</i>	COUN	0.3084	47
<i>Filnia terminalis</i>	FITE	0.0092	14
<i>Hexarthra mira</i>	HEMI	0.0002	1
<i>Kellicottia bostoniensis</i>	KEBO	0.0265	21
<i>Kellicottia longispina</i>	KELO	0.0118	22
<i>Keratella cochlearis</i>	KECO	0.3901	54
<i>Keratella hiemalis</i>	KEHI	0.0001	1
<i>Keratella quadrata</i>	KEQU	0.0004	2
<i>Monostyla lunaris</i>	MOLU	<0.0001	1
<i>Ploesoma hudsoni</i>	PLHU	0.0333	44
<i>Polyarthra dolichoptera</i>	PODO	0.0923	42
<i>Polyarthra major</i>	POMA	0.0287	18
<i>Pompholyx sulcata</i>	POSU	0.0048	4
<i>Synchaeta sp.</i>	SYNC	0.0007	4
<i>Trichocerca elongata</i>	TREL	0.0111	21
<i>Trichotria tetractis</i>	TRTE	0.0001	1

Table 6. Crustacean and rotifer taxa in each ISRO study lake.

Lake	Species
AHMIK	<i>Asplanchna priodonta</i> <i>Bosmina longirostris</i> <i>Ceriodaphnia</i> sp. <i>Conochilus unicornis</i> <i>Daphnia ambigua</i> <i>Daphnia pulex</i> <i>Daphnia retrocurva</i> <i>Diaptomus oregonensis</i> <i>Filinia terminalis</i> <i>Kellicottia bostoniensis</i> <i>Kellicottia longispina</i> <i>Keratella cochlearis</i> <i>Mesocyclops edax</i> <i>Ploesoma hudsoni</i> <i>Polyarthra dolichoptera</i> <i>Polyarthra major</i> <i>Trichocerca elongata</i> <i>Tropocyclops prasinus</i>
AMYGDALOID	<i>Bosmina longirostris</i> <i>Diaphanosoma birgei</i> <i>Holopedium gibberum</i> <i>Kellicottia bostoniensis</i> <i>Keratella cochlearis</i> <i>Ploesoma hudsoni</i> <i>Polyarthra dolichoptera</i>
ANGLEWORM	<i>Acanthocyclops vernalis</i> <i>Asplanchna priodonta</i> <i>Bosmina longirostris</i> <i>Conochilus unicornis</i> <i>Daphnia retrocurva</i> <i>Diaphanosoma birgei</i> <i>Diaptomus oregonensis</i> <i>Holopedium gibberum</i> <i>Kellicottia longispina</i> <i>Keratella cochlearis</i> <i>Mesocyclops edax</i> <i>Ploesoma hudsoni</i> <i>Polyarthra dolichoptera</i>

BEAVER

Trichocerca elongata
Trichotria tetractis
Tropocyclops prasinus
Asplanchna priodonta
Conochilus unicornis
Daphnia pulex
Diaptomus oregonensis
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Tropocyclops prasinus

BENSON

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Filinia terminalis
Holopedium gibberum
Kellicottia longispina
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata

CHICKENBONE

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Diaphanosoma birgei
Diaptomus oregonensis
Filinia terminalis
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Tropocyclops prasinus

DAISYFARM POND

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Diaphanosoma birgei
Holopedium gibberum
Kellicottia longispina
Keratella cochlearis

DESOR

Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata
Acanthocyclops vernalis
Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Chydorus sp.
Conochilus unicornis
Daphnia ambigua
Daphnia galeata mendotae
Diaphanosoma birgei
Diaptomus oregonensis
Filinia terminalis
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Keratella hiemalis
Keratella quadrata
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Synchaeta sp.
Tropocyclops prasinus

DUSTIN

Acanthocyclops vernalis
Daphnia galeata mendotae
Filinia terminalis
Holopedium gibberum
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major

EPIDOTE

Acanthocyclops vernalis
Bosmina longirostris
Conochilus unicornis
Diaptomus oregonensis
Kellicottia bostoniensis
Keratella cochlearis

EVA

Keratella cochlearis
Polyarthra dolichoptera
Synchaeta sp.

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Filinia terminalis
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata

FELDTMANN

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia ambigua
Diaptomus oregonensis
Holopedium gibberum
Keratella cochlearis
Monostyla lunaris
Ploesoma hudsoni
Polyarthra dolichoptera

FORBES

Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Diaphanosoma birgei
Diaptomus oregonensis
Holopedium gibberum
Kellicottia longispina
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata
Tropocyclops prasinus

GEORGE

Acanthocyclops vernalis
Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Diaptomus oregonensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra major
Trichocerca elongata

HALLORAN

Asplanchna priodonta
Conochilus unicornis
Daphnia ambigua
Diaptomus oregonensis
Holopedium gibberum
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata
Tropocyclops prasinus

HARVEY

Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae
Diaphanosoma birgei
Diaptomus oregonensis
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera

HATCHET

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Diaphanosoma birgei
Diaptomus oregonensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera

INTERMEDIATE

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae

JOHN

Diaphanosoma birgei
Filinia terminalis
Kellicottia bostoniensis
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata
Tropocyclops prasinus

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae
Diacyclops thomasi
Diaptomus oregonensis
Filinia terminalis
Kellicottia longispina
Keratella cochlearis
Ploesoma hudsoni
Polyarthra major
Synchaeta sp.

LESAGE

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Diaphanosoma birgei
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata

LINKLATER

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major

LIVERMORE

Trichocerca elongata
Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Diaphanosoma birgei
Filinia terminalis
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata
Tropocyclops prasinus

MASON

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Diaptomus oregonensis
Filinia terminalis
Holopedium gibberum
Kellicottia bostoniensis
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata

MCDONALD

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae
Diaptomus oregonensis
Filinia terminalis
Keratella cochlearis
Ploesoma hudsoni
Trichocerca elongata

MT. FRANKLIN

Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera

MUD

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Daphnia ambigua
Daphnia retrocurva
Diaphanosoma birgei
Diaptomus oregonensis
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata
Tropocyclops prasinus

OTTER

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Filinia terminalis
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata

PATTERSON

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Diaphanosoma birgei
Diaptomus oregonensis
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra major
Tropocyclops prasinus

RICHIE

Bosmina longirostris
Conochilus unicornis
Daphnia galeata mendotae
Diaphanosoma birgei
Diaptomus oregonensis
Kellicottia bostoniensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Tropocyclops prasinus

SARGENT

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae
Daphnia retrocurva
Diacyclops thomasi
Diaptomus oregonensis
Filinia terminalis
Hexarthra mira
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Pompholyx sulcata
Trichocerca elongata

SCHOLTZ

Asplanchna priodonta
Bosmina longirostris
Diaptomus oregonensis
Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Ploesoma hudsoni
Polyarthra major
Trichocerca elongata

SHEEHB

Bosmina longirostris
Conochilus unicornis
Filinia terminalis

SISKIWIT

Kellicottia bostoniensis
Kellicottia longispina
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Pompholyx sulcata

Asplanchna priodonta
Bosmina longirostris
Ceriodaphnia sp.
Conochilus unicornis
Daphnia galeata mendotae
Diacyclops thomasi
Diaptomus oregonensis
Kellicottia longispina
Keratella cochlearis
Keratella quadrata
Mesocyclops edax
Ploesoma hudsoni
Polyarthra dolichoptera
Trichocerca elongata
Tropocyclops prasinus

WAGEJO

Asplanchna priodonta
Bosmina longirostris
Conochilus unicornis
Kellicottia longispina
Keratella cochlearis
Polyarthra dolichoptera
Pompholyx sulcata
Trichocerca elongata

WALLACE

Bosmina longirostris
Conochilus unicornis
Diaphanosoma birgei
Diaptomus oregonensis
Keratella cochlearis
Ploesoma hudsoni
Polyarthra dolichoptera
Polyarthra major
Trichocerca elongata

WHITTLESEY

Bosmina longirostris
Daphnia galeata mendotae
Kellicottia bostoniensis

Table 7. Number of zooplankton samples (N), zooplankton species richness (S), species diversity (H), and redundancy (R) for 36 inland lake, Isle Royale National Park.

Lake	N	S	H	R
AHMIK	4	9.75	1.60	0.303
AMYGDALOID	1	7.00	1.60	0.179
ANGLEWORM	4	9.75	1.68	0.258
BEAVER	1	9.00	1.07	0.512
BENSON	1	10.00	0.73	0.684
CHICKENBONE	1	12.00	1.51	0.393
DAISYFARM POND	1	10.00	0.80	0.652
DESOR	4	13.00	2.09	0.184
DUSTIN	1	11.00	1.17	0.513
EPIDOTE	1	8.00	1.31	0.369
EVA	1	12.00	1.02	0.591
FELDTMANN	3	7.00	1.47	0.218
FORBES	1	12.00	1.82	0.266
GEORGE	1	9.00	1.03	0.533
HALLORAN	1	10.00	1.50	0.349
HARVEY	1	9.00	1.15	0.475
HATCHET	1	8.00	1.73	0.167
INTERMEDIATE	1	15.00	2.39	0.118
JOHN	1	13.00	1.54	0.402
LESAGE	1	11.00	1.98	0.174
LINKLATER	1	8.00	1.79	0.139
LIVERMORE	1	13.00	1.76	0.312
MASON	1	13.00	2.00	0.219
MCDONALD	1	10.00	1.42	0.381
MT. FRANKLIN	1	6.00	1.06	0.410
MUD	3	7.33	1.47	0.224
OTTER	1	9.00	1.21	0.449
PATTERSON	1	11.00	1.46	0.391
RICHIE	1	10.00	1.88	0.184
SARGENT	4	8.50	1.28	0.381
SCHOLTZ	1	9.00	0.60	0.728
SHESHEEB	1	9.00	1.98	0.099
SISKIWIT	4	7.75	1.67	0.159
WAGEJO	1	8.00	0.40	0.807
WALLACE	1	9.00	1.11	0.496
WHITTLESEY	1	3.00	1.01	0.080

Table 8. The number of lake samples and frequency of occurrence in which ISRO rotifer taxa were greater than 0.10 in relative abundance and greater than or equal to 0.50 in relative abundance (rotifer taxa only). The total frequency of occurrence (number and percent) is shown. There were 55 lake samples.

Taxa	<u>Total Occurrence</u>		<u>>0.10</u>		<u>≥0.50</u>	
	Number	%	Number	%	Number	%
KECO	54	98.2	44	80.0	16	29.1
COUN	47	65.5	33	60.0	5	9.1
PODO	42	76.4	21	38.2	5	9.1
PLHU	44	80.0	19	34.6	0	0.0
KEBO	21	38.2	9	16.4	2	3.6
KELO	22	40.0	8	14.6	0	0.0
POMA	18	32.7	5	9.1	2	3.6
FITE	14	25.5	3	5.5	1	1.9
POSU	4	7.3	2	3.6	0	0.0
TREL	21	36.2	2	3.6	0	0.0
ASPR	31	56.4	1	1.9	1	1.9
KEQU	2	3.6	1	1.9	0	0.0
HEMI	1	20.0	0	0	0	0.0
TRTE	1	1.8	0	0	0	0.0
KEHI	1	1.8	0	0	0	0.0
SYNC	4	7.3	0	0	0	0.0
MOLU	1	1.8	0	0	0	0.0

Table 9. The number of lake samples and frequency of occurrence in which ISRO crustacean taxa were greater than 0.10 in relative abundance and greater than or equal to 0.50 in relative abundance (crustacean taxa only). The total frequency of occurrence (number and percent) is shown. There were 55 lake samples.

Taxa	<u>Total Occurrence</u>		<u>>0.10</u>		<u>≥0.50</u>	
	Number	%	Number	%	Number	%
BOLO	46	83.6	46	83.6	22	40.0
DIOR	31	56.4	23	41.8	4	7.3
TRPR	17	30.9	15	27.3	2	3.0
DAGA	21	38.2	14	25.5	3	5.5
DIBI	17	30.9	11	20.0	0	0.0
MEED	12	21.8	8	14.6	1	1.8
CERI	16	29.1	6	10.9	2	3.6
HOGI	10	18.2	4	7.3	0	0.0
DITH	4	7.3	4	7.3	0	0.0
DARE	5	9.1	3	5.5	1	1.8
ACVE	5	9.1	3	5.5	0	0.0
DAAM	6	10.9	3	5.5	2	3.6
DAPU	3	5.6	2	3.6	0	0.0
CHYD	1	1.8	0	0.0	0	0.0

Table 10. Rotifer densities (per m³) in 55 samples from 36 lakes at Isle Royale National Park.

Lake	Density
AHMIK 1	44199.24
AHMIK 2	1747.88
AHMIK 3	4821.74
AHMIK 4	8196.95
AMYGDALOID	1958.06
ANGLEWORM 1	14973.75
ANGLEWORM 2	1205.43
ANGLEWORM 3	2216.66
ANGLEWORM 4	14224.12
BEAVER	63365.64
BENSON	94475.88
CHICKENBONE	16876.07
DAISYFARM POND	157739.63
DESOR 1	5450.28
DESOR 2	3415.40
DESOR 3	1792.70
DESOR 4	1775.03
DUSTIN	44549.39
EPIDOTE	21657.63
EVA	19072.64
FELDTMANN 1	668111.73
FELDTMANN 2	261.18
FELDTMANN 3	1707.70
FORBES	3857.39
GEORGE	46157.96
HALLORAN	18634.00
HARVEY	42824.62
HATCHET	7533.96
INTERMEDIATE	5357.48
JOHN	9553.06
LESAGE	15972.00
LINKLATER	3080.55
LIVERMORE	20920.97
MASON	2787.57
MCDONALD	42458.06
MT. FRANKLIN	43571.41

MUD 1	37368.45
MUD 2	7232.60
MUD 3	11786.46
OTTER	31642.64
PATTERSON	92577.32
RICHIE	12440.08
SARGENT 1	29857.67
SARGENT 2	16876.07
SARGENT 3	17117.16
SARGENT 4	15570.19
SCHOLTZ	3099.69
SHESHEEB	18443.14
SISKIWIT 1	5062.82
SISKIWIT 2	1291.54
SISKIWIT 3	6888.19
SISKIWIT 4	415.87
WAGEJO	116279.27
WALLACE	199700.21
WHITTLESEY	1205.43

Table 11. Crustacean densities (per m³) in 55 samples from 36 lakes at Isle Royale National Park.

Lake	Density
AHMIK 1	9375.60
AHMIK 2	1325.98
AHMIK 3	2640.47
AHMIK 4	2209.96
AMYGDALOID	1958.83
ANGLEWORM 1	2385.75
ANGLEWORM 2	1356.11
ANGLEWORM 3	351.58
ANGLEWORM 4	3174.31
BEAVER	2893.04
BENSON	12456.15
CHICKENBONE	2893.04
DAISYFARM POND	8196.95
DESOR 1	1291.54
DESOR 2	3540.96
DESOR 3	2384.37
DESOR 4	2447.96
DUSTIN	1374.19
EPIDOTE	3214.49
EVA	1253.65
FELDTMANN 1	19186.49
FELDTMANN 2	234.39
FELDTMANN 3	502.26
FORBES	1125.07
GEORGE	6855.89
HALLORAN	4972.41
HARVEY	6132.91
HATCHET	3314.94
INTERMEDIATE	5022.64
JOHN	998.79
LESAGE	3616.30
LINKLATER	3482.36
LIVERMORE	8486.25
MASON	2884.43
MCDONALD	9040.75

MT. FRANKLIN	3850.69
MUD 1	13500.86
MUD 2	6428.98
MUD 3	2410.87
OTTER	3683.27
PATTERSON	26157.92
RICHIE	2824.16
SARGENT 1	10941.63
SARGENT 2	31341.28
SARGENT 3	5625.36
SARGENT 4	3766.98
SCHOLTZ	452.04
SHESHEEB	6589.71
SISKIWIT 1	3616.30
SISKIWIT 2	832.32
SISKIWIT 3	4285.99
SISKIWIT 4	436.97
WAGEJO	4400.79
WALLACE	8196.95
WHITTLESEY	1406.34

densities, crustacean densities, species richness, and species diversity were not strongly correlated to any of the environmental variables (Table 12).

DCA demonstrated that most of the rotifer taxa had a high probability of co-occurring (Species Group A; Fig. 2). The variant taxa included POMA (lower right of figure), KEBO (middle of upper portion of figure), and KEQU, FITE, and SYNC. DCA for samples showed that most lakes (Sample Group A) were dominated by taxa in Species Group A (Fig. 3; Table 13). Lakes in Sample Group B, located in ordination space near Sample Group A lakes, included combinations of taxa in Sample Group A and FITE, KEBO, and KEQU (Table 13). Dustin Lake and Whittlesey Lake were dominated by KEBO, whereas Lake George and Scholtz Lake were dominated by POMA (Table 13). Although these lakes occurred in the same drainage basin in the park, there were no obvious reasons why these four lakes were outliers based on their physical and environmental characteristics (Table 2; Appendices 1 and 2).

As with the rotifers, DCA demonstrated that most crustacean taxa had a high probability of co-occurring (Species Group A; Fig. 4). The exceptions were DARE (top of the figure), DAAM (lower right of figure), and TRPR and DAPU (near left center of the figure). DCA for samples showed that most lakes (Sample Group A) were dominated by taxa in Species Group A (Fig. 5; Table 14). Sample Group B, located near Sample Group A, was dominated by combinations of BOLO, TRPR, DARE, and DIOR (Table 14). Mud Lake 2 (upper left corner of figure) was dominated by DARE, whereas sample 3 from Mud Lake and sample 4 from Ahmik Lake (lower right corner of figure) were dominated by DAAM (Table 14). The reasons for these three outlier samples were unclear based on their physical characteristics (Table 2), and for Ahmik Lake, its environmental characteristics (Appendices 1 and 2).

Table 12. Pearson correlation coefficients (R^2) for rotifer densities (ROTDEN), crustacean densities (CRUSDEN), species richness (ZOOSP), zooplankton diversity (ZOOH), and selected environmental variables.

Variable	ROTDEN	CRUSDEN	ZOOSP	ZOOH
ROTDEN	1.000			
CRUSDEN	0.544	1.000		
ZOOSP	-0.043	0.065	1.000	
ZOOH	-0.610	-0.046	0.450	1.000
pH	-0.059	-0.038	-0.006	-0.109
Color	0.189	0.203	0.075	-0.159
Chlorophyll	0.227	0.027	0.151	0.003
DOC	0.150	0.215	0.138	-0.126
Total Phosphorus	0.552	0.359	0.075	0.267
Total Nitrogen	0.144	0.156	0.329	-0.087
Secchi Disk	-0.375	-0.143	-0.145	0.274
Lake Area	-0.193	-0.082	-0.125	0.172
Lake Elevation	0.109	-0.027	0.026	0.043
Lake Depth	-0.284	-0.116	-0.093	0.246

Detrended Correspondence Analysis of Isle Royale Rotifer Data

Species Scores

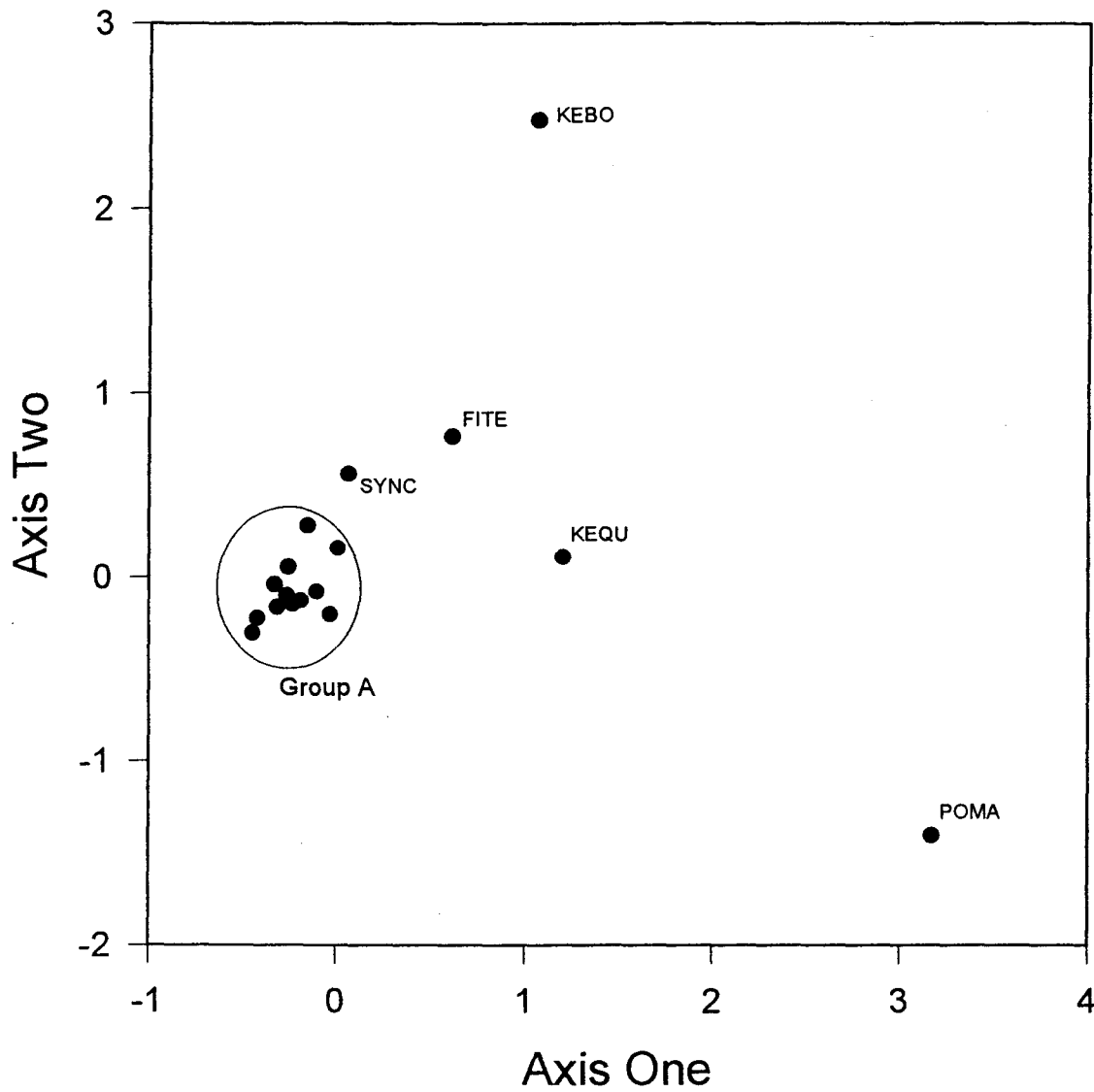


Figure 2: Ordination of the rotifer taxa in 55 samples from Isle Royale National Park lakes by detrended correspondence analysis.

Detrended Correspondence Analysis of Isle Royale Rotifer Data

Sample Scores

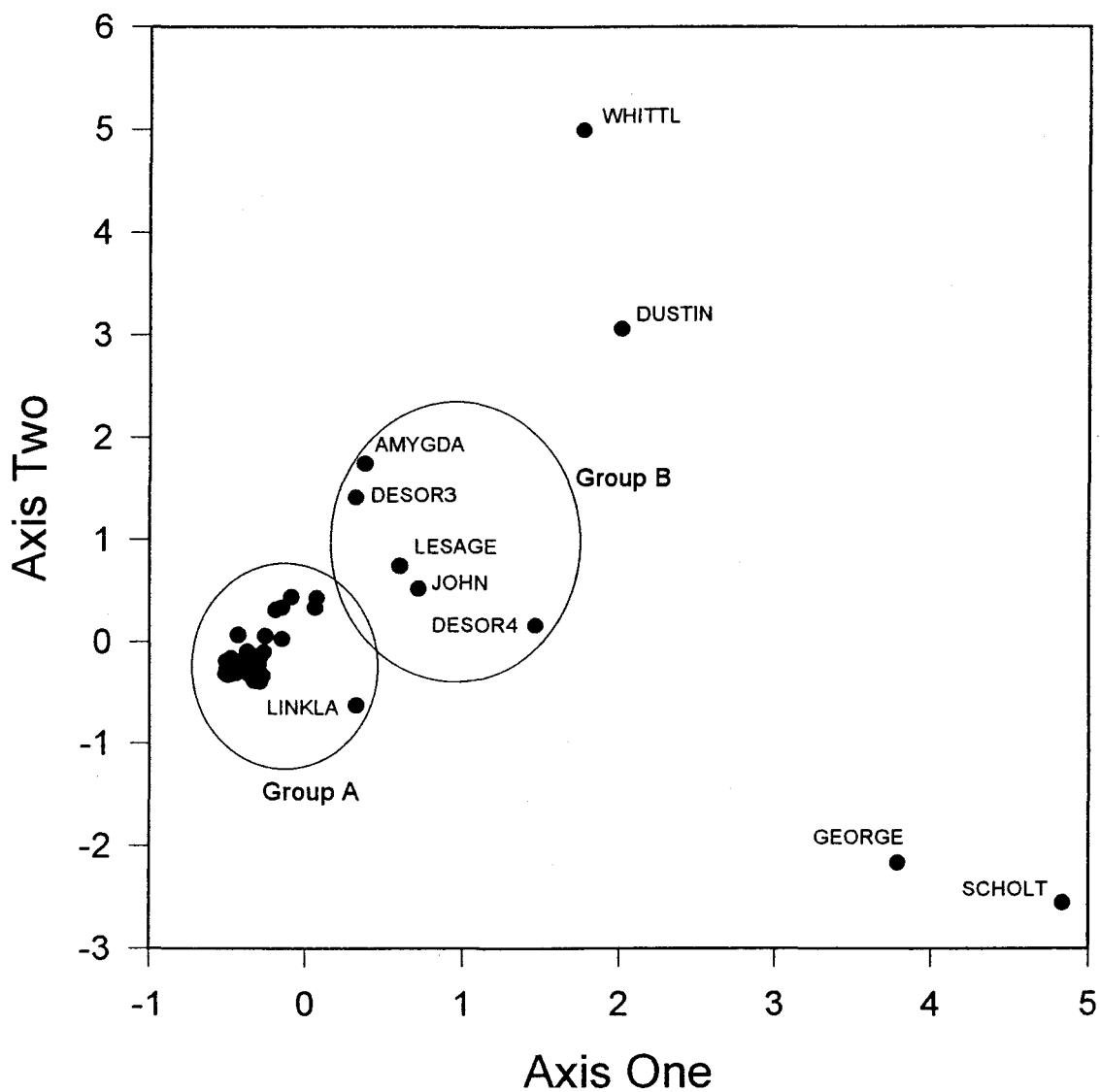


Figure 3. Ordination of the 55 rotifer samples from 36 Isle Royale National Park lakes by detrended correspondence analysis.

Table 13. Relative abundances of rotifer taxa in each ISRO lake sample. Only taxa ≥ 0.10 are shown.

Lake	Taxa (relative abundance)
Ahmik 1	KECO (.76), COUN (.16)
Ahmik 2	PLHU (.43), COUN (.14), PODO (.10), KELO (.10)
Ahmik 3	POMA (.52), COUN (.18), PLHU (.11)
Ahmik 4	PODO (.75), KECO (.16)
Amygda	KECO (.39), KEBO (.39), PLHU (.15)
Angle 1	KECO (.52), PLHU (.21), KELO (.10)
Angle 2	KECO (.50), PODO (.21), KELO (.13)
Angle 3	PLHU (.34), COUN (.28), PODO (.19), KELO (.16)
Angle 4	KECO (.65), KELO (.23)
Beaver	COUN (.56), KECO (.33)
Benson	COUN (.86)
Chiche	KECO (.49), PLHU (.36), COUN (.10)
Daisyf	KECO (.78), COUN (.17)
Desor 1	KECO (.59), KELO (.10)
Desor 2	KECO (.35), PLHU (.29), PODO (.15)
Desor 3	COUN (.28), KEBO (.28), KELO (.21), KECO (.10)
Desor 4	KEQU (.25), COUN (.16), KELO (.16), POMA (.16), KELO (.12)
Dustin	KEBO (.65), POMA (.14), FITE (.14)
Epidot	KECO (.51), COUN (.34)
Eva	PODO (.76)
Feldt 1	COUN (.50), KECO (.26), PODO (.20)
Feldt 2	PLHU (.46), KECO (.23), COUN (.15)
Feldt 3	PODO (.53), KECO (.35), COUN (.12)
Forbes	KECO (.67)
George	POMA (.74), COUN (.16)
Haller	PODO (.46), KECO (.30), COUN (.16)
Harvey	KECO (.79), PLHU (.11)
Hatch	KECO (.40), COUN (.28), PODO (.19), ASPR (.12)
Interm	COUN (.28), KECO (.18), TREL (.15), KEBO (.13), ASPR (.12)
John	FITE (.51), COUN (.28)
Lesage	COUN (.23), KEBO (.23), KECO (.19), PODO (.16)
Linkla	KECO (.37), PLHU (.30), POMA (.13)
Livirm	KECO (.56), PODO (.17), COUN (.11)
Mason	KECO (.34), PLHU (.30), COUN (.11), KEBO (.11)
McDon	COUN (.59), KECO (.23), TREL (.14)

MtFran	KECO (.72), PODO (.15)
Mud 1	KECO (.44), COUN (.24), KEBO (.13)
Mud 2	KECO (.67), COUN (.22), KELO (.11)
Mud 3	KECO (.18), COUN (.21), PODO (.11)
Otter	KECO (.62), COUN (.19), PODO (.13)
Patter	KECO (.68), COUN (.18), PLHU (.11)
Richie	COUN (.41), PLHU (.26), KECO (.17), PODO (.13)
Sarge 1	KECO (.43), KELO (.30), COUN (.13), POSU (.10)
Sarge 2	PLHU (.49), KECO (.40)
Sarge 3	KECO (.70), PLHU (.30)
Sarge 4	KECO (.87)
Scholt	POMA (.92)
Sheshe	COUN (.24), POSU (.22), KECO (.20), FITE (.11)
Siski 1	KECO (.81), PLHU (.19)
Siski 2	PLHU (.43), COUN (.27) PODO (.23)
Siski 3	PODO (.40), COUN (.18), KECO (.16), PLHU (.11)
Siski 4	PODO (.64), PLHU (.25)
Wagejo	KECO (.93)
Wallace	COUN (.58), KECO (.33)
Whittl	KEBO (1.0)

Detrended Correspondence Analysis of Isle Royale Crustacean Data

Species Scores

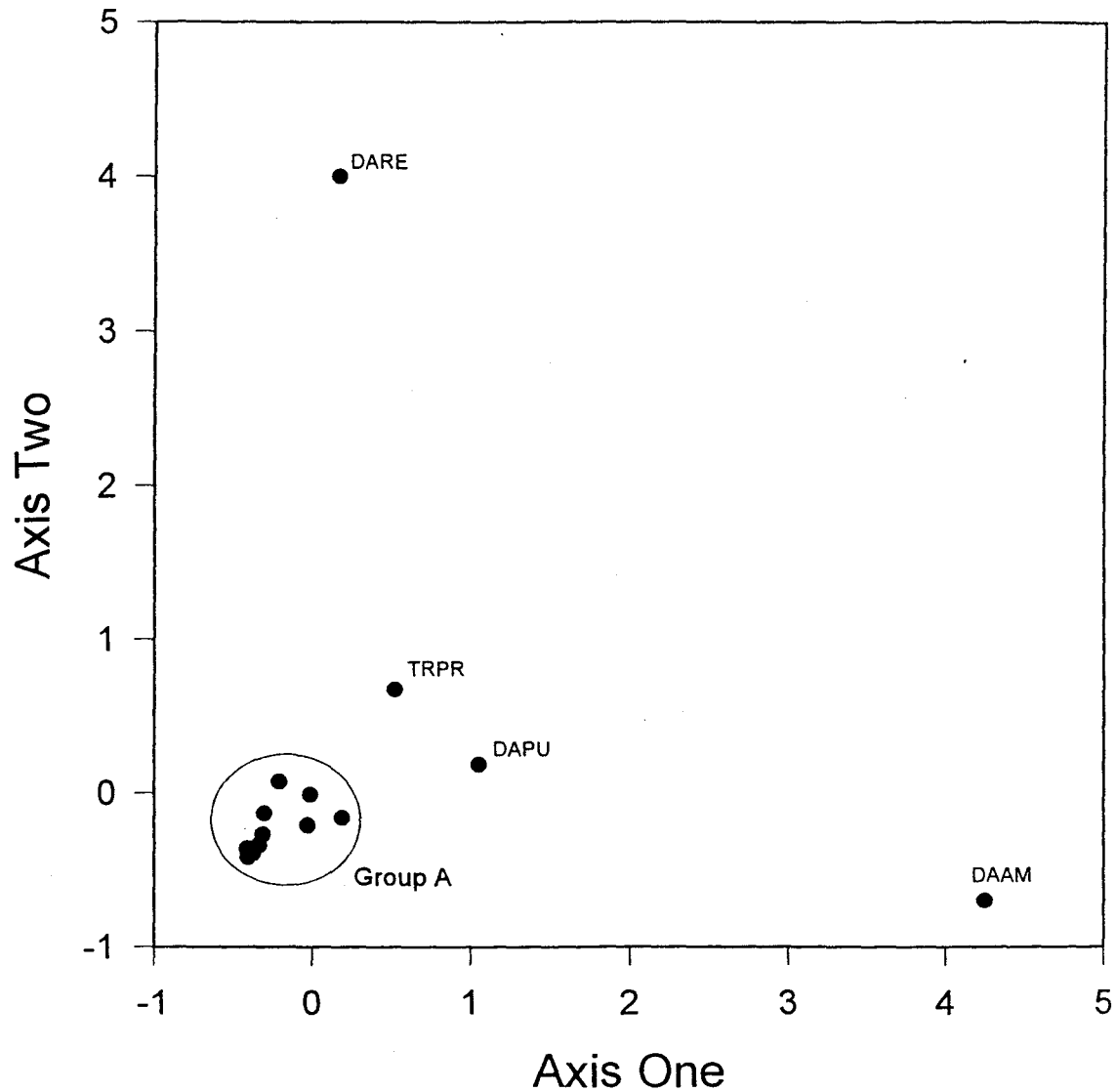


Figure 4. Ordination of crustacean taxa in 55 samples from Isle Royale National Park lakes by detrended correspondence analysis.

Detrended Correspondence Analysis of Isle Royale Crustacean Data

Sample Scores

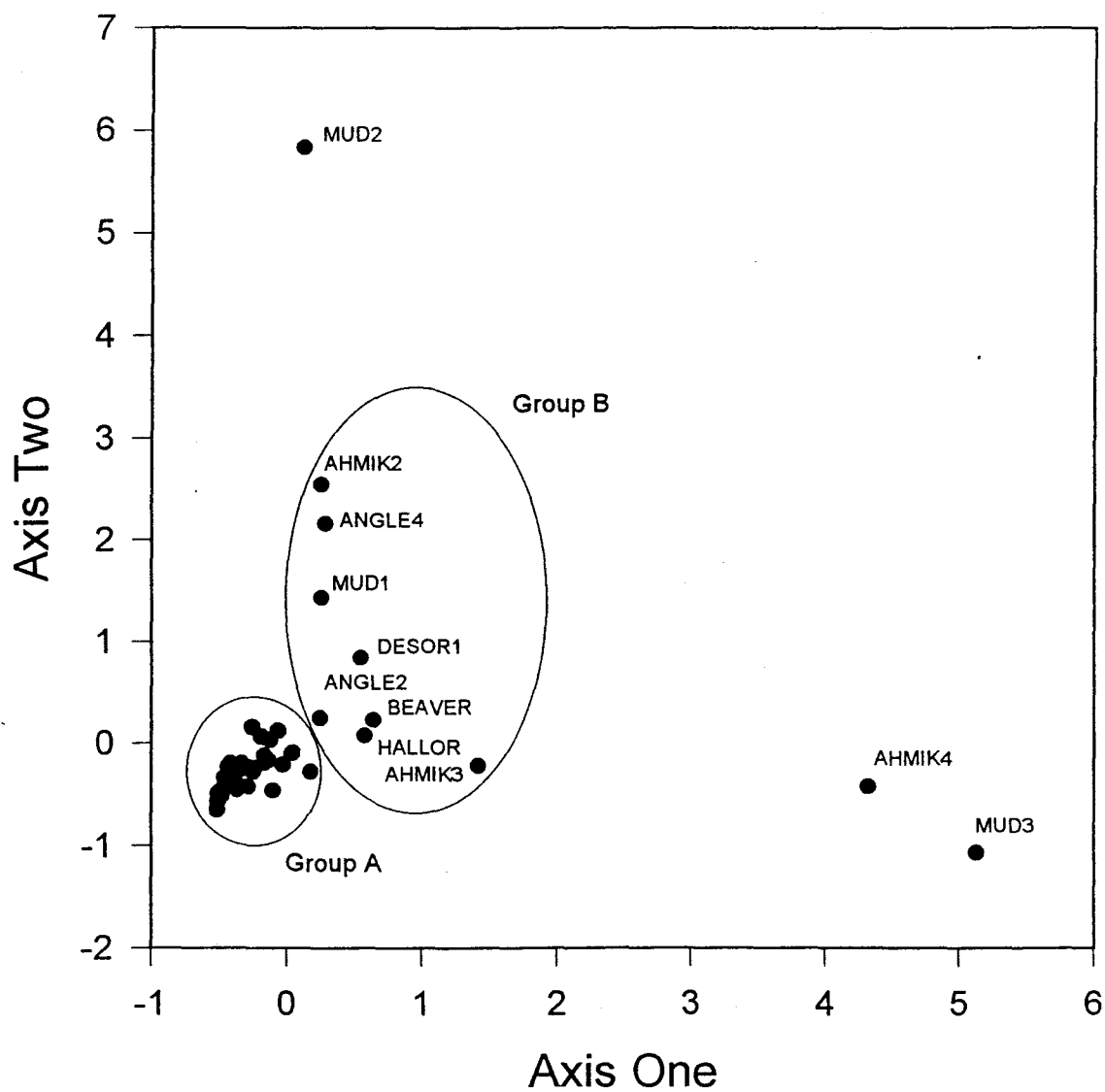


Figure 5. Ordination of the 55 crustacean samples from 36 Isle Royale National Park lakes by detrended correspondence analysis.

Table 14. Relative abundances of crustacean taxa in each ISRO lake sample. Only taxa ≥ 0.10 are shown.

Lake	Taxa (relative abundance)
Ahmik 1	MEED (.52), BOLO (.29), DIOR (.14)
Ahmik 2	BOLO (.32), TRPR (.32), DARE (.32)
Ahmik 3	BOLO (.38), DAPU (.33), DIOR (.17), DAAM (.17)
Ahmik 4	DAAM (.67), TRPR (.33)
Amygda	BOLO (.83)
Angle 1	BOLO (.37), MEED (.37), DIOR (.14), HOGI (.12)
Angle 2	ACVE (.39), TRPR (.31), DIOR (.23)
Angle 3	BOLO (.57), HOGI (.33)
Angle 4	TRPR (.46), DARE (.23), BOLO (.15), DIBI (.15)
Beaver	DIOR (.53), TRPR (.27), DAPU (.20)
Benson	BOLO (.99)
Chiche	BOLO (.46), DIBI (.19), DIOR (.15), TRPR (.15)
Daisyf	BOLO (.76), DIBI (.16)
Desor 1	TRPR (.77), DIOR (.12), BOLO (.10)
Desor 2	DIOR (.41), TRPR (.17), DAGA (.17), BOLO (.10)
Desor 3	BOLO (.68), ACVE (.14)
Desor 4	BOLO (.53), DAGA (.12), DIOR (.12)
Dustin	DAGA (.88)
Epidot	BOLO (.76), DIOR (.21)
Eva	BOLO (.69), MEED (.25)
Feldt 1	BOLO (.55), HOGI (.43)
Feldt 2	BOLO (.80), DIOR (.20)
Feldt 3	BOLO (.50), CERI (.50)
Forbes	HOGI (.29), DAGA (.14), DIBI (.14), BOLO (.14), DIOR (.14), TRPR (.14)
George	BOLO (.52), DIOR (.24), ACVE (.24)
Haller	DIOR (.60), TRPR (.28)
Harvey	DIBI (.38), DIOR (.25), CERI (.19), MEED (.13)
Interm	BOLO (.42), DAGA (.17), DIBI (.17), MEED (.13)
John	DITH (.43), BOLO (.29), CERI (.14)
Lesage	BOLO (.33), DAGA (.33), DIBI (.33)
Linkla	BOLO (.50), CERI (.50)
Livirm	BOLO (.60), TRPR (.20), DIBI (.14)
Mason	BOLO (.80)
McDon	BOLO (.30), DIOR (.28), CERI (.25), DAGA (.12)
MtFran	DAGA (.53), BOLO (.47)

Mud 1	TRPR (0.50), BOLO (.25), DARE (.13), DIBI (.13)
Mud 2	DARE (.83), BOLO (.17)
Mud 3	DAAM (.83), DIOR (.17)
Otter	BOLO (1.00)
Patter	BOLO (.72), TRPR (.20)
Richie	BOLO (.44), TRPR (.25), DIBI (.13)
Sarge 1	DIOR (.25), DAGA (.17), BOLO (.17), MEED (.17), DITH (.17)
Sarge 2	— (0.00)
Sarge 3	BOLO (.33), DITH (.33), MEED (.22), DAGA (.11)
Sarge 4	BOLO (.50), CERI (.50)
Scholt	DIOR (.88), BOLO (.13)
Sheshe	BOLO (1.0)
Siski 1	BOLO (.71), DIOR (.29)
Siski 2	DIOR (.54), CERI (.15), MEED (.15), DAGA (.15)
Siski 3	DAGA (.31), BOLO (.19), DIOR (.19), TRPR (.19), DITH (.13)
Siski 4	BOLO (.77), DAGA (.24)
Wagejo	BOLO (1.0)
Wallace	BOLO (.93)
Whittl	DAGA (.75), BOLO (.25)

Discussion

Although the study lakes exhibited a relatively large range of surface areas and maximum depths, the results (Figs. 3 and 5) clearly demonstrated that most lakes had very similar rotifer and crustacean zooplankton assemblages. The few exceptions were not clearly linked with any morphological or environmental variables. For lakes sampled more than once, the structures of the zooplankton assemblages showed limited temporal changes in most cases. The fact that the number of taxa and abundances of rotifers were greater than those of crustaceans was expected (Wetzel 1983). Possible relationships between the structure of zooplankton assemblages in park lakes and fish predation were not resolved due to the high degree of similarity of the crustacean zooplankton assemblages (Fig. 3) and the wide variation in crustacean densities among inland park lakes.

Little zooplankton data from the Greater Lake Superior Area were available to compare the assemblages at ISRO. Six of the 13 common rotifer taxa inhabiting Lake Superior were collected in ISRO lakes, whereas 7 of 15 common crustacean taxa were collected in park lakes (Table 15). However, unlike ISRO lakes, the Lake Superior crustacean zooplankton assemblage was dominated by *Diaptomus sicilis*, *D. Ashlandi*, and *Diacyclops bicuspidatus thomasi* (Patalas 1972; Watson 1974).

Bosmina longirostris (BOLO) was the most cosmopolitan crustacean taxon in park lakes and inland lakes across Ontario Canada (Table 16). The other taxa collected in park lakes with frequencies of occurrence of >20% were highly variable among Ontario lakes relative to park lakes (Table 16). For example, *Daphnia retrocurva* (DARE) and *Holopedium gibberum* (HOGI) occurred in 9.1 % and 18.2 % of park lakes, but their occurrences ranged from 13.0 - 72.0 % and 49.0-84.1 % in Ontario lakes, respectively.

Table 15. ISRO crustacean and rotifer taxa that are common in Lake Superior. From Patalas (1972) and Watson (1974).

Group	Taxa	Acronyms
Rotifers	<i>Conochilus unicornis</i>	COUN
	<i>Filinia</i> sp	FILI
	<i>Kellicottia longispina</i>	KELO
	<i>Keratella cochlearis</i>	KECO
	<i>Keratella quadrata</i>	KEQU
	<i>Synchaeta</i> sp.	SYNC
Crustaceans	<i>Diaptomus oregonensis</i>	DIOR
	<i>Mesocyclops edax</i>	MEED
	<i>Bosmina longirostris</i>	BOLO
	<i>Daphnia galeata mendotae</i>	DAGA
	<i>Daphnia retrocurva</i>	DARE
	<i>Holopedium gibberum</i>	HOGI
	<i>Diacyclops bicuspidatus thomasi</i>	DITH

Table 16. Percentage of lakes in Ontario Canada inhabited by ISRO crustacean taxa.

Taxa	Experimental Lakes Area ¹	Canadian Shield ²	Northwestern ³	Northern ³	North-Central ⁴
BOLO	91	92	56	92 ⁵	97
DIOR	41	0	0	0	56
TRPR	80	0	74	5	92
DAGA	35	40	93	80	52
DIBI	0	52	80 ⁵	51 ⁵	0
MEED	0	88	73	46	21
CERI	17	3	18	26	24 ⁵
HOGI	69	68	77	49	84
DITH	0	27	0	0	0
DARE	35	13	61	72	27
ACUE	0	0	2	0	0
DAAM	0	0	0	0	0
DAPU	0	52	10	5	35
CHYD	18	7	80 ⁵	82 ⁵	0

¹Patalas (1971).

²Keller and Conlon (1994).

³Keeler and Pitblando (1989).

⁴Shaw and Kelso (1992).

⁵Genus I. D. only.

Rotifer assemblages have received very little attention in the Greater Lake Superior Area. Shaw and Kelso (1992) showed that north-central Ontario lakes were most frequently inhabited by *Keratella cochlearis*, *Kellicottia bostoniensis*, and *K. longispina*. This result was similar to that of Chengalath and Fernando (1973) for lakes across Ontario, except that *K. bostoniensis* had a low frequency of occurrence (Table 17). Although *K. cochlearis* had a high frequency of occurrence in Ontario lakes and ISRO lakes, *Conochilus unicornis* was only common in ISRO lakes. Rotifer taxa with the highest frequencies of occurrence in northern Michigan lakes were similar to those in ISRO lakes (Table 17).

Although the present study provided insights about the zooplankton assemblages of inland park lakes in 1995-96, the taxonomic structures of assemblages may exhibit substantial interannual variations (Arnott et al., 1998). Therefore, we recommend that park management initiate a long-term monitoring program to assess interannual variation of water quality and the structure of zooplankton assemblages in selected lakes. The lakes should be distributed across the landscape of the park and include a range of sizes, depths, and water qualities. Based on cluster analysis of morphological and water quality characteristics of the lakes sampled in 1995-96, five cluster groups provided the best pattern for arranging the lakes (Table 18). We recommend that the proposed study include Patterson Lake (cluster 1), Siskiwit Lake (cluster 2), Feldtmann Lake (cluster 3), Lake Desor (cluster 4), and Angleworm Lake (cluster 5). Furthermore, the lakes that exhibited variant rotifer or crustacean species assemblages during the 1995-96 study (Ahmik, Dustin, George, Mud, Scholtz, and Whittlesey) should also be re-sampled to document the temporal stabilities of these assemblages. Collectively, these selected lakes represent the range of zooplankton assemblages observed in 1995-96 (Figs. 2 - 5). The

Table 17. Frequency and percent occurrence of ISRO rotifer taxa in lakes of north-central Ontario (Shaw and Kelso 1992), northern Michigan (Stemberger 1990), and various parts of Ontario (Chengalath and Fernando 1973). Results from the present study are also shown.

Taxa	<u>Present Work</u>		<u>N-C Ontario¹</u>		<u>Northern Michigan²</u>		<u>Ontario³</u>	
	n	%	n	%	n	%	n	%
<i>Keratella cochlearis</i>	54	98.2	127	96.2	40	100	143	94.1
<i>Conochilus unicornis</i>	47	65.5	46	34.9	37	92.5	44	29.0
<i>Polyarthra dolichoptera</i>	42	76.4	0	0	32	80.0	33	21.7
<i>Ploesoma hudsoni</i>	44	80.0	0	0	10	25.0	0	0
<i>Kellicottia bostoniensis</i>	21	38.2	125	94.7	24	60.0	38	0.25
<i>Kellicottia longispina</i>	22	40.0	103	78.0	37	92.5	111	73.0
<i>Keratella quadrata</i>	2	3.6	66	50.0	24	60.0	49	32.2
<i>Asplanchna priodonta</i>	31	56.4	33	25.0	31	77.5	79	52.0

¹possible n = 132

²possible n = 40

³possible n = 152

Table 18. Results of a cluster classification on inland park lakes based on elevation (m), surface area (ha), maximum depth (m), Secchi disk clarity (m), conductivity ($\mu\text{S}/\text{cm}$), pH, dissolved organic carbon (mg/L), total phosphorus ($\mu\text{g}/\text{L}$), and total nitrogen ($\mu\text{g}/\text{L}$). Note that only lakes with morphological and water quality data were included in the analysis.

Cluster	Lakes
1	Ahmik, Amygdaloid, Beaver, Dustin, Epidote, Eva, George, Livermore, Mason, McDonald, Otter, Patterson, Wagejo, Forbes, John, Linklater, Schultz, Shesheeb
2	Siskiwit
3	Feldtmann, Richie, Sargent
4	Desor
5	Angleworm, Chickenbone, Halloran, Intermediate, Lesage, Whittlesey, Benson, Harvey, Hatchet

lakes should be sampled at least twice each year, preferably in late July-early August and in September, following the water quality and zooplankton sampling methods used in this study.

In summary, the results suggest that the crustacean and rotifer assemblages were very similar among park lakes, with BOLO, KECO, and COUN having the highest frequencies of occurrence. Thus, any influences of environmental variation across the landscape, season, and the presence or absence of fish were not evident. The dominant crustacean taxa in Lake Superior were different from those of inland park lakes. BOLO was the most cosmopolitan crustacean taxon in Ontario lakes and inland park lakes, whereas KECO was the most common rotifer taxon among Ontario, northern Michigan, and inland park lakes.

Acknowledgments

We thank Jack Oelfke, Resource Management Specialist, Isle Royale National Park, for his interests and logistical support of the project. We thank Larry Kallemeyn, Fisheries Biologist, Voyageurs National Park, and his field crews for collecting the zooplankton samples and providing the morphological and environmental data. Larry Kallemeyn and Roy Irwin reviewed the draft report. This project was funded by the Water Resources Division of the National Park Service, Isle Royale National Park, and the USGS-Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon.

Literature Cited

- Arnott, S. E., J. J. Magnuson, N. D. Yan. 1998. Crustacean zooplankton species richness: single-and multiple-year estimates. *Can. J. Fish. Aquatic Sci.* 55:1573-1582.
- Chengalath, R. and C. H. Fernando. 1973. The plankton rotifera of Ontario with records of distributions and notes on some morphological variation. *Can. Field-Natur.* 87:267-277.

- Jongman, R. H. G., C. J. F. Ter Braak, O. F. R. Tongeren. 1987. Data analysis in community and landscape ecology. Pudoc Wageningen, The Netherlands, 299p.
- Kallemeyn, L. 1999. A comparison of fish communities from 1929 and 1995-97 from 32 inland lakes in Isle Royale National Park. National Park Service, Voyageurs National Park. 183p.
- Keller, W. and M. Conlon. 1994. Crustacean zooplankton communities and lake morphometry in Precambrian Shield Lakes. *Can. J. Fish. Aquatic Sci.* 51:2424-2434.
- Keeler, W. and J. R. Pitblando. 1989. The distribution of crustacean zooplankton in northern Ontario, Canada. *J. Biogeography* 16:249-259.
- Larson, G. L., G. Lomnický, R. Hoffman, W. J. Liss, and E. Deimling. 1999. Integrating physical and chemical characteristics of lakes into the glacially influenced landscape of the North Cascade Mountain Range. *Environ. Manage.* 24:219-228.
- Larson, G. L., A. Wones, C. D. McIntire, and B. Samora. 1994. Interpreting limnological characteristics of high mountain lakes into the landscape of a natural area. *Environmental Management* 18: 871-888
- Linn, R. M. 1966. Forests and trees of Isle Royale National Park. Isle Royale Natural History Association, Houghton, MI.
- McIntire, C. D. and W. S. Overton. 1971. Distributional patterns in assemblages of attached diatoms from Yaquina Estuary, Oregon. *Ecology* 52:758-777.
- Patalas, K. 1971. Crustacean plankton communities in forty-five lakes in the Experimental Lakes Area, northwestern Ontario. *J. Fish. Res. Bd. Canada* 28:231-244.
- Patalas, K. 1972. Crustacean plankton and the eutrophication of St. Lawrence Great Lakes. *J. Fish. Res. Bd. Canada* 29:1451-1462.

- Shaw, M. A. and J. R. M. Kelso. 1992. Environmental factors influencing zooplankton species composition of lakes in north-central Ontario, Canada. *Hydrobiol.* 241:141-154.
- Shelton, N. 1975. The life of Isle Royale. US Department of the Interior, National Park Service, Natural History Series, Washington D.C. 142p.
- Stemberger, R. S. 1990. An inventory of rotifer species diversity of northern Michigan inland lakes. *Arch. Hydrobiol.* 118:282-302.
- Watson, N. H. F. 1974. Zooplankton of the St. Lawrence Great Lakes - Species composition, distribution, and abundance. *J. Fish. Res. Bd. Canada* 31:783-794.
- Wetzel, R. G. 1983. *Limnology*. Saunders College Publishing, New York. 767 p.
- Wilkinson, L. 1987. *SYSTAT: The system for statistics*. SYSTAT, Inc. Evanston, Illinois.

Appendix 1. Water temperature (°C), Secchi disk readings (m) and concentration ($\mu\text{g/L}$) of total phosphorus, orthophosphate-P, total nitrogen, nitrate-N, and ammonia-N. Note that no data were available for Mud Lake, Daisyfarm Pond, Mount Franklin Pond, and Wallace Lake.

Lake	Date	Temp	Secchi	Total-P	Ortho-P	Total-N	N03-N	NH4-N
Ahmik	9/9/95	16.8	2.7	0.012	0.0012	0.65	0.0030	0.0270
Amygdaloid	7/18/96	17.7	3.5	0.010	0.0010	0.35	0.0025	0.0025
Angleworm	7/5/95	20.0	5.0	0.007	0.0010	0.28	0.0120	0.0060
Beaver	6/26/96	20.2	2.0	0.010	0.0020	0.61	0.0025	0.0110
Benson	7/12/95	20.7	2.0	0.018	0.0070	0.44	0.0080	0.0050
Chickenbone	8/27/95	22.5	2.4	0.013	0.0010	0.54	0.0160	0.0130
Desor	8/22/96	20.2	3.5	0.007	0.0010	0.61	0.0130	0.0190
Dustin	7/24/96	19.8	2.5	0.011	0.0010	0.40	0.0025	0.0070
Epidote	7/30/96	17.0	2.5	0.005	0.0010	0.47	0.0025	0.0110
Eva	9/6/95	20.5	2.1	0.014	0.0020	0.64	0.0120	0.0150
Feldtmann	6/13/96	21.6	2.3	0.013	0.0010	0.49	0.0030	0.0090
Forbes	8/2/95	23.5	2.9	0.011	0.0060	0.30	0.0070	0.0050
George	7/25/96	20.1	2.7	0.009	0.0010	0.41	0.0025	0.0025
Halloran	6/16/96	20.5	2.7	0.010	0.0030	0.46	0.0190	0.0110
Harvey	7/27/95	24.2	3.8	0.010	0.0080	0.40	0.0110	0.0050
Hatchet	7/30/95	23.4	2.5	0.007	0.0120	0.41	0.0025	0.0050
Intermediate	8/10/95	24.1	3.1	0.014	0.0025	0.47	0.0025	0.0050
John	7/31/96	18.5	3.0	0.006	0.0010	0.43	0.0025	0.0100
Lesage	8/23/95	23.6	2.6	0.010	0.0025	0.34	0.0025	0.0050
Linklater	6/28/95	21.3	2.0	0.011	0.0050	0.38	0.0110	0.0050
Livermore	8/25/95	21.5	2.6	0.010	0.0025	0.32	0.0050	0.0050
Mason	7/19/95	20.3	2.6	0.008	0.0050	0.41	0.0090	0.0050
McDonald	7/1/96	21.5	2.1	0.012	0.0010	0.52	0.0025	0.0110
Otter	6/28/96	23.2	2.3	0.010	0.0010	0.35	0.0110	0.0120
Patterson	9/8/95	17.3	1.7	0.012	0.0025	0.51	0.0070	0.0050
Richie	8/13/95	21.5	2.8	0.010	0.0025	0.45	0.0025	0.0050
Sargent	6/16/95	20.3	4.5	0.012	0.0020	0.40	0.0030	0.0030
Scholtz	7/26/96	20.4	1.5	0.008	0.0030	0.52	0.0120	0.0090
Shesheeb	6/28/95	21.1	2.5	0.011	0.0025	0.36	0.0070	0.0050
Siskiwit	8/10/96	19.5	9.0	0.014	0.0010	0.27	0.0270	0.0140
Wagejo	7/2/95	19.9	1.3	0.017	0.0025	0.35	0.0110	0.0050
Whittlesey	7/16/95	21.5	3.4	0.007	0.0025	0.25	0.0210	0.0050

Appendix 2. Conductivity ($\mu\text{S}/\text{cm}$), total dissolved solids (mg/L), pH, and dissolved organic carbon (mg/L) for ISRO study lakes. Note that no data were available for Mud Lake, Daisyfarm Pond, Mount Franklin Pond, and Wallace Lake.

Lake	Date	Cond.	TDS	pH	DOC
Ahmik	9/9/85	91.5	48	7.69	13.5
Amygdaloid	7/18/96	64.5	34	7.65	9.7
Angleworm	7/5/95	50.7	24	7.45	6.2
Beaver	6/26/96	93.9	45	7.66	12.2
Benson	7/12/95	57.4	30	7.55	9.8
Chickenbone	8/27/95	79.3	42	7.82	9.9
Desor	8/22/96	88.1	47	7.87	7.3
Dustin	7/24/96	56.8	30	7.69	7.5
Epidote	7/30/96	68.3	36	7.37	15.3
Eva	9/6/95	91.1	48	7.78	14.7
Feldtman	6/13/96	58.4	28	7.36	12.4
Forbes	8/2/95	66.5	35	7.63	8.6
George	7/25/96	91.6	48	7.89	10.3
Halloran	6/16/96	50.7	24	7.43	9.8
Harvey	7/27/95	66.0	34	8.91	8.9
Hatchet	7/30/95	75.5	39	7.69	11.7
Intermediate	8/10/95	55.3	28	7.40	10.1
John	7/31/96	99.5	52	7.77	13.9
Lesage	8/23/95	61.7	32	7.57	9.6
Linklater	6/28/99	99.5	47	7.50	10.1
Livermore	8/25/95	79.9	42	7.75	7.8
Mason	7/19/95	58.6	31	7.51	15.2
McDonald	7/1/96	88.7	41	7.68	12.1
Otter	6/28/96	69.8	33	7.60	8.3
Patterson	9/8/95	93.1	49	7.58	15.1
Richie	8/13/95	68.2	36	7.53	9.6
Sargent	6/16/95	84.5	38	7.66	8.7
Scholtz	7/26/96	68.2	36	7.66	12.5
Shesheeb	6/28/99	96.7	45	7.48	9.9
Siskiwit	8/10/96	65.0	34	7.90	5.0
Wagejo	7/2/99	68.4	32	7.32	10.0
Whittlesey	7/16/95	54.1	28	7.79	8.3