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Specific diversity and community structure of Rotifera in a salinity series of Ethiopian inland waters

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Abstract

The communities of planktonic Rotifera in thirty localities in Ethiopia were examined. All the localities lay at altitudes of over 1100 m and some were over 2000 m. The salinities ranged from 0.12 to 56.3‰ and in those lakes with salinities over 2‰ there was a marked reduction in the number of rotifer species, with *Brachionus dimidiatus* the most frequently dominant. The mean momentary species number in these Ethiopian samples is significantly higher than the means given by Pennak (1947) for Colorado and the rest of the world. Long-term planktonic species numbers in lakes Ziway and Awasa were about three times the mean momentary species number. The dominance ratios in the samples ranged from 19 to 91, but in general were lower than those given by Pennak. The most frequently dominant species were members of the family Brachionidae. Comparison with the data of Tonolli (1962) on the Lago Maggiore indicates that more data are needed on species diversity and dominance before valid geographical comparisons can be made.

Introduction

The inland waters of Ethiopia show great variation in salinity from one locality to another. They provide a series in which it is possible to study the change in community structure as the salinity increases. The present paper is concerned with the details of these changes in the Rotifera. In addition we examine the diversity and community structure of rotifers in a number of localities where salinity is not the major factor.

Although Ethiopia lies entirely within the tropics, a considerable area has its climate modified by high altitude. One might therefore expect that some of the freshwater organisms would show similarities to those from the temperate regions. The presence of the widespread Palaearctic species *Daphnia obtusa* in the Bale Mountains (Löffler, 1978) is an example; another is the presence of a member of the genus *Arctodiaptomus* in the same area (Dussart, 1974).

All the water bodies sampled in this study lie at altitudes above 1100 m, and some are over 2000 m above sea-level, so one might expect the associations of rotifers to show some similarities to those of temperate regions. We have approached this problem from two directions. The first is to examine the species composition of the planktonic rotifer fauna of Ethiopia. The second approach is to look at the composition of the communities in terms of diversity and dominance to see how these aspects of community structure

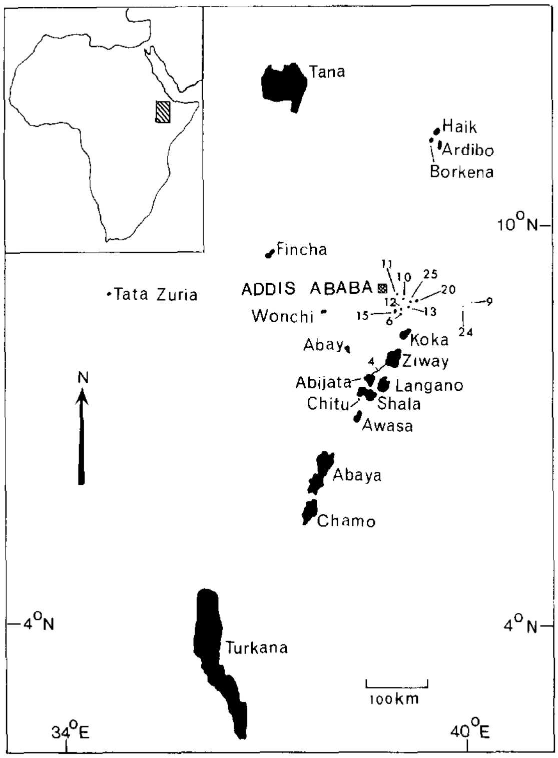

Fig. 1. Map to show the localities sampled. The only locality not shown is no. 5, L. Alemaya, which lies to the east of the area shown in the map.

compare with the available information from temperate regions.

Material and methods

Samples were taken from each water body using either a 64 μm or 55 μm mesh net. They were preserved in 5% formaldehyde. For each sample at least 100 rotifers were critically identified. The relative abundance of each species was estimated by mixing a subsample with a drop of lactic acid on a glass slide and making a temporary mount with a 50 x 22 mm coverslip. The slide was moved with a mechanical stage on a Nikon Labphot microscope, and was systematically searched for rotifers. The sequence in which rotifers were encountered was essentially random, and the counts are reasonable estimates of the relative abundance of each species.

List of localities

1. Lake Abay (7° 56 N – 38° 22 E) Alt. 1850 m. Depth 4 m. 20.IV.84.
2. Lake Abaya (6° 20 N – 37° 50 E) Alt. 1169 m. Depth 13 m. 30.IX.84, 12.X.86.
3. Lake Abijata (7° 37 N – 38° 35 E) Alt. 1580 m. Depth 14 m. 13.VII.86.
4. Adami Tulu (= Bulbula) River (7° 43 N – 38° 39 E) Alt. 1599 m. 26.II.84.
5. Lake Alemaya (9° 24 N – 42° 01 E) Alt. 2050 m. 16.VIII.87.
6. Lake Aranguadi (8° 41 N – 38° 59 E) Alt. 1900 m. Depth 32 m. 6.IV.84.
7. Lake Ardibo (11° 14 N – 39° 46 E) Alt. 2100 m. 12.VIII.87.
8. Lake Awasa (7° 03 N – 38° 36 E) Alt. 1675 m. Depth 22 m. Numerous samples 1984–87.
9. Awash Arba Pond (9° N – 40° 10 E) Alt. 1100 m. 17.VII.87.
10. Lake Babogaya (= Kuriftu) (8° 48 N – 39° 04 E) Alt. 1600 m. 20.V.83, 16.VIII.86, 18.VIII.87.
11. Akaki Reservoir (8° 48 N – 38° 42 E) Alt. 1200 m. 31.XII.87.
12. Lake Bishoftu (8° 44 N – 38° 59 E) Alt. 1870 m. Depth 87 m. 24.III.84, 13.IV.84.
13. Lake Biete Mengest (8° 46 N – 38° 59 E) Alt. 1850 m. Depth 38 m. 24.III.84.
14. Borkena Swamp (11° 05 N – 39° 45 E) Alt. 1850 m. 1.X.86.
15. CBIS Reservoir (near Debre Zeit) (8° 45 N – 39° E) Alt. 1900 m. 26.II.84, 22.VII.86.
16. Lake Chamo (5° 50 N – 37° 34 E) Alt. 1108 m. Depth 13 m. 29.IX.84.
17. Lake Chitu (7° 24 N – 38° 25 E) Alt. 1540 m. Depth 20.5 m. 1.IV.84.
18. Lake Fincha (9° 30 N – 37° 12 E) Alt. 2225 m. Depth 13 m. 17.II.85.
19. Lake Haik (11° 21 N – 39° 42 E) Alt. 2030 m. Depth 88 m. 11.II.84.
20. Lake Kilole (8° 48 N – 39° 05 E) Alt. 2000 m. Depth 6.4 m. 13.IV.84.
21. Koka Dam (= L. Galilea) (8° 23 N – 39° 04 E) Alt. 1591 m. Depth 8 m. 16.VIII.86.
22. Lake Langano (7° 37 N – 38° 35 E) Alt. 1582 m. Depth 48 m. 2.IV.84.

23. Ditch near Langano (7° 40 N – 38° 40 E) Alt. 1583 m. 16.VIII.86.
24. Lake Metahara (8° 58 N – 40° E) Alt. 1200 m. 17.VIII.87.
25. Lake Pawlo (8° 47 N – 38° 59 E) Alt. 1870 m. Depth 65 m. 6.IV.84, 16.VIII.86, 18.VIII.87.
26. Lake Shala (7° 28 N – 38° 30 E) Alt. 1558 m. Depth 266 m. 1.IV.84, 14.VII.86.
27. Lake Tana (12° N – 37° 20 E) Alt. 1820 m. Depth 14 m. 9.X.81, 23.IV.84 (littoral).
28. Lake Tata Zuria (8° 30 N – 34° 10 E) Alt. 1450 m. 22.VIII.85.
29. Lake Wonchi (8° 48 N – 37° 54 E) Alt. 2850 m. 22.VII.87.
30. Lake Ziway (Zwai, or Zwei) (8° N – 38° 49 E) Alt. 1636 m. Depth 9 m. 12 samples: VI.83 – VII.86.

List of species

The number(s) after each species refer to the locality numbers given above. As well as our own records the list includes species recorded by Bryce (1931) and Cannicci & Almagia (1947) (C & A).

Anuraeopsis coelata (De Beauchamp, 1932): 8, 10, 18, 28.
Anuraeopsis fissa (Gosse, 1851): 1, 4, 8, 10, 16, 18, 19, 28.
Anuraeopsis navicula (Rousselet, 1910): 19.
Ascomorpha saltans Bartsch, 1870: 1, 8, 14, 18, 22, 30.
Asplanchna brightwelli Gosse, 1853: 9, 21, 22.
Asplanchna priodonta Gosse, 1850: 8.
Asplanchna sieboldi (Leydig, 1854): 1, 10, 12, 13, 14, 15, 25, 30.
Brachionus angularis Gosse, 1851: 1, 2, 4, 5, 8, 9, 10, 11, 14, 15, 16, 19, 21, 22, 25, 28, 30.
Brachionus bennini Leissling, 1924: 23.
Brachionus budapestinensis Daday, 1885: 14.
Brachionus calyciflorus Pallas, 1766: 1, 4, 5, 8, 9, 10, 11, 12, 13, 14, 16, 21, 22, 25.
Brachionus caudatus Barrois & Daday, 1894: 1, 4, 5, 8, 11, 21, 25, 30.
Brachionus dimidiatus (Bryce, 1931): 3, 6, 11, 13, 17, 24, 26.
Brachionus falcatus Zacharias, 1898: 1, 8, 15, 28.
Brachionus forficula Wierzejski, 1891: C & A.
Brachionus patulus O.F. Müller, 1786: 10, 14, 15.
Brachionus plicatilis O.F. Müller, 1786: 3, 6, 17, 24, 26.
Brachionus quadridentatus Hermann, 1783: 2, 8, 14, 19.
Brachionus rubens Ehrenberg, 1838: 5, 9, 15, 27, 30.
Brachionus sessilis Varga: 1951: 2.
Brachionus urceolaris O.F. Müller, 1773: 8, 10, 12, 13, 14, 25.
Cephalodella catellina (O.F. Müller, 1786): 19, 22.
Collotheca ornata (Ehrenberg, 1832) var *natans* (Tschugunoff, 1921): 2.
Colurella obtusa (Gosse, 1886): 8.
Colurella uncinata (O.F. Müller, 1773): 27.
Conochilus sp.: 1, 4, 8, 10, 21, 29, 30.
Diplois daviesiae Gosse, 1886: 15.
Encentrum sp.: 19.
Epiphanes macrourus (Barrois & Daday, 1894): 14, 21.
Euchlanis dilatata Ehrenberg, 1832: 8, 27.
Euchlanis oropha Gosse, 1887: 27.
Euchlanis parva Rousselet, 1892: 9, 14, 19.
Euchlanis triquetra Ehrenberg, 1838: Bryce (1931).
Filinia longiseta (Ehrenberg, 1834): 2, 9, 10, 14, 15, 21, 22, 25.
Filinia opoliensis (Zacharias, 1898): 1, 2, 15, 16, 21, 28.
Filinia terminalis (Plate, 1886): 1, 2, 4, 8, 10, 16, 21, 22, 24, 27, 30.
Gastropus hyptopus (Ehrenberg, 1838): 21.
Gastropus stylifer Imhof, 1891: 10.
Hexarthra jenkinae (De Beauchamp, 1932): 3, 12, 13, 17, 24, 26.
Hexarthra mira (Hudson, 1871): 1, 2, 5, 7, 8, 9, 14, 18, 21, 22, 28, 29, 30.
Horaella brehmi Donner, 1949: 8.
Keratella cochlearis (Gosse, 1851): 8, 9, 15, 29.
Keratella procurva (Thorpe, 1891): 22.
Keratella quadrata (O.F. Müller, 1786): 7, 8.
Keratella tecta (Gosse, 1886): 10, 15.
Keratella tropica (Apstein, 1907): 1, 2, 4, 7, 8, 9, 11, 15, 16, 18, 19, 28, 29, 30.
Lacinularia elliptica Shephard, 1897: 26.

Lecane acus Harring, 1913: Bryce (1931).
Lecane bifurca (Bryce, 1892): Bryce (1931).
Lecane bulla (Gosse, 1886): 1, 2, 4, 5, 8, 11, 14, 16, 19, 29, 30.
Lecane closterocerca (Schmarda, 1859): 1, 8, 25.
Lecane decipiens (Murray, 1913): Bryce (1931).
Lecane elachis (Harring & Myers, 1926): Bryce (1931).
Lecane furcata (Murray, 1913): 14.
Lecane flexilis (Gosse, 1889): Bryce (1931).
Lecane hamata (Stokes, 1896): 8, 15, 28.
Lecane inopinata (Harring & Myers, 1926): 8.
Lecane leontina (Turner, 1892): 14.
Lecane luna (O.F. Müller, 1776): 5, 8, 19, 30.
Lecane lunaris (Ehrenberg, 1832): 8, 29.
Lecane papuana (Murray, 1913): 2, 7, 8, 14, 30.
Lecane sympoda (Hauer, 1929): 8.
Lecane tenuiseta Harring, 1914: Bryce (1931).
Lecane ungulata (Gosse, 1887): Bryce (1931).
Lecane zwaiensis Bryce, 1931.
Lepadella ehrenbergi (Perty, 1850): 8, 27.
Lepadella ovalis (O.F. Müller, 1786): Bryce (1931).
Lepadella patella (O.F. Müller, 1786): 8, 9, 10, 12, 19, 25, 28.
Lophocharis salpina (Ehrenberg, 1834): 8.
Mytilina mucronata (O.F. Müller, 1773): Bryce (1931).
Mytilina ventralis (Ehrenberg, 1832): 8, 19, 27.
Platyias quadricornis (Ehrenberg, 1832): Bryce (1931).
Ploesoma lenticulare Herrick, 1885: 8.
Pompholyx complanata Gosse, 1851: C & A.
Pompholyx sulcata (Hudson, 1885): 10, 14.
Polyarthra dolichoptera Idelson, 1925: 1, 7, 8, 10, 15, 16, 21, 27.
Polyarthra vulgaris Carlin, 1943: 2, 8, 14, 15, 21, 25, 28, 29.
Rotaria neptunia (Ehrenberg, 1832): 2, 15.
Synchaeta pectinata Ehrenberg, 1832: 1, 15, 28.
Scaridium longicaudum (O.F. Müller, 1786): 27.
Testudinella patina (Hermann, 1783): 2, 8.
Trichocerca bicristata (Gosse, 1887): 19.
Trichocerca brachyura (Gosse, 1851): Bryce (1931).
Trichocerca chattoni (De Beauchamp, 1907): 18, 26, 29.
Trichocerca gracilis (Tessin, 1890): 1, 8, 28, 30.
Trichocerca pusilla (Lauterborn, 1898): 8, 30.
Trichocerca rattus (O.F. Müller, 1776): Bryce (1931) (as *cristata*, Harring)
Trichocerca ruttneri Donner, 1953: 4, 30.
Trichocerca similis (Wierzejski, 1893): 18, 19.
Trichocerca tenuior (Gosse, 1886): 30.
Trichotria tetractis (Ehrenberg, 1830): 8.
Wolga spinifera (Western, 1894): 15.

Specific diversity

Table 1 shows the number of species, dominance and dominant species of the samples from the lakes for which we have salinity data. They are arranged in a sequence of increasing salinity. Once the salinity gets above 2‰ the samples are dominated by *Brachionus dimidiatus* (7 samples) or *B. plicatilis* (1 sample). There is also a significant drop in the number of species above 2‰. The mean number of species in the ten lakes below 2‰ is 8.4 ± 0.72, while in the lakes above 2‰ the mean value is 3.0 ± 0.33.

The momentary species compositions in the water bodies not included in the salinity series are shown in Table 2. They range up to 19 species per sample. The mean momentary species composition for all our Ethiopian samples is given in Table 3. As most of the lakes are represented by a single sample it is important to gain a perspective on the significance of such samples. As an aid to this the table also gives the mean value for Lake Awasa alone, based on 19 samples, and for Lake Ziway, based on 12 samples. The variation in a single lake (as indicated by the standard error of the mean) is similar to the variation found in momentary samples from a range of lakes. The value for all the samples together ($n = 62$) gives a mean value of 8.4 species per sample. This is significantly higher than the mean value for lakes in Colorado calculated by Pennak (1957). It is also higher than Pennak's value for the rest of the world. The figures given by Arcifa (1984) for the numbers of genera in Brazilian reservoirs are also given in Table 3, and confidence limits have been calculated. It should be kept in mind that the

Table 1. Momentary species composition of planctonic rotifers in Ethiopian lakes. The salinity series.

Lake	Salinity ‰	No. species	Dominance	Dominant species
Fincha	0.12	7	33	*Hexarthra mira*
Koka	0.32	9	19	*H. mira & Brachionus calyciflorus*
Ziway	0.35	7.8*	50*	*B. angularis* (10), *B. calyciflorus* (2)
Abaya (Sep. 84)	0.77	9	43	*H. mira*
Abaya (Oct. 86)	0.77	9	30	*Keratella tropica*
Haik	0.77	14	35	*Anuraeopsis fissa*
Awasa	0.90	8.6*	40*	*B. angularis* (7), *B. caudatus* (4) *K. tropica* (5), *H. mira* (2) *Lecane bulla* (1).
Pawlo (Apr. 84)	0.93	5	76	*Hexarthra jenkinae*
Pawlo (Aug. 86)	0.93	7	39	*Filinia longiseta*
Chamo	1.10	8	57	*B. angularis*
Langano	1.88	10	83	*Polyarthra vulgaris*
Bishoftu	1.92	6	74	*Hexarthra jenkinae*
Biete Mengest	2.57	5	91	*Brachionus dimidiatus*
Turkana**	2.89	3	94	*B. dimidiatus*
Aranguadi	5.54	3	91	*B. dimidiatus*
Abijata	16.2	3	76	*B. dimidiatus*
Shala (Apr. 84)	21.5	3	58	*B. dimidiatus*
Shala (Jul. 86)	21.5	2	56	*Brachionus plicatilis*
Chitu	38.3	3	70	*B. dimidiatus*
Metahara	56.3	2	67	*B. dimidiatus*

* Based on samples on 12 dates (Ziway), or 19 dates (Awasa)
** Sampled near Ferguson Gulf, Kenya, by J.G., Dec. 79.

Table 2. Momentary species composition of planktonic rotifers in Ethiopian inland waters. Localities *without salinity data.*

Locality	No. species	Dominance	Dominant species
L. Abay	17	28	*Brachionus angularis*
Adami Tulu River	9	63	*Brachionus angularis*
L. Alemaya	7	48	*Brachionus rubens*
L. Ardibo	6	75	*Hexarthra mira*
Awash Arba Pond	12	36	*Branchionus angularis*
Akaki	6	48	*Branchionus caudatus*
Borkena	19	49	*Brachionus calyciflorus*
CBIS Res. (4 Feb. 84)	6	89	*Keratella tropica*
CBIS Res. (26 Feb. 84)	8	85	*Keratella tropica*
CBIS Res. (22 Aug. 86)	14	47	*Brachionus patulus*
L. Babogaya (Aug 86)	6	47	*Polyarthra dolichoptera*
L. Babogaya (Aug. 87)	9	48	*Gastropus stylifer*
L. Tata Zuria	12	53	*Brachionus angularis*
L. Wonchi	9	33	*Hexarthra mira*

Table 3. Momentary species numbers of rotifers in plankton samples.

	L. Awasa	L. Ziway	Combined Ethiopian lakes	Colorado	World	Brazil
No. samples	19	12	61	148	163	47
Mean No. spp.	8.6	7.8	8.4	4.8	5.5	7.5*
S.E. of mean	0.72	0.41	0.41	0.17	0.21	0.4
99% confidence	7.0–10.2	6.8–8.7	7.5–9.3	4.4–5.2	5.1–6.0	6.6–8.4

* Minimum number based on genera (cf. Arcifa, 1984)

numbers for species are almost certainly higher. The numbers for Brazil are in the same range as those for Ethiopia, and again significantly higher than the means given by Pennak (1957.

Long-term specific diversity, or the number of species found when a lake is sampled at frequent intervals over a year or more, is naturally higher than momentary diversity. We have few long-term data from Ethiopia. In Lake Awasa 40 species were recorded in samples spanning four years (Mengestou, Green & Fernando, in press), but these samples included some littoral species. The longer a series of samples, the more littoral species are likely to be found as scattered individuals, even out in the open water. In Lake Ziway we have found 20 species in a series of 12 samples spanning over a year. Bryce (1931) recorded 29 species from Lake Ziway, but two of his five samples were taken near the mouth of an inflow, and included littoral forms not found in our samples (Table 4). Two of the species recorded by Bryce: *Brachionus dimidiatus* and *B. plicatilis*, indicate more saline conditions. They came from the mouth of a channel called the Suc-Suci which connects the saline lake Abiata with L. Ziway. Two additional species have been recorded from L. Ziway by Cannicci and Almagia (1947) who record *Brachionus falcatus* and *B. forficula*. These records bring the long-term total for L. Ziway up to 42 species. Of these species 18 are not euplanktonic, so the long-term total of planktonic species is 24. Similarly, of the 40 species recorded from L. Awasa 13 species are not strictly planktonic, reducing the total to 27. So for Ethiopia we have reasonably good data for two lakes giving mean momentary species numbers of 7.8 and 8.6 with long-term planktonic species numbers of 24 and 27.

The importance of restricting the comparison as far as possible to the planktonic species can be illustrated by a sample taken from the littoral of L. Awasa on 18 Dec. 84, which contained 25 species, only 8 of which were truly planktonic. In this example a single sample from the littoral contained a number of species approximately equal to the long-term planktonic species number.

Dominance

Tables 1 and 2 also give the dominance index for each sample. The range is from 19 to 91, with a mean of 54.3 for the samples excluding Lakes Awasa and Ziway. In Table 5 comparisons are made with the data given by Pennak (1957). Although it was not possible to calculate confidence limits for his data it is clear that his values lie outside the 99% confidence limits of the Ethiopian data. The general level of dominance in the Ethiopian samples is significantly lower than in samples from Colorado or the rest of the world.

If we exclude the lakes dominated by *Brachionus dimidiatus* and *B. plicatilis* (i.e. those with salinities over 2‰) we have in Table 1 and 2 a total of 56 samples, including those from Lakes Awasa and Ziway. If the last two are omitted we have 25 samples. Table 6 presents an analysis of the occurrence and dominance of the species dominant in at least one sample. An interesting feature of this table is that the first four

Table 4. Rotifera in Lake Ziway.

Species	Bryce (1931)	Cannicci & Almagia (1947)	Present study
Anauraeopsis fissa	+	–	+
Ascomorpha saltanus	–	–	+
Asplanchna sieboldi	–	+	+
Asplanchna brightwelli	+	–	–
Brachionus angularis	+	+	+
Brachionus calyciflorus	+	+	+
Brachionus caudatus	+	–	+
Brachionus dimidiatus	+	–	–
Brachionus falcatus	–	+	–
Brachionus forficula	–	+	–
Brachionus patulus	+	–	–
Brachionus plicatilis	+	–	–
Brachionus rubens	–	–	+
Conochilus sp.	–	–	+
Diplois daviesiae	+	–	–
Euchlanis dilatata	+	–	–
Euchlanis parva	+	–	–
Filinia longiseta	+	+	–
Filinia terminalis	–	–	+
Hexarthra mira	+	–	+
Keratella tropica	+	+	+
Lecane acus	+	–	–
Lecane arcuata	+	–	–
Lecane bulla	–	–	+
Lecane closterocerca	+	–	–
Lecane elachis	+	–	–
Lecane flexilis	+	–	–
Lecane luna	+	–	+
Lecane lunaris	+	–	+
Lecane papuana	–	–	+
Lecane tenuiseta	+	–	–
Lecane ungulata	+	–	–
Lecane Zwaiensis	+	–	–
Mytilina mucronata	+	–	–
Mytilina ventralis	+	–	+
Polyarthra vulgaris	+	–	–
Scaridium longicaudum	+	–	–
Trichocerca gracilis	–	–	+
Trichocerca pusilla	+	–	+
Trichocerca ruttneri	–	–	+
Trichocerca tenuior	–	–	+
Trichocerca sp. indet	–	–	+

species all belong to the family Brachionidae. All four species are widespread and dominant in several localities. They form a contrast with *Lecane bulla* which is almost equally widespread, but rarely dominant. *Hexarthra mira* has a frequency and dominance distribution similar to that of the Brachionids.

Similarity analysis

We have calculated similarity on a presence or absence basis using the Sörensen index : -

$$S = \frac{2c}{a + b} \times 100$$

where a is the number of species in one association, b is the number in the other association, and c is the number of species in common.

To gain some idea of the significance of such an index it is necessary to compare samples taken within one lake to see what variation occurs. We have done this in two ways. First we took a series of samples from Lake Awasa on one day. The samples were taken by means of vertical hauls from close to the bottom to the surface in regions with depths of 5, 10, 12, 15 and 20 m. The Sörensen indices of all possible comparisons ranged from 80 to 96. the lowest value was for the comparison between the stations at 5 m and 10 m, and the highest index was for the stations at 10 m and 12 m.

The second method of comparison was to compare samples taken from the same lake at different times of year. We compared December 1985 with each month in turn, getting a range of Sörensen indices from 77 to 100. We also compared June 1983 with each month in turn, getting a range from 73 to 86. A comparison of June 1983 with June 1984 and 1986 gave indices of 86 and 75. None of the comparisons within this lake fell below 70. We also have seasonal data for Lake Ziway, and a comparison of June 1983 with the other months gave a range of 59 to 82, and an even lower figure was obtained in a comparison between June 83 and July 86 which produced an index of 53.

Comparisons between the lakes in the salinity series are shown in Table 7. Arranging the lakes in this way produces zero values in the top right and bottom left quadrants, with low or moderate values in the top left quadrant, and very high

Table 5. Dominance in planktonic rotifer communities.

	L. Awasa	L. Ziway	Combined Ethiopian lakes	Colorado	World
No. samples	19	12	61	–	–
Mean dominance	40.4	50.4	49.2	63.6	64.4
S.E. of mean	2.8	2.8	2.2	–	–
99% confidence	46–62	34–47	44–54	–	–

values in the bottom right quadrant. This indicates that at low salinities other factors are influencing the specific composition of the rotifers, but at high salinities there is a distinctive planktonic rotifer community.

Lake Pawlo appears to be slightly out of place in Table 7. This is brought about by the presence of *Hexarthra jenkinae* instead of *H. mira*. There may be a simple geographical explanation for this. Lake Pawlo is one of the Bishoftu crater lakes (cf Prosser, Wood & Baxter, 1968), all of which are close to the town of Debre Zeit, and all of which lack *Hexarthra mira*, but have *H. jenkinae* instead.

Table 8 shows the Sörensen indices of the lakes for which we have no salinity data. Most of the values are low or moderate, with few over 50. This indicates that none of these water bodies is particularly saline, with the table corresponding to the upper left quadrant of Table 7. This conclusion is reinforced by the fact that *Brachionus dimidiatus* was found only in Akaki, and then not as a dominant.

Discussion

In a study of chemical and algal relationships in a salinity series of Ethiopian inland waters Wood

Table 6. Occurrence and dominance of rotifer species in samples from non-saline (< 2‰) inland waters in Ethiopia. Only species which are dominant in at least one locality are included. Note that the numbers for occurrence may be greater than in the systematic list, which refers to localities, while the present table refers to all samples. The species are arranged in rank order of occurrence in the samples.

Species	All samples (n = 56)		Samples excluding lakes Awasa and Ziway (n = 25)	
	Occurrence	Dominant	Occurrence	Dominant
Brachionus angularis	49	22	19	5
Brachionus calyciflorus	45	4	15	2
Keratella tropica	41	8	13	3
Brachionus caudatus	37	5	6	1
Lecane bulla	38	1	9	–
Hexarthra mira	33	7	11	5
Polyarthra dolichoptera	12	1	7	1
Polyarthra vulgaris	10	1	8	1
Anuraeopsis fissa	10	1	5	1
Filinia longiseta	8	1	8	1
Brachionus patulus	5	1	5	1
Hexarthra jenkinae	4	2	4	2
Brachionus rubens	4	1	3	1
Gastropus stylifer	1	1	1	1

Table 7. Sörensen indices of similarity of rotifer associations in lakes of the salinity series.

	F	K	Z	A	H	A	P	C	L	B	B	T	A	A	S	C	M
Fincha	–	10	29	26	19	33	0	27	24	0	0	0	0	0	0	0	0
Koka	10	–	50	41	7	60	52	48	52	11	11	0	0	0	0	0	0
Ziway	29	50	–	50	26	78	47	67	47	15	17	0	0	0	0	0	0
Abaya	26	41	50	–	33	40	31	42	38	0	0	0	0	0	0	0	0
Haik	19	7	26	33	–	37	17	36	8	10	0	0	0	0	0	0	0
Awasa	33	60	78	40	37	–	38	53	38	12	13	0	0	0	0	0	0
Pawlo	0	52	47	31	17	38	–	44	50	63	53	15	0	15	15	15	0
Chamo	27	48	67	42	36	53	44	–	33	14	15	0	0	0	0	0	0
Langano	24	52	47	38	8	38	50	33	–	13	13	0	0	0	0	0	0
Bishoftu	0	11	15	0	10	12	63	14	13	–	72	22	22	22	22	22	0
Biete Mengest	0	11	17	0	0	13	53	15	13	72	–	50	25	50	50	50	29
Turkana	0	0	0	0	0	0	15	0	0	22	50	–	67	100	100	100	80
Aranguadi	0	0	0	0	0	0	0	0	0	22	25	67	–	67	67	67	80
Abiata	0	0	0	0	0	0	15	0	0	22	50	100	67	–	100	100	80
Shala	0	0	0	0	0	0	15	0	0	22	50	100	67	100	–	100	80
Chitu	0	0	0	0	0	0	15	0	0	22	50	100	67	100	100	–	80
Metahara	0	0	0	0	0	0	0	0	0	0	29	80	80	80	80	80	–

Table 8. Sörensen indices of similarity of rotifer associations in Ethiopian lakes without salinity data.

	Ab	Ad	Al	Ar	Aw	Ak	Bo	CB	Ku	Ta	Wo
Abay	–	69	42	35	35	44	33	41	44	55	46
Adami Tulu	69	–	50	27	38	67	21	15	42	38	11
Alemaya	42	50	–	15	42	62	31	8	18	21	13
Ardibo	35	27	15	–	22	17	16	17	10	33	40
Awash Arba	35	38	42	22	–	33	32	35	30	33	19
Akaki	44	67	62	17	33	–	24	17	19	22	27
Borkena	33	21	31	16	32	24	–	28	41	19	29
CBIS	41	15	8	17	35	17	28	–	38	35	31
Kuriftu	44	42	18	10	30	19	41	38	–	30	25
Tata Zuria	55	38	21	33	33	22	19	35	30	–	29
Wonchi	46	11	13	40	19	27	29	31	25	29	–

Table 9. Sörensen indices of similarity of planktonic rotifer associations in two Ethiopian lakes compared with two European lakes. Data for the Lago Maggiore from Tonolli (1962); data for Lake Constance from Walz, Elster & Mezger (1987).

	Awasa	Ziway	Maggiore	Constance
Awasa	–	60	39	35
Ziway	60	–	25	24
Maggiore	39	25	–	62
Constance	35	24	62	–

and Talling (1988) found that certain algal species were characteristic of waters of restricted salinity ranges. Desmids and *Melosira* spp. were found in low salinities, *Planctonema lauterborni* in intermediate salinities and *Spirulina platensis* in high salinities. *Microcystis aeruginosa* was found over a wide range of salinity, from L. Haik (0.8‰) to L. Turkana (2.9‰). We were able to study the planktonic rotifers in 17 of the 19 lakes for which Wood and Talling listed algal data. We found a clear-cut change in the rotifer fauna above a salinity of 2‰,

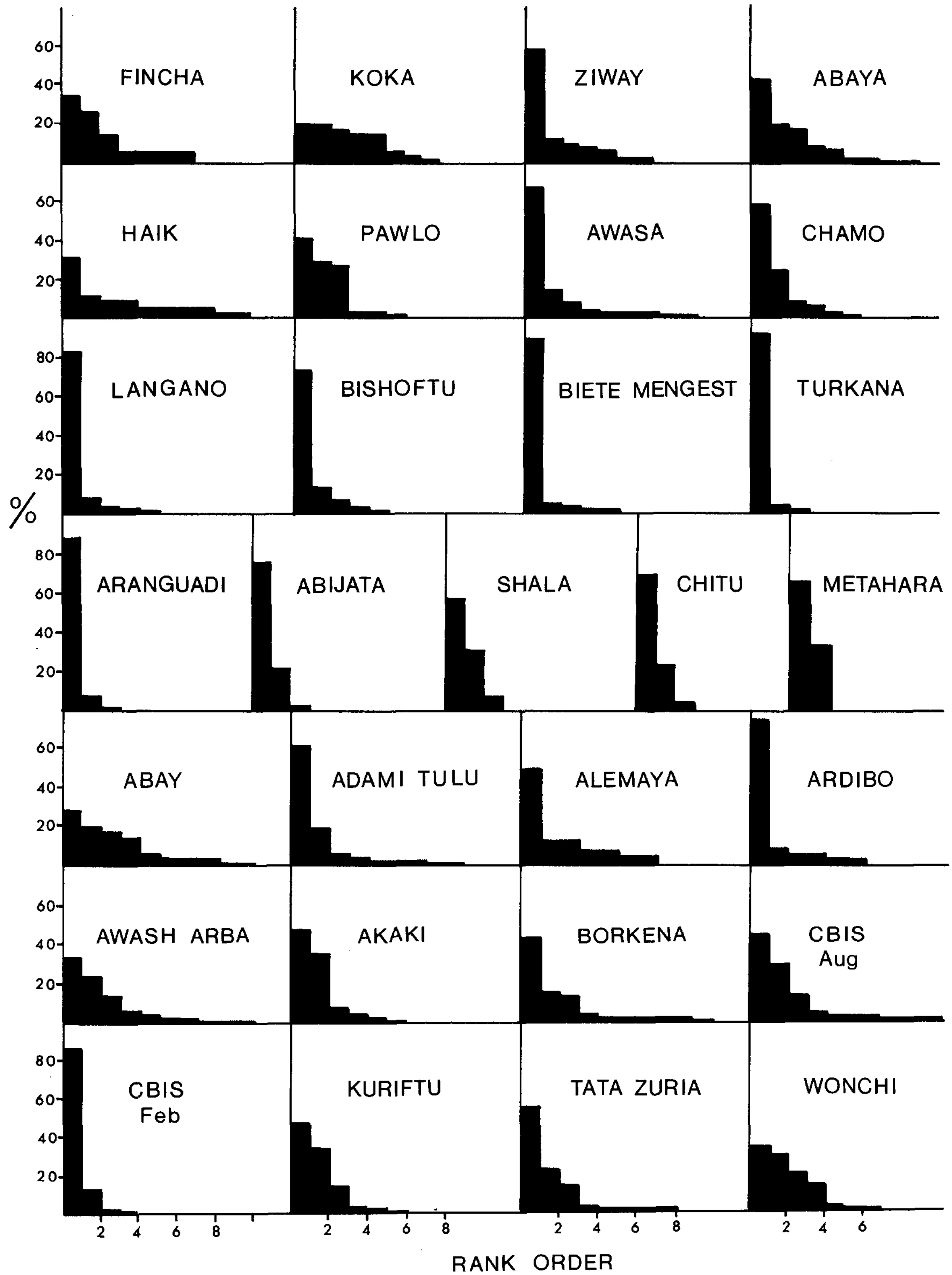

Fig. 2. Rank order histograms of rotifers in samples from Ethiopian inland waters. The top four rows are the lakes of the salinity series.

with *Brachionus dimidiatus* becoming the most frequently dominant species. At a salinity of 2‰ the algae were dominated by *Microcystis aeruginosa*, with a change to dominance by *Spirulina platensis* in most of the lakes with salinities of 5‰ or more. At the higher salinities the algae showed variations not shown by the rotifers. This was particularly well shown in Lake Shala, a large, deep (266 m), apparently unproductive lake with a salinity of 21.5‰. The dominant alga in Lake Shala was *Anomoeoneis sphaerophora* instead of the more usual *Spirulina platensis*, but the planktonic rotifer community was similar to all the other strongly saline lakes, as shown by the high similarity values in Table 7. This lack of correspondence between the salinities at which the communities of algae and rotifers change is an indication that the change in the rotifer community is more a matter of specific physiological tolerance of increased salinity than of any change in the algae available as food.

The similarities between the rotifer associations in Ethiopian and temperate lakes can be estimated in various ways. First the Sörensen index can be used. Table 9 shows a comparison between the two Ethiopian lakes for which we have long-term data and two European lakes. Comparisons within a continent give indices of 60 and 62, but the indices are lower when the Ethiopian lakes are matched against the European lakes. The indices for Awasa are higher than those for Ziway. There is no obvious reason why this should be so. The altitudinal difference of 40 m does not seem sufficient to cause the greater similarity of Lake Awasa to the temperate lakes. The indices for Lake Ziway are similar to the value obtained by Green (1972) when comparing Lake Albert (alt. 616 m) with the Lago Maggiore. At the levels of these lakes the altitudinal differences seem to be relatively unimportant. The two Ethiopian lakes accord well with the latitudinal gradient described by Green (op. cit.).

Another method of comparison is to use the momentary species composition. Table 3 shows that the Ethiopian lakes as a whole show a significantly greater number of species than Pennak (1957) found in his Colorado lakes. However, the momentary species composition of the planktonic rotifers in the Lago Maggiore gives a very different perspective. The detailed data of Tonolli (1962) show that at any one time the number of species ranged from 24 to 29, with a mean of 27.1, and a long-term total of 32. These data indicate a need to revise the ideas of Pennak (1957), and to look at the ways in which both the momentary and long-term species numbers vary geographically. The Lago Maggiore data also introduce the idea of stability in species number, and this may also be worthy of analysis on a geographical basis.

A third approach in the comparison with temperate lakes is an examination of dominance ratios. The rank order distributions of the Ethiopian lakes are shown in Fig. 2., and the dominance ratios are given in Table 1 and 2. When compared to the mean dominance ratios for Colorado the Ethiopian values are significantly lower. In Table 10 we have calculated the dominance ratios for the Lago Maggiore during the course of a year. The numbers are consistently below those given by Pennak (1957) for Colorado and the rest of the world. The general trend from Colorado to Ethiopia and the Lago Maggiore indicate a broad tendency to a decrease in domi-

Table 10. Lago Maggiore: dominant species of planktonic rotifers at approximately monthly intervals, Sept. 1957–Sept. 1958. Data calculated from Tonolli (1962).

Date	Dominant species	Dominance (%)
9–10 Sep. 57	*Polyarthra vulgaris*	17
9–10 Oct. 57	*Ploesoma truncatum*	17
14–15 Nov. 57	*Polyarthra proloba*	19
16–17 Dec. 57	*Asplanchna priodonta*	37
27–28 Jan. 58	*Keratella quadrata*	37
5–6 Mar. 58	*Keratella quadrata*	42
31 Mar–1 Apr. 58	*Keratella cochlearis*	18
29–30 Apr. 58	*Keratella cochlearis*	15
28–29 May. 58	*Keratella cochlearis*	31
16–17 Jun. 58	*Keratella cochlearis*	33
7–8 Jul. 58	*Keratella cochlearis*	29
28–29 July 58	*Polyarthra vulgaris*	15
19–21 Aug. 58	*Ploesoma truncatum*	22
9–10 Sep. 58	*Ploesoma truncatum*	35
	Mean	26.2 S.E. 2.56
		99% confidence range 20–32

nance with an increase in momentary species number. The detailed rank order histograms in Fig. 2 show that there is a great deal of variation in this relationship. We clearly need many more analyses of momentary species composition and dominance on a seasonal basis from a wide range of geographical areas.

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