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ASSESSING SIMILARITY BETWEEN SAMPLES OF PLANKTON*

J. MAUCHLINE

The Dunstaffnage Marine Research Laboratory, Oban, Argyll, Scotland

ABSTRACT

The study of the distributions of species of plankton organisms relative to each other within a confined sea area is emerging as an important and difficult problem. Much interest is attached to the comparison of pairs of entire samples rather than comparing the data from pairs of species. There is a considerable advantage in reducing the complex data, frequently consisting of counts of individuals of all species occurring in each sample, to a form in which they can be examined pictorially. This would then allow groups of similar or dissimilar samples to be more readily related spatially or temporally to each other.

Several data treatments which have been reported to do this have been examined and compared in this investigation. Samples of hypoplankton were taken in Loch Etive, Argyll, Scotland and the numbers of individuals of different species counted. The data were then analysed by several methods and the results presented in the form of trellis diagrams, a relatively old and attractive form of presentation. The different analyses produced slightly different results but they do present the investigator with several methods of treating complex data. The specific method selected depends on what information is required from the samples and, to some degree, on whether further and more detailed statistical tests are going to be made. These forms of analyses can indicate possible groupings of samples which might be selected as starting points in a larger multiple correlation analyses.

Other possible methods of treating the data, although not used in this paper, are mentioned and the authorities quoted because the literature on this subject is scattered and could usefully be listed.

INTRODUCTION

MORE efficient methods of sampling plankton quantitatively in a given volume of water are being continually developed. This frequently gives rise to large numbers of samples and much data especially in using multiple samplers or one such as the Hardy-Longhurst (Longhurst *et al.*, 1966). There is a considerable advantage to be gained by reducing this mass of raw data to a pictorial form which relates one sub-sample to another ; this would then allow groups of sub-samples to be selected for further more detailed statistical examination. This form of preliminary analysis would also have considerable value in studying changes in population constitution along a transect, for example from an unpolluted area into a polluted area.

Studies of the hypoplankton, the aggregations of planktonic organisms living close to the mud/water interphase, have been made in a Scottish sea loch, Loch Etive, and provide the data used to examine some of the methods of statistical analyses advocated in the literature.

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Sampling method

A beam trawl incorporating a stramin net was used to sample the hypoplankton. The trawl has wide runners which enable it to slide across muddy bottoms without the net becoming filled with mud. Hauls were made over one kilometer of distance so that the samples are semi-quantitative. The samples were preserved in formalin and the numbers of individuals of the different species later counted. These samples were taken during the period October 1967 to December 1969 at varying combinations of the stations shown in Fig. 1.

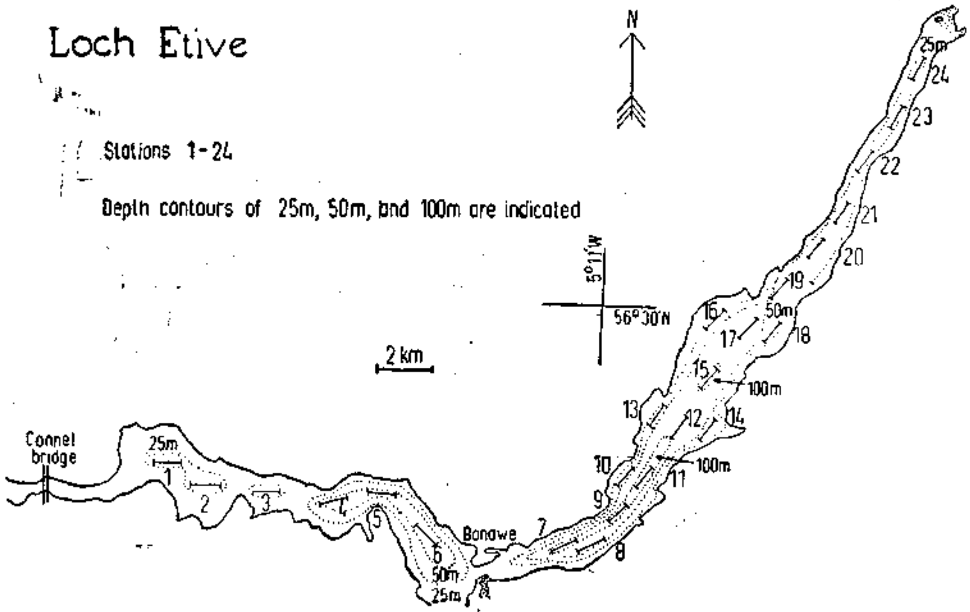

FIG. 1. Map of Loch Etive, Argyll, showing stations sampled.

Results

Detailed analyses of the series of samples taken in November, 1967, March and May, 1968, were made (Tables 1, 2 & 3). *Sagitta elegans, Calanus finmarchicus* and *Pareuchaeta norvegica* were the dominant species in the vast majority of hauls. The depths at stations 1-6 and 17-24 are much less (Fig. 1) than in the deep upper basin where most of stations 7-16 are sited. *Pareuchaeta norvegica* occurs most commonly in west coast lochs (e.g. Upper Loch Fyne, Firth of Clyde) where depths of 100 to 150 m are present. Thus *P. norvegica* assumes greater dominance in Loch Etive at stations 7-16 than elsewhere. Likewise the euphausiids *Meganyctiphanes norvegica* and *Thysanoessa raschii* are more common in this deep basin than in the lower loch.

A series of hauls taken at Station 6 were analysed in detail (Table 4) and the dominance of *S. elegans* and *C. finmarchicus* in this shallow region of the loch is evident with *P. norvegica* not so important. Appreciable numbers of decapod larvae were present, especially in the hauls taken during August and October; these larvae occurred in large numbers at stations 7-24 during these two months and seem to be a feature of the Loch Etive late summer plankton because they were also present in 1969.

The term 'Other Crustacea' in Tables 1-4 includes occasional individuals of the cumacean species *Diastylis tumida* (Lilljeborg), *Leptostyllus villosa* G.O. Sars, and *Eudorella emarginata* (Krøyer) and any other rare Crustaceans ; the most common amphipods found were *Westwoodilla megalops* G.O. Sars and *Ampellisca tenuicornis* Lilljeborg. These species occurred throughout the length of the loch in varying numbers.

TABLE 1. *Number of Individuals per haul at*

Species	Stations 1	2	3	4	5	6	7	8	9	10
Sagitta elegans Verrill	24	211	713	1349	5256	5524	178	95	265	191
Calanus finmarchicus (Gunn)	6	7	28	148	274	413	942	449	4567	1092
Pareuchaeta norvegica (Boeck)	—	—	—	62	207	238	787	214	6057	280
Acartia clausii Giesbrecht	1	—	1	—	1	1	—	—	—	—
Schistomysis ornata (G. O. Sars)	1	2	5	6	18	24	1	—	1	5
Erythrops serrata (G. O. Sars)	—	4	18	2	2	26	6	—	7	1
Leptomysis gracilis (G. O. Sars)	4	4	4	7	16	13	1	—	—	—
Mysidopsis didelphys Norman	6	10	58	3	3	4	—	—	—	—
Anchialina agilis (G. O. Sars)	—	6	7	1	—	—	—	—	—	—
Pseudomma affine G. O. Sars	—	—	—	—	7	3	—	—	—	—
Gastrosaccus normani G. O. Sars	—	—	1	—	—	—	—	—	—	—
Hemimysis lamornae (Couch)	—	—	1	—	—	—	—	—	—	—
Siriella clausii G. O. Sars	—	1	—	—	—	1	—	—	—	—
Nyctiphanes couchii (Bell)	—	—	—	—	1	—	—	—	—	—
Meganyctiphanes norvegica (M. Sars)	—	—	—	—	1	—	—	2	7	4
Thysanoessa raschii (M. Sars)	—	—	—	—	2	9	—	—	12	25
Eualus gaimardi (H. Milne-Edwards)	—	—	—	1	—	—	—	—	—	—
Dichelopandalus bonnieri (Caullery)	—	—	—	—	1	—	—	—	—	—
Pandalina brevirostris (Rathke)	—	—	2	1	1	—	—	—	—	—
Pandalus montagui Leach	—	2	4	5	3	—	—	—	—	1
Pandalus propinquus G. O. Sars	—	—	—	—	—	—	2	—	—	—
Crangon allmani Kinahan	—	3	2	35	37	67	10	6	5	3
Pontophilus spinosus (Leach)	—	—	—	—	5	1	—	—	2	—
Philocheras bispinosus bispinosus (Hailstone & Westwood)	—	—	—	—	—	2	—	—	—	—
Nephrops norvegicus (L)	—	—	—	—	—	1	—	—	—	—
Calocaris macandreae (Bell)	—	—	—	—	—	—	—	1	1	1
Amphipods	—	4	22	8	3	7	6	1	4	2
Caprella linearis	6	3	5	2	—	—	—	—	—	—
Isopod	—	—	1	—	—	—	—	—	—	—
Cumacea	—	—	3	1	5	2	1	—	8	1
Other Crustacea	1	1	3	—	—	1	2	—	—	—
Pleurobrachia pileus (Müller)	—	—	—	—	—	4	—	—	—	—
Hydromedusae	—	—	2	—	—	1	—	—	—	—
Aurelia aurita Lamarck	—	—	—	—	2	—	—	—	—	—
Cyanea capillata Esch.	—	—	—	—	—	—	—	—	—	—
Fish	1	—	1	6	—	2	1	—	—	—
Totals	50	258	881	1637	5845	6344	1937	768	10,936	1606

Table 5 lists species found in Loch Etive. The number of species of organisms per haul is usually greatest at stations 1-6, and especially at 5 and 6, less at stations 7-16 and least at stations 17-24.

Trellis Diagrams

One of the simplest diagrams for examining similarity between pairs and between groups of pairs of samples is the trellis diagram. This technique has been used most frequently in the marine field for studying samples of bottom faunal organisms.

different Stations in Loch Etive, November 1967

11	12	13	14	15	16	18	19	20	21	22	23	24	Totals
102	14	299	60	125	72	152	152	534	550	425	381	28	16,700
5430	384	46	388	3104	131	36	40	53	71	38	56	20	17,723
4115	526	109	38	2210	278	49	180	209	145	52	20	7	15,783
—	—	—	—	—	—	—	—	—	—	—	—	—	4
2	1	3	5	4	13	—	21	11	99	17	23	3	265
1	8	1	2	2	—	—	—	—	—	—	—	—	80
—	—	—	—	—	—	—	—	—	—	—	—	—	49
—	—	—	—	—	—	—	—	—	—	—	—	—	84
—	—	—	—	—	—	—	—	—	—	—	—	—	14
—	—	—	—	—	—	—	—	—	—	—	—	—	10
—	—	—	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	2
—	—	—	—	—	—	—	—	—	—	—	—	—	1
12	1	—	—	4	—	—	—	—	—	—	—	—	31
27	18	1	—	45	—	—	—	—	—	—	—	—	139
—	—	—	—	—	—	—	—	—	—	—	—	—	1
—	1	—	—	—	—	1	—	—	—	—	—	—	3
—	—	—	—	—	1	—	—	—	—	—	—	—	5
—	—	1	—	—	—	—	—	—	—	—	—	—	16
—	—	—	—	—	—	1	—	—	—	—	—	—	3
—	—	—	—	5	—	—	—	—	—	—	—	—	173
—	1	—	—	2	—	—	1	—	—	—	—	—	12
—	—	—	—	—	—	—	—	—	—	—	—	—	2
—	—	—	—	—	—	—	—	—	—	—	—	—	1
1	—	1	—	—	—	—	8	21	2	—	1	—	37
—	—	4	—	—	2	—	—	—	—	—	—	—	63
—	—	—	—	—	—	—	—	—	—	—	—	—	16
—	—	—	—	—	—	—	—	—	—	—	—	—	1
—	—	5	4	—	1	—	—	—	—	1	1	—	33
—	—	1	—	—	—	—	—	—	—	—	—	—	9
—	—	—	—	—	—	—	—	—	—	—	—	—	4
1	—	—	—	—	1	—	—	—	—	—	2	—	7
1	—	—	1	4	—	4	—	—	2	—	1	1	16
—	—	—	—	—	1	—	—	—	—	—	—	—	1
—	—	—	—	—	—	—	—	—	—	—	—	—	11
9692	954	471	498	5505	500	243	402	828	869	533	485	59	51,301

The data, however, entered in the diagrams varies considerably and are instanced by the following.

Quotients and Coefficients of Similarity

Jaccard (1902) used a Coefficient of Similarity defined as

$$CS = \frac{c}{a+b-c}$$

where *a* and *b* are the numbers of species in the respective samples and *c* is the number of species common to the two samples.

Sorensen (1948) used a Quotient of Similarity calculated from the formula:

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

where *c* is the number of species common to the two samples and *a* and *b* are the number of species in each of the two samples respectively.

Mountford (1962), however, has shown that both these indices are affected by sample size and has suggested calculation of an Index of Similarity which is relatively independent of sample size:

$$\text{Index}=\frac{2c}{2ab-(a+b)\,c}$$

This Index of Similarity has been calculated for the series of samples of hypoplankton taken in Loch Etive in November, 1967 (Table 1) and the results are shown in Fig. 2. The selection of levels of similarity are arbitrary. Vallentine (1966) used a trellis diagram of Coefficients of Similarity to study Pacific molluscs and Gage (1969) of Quotients of Similarity to compare samples of bottom fauna from Loch Etive; this method is more successful when samples contain large numbers of species and relatively few individuals of each species. Plankton samples, however, have relatively few species and usually two or three of them are very dominant in numbers of individuals. Use of the Index of Similarity can be misleading because two very similar samples consisting predominantly of the same dominant species but having minor species not common to the two samples show little similarity.

Dominance affinity

Renkonen (1938) calculates a Dominance Affinity for each pair of samples in a group. The numbers of individuals of each species in a sample is converted to percentage values and the lowest common percentages of species common to the two samples are summed giving a total minimum common percentage. This has been done for the hypoplankton samples from Loch Etive (Fig. 3). This technique has been applied by Saunders (1960), Wieser (1960) and Warwick and Buchanan (1970) to compare samples of marine bottom faunal organisms and by Whittaker and Fairbanks (1958) in studying the distribution and associations of freshwater planktonic copepods.

Three faunal assemblages are indicated (Fig. 3), one at stations 1-6, one at 7-16 and a third at 18-24. The assemblage in the lower loch is similar to that near the head of the loch. This technique does not take account of changes in total biomass per unit volume of water samples because the data are transformed to percentages.

Correlation Coefficient

Barnes (1952) has described the reasons why, in many instances, raw data from samples cannot be used when applying an analysis of variance. Consequently, in this analyses the counts of individuals of species were transformed to their logarithms and these used in the calculation of the coefficient of correlation between all pairs of samples. Zero values occurred in the hauls and the log transformation used for each number x was : $\log(x+1)$. The correlation coefficient was calculated

$$r = \frac{\Sigma(x-\bar{x})\ (y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2\ \Sigma(y-\bar{y})^2}}$$

This treatment has been applied to the Loch Etive samples for November, 1967, the correlation coefficients multiplied by 100 being shown in Fig. 4.

The same three assemblages, namely at stations 1-6, 7-16 and 18-24 emerge with the assemblage in the lower loch similar to that near the head of the loch.

This technique is most suitable for a strictly quantitative series of samples.

	24	23	22	21	20	19	18	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
24																							
23	67																						
22	80	67																					
23	200	100	50																				
20	200	67	80	200																			
19	80	38	50	83	200																		
18	50	20	22	33	22	17																	
16	50	29	50	17	24	17	10																
15	24	14	20	25	20	25	14	8															
14	100	54	100	53	36	25	25	22	32														
13	17	19	33	19	33	21	7	10	13	26													
12	24	11	24	17	24	30	17	9	57	22	15												
11	40	41	20	50	40	25	14	12	40	32	19	30											
10	15	17	29	19	29	19	7	13	25	22	59	17	25										
9	15	17	29	19	29	33	7	13	43	22	32	33	25	92									
8	29	15	15	20	29	20	11	11	14	9	12	11	14	27	27								
7	15	11	29	11	15	11	11	13	11	22	20	9	8	17	17	11							
6	6	7	13	6	8	9	4	8	9	10	10	8	7	9	11	5	16						
5	13	8	13	9	8	9	9	9	20	15	11	18	10	17	17	8	9	11					
4	11	7	18	8	11	8	4	12	7	14	12	6	5	14	10	7	19	8	12				
3	8	6	8	4	5	4	2	9	4	7	8	3	4	7	5	3	13	8	8	21			
2	8	4	8	6	8	6	3	5	7	8	12	5	5	10	7	6	14	10	8	23	19		
1	13	6	13	10	13	10	5	6	5	8	7	6	5	4	13	4	13	12	6	12	18	18	

FIG. 2. Analysis of hypoplankton hauls at Stations 1-24 in Loch Etive, November, 1967. Index of similarity from Mountford (1962).

TABLE 2. *Number of Individuals per haul at Different Stations in Loch Etive, March* 1968

Species	Stations 5	6	7	8	9	10	11	12	17	18	19	21	23	24	Totals
Sagitta elegans Verrill	3	27	232	167	49	545	88	682	866	114	1234	460	551	588	5606
Spadella cephaloptera (Busch)	1	—	—	—	1	—	—	—	—	—	—	—	—	—	2
Calanus finmarchicus (Gunn)	15	48	834	867	286	2593	277	1512	315	6817	1121	427	324	158	15,594
Pareuchaeta norvegica (Boeck)	—	3	2034	837	1136	1846	474	2468	94	102	150	43	42	26	9255
Schistomysis ornata (G. O. Sars)	2	2	2	4	1	1	—	—	—	—	—	—	1	—	13
Erythrops serrata (G. O. Sars)	—	—	1	8	2	3	1	—	—	—	—	—	—	—	15
Leptomysis gracilis (G. O. Sars)	—	—	—	2	—	—	—	—	—	—	—	—	—	—	2
Anchialina agilis (G. O. Sars)	3	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Pseudomma affine G. O. Sars	4	—	—	—	—	—	—	—	—	—	—	—	—	—	4
Meganyctiphanes norvegica (M. Sars)	—	—	2	10	1	12	11	12	1	—	—	—	—	—	49
Thysanoessa raschii (M. Sars)	—	1	16	85	6	237	6	59	21	—	—	—	—	1	432
Eualus gaimardi (H. Milne-Edwards)	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
Dichelopandalus bonnieri (Caullery)	—	—	—	—	—	—	—	5	—	—	—	—	—	—	5
Pandalus montagui Leach	—	—	1	1	2	—	—	—	—	—	—	—	—	—	4
Crangon allmani Kinahan	20	12	5	2	5	—	9	13	1	—	—	—	—	—	67
Pontophilus spinosus (Leach)	—	—	2	—	—	1	—	—	—	—	—	—	—	—	3
Decapod larvae	8	10	3	—	—	—	—	—	—	—	1	1	2	4	29
Amphipods	4	2	1	—	—	—	1	—	—	—	1	—	1	—	10
Isopods	1	2	—	—	—	—	—	—	—	—	—	—	4	3	10
Cumacea	3	—	—	—	—	—	—	—	—	—	—	—	—	—	3
Other Crustacea	—	—	—	—	—	—	—	—	—	—	—	—	22	3	25
Fish eggs	3	—	—	—	—	—	—	—	—	6	33	27	—	24	93
Fish	3	1	1	1	—	—	1	—	—	—	1	—	1	—	9
Totals	70	108	3134	1984	1489	5238	868	4751	1298	7039	2541	958	949	807	31,234

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TABLE 3. *Number of Individuals per haul at different Stations in Loch Etive May 1968*

Species	Stations 3	5	6	7	9	11	12	15	17	19	20	21	23	Totals
Sagitta elegans Verrill	77	953	3180	343	57	192	155	226	583	1882	1027	745	745	10,148
Calanus finmarchicus (Gunn)	74	2194	8181	11,341	2410	6282	4452	2353	2041	512	1216	243	110	41,409
Pareuchaeta norvegica (Boeck)	4	15	72	804	1051	5697	2088	2254	1176	498	228	149	97	14,133
Schistomysis ornata (G. O. Sars)	—	2	—	—	—	—	—	—	—	—	—	1	—	3
Erythrops serrata (G. O. Sars)	—	3	—	3	3	—	3	4	1	—	—	—	—	17
Pseudomma affine G. O. Sars)	—	1	—	—	—	—	—	—	—	—	—	—	—	1
Meganyctiphanes norvegica (M. Sars)	—	—	—	—	—	4	—	—	—	—	—	—	—	4
Thysanoessa raschii (M. Sars)	—	1	12	2	2	1	1	—	—	—	—	5	—	24
Dichelopandalus bonnieri (Caullery)	—	—	—	5	—	2	15	7	1	—	—	—	—	30
Pandalus montagui Leach	—	1	—	1	1	—	—	—	—	—	—	—	—	3
Pandalus propinquus G. O. Sars)	—	—	—	1	—		—	—	—	—	—	—	—	1
Crangon allmani Kinahan	—	2	1	22	4	11	5	10	1	—	—	—	—	56
Pontophilus spinosus (Leach)	—	—	—	—	—	—	3	2	2	—	—	—	—	7
Decapod larvae	39	125	45	38	12	21	32	38	88	94	310	278	546	1666
Amphipods	—	24	—	3	—	1	—	—	—	—	—	3	—	31
Isopods	—	5	—	—	—	1	—	—	—	—	—	—	—	6
Cumacea	—	1	—	1	—	1	—	—	—	—	1	—	—	4
Other Crustacea	—	—	—	—	—	—	—	—	—	1	—	—	—	1
Hydromedusae	—	8	—	1	—	4	1	—	3	8	—	10	31	66
Aurelia aurita Lamarck	25	—	—	7	—	—	2	—	2	—	—	—	—	36
Fish eggs	—	14	—	14	5	39	9	—	95	42	73	25	31	347
Fish	5	2	1	2	—	1	2	—	—	1	4	3	2	23
Totals	224	3351	11,492	12,588	3545	12,257	6768	4894	3993	3038	2859	1462	1545	68,016

Table 4. *Number of Individuals per haul at Station 6, Loch Etive*

Species	1967 Nov.	1968 March	1968 May	August, 1968 I	II	III	IV	October, 1968 I	II	Total
Sagitta elegans Verrill	5524	27	3180	435	776	1165	741	2020	3168	17,036
Calanus finmarchicus (Gunn)	413	48	8181	559	366	551	725	435	282	11,560
Pareuchaeta norvegica (Boeck)	238	3	72	11	5	4	2	55	21	411
Schistomysis ornata (G. O. Sars)	24	2	—	—	—	—	—	37	55	118
Erythrops serrata (G. O. Sars)	26	—	—	—	1	—	—	1	1	29
Leptomysis gracilis (G. O. Sars)	13	—	—	—	—	—	—	119	121	253
Mysidopsis didelphys Norman	4	—	—	—	—	—	—	—	—	4
Anchialina agilis (G. O. Sars)	—	—	—	—	—	—	—	16	40	56
Pseudomma affine G. O. Sars	3	—	—	—	—	—	—	2	—	5
Hemimysis lamornae (Couch)	—	—	—	—	—	—	—	2	—	2
Siriella clausi G. O. Sars	1	—	—	—	—	—	—	—	—	1
Siriella jaltensis Czerniavsky	—	—	—	—	—	—	—	8	—	8
Siriella norvegica G. O. Sars	—	—	—	—	—	—	—	—	7	7
Praunus inermis (Rathke)	—	—	—	—	—	—	—	15	8	23
Meganyctiphanes norvegica (M. Sars)	—	—	—	—	1	—	—	45	30	76
Thysanoessa raschii (M. Sars)	9	1	12	33	47	6	4	35	15	162
Hippolyte varians Leach	—	—	—	—	—	—	—	1	—	1
Eualus gaimardi (H. Milne-Edwards)	—	—	—	1	—	—	—	—	—	1
Pandalus montagui Leach	—	—	1	21	3	—	—	—	—	25
Crangon allmani Kinahan	67	12	1	—	—	—	—	8	3	91
Pontophilus spinosus (Leach)	1	—	—	—	—	—	—	—	—	1
Philocheras bispinosus bispinosus (Hailstone & Westwood)	2	—	—	—	—	—	—	—	1	3
Nephrops norvegicus (L.)	1	—	—	—	—	—	—	—	—	1
Calocaris macandreae Bell	—	—	—	7	12	10	6	21	18	74
Decapod larvae	—	10	45	53	104	238	120	356	322	1248
Amphipods	7	2	—	1	1	—	2	8	10	31
Other Crustacea	4	1	—	—	9	16	2	5	8	45
Pleurobrachia pileus (Müller)	4	—	—	—	—	—	—	—	—	4
Hydromedusae	1	—	—	1	1	—	3	—	—	6
Aurelia aurita Lamarck	—	—	—	8	6	13	8	—	—	35
Fish (mostly young)	3	2	1	1	1	3	1	3	7	22
Fish eggs	—	—	—	—	—	—	3	1	—	4
Totals	6345	108	11,493	1131	1333	2006	1617	3193	4117	31,343

Calculation of C_λ

Morisita (1959) calculates an index of diversity which he calls C_λ. Use is made of the raw data and he first calculates Simpson's (1949) measure of diversity, λ for each sample:

$$\lambda = \frac{\Sigma n\ (n-1)}{N(N-1)}$$

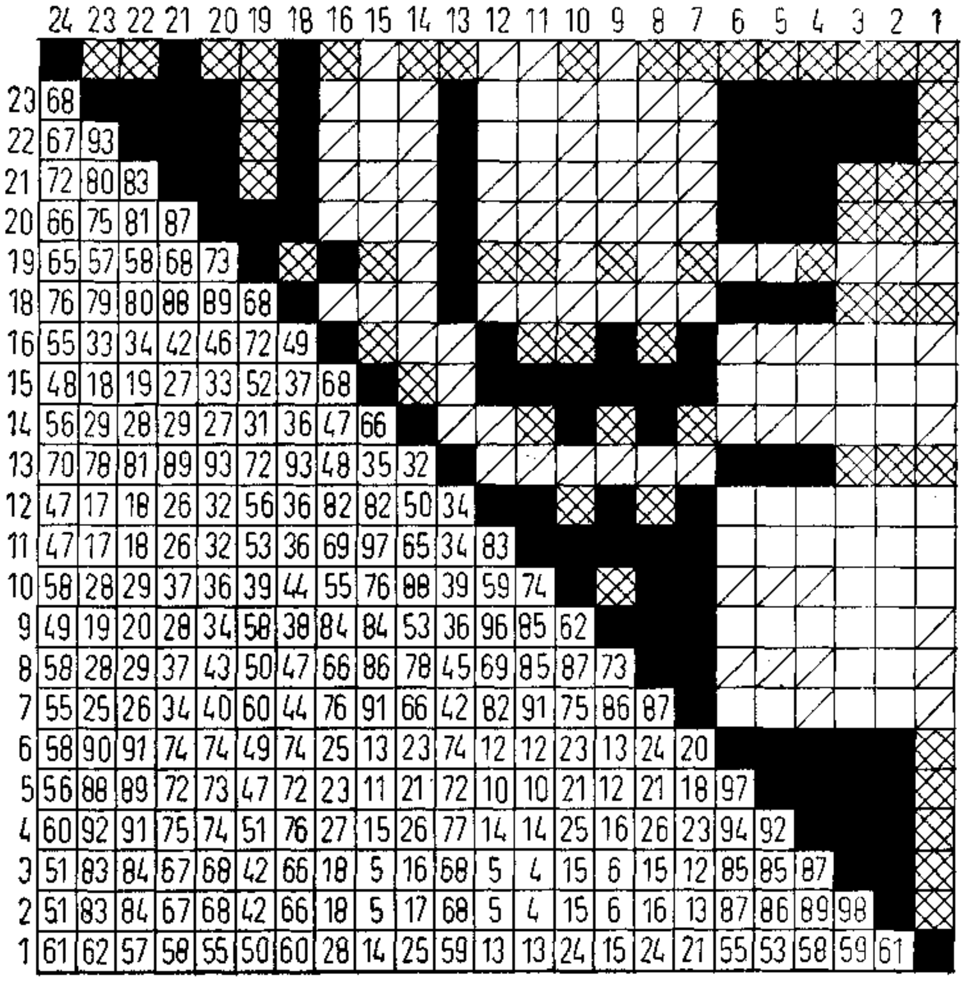
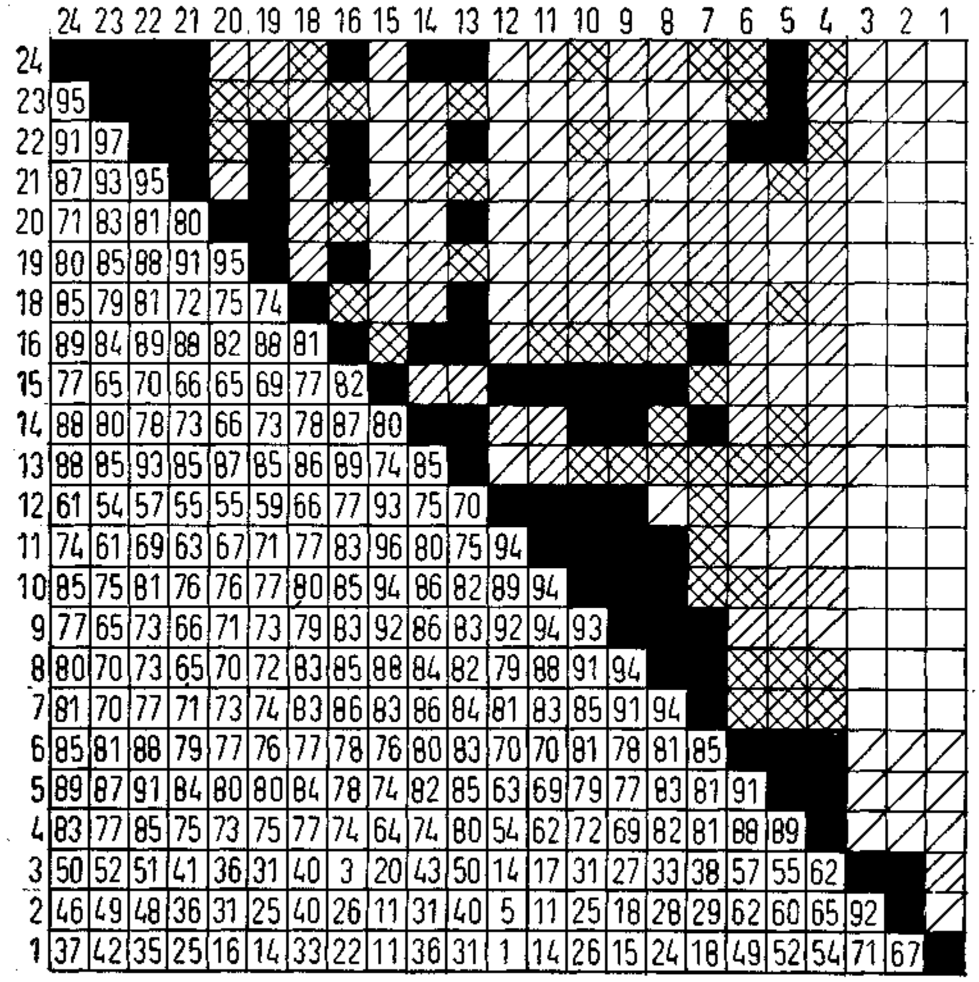


FIG. 3. Analysis of hypoplankton hauls at Stations 1-24 in Loch Etive, November, 1967. Dominance Affinity from Renkonen (1938).

where n is the number of individuals of a species and N the total numbers of individuals of all species in the sample then C_λ is calculated as :

$$C_\lambda = \frac{2\Sigma n_1 n_2}{(\lambda_1 + \lambda_2) N_1 N_2}$$

where n_1 and n_2 are the respective numbers of individuals of the same species in the two samples, λ_1 and λ_2 are the λ values for the two respective samples, and N_1 and N_2 are the respective total numbers of individuals of all species in the two samples. The C_λ values for all pairs of samples of Loch Etive hypoplankton sampled



	24	23	22	21	20	19	18	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
24																							
23	95																						
22	91	97																					
21	87	93	95																				
20	71	83	81	80																			
19	80	85	88	91	95																		
18	85	79	81	72	75	74																	
16	89	84	89	88	82	88	81																
15	77	65	70	66	65	69	77	82															
14	88	80	78	73	66	73	78	87	80														
13	88	85	93	85	87	85	86	89	74	85													
12	61	54	57	55	55	59	66	77	93	75	70												
11	74	61	69	63	67	71	77	83	96	80	75	94											
10	85	75	81	76	76	77	80	85	94	86	82	89	94										
9	77	65	73	66	71	73	79	83	92	86	83	92	94	93									
8	80	70	73	65	70	72	83	85	88	84	82	79	88	91	94								
7	81	70	77	71	73	74	83	86	83	86	84	81	83	85	91	94							
6	85	81	88	79	77	76	77	78	76	80	83	70	70	81	78	81	85						
5	89	87	91	84	80	80	84	78	74	82	85	63	69	79	77	83	81	91					
4	83	77	85	75	73	75	77	74	64	74	80	54	62	72	69	82	81	88	89				
3	50	52	51	41	36	31	40	3	20	43	50	14	17	31	27	33	38	57	55	62			
2	46	49	48	36	31	25	40	26	11	31	40	5	11	25	18	28	29	62	60	65	92		
1	37	42	35	25	16	14	33	22	11	36	31	1	14	26	15	24	18	49	52	54	71	67	

FIG. 4. Analysis of hypoplankton hauls at Stations 1-24 in Loch Etive, November, 1967. Correlation Coefficient of log (x + 1) transformed raw data.

in November 1967 are shown in Fig. 5; the index of diversity, λ, for each sample is given at the bottom of the diagram.

The distribution of C_λ values is closely similar to the Dominance Affinity distributions (Fig. 3). Morisita (1959) compared the working of the C_λ formula to those of Jaccard (1902), Sorensen (1948), Odum (1950) and Whittaker (1952) and found the C_λ to be a more valuable measure of similarity between samples. Ono (1961) used the C_λ measure to compare samples of brachyuran crustaceans.

Non-parametric methods

Various non-parametric methods are applicable to this problem and are detailed in Siegel (1956). More recently, Fager (1968) has reviewed various of these ranking

	24	23	22	21	20	19	18	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
24																							
23	86																						
22	83	99																					
21	88	96	97																				
20	86	94	96	98																			
19	77	67	70	82	87																		
18	93	95	95	94	99	85																	
16	60	32	36	49	57	88	56																
15	60	18	9	28	32	59	38	85															
14	68	30	25	29	26	32	38	52	85														
13	89	95	96	98	100	86	100	57	34	31													
12	51	15	17	29	37	71	39	96	95	65	38												
11	58	16	16	26	31	59	37	86	100	84	33	96											
10	72	31	28	34	33	44	44	65	92	49	38	76	45										
9	53	16	18	31	38	71	40	96	95	67	39	100	96	78									
8	74	33	31	39	41	58	50	78	97	93	45	43	96	98	88								
7	68	28	28	39	43	69	49	91	99	81	46	96	91	90	96	97							
6	79	99	99	93	92	63	92	28	12	23	92	10	10	24	11	26	22						
5	77	99	99	92	91	62	91	27	9	21	91	8	8	22	9	24	20	100					
4	82	100	100	94	93	65	94	30	15	26	80	12	13	28	13	29	25	100	100				
3	78	99	99	93	92	61	92	24	6	19	92	8	5	20	6	22	17	99	99	99			
2	78	99	99	93	92	61	92	23	5	18	92	4	4	20	5	21	16	99	99	99	100		
1	88	87	85	88	85	63	88	30	21	34	87	15	19	36	16	37	30	83	81	85	87	86	
λ	·35	·63	·65	·45	·48	·36	·45	·40	·48	·63	·47	·47	·49	·51	·48	·43	·41	·76	·81	·69	·66	·67	·27

FIG. 5. Analyses of hypoplankton hauls at Stations 1-24 in Loch Etive, November, 1967. C_λ computation of Morisita (1959).

methods. These techniques are most useful when a series of samples are not quantitative or, indeed, when no detailed counts of the organisms in quantitative samples are made but only rankings of species determined.

Discussion

The calculation of Dominance Affinity or the $C\lambda$ of Morisita seem to give results which correspond with a visual inspection of the samples. Consequently, these methods were both applied to samples of hypoplankton taken in Loch Etive in

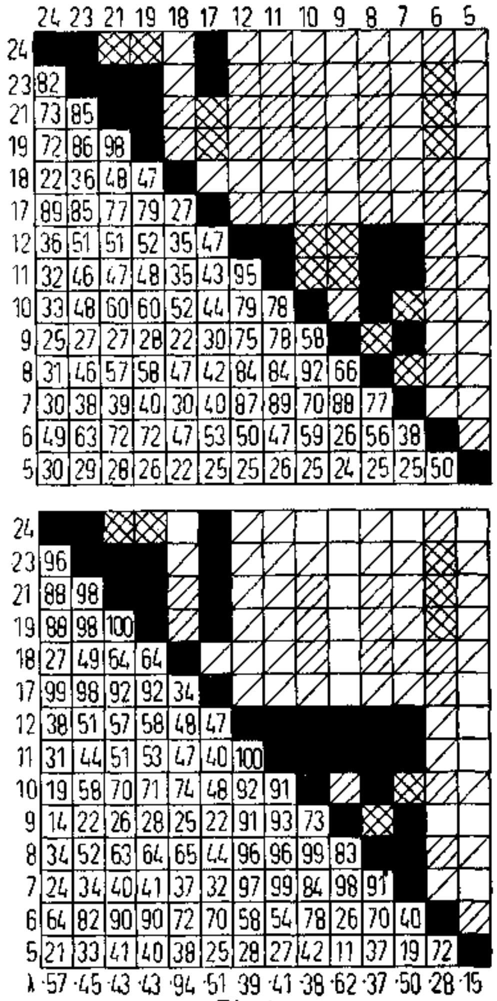


Fig.6

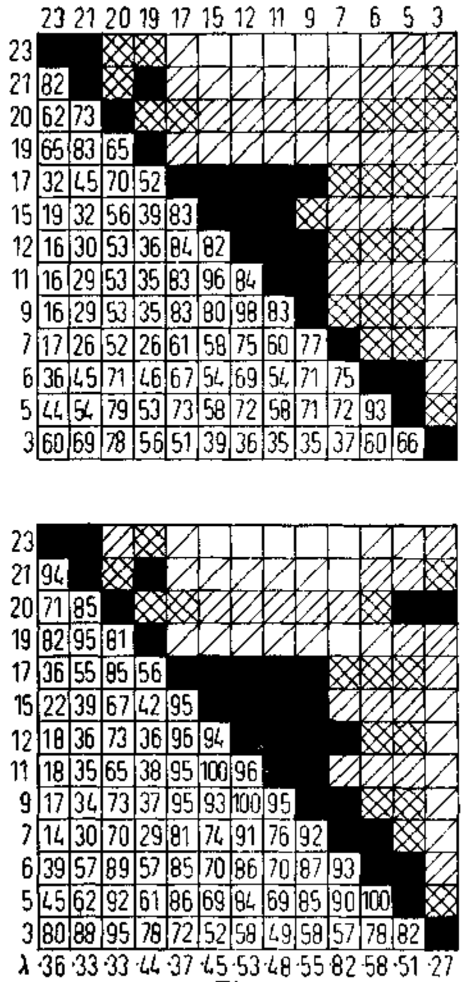


Fig 7

Fig. 6. Analyses of hypoplankton hauls at Stations in Loch Etive, March, 1968. Upper figure: Dominance Affinity of Renkonen (1938); Lower figure: $C\lambda$ of Morisita (1959).

Fig. 7. Analyses of hypoplankton hauls at Stations in Loch Etive, May, 1968. Upper figure: Dominance Affinity of Renkonen (1938); Lower figure: $C\lambda$ of Morisita (1959).

March, and May, 1968 and to a series of samples taken at different times at station 6 (Figs. 6-8). In both March and May (Figs. 6, 7) the three faunal assemblages are suggested by these analyses, the one at stations 3-6 showing similarity to that at the head of the loch. Samples taken on the same day at Station 6 are closely similar (Fig. 8) but differences are evident between samples taken in different months.

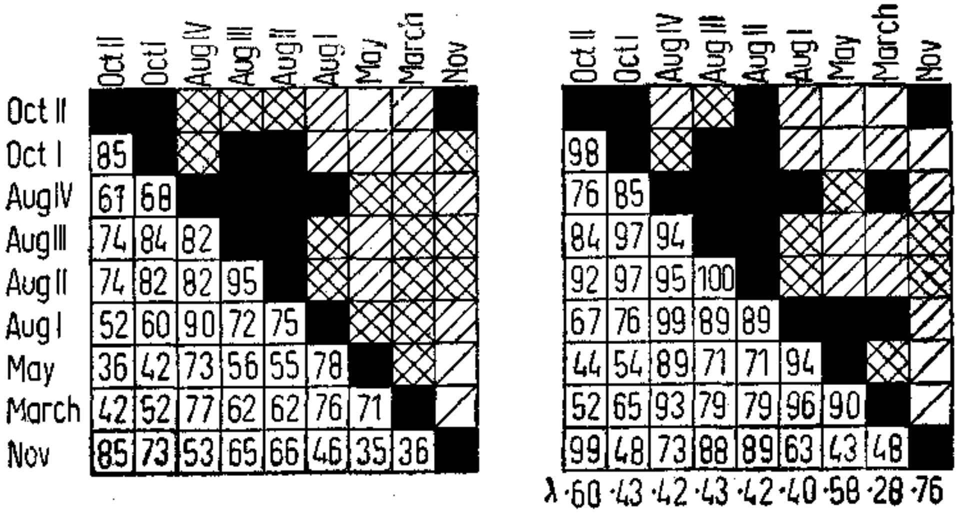


FIG. 8. Analyses of hypoplankton hauls at Station 6 in Loch Etive on different dates. Left figure: Dominance Affinity of Renkonen (1938); Right figure: C_λ of Morisita (1959).

TABLE 5. *Species recorded throughout the loch (Stations 1-24), in both the lower loch and the deep basin of the upper loch (Stations 1-16), and in the lower loch only (Stations 1-6) during the period November 1967 to December 1969*

Stations 1-24	Stations 1-16	Stations 1-6
Sagitta elegans	*Spadella cephaloptera*	*Gastrosaccus normani*
Calanus finmarchicus	*Pleurobrachia pileus*	*Hemimysis lamornae*
Pareuchaeta norvegica	*Mysidopsis didelphys*	*Siriella clausii*
Aurelia aurita	*Anchialina agilis*	*Siriella jaltensis*
Schistomysis ornata	*Pseudomma affine*	*Nyctiphanes couchii*
Erythrops serrata	*Siriella norvegica*	*Eualus gaimardi**
Leptomysis gracilis	*Praunus inermis*	*Eualus pusiolus*
Praunus flexuosus	*Praunus neglectus*	
Meganyctiphanes norvegica	*Hippolyte varians*	
Thysanoessa raschii	*Pandalina brevirostris*	
Dichelopandalus bonnieri	*Pandalus montagui*	
Pandalus propinquus	*Philocheras bispinosus bispinosus*	
Crangon allmani		
Pontophilus spinosus		
Calocaris macandreae		
Nephrops norvegicus		

*also been recorded at Station 23, March 1968.

The method of analyses of samples depends on the purpose of the analyses. The Dominance Affinity and C_λ treatments are suitable for preliminary grouping within a large series of samples and do not require sophisticated calculating machines to carry out. The calculation of correlation coefficients on log-transformed data is more complex and where the series of samples to be analysed is large, the task is much easier if a programmed calculator is available. This analyses is worth while when the samples are quantitative and higher degrees of distinction can be attributed to different coefficients.

The Index of Similarity is most useful when the numbers of species occurring in samples is large and the numbers of individuals of each species small.

The population of hypoplankton in Loch Etive is remarkable. The biomass is much greater than has been found in other Scottish lochs. Upper Loch Fyne, Firth of Clyde, has a dense population of *Pareuchaeta norvegica, Calanus finmarchicus* and *Sagitta elegans* but the volume of plankton caught per unit of distance through which the net is towed is greater in Upper Loch Etive. The prevailing salinity in the deep water at stations 8-15 is normally about 27‰. Euphausiids do not occur in areas of salinity less than about 28‰ (Mauchline and Fisher, 1969) but here in Loch Etive they are living in salinities as low as 26.6‰. Consequently, although Loch Etive is almost land-locked it has a hypoplankton fauna representative of more open situations and no indication of anaerobic conditions developing in the deep water has so far been found.

The hypoplankton at the head of the loch is similar to that in the loch south of Bonawe except that many of the rarer species south of Bonawe do not occur near the head. The depths south of Bonawe are similar to those near the head of the loch, about 60-80 m, whereas in the central part of the loch greater depths, 120-140 m, are found and here the euphausiids and *Pareuchaeta norvegica* are commoner.

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