AN ABSTRACT OF THE THESIS OF

Andrew G. Wones for the degree of Master of Science in General Science presented on May 24, 1988.

Title: Benthic Macroinvertebrates and Sediment Characteristics of a Coastal Dune-Margin Lake (Carter Lake, Douglas County, Oregon)

Redacted for Privacy

Abstract approved: ______________________________

Gary L. Larson

Carter Lake, a freshwater, coastal dune-margin lake, was sampled at the beginning and end of the summer of 1986 to determine the sediment characteristics and benthic macroinvertebrate abundance, biomass, variety, and diversity. The distributions of major benthic habitats were estimated by snorkeling in June and July, 1986. Water temperature and dissolved oxygen were measured throughout the summer of 1986. In July 1987, water temperature, dissolved oxygen, conductivity, alkalinity and pH were determined.

Thermal stratification was not observed during this study and the water column warmed gradually between April and July. Dissolved oxygen remained close to 100% saturation throughout the study. The water level of Carter Lake dropped about 2.5 m between May and October, reducing its surface area by about 40%.

The benthic habitats of Carter Lake were stratified

into four major zones: a sandy temporarily submerged littoral zone; a sandy but permanently submerged littoral zone; a mid-depth zone where a macrophyte, Nitella, grew; and a deep zone with soft mud substrate.

The average density of benthic macroinvertebrates was highest in the shallow permanently submerged zone (>16000 / m^2 in May and October) and lowest in the deep mud zone (2900 / m^2 in May and 4700 / m^2 in October). In May, benthic macroinvertebrate biomass was highest in the shallow zones (1.3 - 2.9 g / m^2 dry weight); in October biomass was highest in the mid-depth zone (4.4 g / m^2 dry weight, excluding crayfish and mussels).

Fifty-three invertebrate taxa were identified from Carter Lake, including three euryhaline crustacean species (Corophium spinicorne, Gnorimosphaeroma oregonensis lutea, and Acanthomysis awatchensis). Corophium spinicorne dominated the macroinvertebrate communities of the shallow areas and sphaeriid clams dominated the deep water community. The mid-depth zone had the most diverse community.

Two species that were abundant in the temporarily submerged area, Corophium spinicorne and Juga plicifera, were found in greater numbers deeper in the lake after the water level dropped, indicating that these species migrate in response to changing water level.

Benthic Macroinvertebrates and Sediment Characteristics of a Coastal Dune Margin Lake (Carter Lake, Douglas County, Oregon)

by

Andrew G. Wones

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Analysis of July 1987 water samples was done by the Cooperative Chemical Analytical Laboratory. Don Pool provided the sharp lines on Figure 1. Dr. Frank Adams allowed me to use his muffle furnace, and Mary Jo Wevers deserves special thanks for taking the time to examine my chironomid slides.

A reading and conference with Keith King entitled "equipment scrounging" should probably be listed on my program for all of the odds and ends he helped me locate in the General Science Department.

I thank my major professor, Gary Larson for his help and concern throughout this effort, and for enabling me to pursue this project in the first place. I would like to thank the members of my committee; Norm Anderson for numerous suggestions and the use of his sampling equipment, Jack Lyford and Frank Dost for their time and sound advice.

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BENTHIC MACROINVERTEBRATES AND SEDIMENT CHARACTERISTICS OF A COASTAL DUNE MARGIN LAKE (CARTER LAKE, DOUGLAS COUNTY, OREGON)

INTRODUCTION

Benthic macroinvertebrates are important in the trophic dynamics of lakes in that they consume detritus, algae, macrophytes, and other invertebrates, and are prey for fish and other predators. The species composition of the benthos is affected by characteristics of the sediment (Moore 1979, 1980, 1981; Meadows 1964a,b,c; Saether 1970; Maitland 1979), dissolved oxygen in the water (Moore 1981), fluctuations in water level (Hunt and Jones 1972; Hynes 1961;), and biotic interactions (Thorp 1986; Post and Cucin 1984; Brinkhurst 1974).

Most studies of coastal lakes in Oregon have been conducted for fisheries management or general water quality assessment. These studies have been done by the Oregon Agricultural Experiment Station (Griffiths and Yeoman 1938), the Oregon Fish Commission (Anonymous 1961, 1962; Kruse and Oakley 1961; McGie and Brueser 1962; Oakley 1962a,b,c,d,e; Skeesick 1970), the Oregon Game Commission (Saltzman 1961a,b,c, 1962), the Oregon Department of Environmental Quality (Larson 1974; McHugh 1972), the United States Geological Survey (Rinella 1979; Sanderson et al 1973) and by Oregon State University (Larson 1975a,b). However, most of the information collected on the benthos lacks detailed information on the methods of collection. As a result, these studies are of little value for comparing the benthic communities among these lakes or identifying temporal changes in these communities. So, although studies of various aspects of Oregon dune lakes have been conducted, the need for baseline studies of the benthos of Oregon coastal dune lakes still exists.

Objectives

The objectives of this study were to:

1. identify and determine the spatial distributions of predominant benthic habitats of Carter Lake,
2. describe the substrate, aquatic vegetation, and water characteristics of these habitats, and
3. compare the abundance, biomass, and diversity of the benthic macroinvertebrate (BMI) organisms in each habitat at the beginning and end of one summer season, 1986.

Study Area

About 45% of the Oregon coast bears sand dunes (Cooper 1958). The sand of dune areas is generally not stationary, but moving and altering the morphology of these areas (Cooper 1958; Fox et al 1978; Hunter et al 1983).

Numerous freshwater lakes are found within the sand dune areas of Oregon. Most, if not all, of these lakes owe their existence to the movement of sand. Deflation areas, where sand has been removed by wind down to the water table in summer, can become lakes with increased precipitation in winter (Bird 1984). Other lakes have formed when streams have been blocked by sand dunes, e.g. Cleawox Lake and Siltcoos Lake (Cooper 1958). A third process of lake formation occurs when a sand dune moves up against a hillside and water collects in the depression formed, e.g. Threemile Lake and Carter Lake (Cooper 1958).

Carter Lake is located between Florence and Reedsport, within the Oregon Dunes National Recreation Area (ODNRA). The lake is 1 km from the ocean and about 20 m above sea level.

Carter Lake has a maximum length of about 1.8 km and a maximum width of about 170 m (Fig. 1). Due to seasonal fluctuations of 2-3 m in the lake level, the size of the lake decreases considerably during the summer. Temporary streams feed the lake at the north end, the south end, and on the east side near the north end (Fig. 1). There is no surface outlet.

Dunes on the west side of Carter Lake rise to 49 m above sea level and are mostly covered by spruce (Picea sitchensis) and pine (Pinus contorta) trees, with some beach grass (Ammophila arenaria). Small areas of bare sand on the dunes do not appear to contribute appreciable quantities of sand into the lake basin at this time. Close to shore Salix and Spirea douglasii grew on both sides of the lake. The area east of the lake was covered with Picea sitchensis and Pinus contorta, except for one area about 15 m wide where scotch broom (Cytisus scoparius) extended

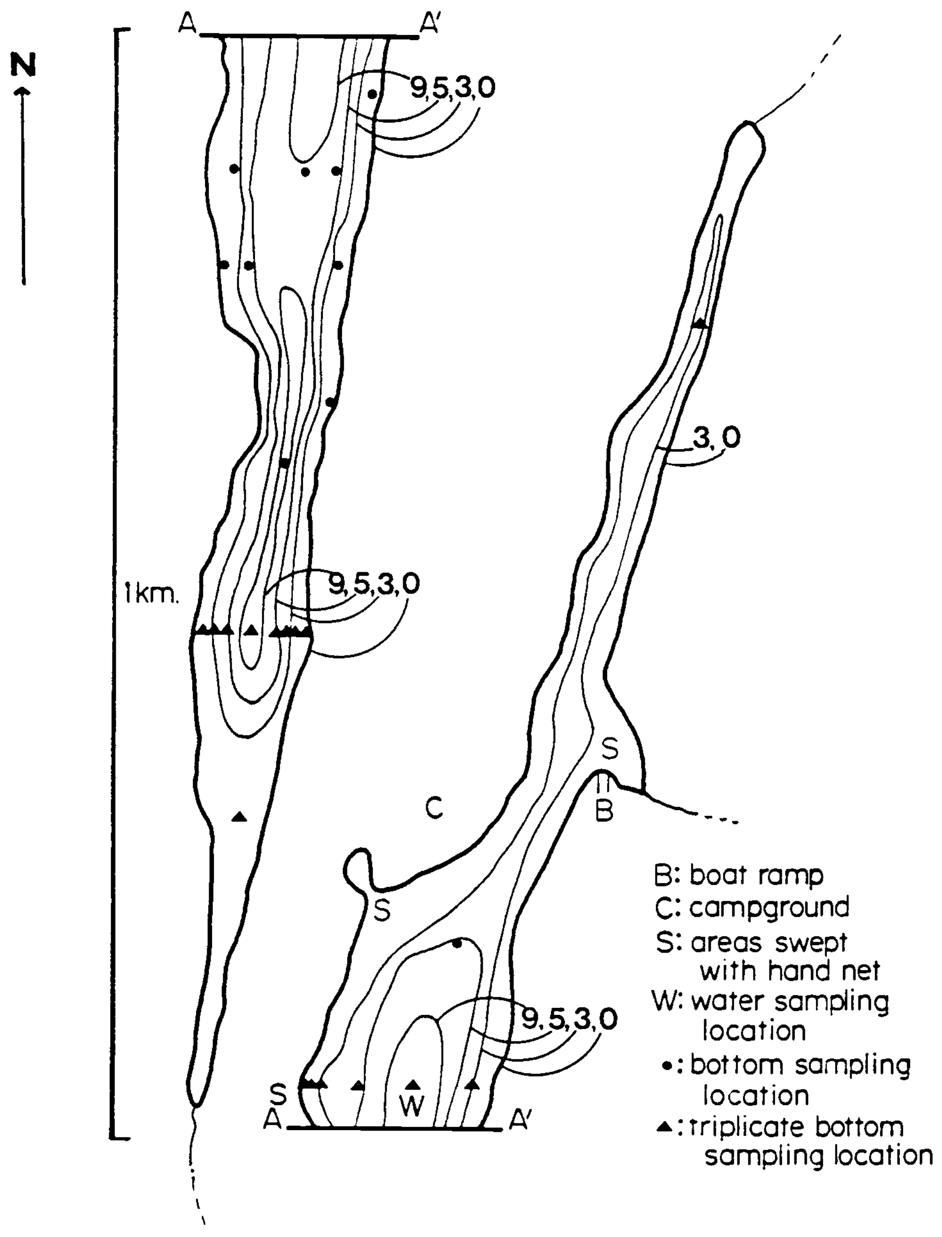

Figure 1. Bathymetric map of Carter Lake, Douglas County, Oregon. Depth contours labeled in meters below maximum lake level.

up the hillside from shore. Sedges (_Carex obnupta_) and mint (_Mentha spicata_) grew up along the margins of the lake in a few areas during winter while the lake level was low.

METHODS

Sampling Plan

Data collection times are summarized in Table 1. The sediment and benthos of Carter Lake were sampled in early May and Early October of 1986. These times were chosen in order to observe seasonal changes. Samples were taken from an 8-foot aluminum John-boat.

Bottom samples for benthic macroinvertebrates (BMI) were taken in triplicate along two line transects and singly at other locations (fig. 1). The augmented line transect sampling strategy was used in order to maximize sampling efficiency (Timms, 1985). Bottom samples were taken at 1, 2, 3, 5, and 9 m depths in May and at 0.5, 2.5, and 6.5 m in October. The difference in sampling depths between May and October correspond to the drop in water level of about 2.5 m. Sampling depths were selected on the basis of visual observations which indicated they would show differences in sediment characteristics, presence of the plant Nitella, and permanence of submergence. A total of 58 bottom samples were taken in May and 32 in October.

Temperature and dissolved oxygen were measured at 1 m intervals over the deepest area on the north transect (fig. 1) in April, May, June, and October, 1986. Secchi disk depth was also measured at this location in May, June and October. On July 12, 1986, only temperature was measured. In addition, temperature, conductivity, alkalinity, pH, and dissolved oxygen were determined on

July 30, 1987.

Table 1. Dates of data collection from Carter Lake, Douglas County, Oregon.

data collected	2/2/86	4/27/86	5/9-11/86	5/16-18/86	6/21-22/86	7/12/86	9/27/86	9/30-10/2/86	7/30/87
	collection dates								
u. obs.	+				+				
depth		+							
benthic			+	+				+	
litt. inv.				+			+		
temp.		+	+		+	+		+	+
d.o.		+	+		+			+	+
Zsd			+		+			+	
pH									+
alk.									+
cond.									+

u. obs. = underwater observations
depth = depth soundings for bathymetry
benthic = benthic samples
litt. inv. = littoral invertebrates
temp. = temperature profile
d.o. = dissolved oxygen
Zsd = Secchi disk depth
alk = alkalinity
cond. = conductivity

Limnological Profile

The bathymetry of the lake was determined by sounding with a weighted polypropylene line marked in 1 m intervals. Depth soundings were taken along seven east to west transects.

Temperature, conductivity, and salinity were measured with a Beckman portable salinometer (model RS 5-3) in 1986. However, conductivity and salinity were below the reliable limit of detection (500 μmhos/cm) of the meter used. In 1987, conductivity, alkalinity, and pH were analyzed by the Cooperative Chemical Analytical Laboratory (CCAL) at Oregon State University on the same day the water samples were taken.

Water samples for dissolved oxygen were taken in triplicate with a VanDorn water sampler. The Winkler titration method was used (Standard Methods, 1965), and all samples were titrated with standard 0.0250 N PAO solution.

Secchi disk depth was measured between 12:00 PM and 2:00 PM from the shady side of the boat with a 25 cm black and white Secchi disk.

Visual Description of Lake Bottom

The first underwater observations were made while snorkeling on February 2, 1986. At that time, a limited area was surveyed on the east and west sides of the lake about 200 m south of the boat ramp. In mid-June, many sections of the lake were examined, and notes were taken on the presence of *Nitella*, *Corophium* tubes, and the type of sediment. A capillary depth gauge was used to determine the vertical distribution of habitat zones.

Area of Habitat Zones

A photocopied bathymetric map of Carter Lake was cut into sections corresponding to habitat zones and weighed on a Mettler balance (model H16). The proportion of the total mass of the lake map comprised by each section was assumed to be equal to the proportion of the area of that section to the total lake area (Cole 1979), which was taken to be 14.985 ha (Oregon SWRB 1973).

Bottom Samples

All bottom samples were taken with a Birge-Ekman grab sampler (225 cm^2 gape). Each sample was emptied into a plastic tub and mixed to achieve homogeneity. Approximately 75 ml of each sample was used for sediment characteristics analysis. These sub-samples were placed in plastic jars or ziplock bags and kept cool until they could be frozen for storage, always within 16 hours of collection. The remainder of each sample was washed in the tub with lake water. Organisms and other low density materials were strained onto a 0.25 mm screen and preserved in 70% ethanol. In some cases, 90% ethanol was added to samples with large amounts of detritus to bring the final ethanol concentration to about 70% .

Sampling of Submerged Marginal Vegetation

In May, some marginal areas in the lake were heavily vegetated with sedges that had grown up while the lake level was low and then were flooded in the spring. Two of these areas were sampled with an aquatic D-net. Selected specimens of each taxa collected were preserved in 70%

ethanol for later identification. In October, one shallow area of submergent vegetation near the boat ramp was sampled in the same manner.

Sediment Characteristics

Sediment samples were analyzed for particle-size composition and organic content. The proportion of a sample lost on ignition (LOI) at 550° C was used as an index of organic content. Each sample was thawed and mixed into a homogeneous slurry. Approximately equal portions (about 30 ml) of the slurry were poured into two pre-ashed, pre-weighed aluminum pans and weighed. The sediment from one pan was placed in a drying oven and the other was washed through a series of sieves (1 mm, 0.5 mm, 0.25 mm, and .125 mm). Sediment was sieved wet in order to prevent clumping or breaking of particles. Sediment material caught on each of the sieves was placed in a separate, pre-ashed, pre-weighed pan and dried simultaneously with the whole sediment sample at 110° C for 24 hours. After drying, the samples were cooled in a desiccator and weighed on a Mettler analytical balance (model H16). Because particles less than 0.125 mm in diameter passed through the finest sieve, the proportion of the total dry weight of these particles was calculated using the formula: $DW_{<.125mm} = ((DW_w / WW_w) * WW_f) - (DW_1 + DW_{.5} + DW_{.25} + DW_{.125})$ (see below for definition of symbols). After weighing, the pans containing the dried samples were wrapped loosely in aluminum foil and ashed in a muffle furnace at 550° C for four hours (Larson 1975a). After ashing, these samples were cooled in a desiccator then weighed. The proportion lost on ignition (pLOI) was calculated as pLOI= (DW - AW) / DW. The pLOI of the smallest fraction (<.125 mm) was calculated as:

$$pLOI_{<.125} = (((DW_w/WW_w) * WW_f)* pLOI_w) - (LOI_1 + LOI_{.5} + LOI_{.25} + LOI_{.125})$$

where:

WW= wet weight

DW = dry weight

AW = ashed weight

LOI= loss on ignition

pLPOI= proportion lost on ignition

$_w$= whole sediment sample

$_f$= sample to be fractionated

$_1$= sediment fraction >1.00 mm in size

$_{.5}$= sediment fraction 0.5 mm - 1.00 mm in size

$_{.25}$= sediment fraction 0.25 mm - 0.5 mm in size

$_{.125}$= sediment fraction 0.125 mm - 0.25 mm in size

$_{<.125}$= sediment fraction <0.125 mm in size.

Sediment density was calculated by weighing five 20 ml portions of wet sediment from each depth and taking the average density in g/ml. Density of sediment from 1 m depth in habitat A was not measured because these samples were used up in organic content and particle size analysis.

BMI Sorting and Identification

Benthic macroinvertebrates were separated from debris, identified and counted under a dissecting microscope (7X to 30X). Identifications were made using the following references: Barnard 1975; Bradley 1908; Burch 1975; Clarke 1981; Edmondson, Ward and Whipple 1959; Menzies 1954; Merritt and Cummins 1984; Pennak 1978, 1953; and Shoemaker 1949. Chironomid genera were identified or confirmed by M. J. Wevers using Wiederholm 1983. Voucher specimens are in the invertebrate zoology and entomology collections at the California Academy of Sciences.

Some non-benthic taxa (Cladocera, Copepoda, Collembola) were collected but were not included in the analysis. Nematodes were also omitted from the analysis because most of them probably washed through the 0.250 mm screen except in samples with large amounts of detritus.

BMI Weighing

Biomass measurements for each sample were made according to the following procedure. Mollusc shells, except of Sphaeriidae (due to their small size) were removed before weighing. *Corbicula* and *Margaritifera* were removed from their shells with a scalpel; *Juga* shells were pierced next to the operculum with pointed forceps and the soft tissue teased out. All individuals of a taxon were placed in a clean, dry, pre-weighed glass vial. Glass vials were placed in a drying oven (50^{o} - 60^{o} C) for 24 hours, cooled in a desiccator, capped, and weighed. All weighing was done with a Mettler balance (model H16). The biomass of small bodied taxa (estimated to be less than 1% of the biomass of a sample) were calculated from the average weight / individual in samples where these taxa were most numerous.

Calculations

The Shannon diversity index, H_e, was calculated with the "DIVERSE" computer program written by C. D. McIntire using the formula $He = -\Sigma P_i * \ln P_i$ where P_i is the proportional abundance of the i^{th} taxon. Taxa diversity was used rather than species diversity due to the difficulty or impossibility of identifying oligochaetes and juvenile insects to the species level. Chironomids were identified to the sub-family (tribe) level for diversity calculations; other taxa were identified to the levels reported in Table 5 (mostly to genera).

All confidence intervals were calculated using the formula $CI = X \pm t * s / \sqrt{n}$. Where X = mean, s=variance, n=number of samples, and t = Students t value (Dixon and Massey 1983).

Linear regressions were calculated with the Lotus 123 computer program.

Weighted numerical abundance and biomass averages for the entire lake were calculated by weighting the average abundance and biomass from each habitat zone by the proportion of the total lake area each zone covered.

RESULTS

Water Characteristics

Carter Lake water warmed gradually without stratification from 13-13.5° C in April to 20-21.5° C in July, then cooled to 15.5-16° C in October. Vertical temperature change in the water column was less than 1° C in April, May, and October, 2° C in June, and 1.5° C in July (Table 2a). The vertical change in dissolved oxygen (D.O.) was less than 1 mg/l on all sampling occasions (Table 2b). Most D.O. values were close to saturation with some values exceeding saturation. The lowest D.O. concentrations (88.8 % saturation) were found at the maximum depth in June 1986 and July 1987. No difference in conductivity, pH, or alkalinity was observed between the surface and mid depths, and all three were only slightly lower at the bottom when sampled in July, 1987 (Table 2c).

Secchi disk depth was 4.0 m in May and 4.5 m in June and October.

Benthic Habitat Characteristics

Visual observations indicated that benthic habitats were stratified with depth into 4 major zones. The characteristics and approximate area of coverage of these habitat zones are summarized in Table 3.

The shallowest habitat zone (A) was flooded in the spring of 1986. The highest water level was observed in

Table 2a. Water temperature (^{o} C) data from Carter Lake, Douglas County, Oregon.

Depth(m)	4/27/86	5/11/86	6/22/86	7/12/86	10/1/86	7/30/87	10/12/77	3/2/48	9/?/48
surface	13.5	14.0	20.5	21.5	16.0	21.0	15.80	9.40	18.90
1	13.5	14.0	20.5	21.5	15.5		15.60		
2	14.0	14.0	20.5	21.5	15.5		15.50		
3	13.5	14.0	20.5	21.0	15.5	21.0	15.30		18.90
4	13.5	14.0	20.5	21.0	15.5				
5	13.0	14.0	20.5	20.5	15.5				
6	13.0	14.0	20.5	20.5	15.5	20.0			16.70
7	13.0	14.0	19.0	20.0					14.40
8	13.0	13.5	18.5					7.80	
Reference	A	A	A	A	A	A	B	C	C

A. This study
B. Rinella 1979
C. Saltzman 1961a

Table 2b. Dissolved oxygen data from Carter Lake, Douglas County, Oregon.

	4/27/86		5/11/86		6/22/86		10/1/86	
Depth(m)	(mg/l)	% sat.	(mg/l)	% sat.	(mg/l)	% sat.	(mg/l)	% sat.
surface	10.23	101.7	9.68	97.5	8.83	100.8	9.37	97.6
1	10.30	102.1	9.95	100.2	8.83	101.1	9.50	98.5
2	10.87	108.7	9.83	98.5	8.80	100.6	9.40	97.5
3	9.50	104.3	9.93	99.5	8.70	99.3	9.50	98.5
4	10.27	101.8	9.70	97.0	8.83	100.8	9.47	98.0
5	10.30	101.5	9.97	99.9	8.86	101.1	9.27	96.0
6	10.23	100.8	9.73	97.3	8.86	100.9	9.03	93.5
7	10.53	103.7	9.78	98.0	8.85	98.0		
8	10.27	101.0	9.35	93.5	8.10	88.8		
Reference	A	A	A	A	A	A	A	A

	7/30/87		10/12/77		3/2/48		9/?/48	
Depth(m)	(mg/l)	% sat.	(mg/l)	% sat.	(mg/l)	% sat.	(mg/l)	% sat.
surface	8.85	102.0	10.00	104.20	9.70	87.50	8.00	88.60
1								
2								
3	8.75	100.8	9.90	102.10				
4								
5								
6	7.85	88.8					2.90	30.80
7							1.00	10.10
8					9.80	85.10		
Reference	A	A	B	B	C	C	C	C

A. This study
B. Rinella 1979
C. Saltzman 1961a

Table 2c. Conductivity, Alkalinity, and pH data from Carter Lake, Douglas County, Oregon.

Depth(m)	7/30/87 Cond. (μmhos)	7/30/87 Alkalinity ($CaCO_3$ mg/l)	7/30/87 pH	10/12/77 pH	3/2/48 pH	9/?/48 pH
surface	133.65	13.48	7.20	6.80	6.80	6.70
3	133.65	13.48	7.20	6.70		
6	130.62	13.38	6.90			6.30
7.3						6.20
9.75					6.70	
Reference	A	A	A	B	C	C

A. This study
B. Rinella 1979
C. Saltzman 1961a

Table 3. Characteristics of the major habitat zones of Carter Lake, Douglas County, Oregon, including benthic macroinvertebrate abundance and biomass. Data collected in 1986.

		Benthic Habitats			
Habitat zone		A	B	C	D
Depth (m)	(May)	0-2.5	2.5-4	4-6	6-9
	(Oct)	-2.5-0	0-1.5	1.5-3.5	3.5-6.5
Sediment type		sand	sand	sand + mud	soft mud
Submerged		* April-Oct	permanently	permanently	permanently
%LOI range		0-3	1-3	2-7	12-16
average sediment density		1.84	1.92	1.63	1.35
% sediment	>0.50 mm	1.7-3.9	4.1	4.6	19.2
particle	.125-.50 mm	95.3-92.5	91.2	83.0	50.6
size	<0.125 mm	2.7-3.6	5.8	12.4	30.3
Macrophytes		none	none	Nitella	none
Temperature	(May)	14.2	14.0	14.0	13.4-14.0
	(Oct)	dry	15.8	15.5	15.5
Oxygen mg/l	(May)	9.68-9.95	9.70-9.93	9.70-9.97	9.35-9.78
	(Oct)	dry	9.37-9.50	9.40-9.50	9.27-9.47
Area (ha)		6.07	3.45	2.01	3.45
% of lake area	(May)	40.5	23.1	13.4	23.0
	(Oct)	0.0	38.8	22.5	38.7
total BMI	***(May)	5.01	5.76	0.54	0.98
abundance $X10^8$	***(Oct)	dry	5.71	3.13	1.61
% of total BMI	(May)	40.7	46.8	4.4	8.0
abundance	(Oct)	dry	54.4	30.2	15.4
total BMI	***(May)	127.48	194.28	20.37	16.13
biomass (kg)	***(Oct)	dry	100.47	185.38	34.69
**	***(Oct)	dry	100.47	87.49	34.69
% of total BMI	(May)	49.4	36.4	8.0	6.2
biomass	(Oct)	dry	31.1	58.1	10.8
	**(Oct)	dry	50.0	32.8	17.3

* Zone A was completely submerged in April when the water level was highest. The water level dropped throughout the summer until zone A was completely exposed in October.

** The weights of *Margaritifera falcata* and *Pacifastacus leniusculus* were excluded in calculating the values in these rows.

***Total abundance and biomass values were calculated by multiplying average values per m^2 by the area in the corresponding habitat zone.

April and gradually this area was exposed again as the water level dropped throughout the summer. Numerous Corophium tubes (spaced as close as 0.5 - 1.0 cm apart) projected above the sediment about 1.0 cm. In very shallow water (< 20 cm deep) wave action appeared to have an impact and Corophium tubes did not project above the sediment, however, the entrances to their burrows were visible at the sediment surface. Mysid shrimp (Acanthomysis awatchensis) were seen swimming just above the sediment in these wave washed areas. Some areas of marginal vegetation (Carex obnupta and Mentha spicata) were flooded in April and these plants died back while still submerged. Allochthonous organic matter (leaves, conifer needles, bark) was found in some patches in zone A, however, the sediment was mostly clean sand. The average sediment density was 1.84 g/ml and organic content was less than 2% (Table 4). Over 40% of the sediment particles were 0.125 mm - 0.50 mm in diameter (Fig. 2). While the organic content of these particles, as well as in the < .0125 mm fraction, was less than 3% (Fig. 3), these fractions contained most of the total organic matter of the zone A sediment (Fig. 4).

Table 4. Density and organic content (% weight loss on ignition) of Carter Lake sediments. Density was averaged from samples collected in May and October, 1986. All values are given ± 95 % confidence limit.

HAB. ZONE	DEPTH (May)	DENSITY (g/ml) May and Oct	% LOI May	% LOI October
A	1	-	1.76 ± 2.53	
A	2	1.84 ± 0.144	1.74 ± 0.73	
B	3	1.92 ± 0.080	1.66 ± 0.50	2.79 ± 0.48
C	5	1.63 ± 0.234	3.40 ± 1.12	4.96 ± 2.95
D	9	1.35 ± 0.061	15.38 ± 0.91	14.56 ± 1.87

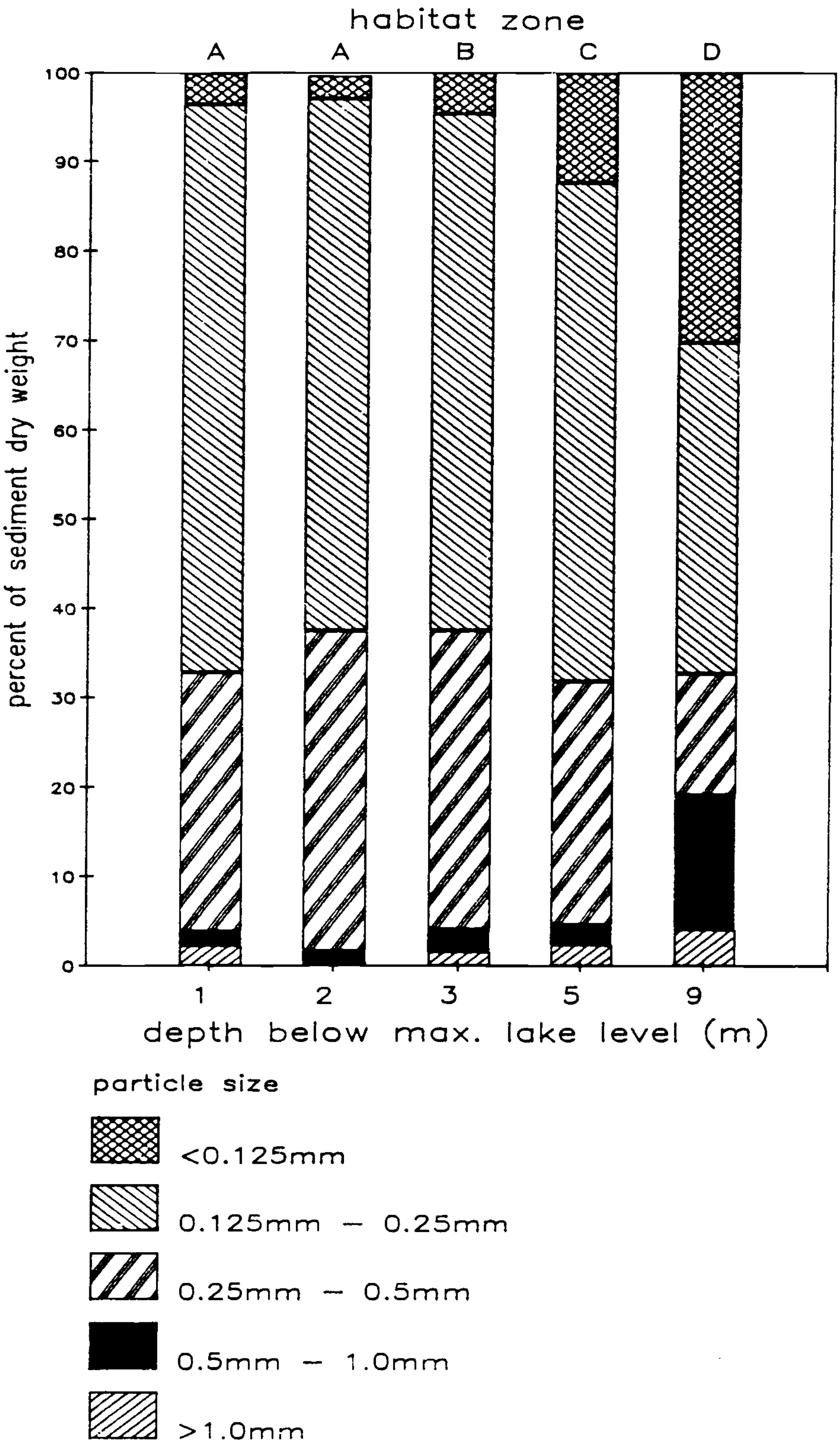

Figure 2. Particle size composition of sediments from Carter Lake habitat zones. May and October samples combined.

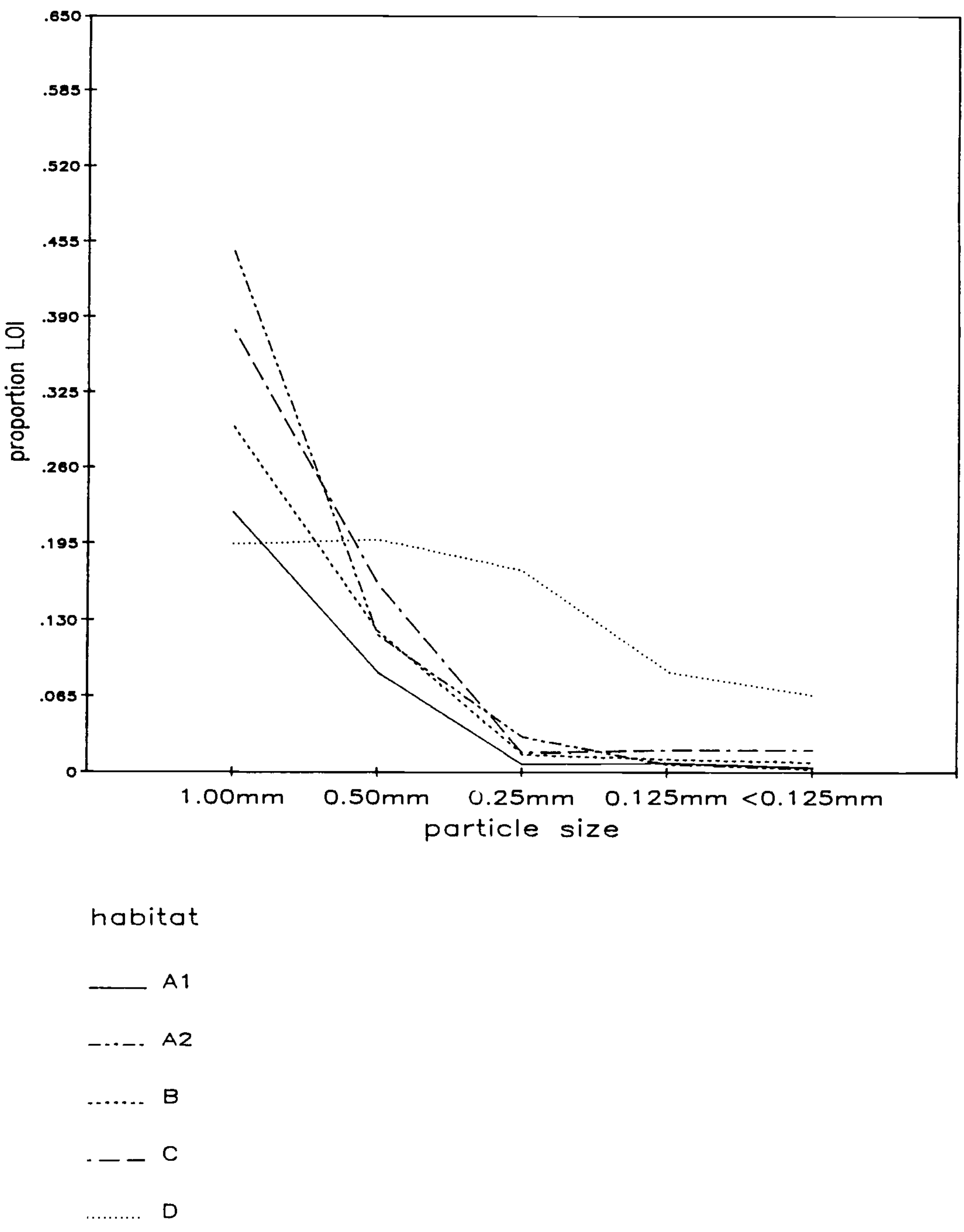

Figure 3. Organic content (proportion loss on ignition) of size fractions of sediments from Carter Lake habitat zones. May and October samples combined. Lines A1 and A2 represent sediments from 1 m and 2 m depth, respectively, in habitat A.

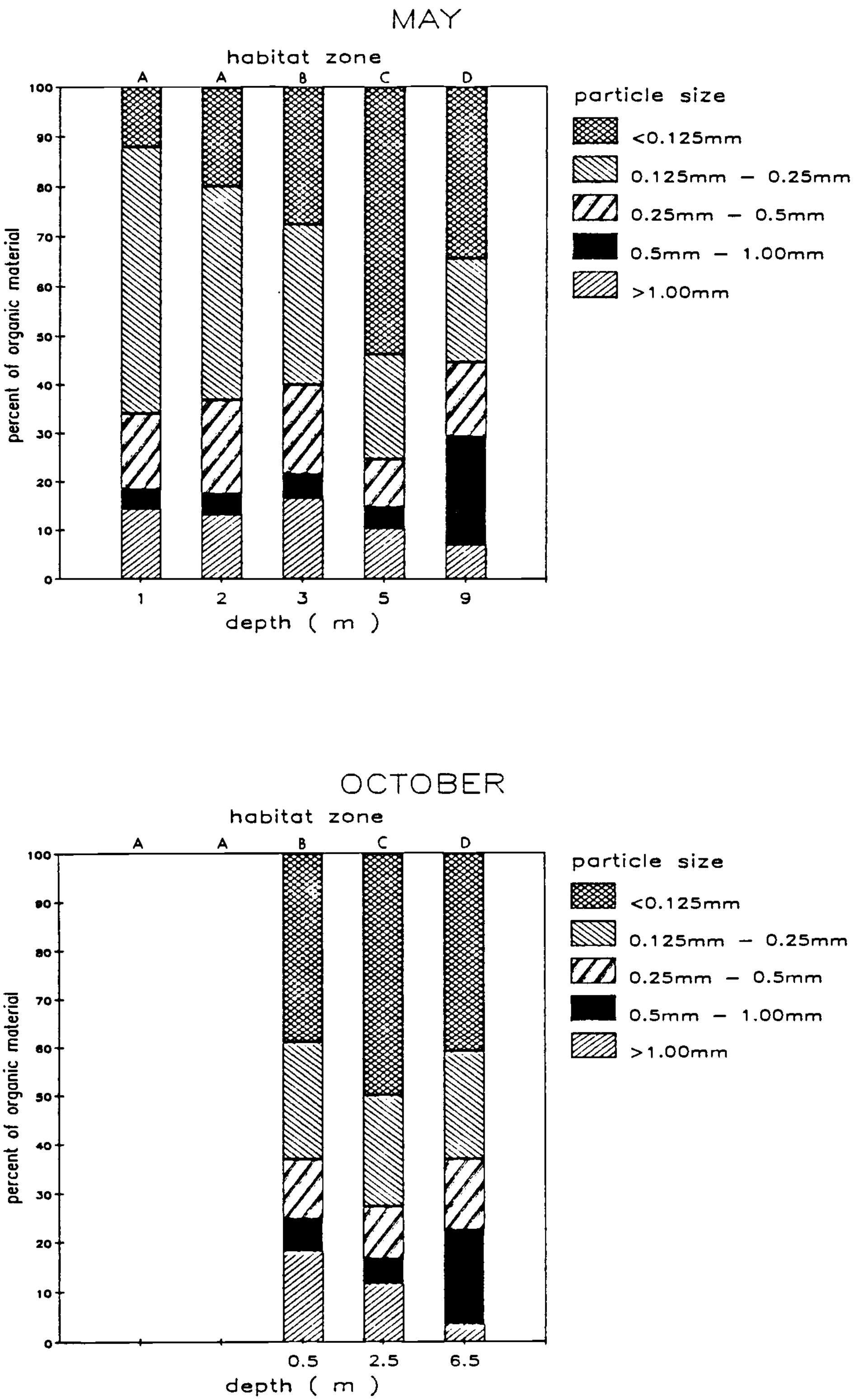

Figure 4. Particle size distribution of the organic matter in sediments from Carter Lake habitat zones.

The sediment density (Table 4), organic content (Table 4), particle size composition (Fig. 2), and organic content of sediment size fractions (Fig. 3) were all similar in zones A and B. However, the organic matter in the finest sediment fraction made up a larger percentage of the total organic content in habitat B sediment (Fig. 4).

Habitat zone C was defined as the range in depth where a submerged macrophyte, Nitella was found ($\leq$ 2 m below habitat zone B). Nitella was observed in about 50% of this area, but generally in >50% on the west side and <50% on the east side of the lake. In some places Nitella growth was dense enough to obscure the sediment from sight. Four of the twelve samples collected from this zone in May and three of the twelve samples collected in October contained no Nitella. Within this zone no discernable differences in the BMI communities of samples with and without Nitella were observed. Some crayfish (Pacifastacus leniusculus) and mussels (Margaritifera falcata) were seen in this zone.

The sediment of zone C was less dense and higher in organic content (Table 4) than the sediments of zones A and B. Fine particles (< 0.125 mm) made up a greater percentage of the sediment of zone C than in the shallower zones (Fig. 2). As in zones A and B, the 0.250, 0.125, and <0.125 mm fractions of the sediment were low in organic content (Fig. 3). However, the finest particles (<0.125

mm) contained over 50% of the total organic matter in this zone (Fig. 4), a higher percentage than at any other zone.

The deepest habitat zone (D) was characterized by soft brown sediment dotted with burrows (probably *Hexagenia*) approximately 5 - 10 cm apart. A few mussels (*M. falcata*) also were observed in this zone.

Zone D sediment was lower in density (Table 4), higher in organic content (Table 4), and more evenly distributed into different particle sizes (Fig. 2) than the sediment of the other zones. There was virtually no sand in zone D, and the organic content of the 0.250 mm, 0.125 mm, and < 0.125 mm sized particles was several times higher than in any other zone (Fig. 3). The organic material of zone D sediment was distributed into different sized particles (Fig. 4) in roughly the same proportions as the sediment as a whole (Fig. 2).

Carter Lake sediments ranged from sand in the shallow areas to mud in the deepest areas. Two measures of position on this gradient are the sediment density and organic content (Table 4), both of which were correlated with depth (R^2 = .715 and .745 respectively). The sediment organic content was lowest in zones A and B, and increased with increasing depth below habitat zone B. There was no significant seasonal difference in the organic content of sediment in zones C and D. The organic content in zone B sediment was, however, slightly higher in October than it was in May.

Benthic Macroinvertebrate Community Composition

Checklist Of Taxa

Fifty-three BMI taxa were identified from Carter Lake (Tables 5a and 5b). These included 1 Turbellaria, 3 pelecypod, 2 gastropod, at least 2 oligochaete, 1 Hirudinea, 1 Acarina, 8 crustacean, and 35 insect taxa. Sixteen of the insect taxa were chironomid genera. Three euryhaline crustacean species (Eriksen 1968), *Corophium spinicorne*, *Acanthomysis awatchensis*, and *Gnorimosphaeroma oregonensis lutea* were collected.

Habitat C had the greatest number (32) of BMI taxa, nine of which were found exclusively in this habitat. Habitat zones A and B had 3 taxa exclusive to each, with totals of 20 and 26 taxa, respectively. Habitat zone D had the fewest taxa (15), *Chaoborus* being the only taxon found exclusively in this zone. Sampling marginal vegetation with a net yielded 27 taxa, including 11 that were not collected elsewhere.

In comparing the BMI communities within Carter Lake, the average taxa density (number of taxa in a given area; Simpson 1964) is useful in that a comparable unit, the area of one grab sample, is used. The average number of taxa per sample was highest in habitat C in both May and October at 8.5 and 14.33, respectively (Table 6). Habitat B samples were the second highest (6.75 in May and

Table 5a. List of non-insect taxa identified from Carter Lake, Douglas County, Oregon.

Habitat Zone	A	B	C	D	S
Platyhelminthes					
Turbellaria	-	-	O	-	-
Mollusca					
Pelecypoda					
Unionacea					
MARGARITIFERIDAE					
Margaritifera falcata	-	-	O	-	-
Heterodonta					
SPHAERIIDAE	M	B	B	B	O
CORBICULIDAE					
Corbicula fluminea	-	M	M	-	-
Gastropoda					
PHYSIDAE					
Physa	-	-	-	-	O
PLEUROCERIDAE					
Juga plicifera (Lea, 1838)	M	B	B	-	B
Annelida					
Oligochaeta					
TUBIFICIDAE	M	B	B	B	-
other Oligochaetes	M	B	B	B	B
Hirudinea					
Rhynchobdellida					
GLOSSIPHONIIDAE	-	M	-	-	-
Arthropoda					
Arachnida					
Acarina	-	B	B	O	B
Crustacea					
Ostracoda					
Podocopa	M	B	B	O	-
Malacostraca					
Mysidacea					
MYSIDAE					
Acanthomysis awatchensis (Brandt 1851)	M	M	M	-	B
Isopoda					
Flabellifera					
SPHAEROMIDAE					
Gnorimosphaeroma oregonensis lutea (Menzies 1954)	M	B	B	-	B
Asellota					
ASELLIDAE					
Asellus	-	O	-	-	-
Amphipoda					
TALITRIDAE					
Hyalella azteca	M	O	O	O	B
GAMMARIDAE					
Anisogammarus	M	B	B	-	B
COROPHIIDAE					
Corophium spinicorne	M	B	B	B	B
Decapoda					
ASTACIDAE					
ASTACINAE					
Pacifastacus leniusculus	-	-	B	-	M

M- collected in May
O- collected in October
B- collected in both May and October
-- not collected
S- area swept with D-net

Table 5b. List of insect taxa identified from Carter Lake, Douglas County, Oregon.

Habitat Zone	A	B	C	D	S
Insecta					
Ephemeroptera					
BAETIDAE					
Baetis	-	-	-	-	O
EPHEMERIDAE					
Hexagenia	M	O	B	B	O
Odonata					
Zygoptera					
COENAGRIONIDAE	-	-	-	-	B
Anisoptera					
LIBELLULIDAE					
Libellula	-	-	-	-	O
Hemiptera					
GERRIDAE					
Gerris	-	-	-	-	O
CORIXIDAE					
Callicorixa	-	-	-	-	O
unidentified	-	-	-	-	M
Megaloptera					
SIALIDAE					
Sialis	M	-	B	B	-
Trichoptera					
LEPTOCERIDAE					
Mystacides	-	O	O	-	-
Oecetis	-	O	B	-	M
unidentified	-	O	B	-	O
Lepidoptera	M	-	-	-	-
Coleoptera					
GYRINIDAE					
Gyrinus	-	-	-	-	O
DYTISCIDAE					
Uvarus	-	-	-	-	O
HALIPLIDAE					
Haliplus	-	O	O	-	B

Habitat Zone	A	B	C	D	S
Diptera					
TIPULIDAE	M	-	-	-	-
CHAOBORIDAE					
Chaoborus	-	-	-	B	-
CERATOPOGONIDAE	M	B	B	B	B
CHIRONOMIDAE					
Tanypodinae					
Larsia		O			O
Procladius			O		
Psectrotanypus					O
unidentified	M	B	B	B	O
Orthocladiinae					
Heterotrissocladius			O		
Hydrobaenus			O		
Parametriocnemus	M	O			
Psectrocladius					O
unidentified	M	B	B	B	O
Chironomini					
Cryptochironomus	M	O			
Demicryptochironomus			O		
Dicrotendipes			O		
Endochironomus			M		
Paracladopelma (*nigritula* group)			O	O	
Phaenopsectra			O		O
Polypedilum			O		
unidentified	M	B	B	B	B
Tanytarsini					
Tanytarsus			O		O
Zavrelia					O
unidentified	M	B	B	B	B
TABANIDAE					
Chrysops	-	O	-	-	-
Silvius	M	-	-	-	-
EMPIDIDAE					
Chelifera	-	O	O	-	-

M= collected in May
O= collected in October
B= collected in both May and October
-= not collected
S= area swept with D-net

Table 6. Benthic macroinvertebrate community structure parameters for the habitat zones of Carter Lake, Douglas County Oregon.

		habitat zone			
		A	B	C	D
H_e	(May)	0.730	0.486	2.103	1.276
H_e	(Oct)	-	1.330	2.130	1.739
number of taxa	(May)	20	17	20	12
number of taxa	(Oct)	-	22	24	15
av. taxa/sample	(May)	5.12	6.75	8.5	4.75
av. taxa/sample	(Oct)	-	11.25	14.33	7.5
indiv. counted	(May)	4426	4500	688	511
indiv. counted	(Oct)	-	4419	4194	838
samples	(May)	24	12	12	8
samples	(Oct)	0	12	12	8

H_e = Shannon diversity index, log base e

number of taxa = number of taxa used in calculating H_e, Chironomidae identified to tribe level

av. taxa/sample = average number of taxa in a 225 cm^2 sample

indiv. counted = the total number of individuals counted from each habitat

samples = the total number of samples collected from each habitat

11.25 in October) and habitat D samples were the lowest (4.75 in May and 7.5 in October). In May, habitat A samples ranked between those from D and B. The average number of taxa were significantly greater in October than in May in habitat zones B, C, and D.

The BMI community of habitat zone C had the highest taxa diversity (measured by the Shannon diversity index) (Table 6). Zone D was second highest in diversity followed by zone B in October and zone A in May. Zone B in May had the lowest diversity of any zone at any time.

Abundance

The density of benthic macroinvertebrates was greatest in habitat B in both May and October with no significant seasonal difference (Fig. 5). In May, samples from habitat A had somewhat (though not significantly) lower average abundances than did samples from zone B. In October, Samples from habitat C did show a significant increase in abundance from what was observed in May. Samples from habitat D had low abundance with no significant seasonal change.

In May, the average abundance was highest in samples with low sediment organic content and decreased with increasing organic content. In October, however, the highest average abundance occurred in samples with 2 - 4% sediment LOI (Fig. 6).

The benthic macroinvertebrate community composition of

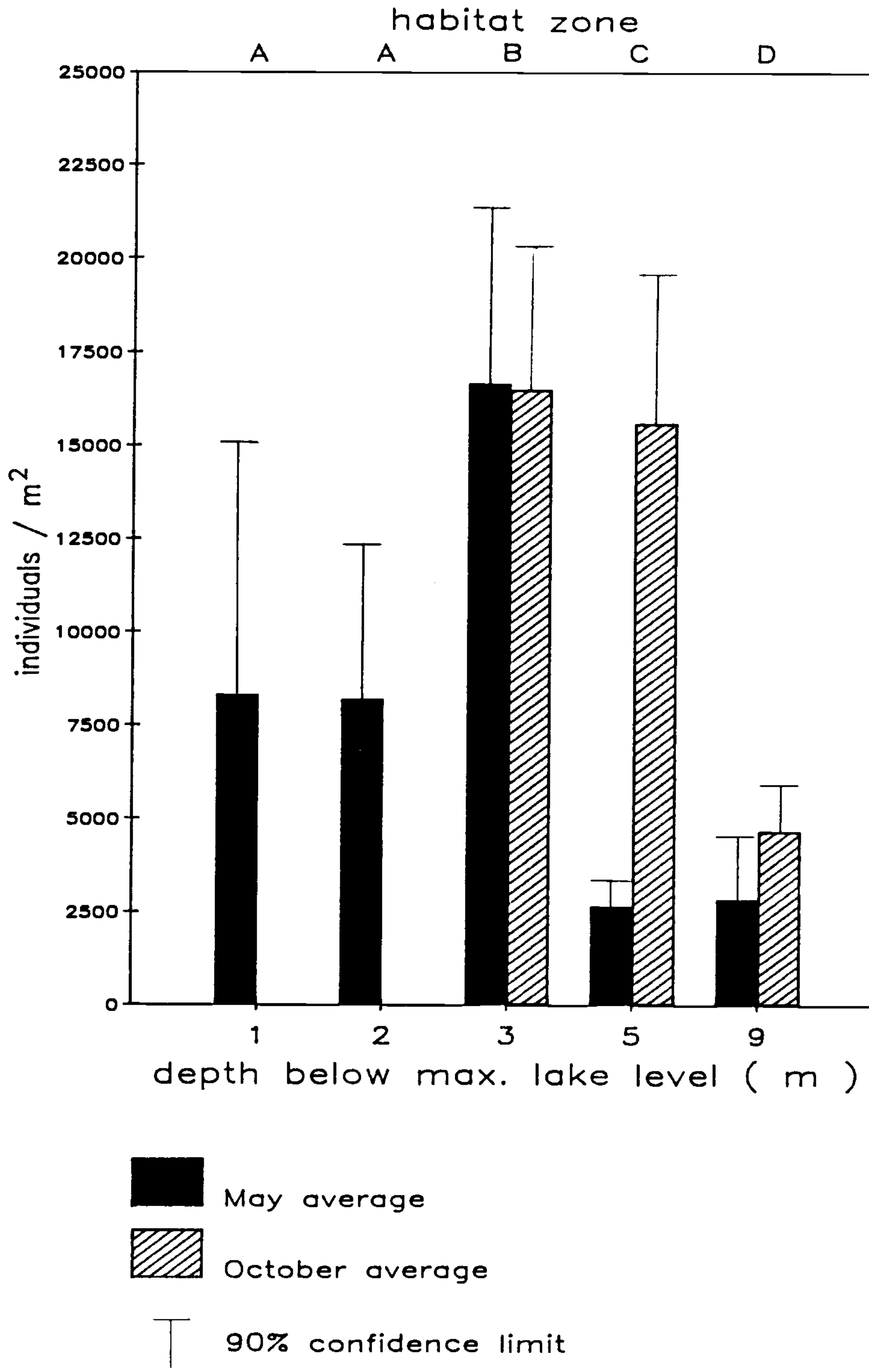

Figure 5. Numerical abundance of benthic macroinvertebrates in Carter Lake habitat zones.

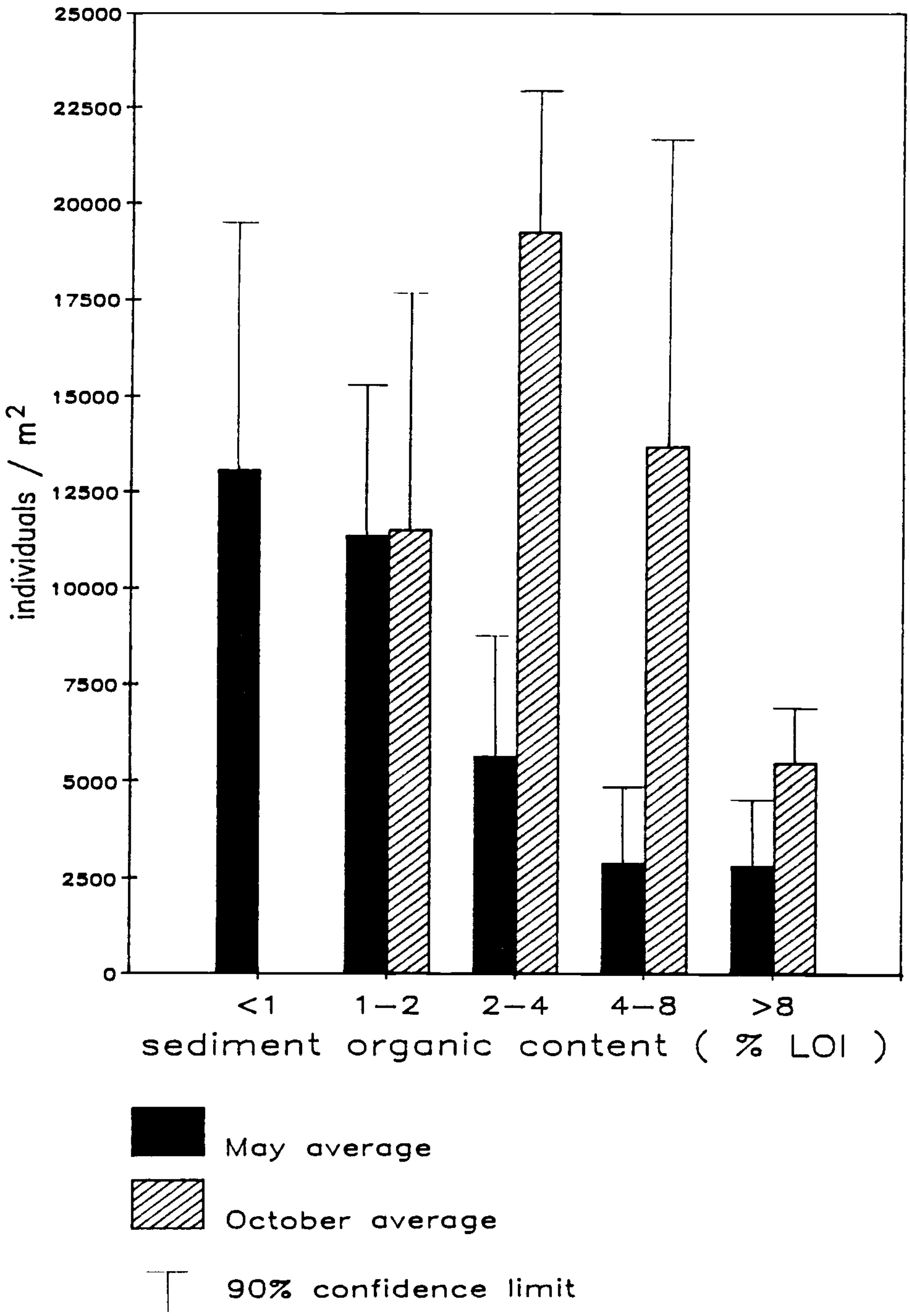

Figure 6. Numerical abundance of benthic macroinvertebrates VS sediment organic content (% weight loss on ignition).

Carter Lake is dominated by the tubicolous amphipod *Corophium spinicorne* (Figs. 7a and 7b). It accounted for about 80% of the BMI in May and 50% in October. The importance of *Corophium* to the total abundance can be seen in the similarities of figures 8a and 5, and figures 8b and 6. Other taxa that were of numerical importance in October were Sphaeriidae, Chironomidae, non-tubificid Oligochaetes, Tubificidae, and to some extent *Hexagenia* and Ostracoda.

The benthic communities in May and October change from *Corophium* dominated in shallow water (habitat zones A and B) to Sphaeriidae dominated in deep water (habitat D). A more diverse community containing both of these taxa was found at intermediate depth (habitat C). About 60% of the individuals in habitat D in May and about 40% in October were sphaeriid clams.

Biomass

The distribution of BMI biomass (Fig. 9a) was similar to the distribution of total abundance. The lowest observed average biomass was 0.47 g dry weight / m^2 in habitat D in May. The highest average biomass was 9.25 g dry weight / m^2 in habitat B in October. This high figure was largely due to one specimen of the bivalve, *Margaritifera falcata* (>.8 g), and two specimens of the crayfish, *Pacifastacus leniusculus* (>0.4 g each). If these three individuals are omitted, habitat B still had the highest average biomass at 4.36 g/m^2. The mean weighted biomass for the entire lake

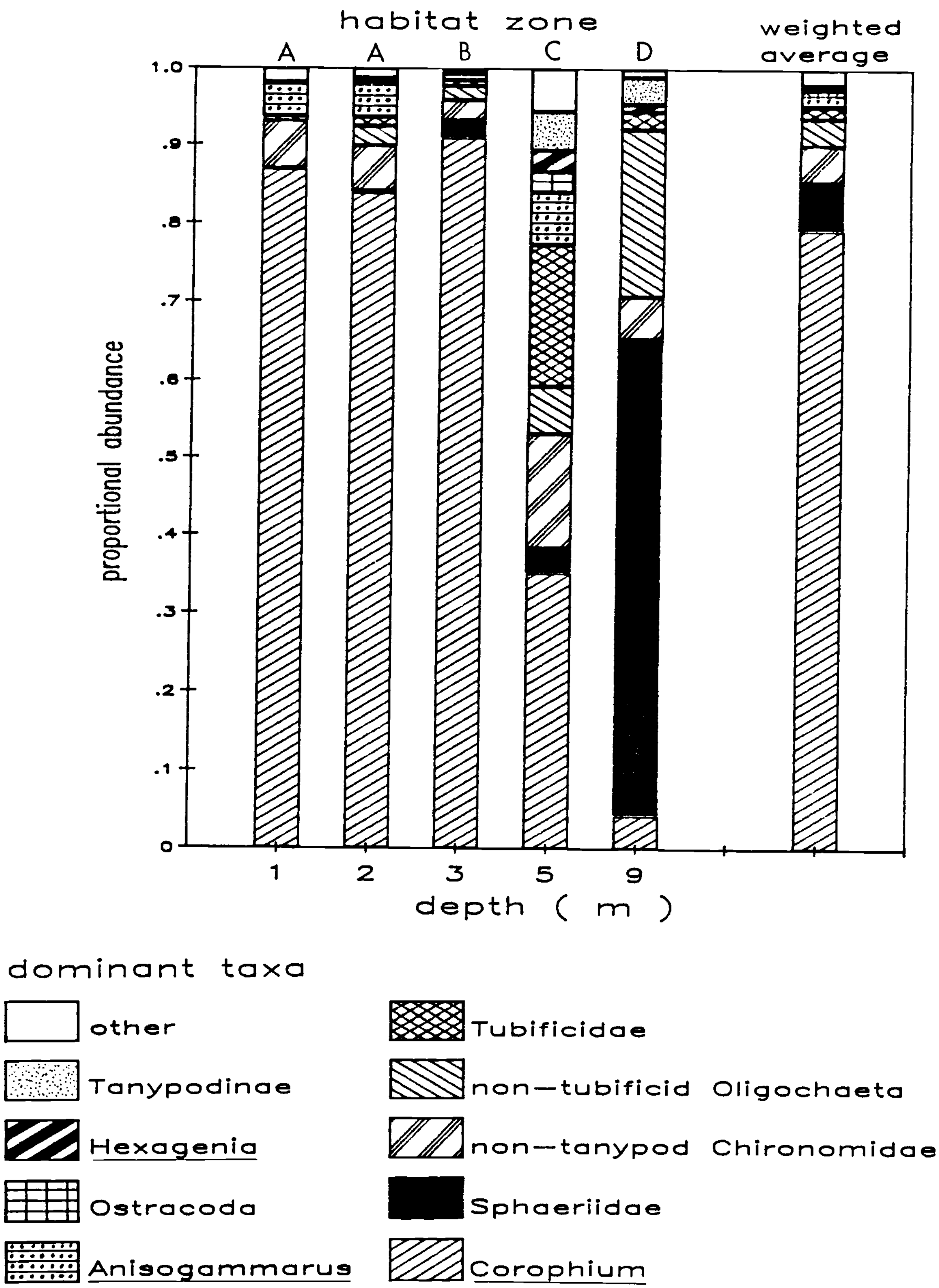

Figure 7a. Proportional abundance of dominant benthic macroinvertebrate taxa in Carter Lake habitat zones in May.

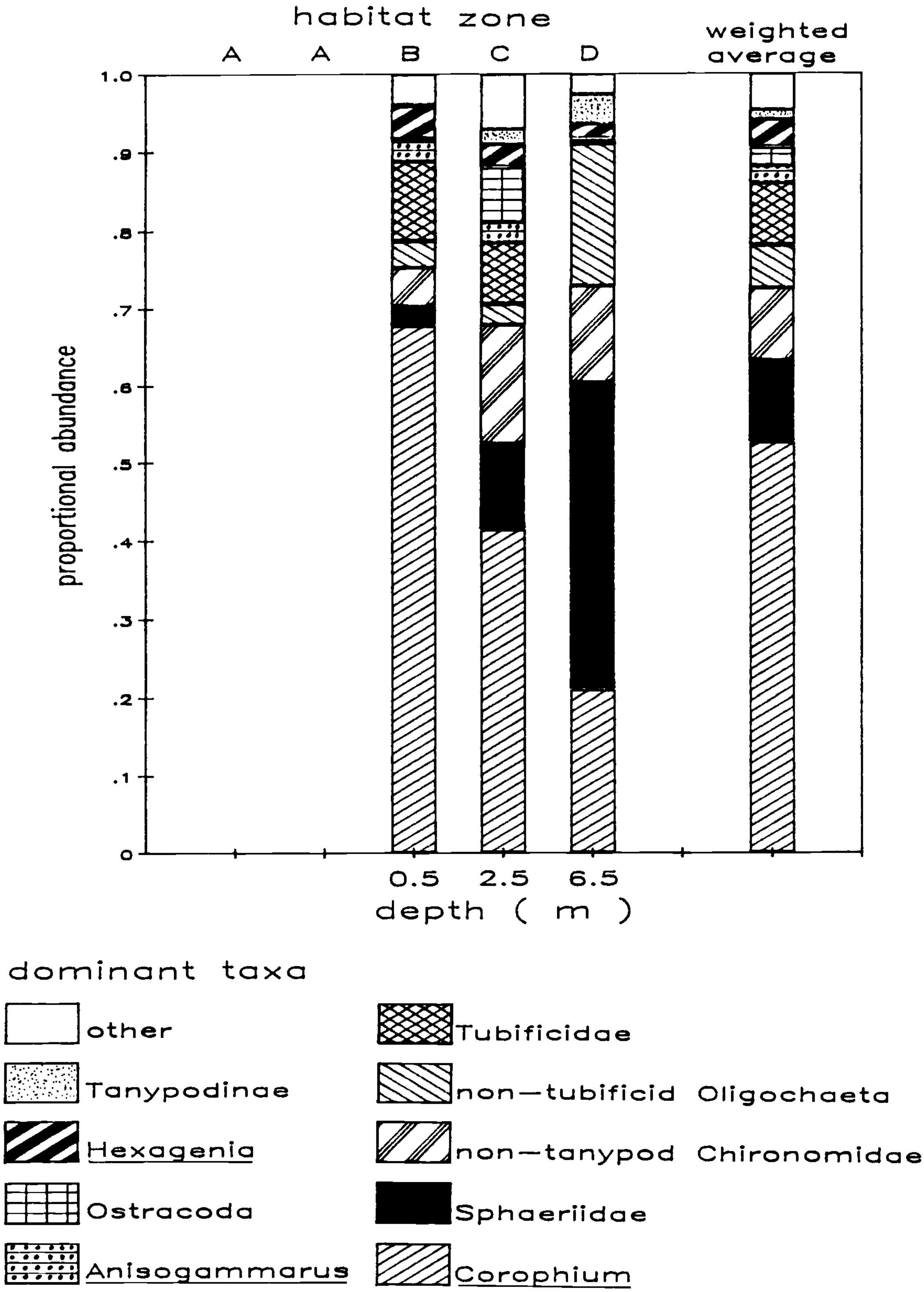

Figure 7b. Proportional abundance of dominant benthic macroinvertebrate taxa in Carter Lake habitat zones in October.

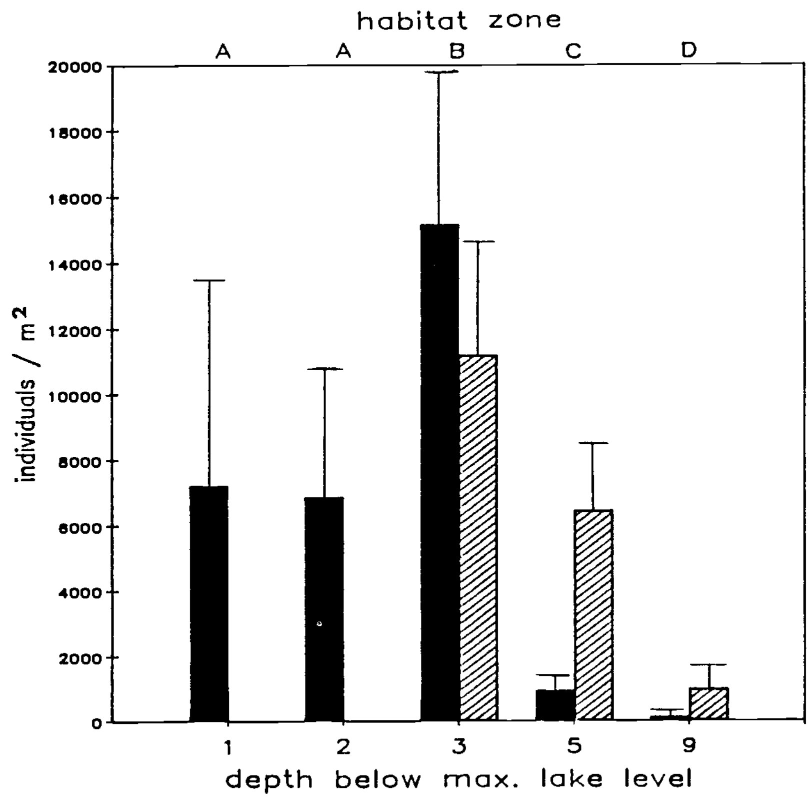

Figure 8a. Corophium spinicorne abundance in Carter Lake habitat zones.

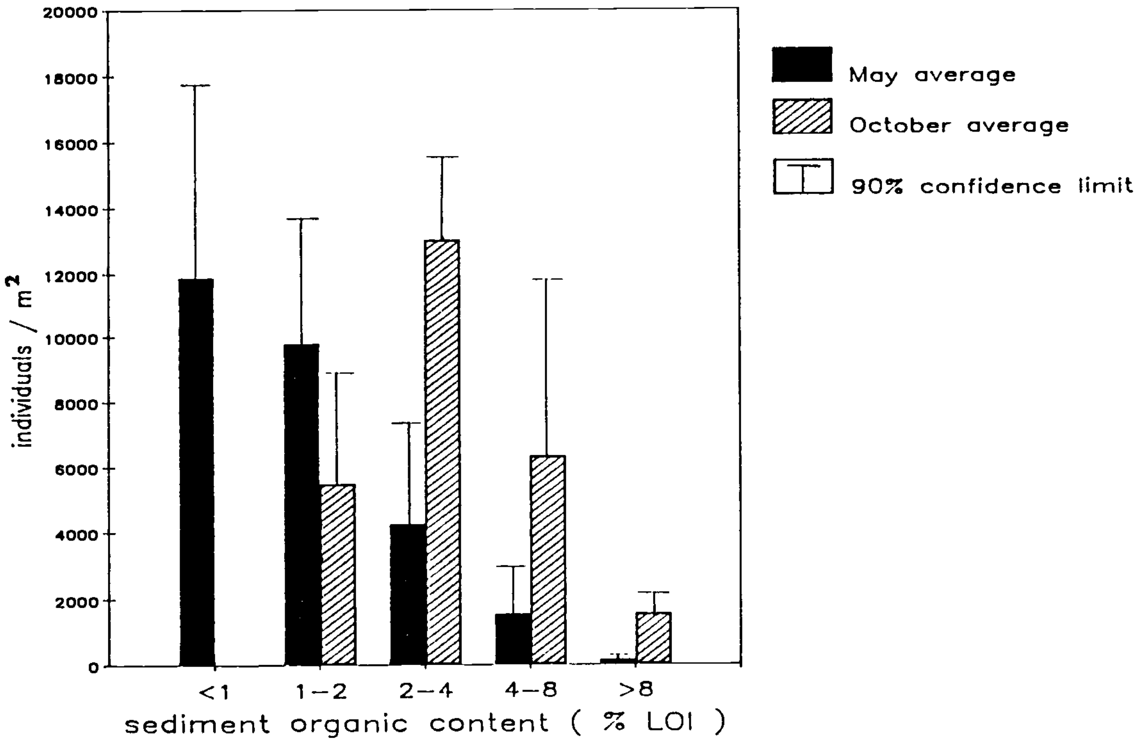

Figure 8b. Corophium spinicorne abundance VS sediment organic content (% weight loss on ignition) in Carter Lake.

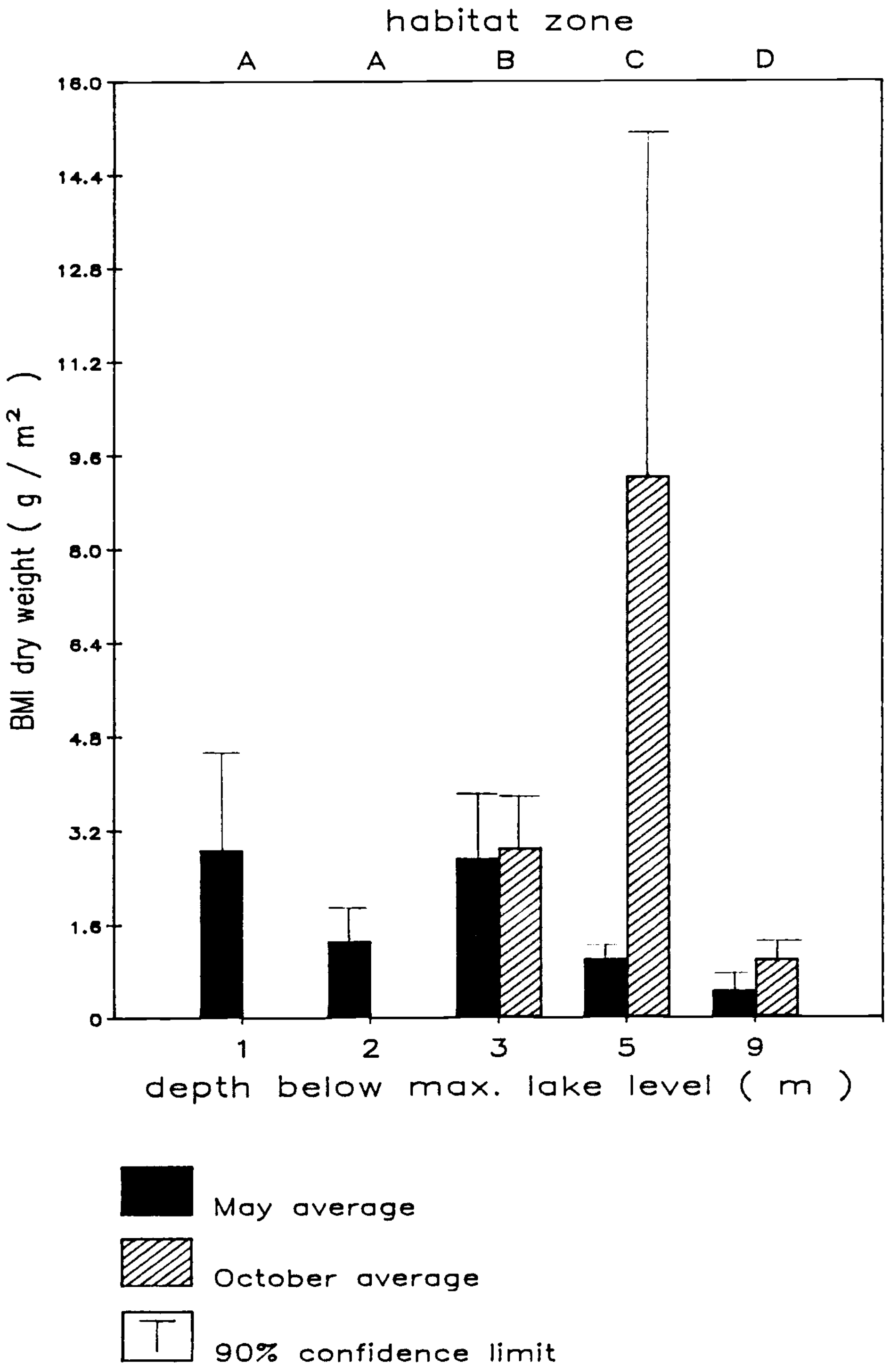

Figure 9a. Benthic macroinvertebrate biomass in Carter Lake habitat zones.

was 2.58 g/m^2 in May and 3.61 g/m^2 in October. If the specimens of *Margaritifera* and *Pacifastacus* collected in October are excluded (Fig. 9b), the October mean weighted biomass for the entire lake was 2.25 g / m2. *M. falcata* and *P. leniusculus* were not collected in May.

While the spatial distribution of biomass in the lake is similar to that of abundance, the taxonomic composition of the biomass (Figs. 10a, 10b, and 10c) is quite different from the taxonomic composition of numerical abundance (Figs. 7a and 7b).

In May, the major contributors to the biomass were (in order of importance) : *Corophium*, *Juga*, non-tubificid Oligochaeta, Tubificidae, *Hexagenia*, Sphaeriidae, and Chironomidae (Figs. 10a, 11a and 11b). *Juga* and *Corophium* contributed the most to the biomass in habitat A. In habitat B, *Juga* biomass was very small and non-tubificid oligochaetes were the most important. Contributors to the biomass in habitat C were diverse with Tubificidae, *Corbicula*, and *Hexagenia* being the most important. In habitat D, *Hexagenia* made up 52% of the benthic biomass with Sphaeriidae, non-tubificid oligochaetes and Chironomidae also making significant contributions.

In October, the most important contributors to the benthic biomass were (in order of importance) *M. falcata*, *Pacifastacus*, non-tubificid oligochaetes, *Juga*, *Corophium*, Tubificidae, and *Hexagenia* (Figs. 10b, 11c, and 11d). The proportional abundance in habitat B was similar to what it

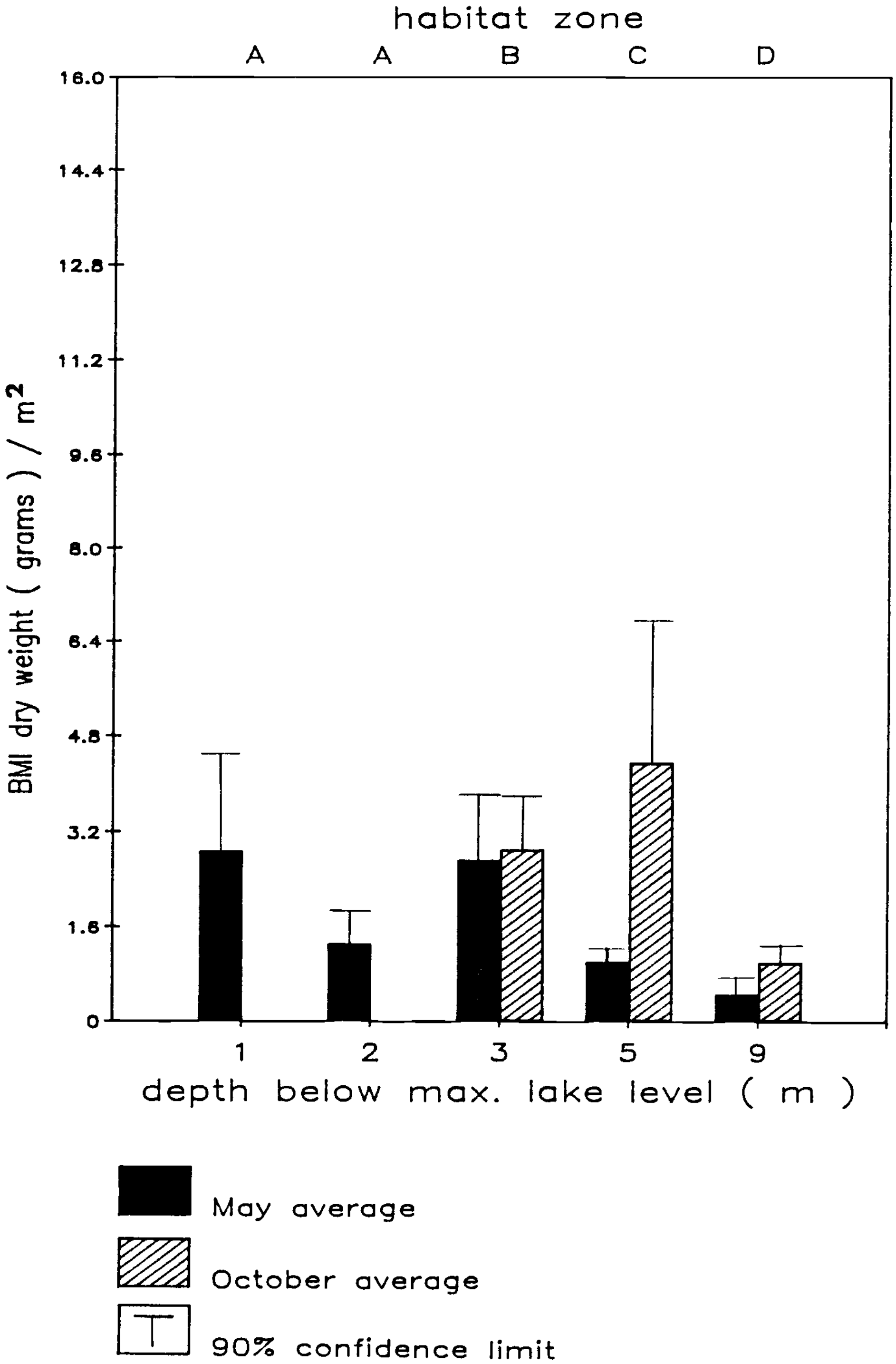

Figure 9b. Benthic macroinvertebrate biomass (Margaritifera and Pacifastacus excluded) in Carter Lake habitat zones.

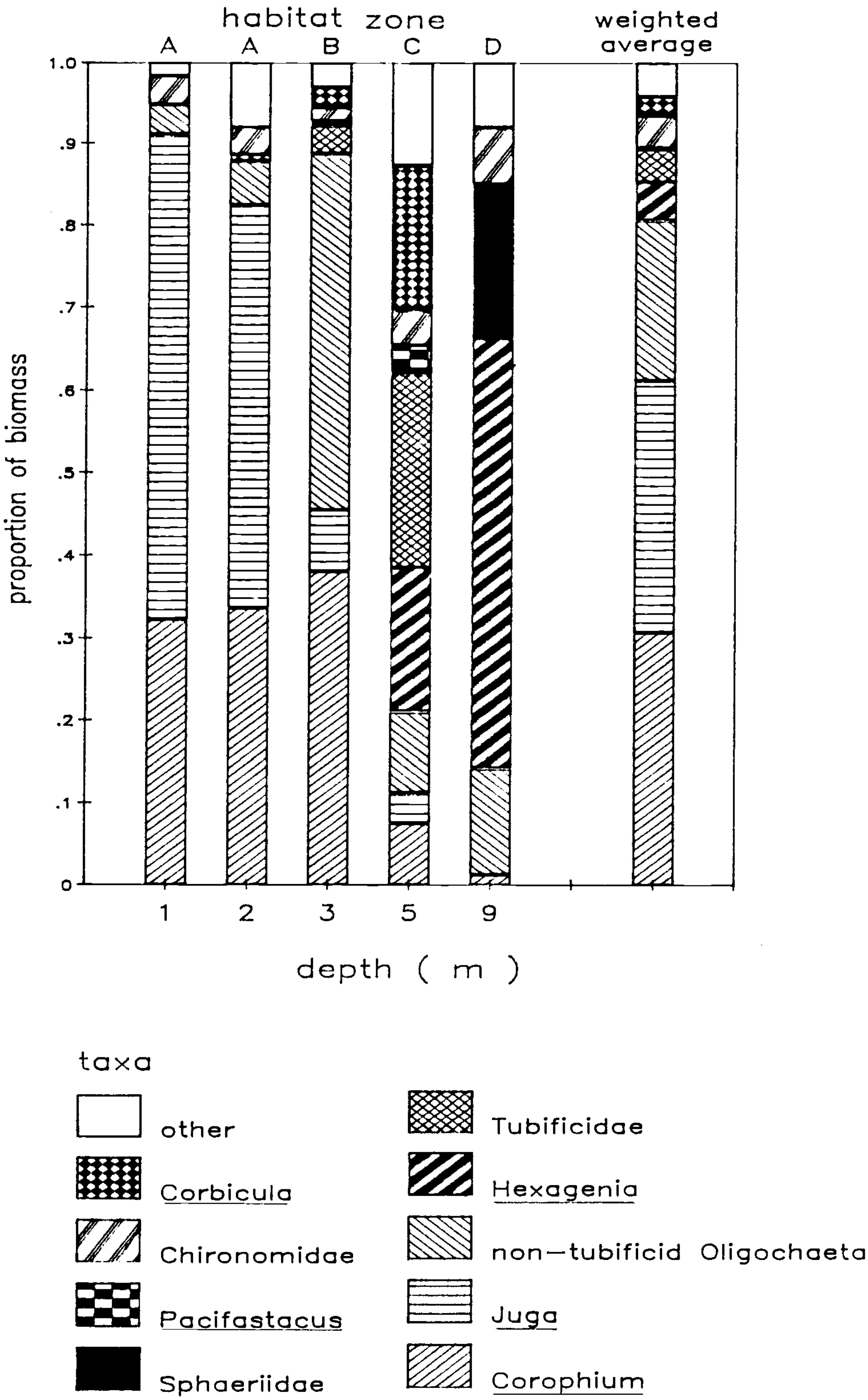

Figure 10a. Proportional biomass of benthic macroinvertebrate taxa in Carter Lake habitat zones in May.

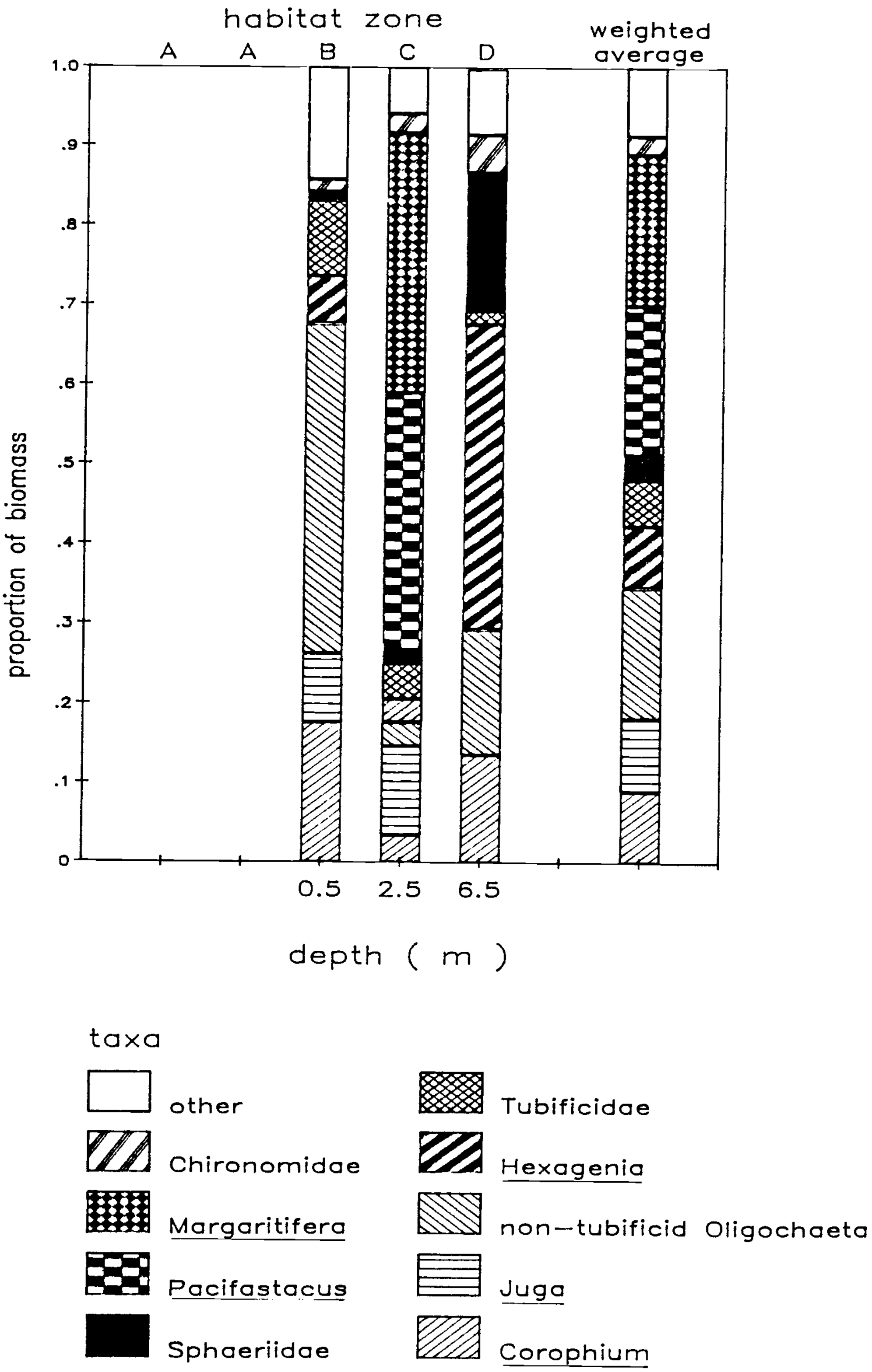

Figure 10b. Proportional biomass of benthic macroinvertebrate taxa in Carter Lake habitat zones in October.

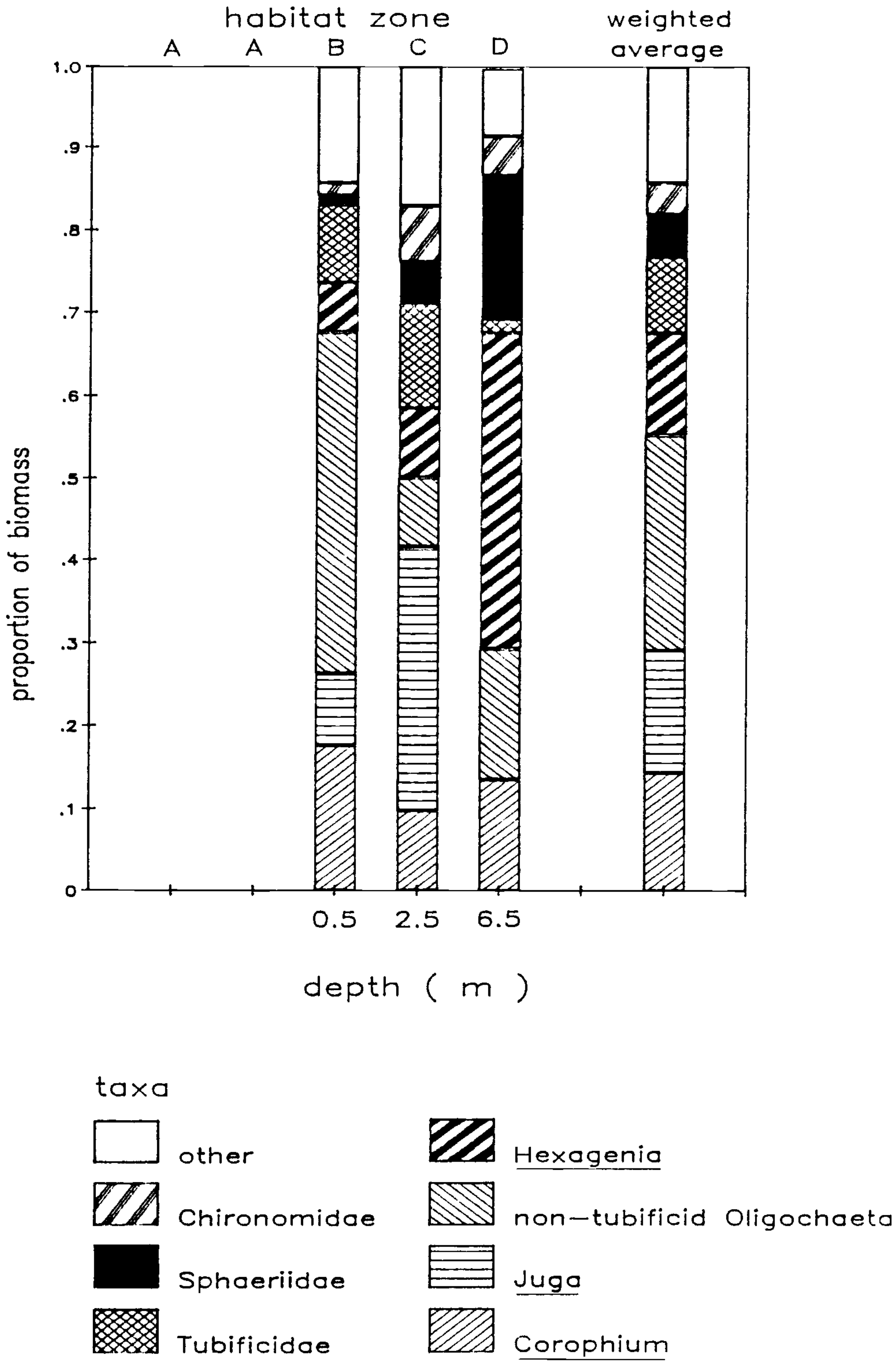

Figure 10c. Proportional biomass of benthic macroinvertebrate taxa (Margaritifera and Pacifastacus excluded) in Carter Lake habitat zones in October.

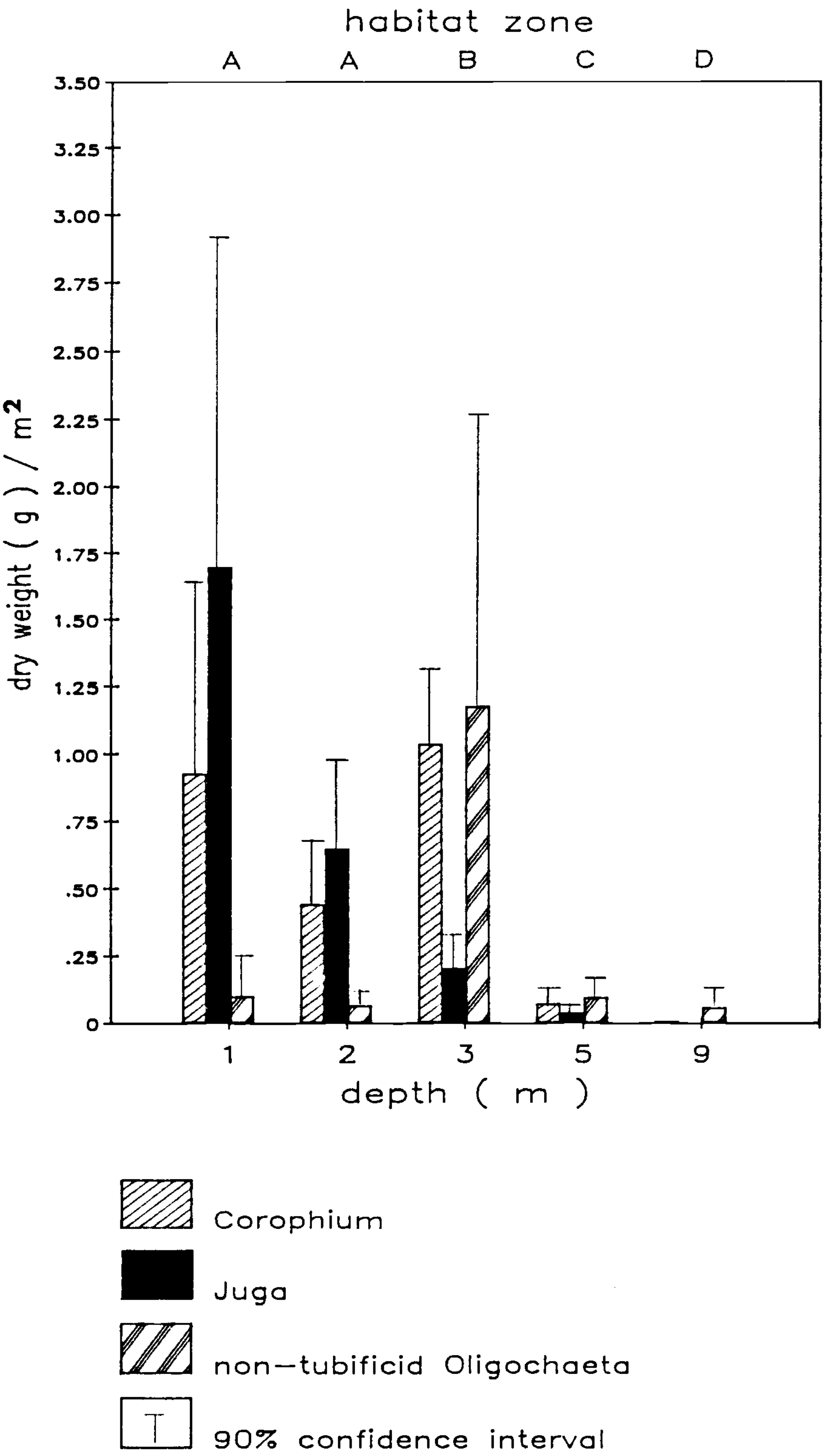

Figure 11a. Average biomass of <u>Corophium spinicorne</u>, <u>Juga plicifera</u>, and non-tubificid Oligochaeta in Carter Lake habitat zones in May.

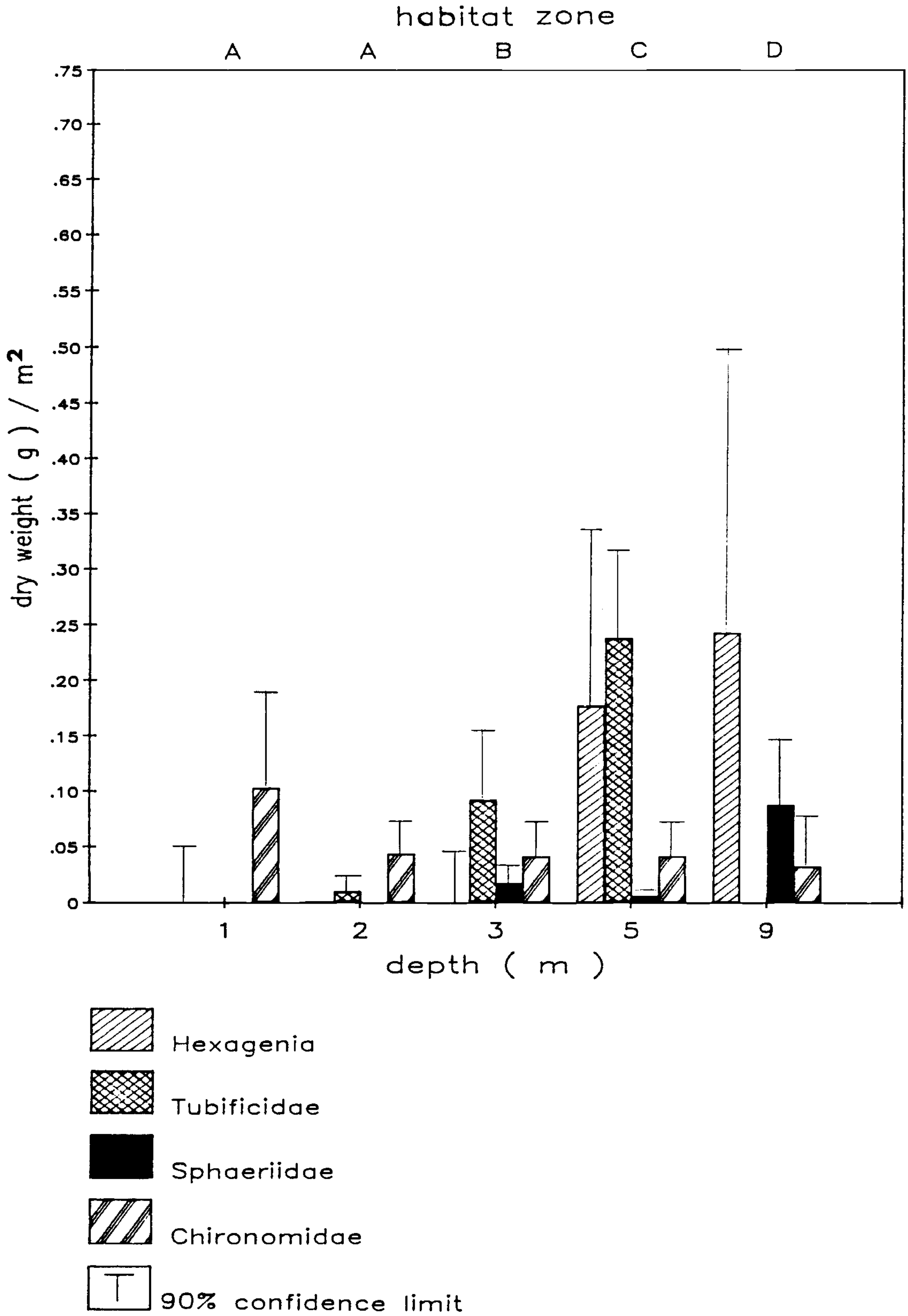

Figure 11b. Average biomass of Hexagenia, Tubificidae, Sphaeriidae, and Chironomidae in Carter Lake habitat zones in May.

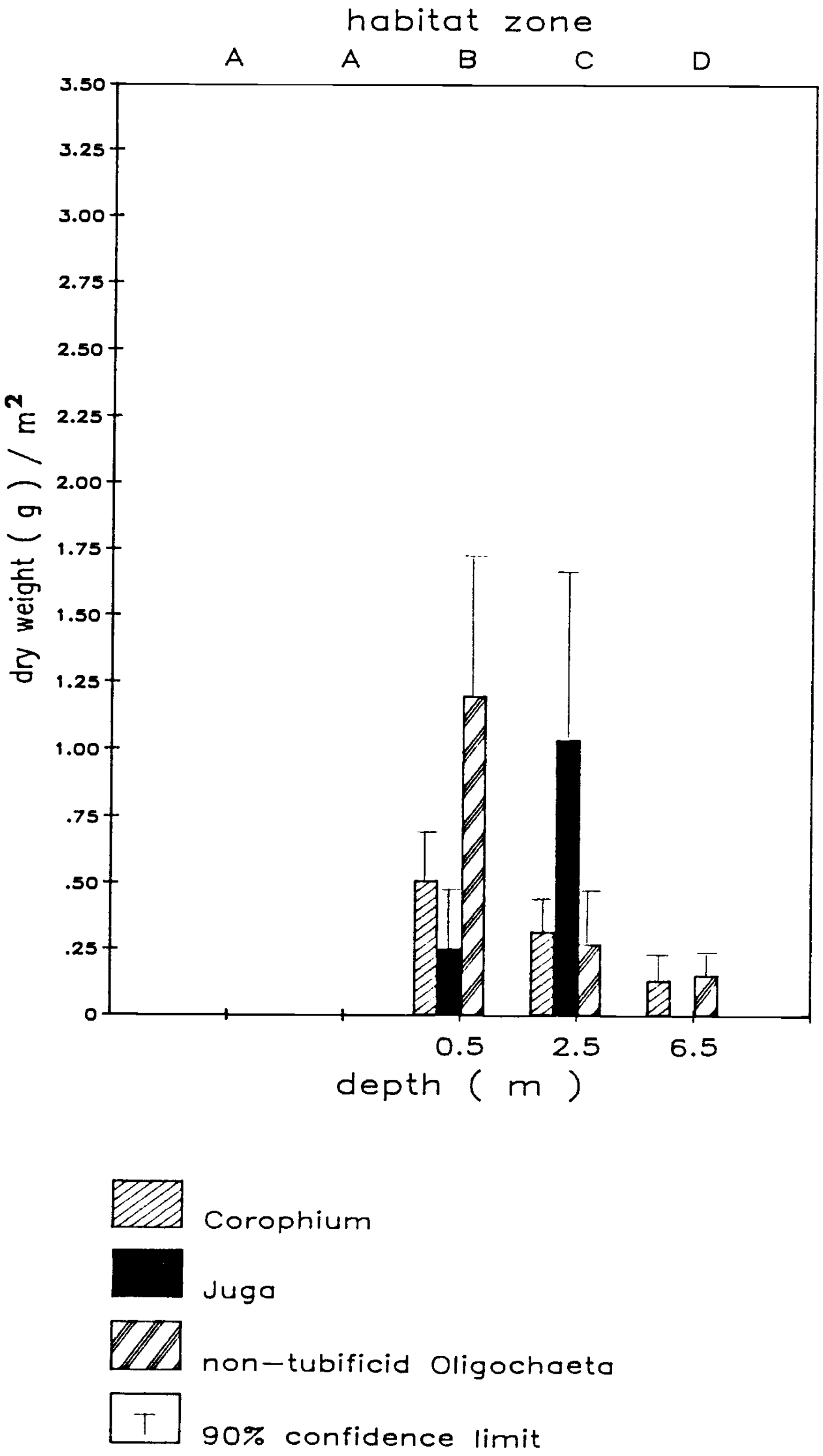

Figure 11c. Average biomass of Corophium spinicorne, Juga plicifera, and non-tubificid Oligochaeta in Carter Lake habitat zones in October.

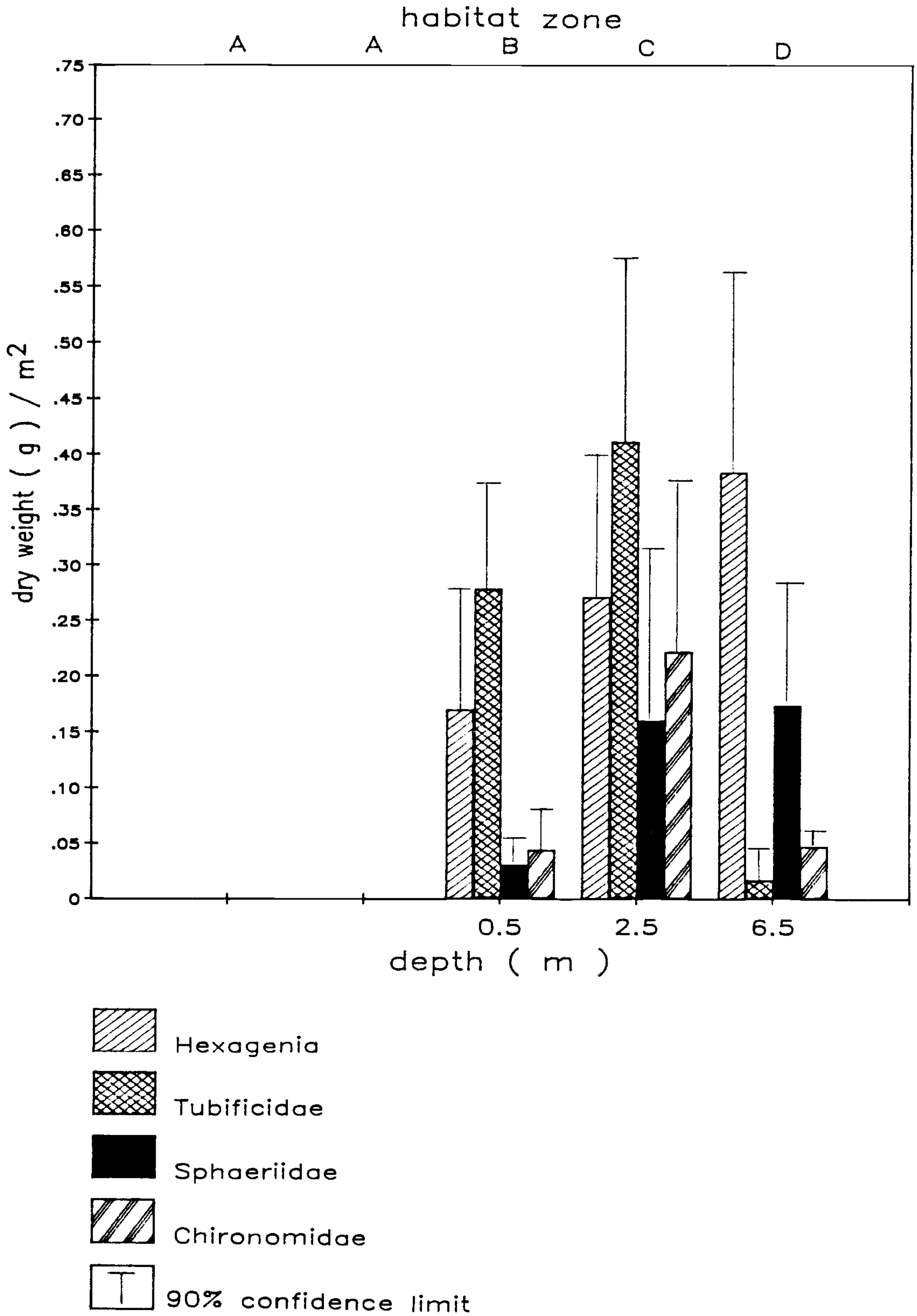

Figure 11d. Average biomass of Hexagenia, Tubificidae, Sphaeriidae, and Chironomidae in Carter Lake habitat zones in October.

was in May except that Corophium made up a smaller proportion. In habitat C, M. falcata and Pacifastacus each made up about 32% of the biomass. The remainder of the biomass was diverse with Juga, Tubificidae, and Corophium being the most important (Fig. 10c). Hexagenia was the dominant contributor to the biomass in habitat D in October (Fig. 10b) as it was in May (Fig. 10a) with Sphaeriidae and non-tubificid oligochaetes second and third in importance. Corophium was also a significant part of the biomass in habitat D in October in contrast to its absence from this zone in May.

Fish stomach contents

The stomach contents of two 26-27 cm rainbow trout (Salmo gairdneri) that were caught from the lake in May were examined and the results are shown in Table 7. A yellow perch (Perca flavescens) that was caught in May vomited several Corophium when brought into the boat; this fish was released.

Table 7. Stomach contents of two rainbow trout (Salmo gairdneri) caught from Carter Lake, Douglas County, Oregon in May, 1986.

taxa	trout #1	trout #2
Sphaeriidae	1	-
Juga plicifera	-	3
Acanthomysis awatchensis	4	-
Corophium spinicorne	14	1
Hexagenia	4	1
total	19	5

DISCUSSION

Water Characteristics

The 2.5 m drop in water level between May and October 1986 resulted in a 40% decrease in lake area that left habitat zone A exposed. The drop in water level coincided with an increase of some shallow water animals (*Corophium* and *Juga*) in deeper portions of the lake basin. In October, numerous empty *Corophium* tubes were found washed up on the lake shore in areas that had supported a dense population of *Corophium* earlier in the summer, indicating that these areas had been recently disturbed.

In addition to direct alteration of benthic habitats, water level fluctuations can determine the zonation of aquatic vegetation through wave action, drying, and light limitation (Smith et al 1987 after Quennerstedt 1958; Hunt and Jones 1972). In Carter Lake, the distribution of *Nitella* appears to be influenced by water level as it was only found in a 2 m depth range well below the lowest observed water level. Marginal vegetation also was affected by fluctuating water level. *Carex* and *Mentha* grew in some areas of habitat A and were covered by high water in April. This vegetation may have been an important food source for detritivores (numerous *Juga* were observed grazing on submerged *Carex* in shallow water in May), and provided surfaces for invertebrates to cling to until it died back (mid-June). At low water in October, the only submerged vegetation observed, other than *Nitella*, grew in a small area by the boat ramp.

Carter Lake is probably polymictic (i.e. having continuous mixing or several periods of mixing during the year), resulting in very similar water characteristics at all depths. Seasonal temperature changes on the Oregon coast are generally gradual, leading to deeper mixing of surface waters than would occur with rapid warming. Because Carter Lake is fairly shallow, especially in late summer, deep mixing results in holomixis. Green (1975) described this deep mixing phenomenon associated with gradual daily temperature increase in Lake Ototoa, a coastal dune lake in New Zealand which is also subject to a mild oceanic climate (Green,1975). The north-south orientation of Carter Lake exposes it to wind, since winds on the Oregon coast generally blow northwest to southeast in the summer and southwest to northeast in the winter (Cooper, 1958). For these reasons, thermal stratification may be unusual at Carter Lake. Nevertheless, in contrast to the results of this study, thermal and chemical stratification was observed at Carter Lake in September, 1948 (Saltzman, 1961a) (Tables 2a,b). Average daily air temperatures in the area were lower in the first four months of 1948 than in 1986, similar in May through July of both years, and higher in August and September of 1948 than in 1986 (fig. 12) (U.S. Department of Commerce, 1948 ; National Oceanographic and Atmospheric Administration 1986). These temperature differences may have accounted, at least in

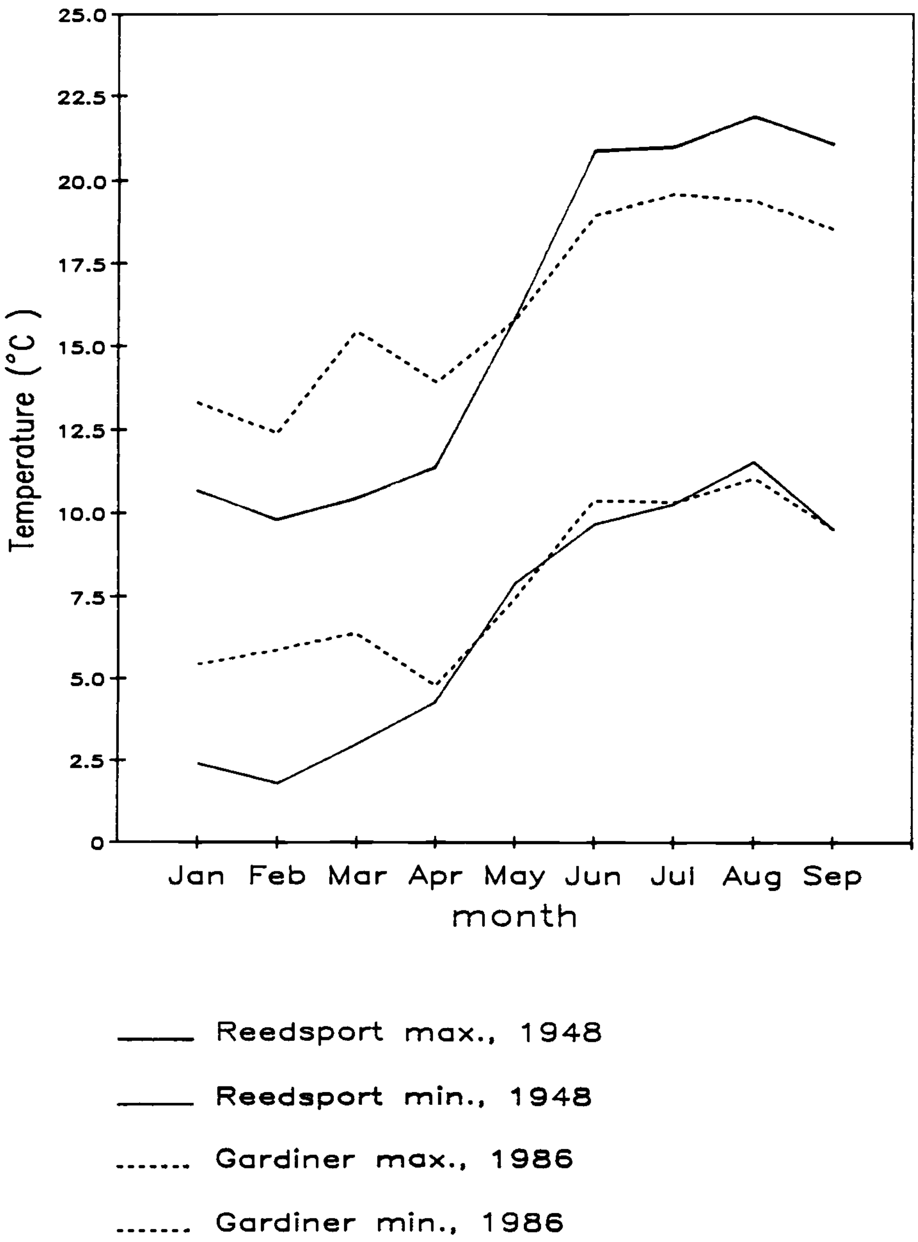

Figure 12. Monthly average daily air temperature maxima and minima, January through September 1948 and 1986.

part, for the stratification in 1948. Thermal stratification is an important factor in determining the distribution of the benthos in that the deep water areas of stratified lakes can become very low in oxygen, as was recorded in 1948 (Saltzman, 1961a) (Table 2b). Because Carter Lake did not stratify in 1986, differences in water chemistry from surface to bottom were slight, and probably not great enough to be of any importance in determining the BMI community composition and distribution.

Dune lakes vary greatly size, basin shape, and water quality (Tables 8a and 8b). Some, like Carter Lake, seldom stratify, while others in more protected basins do. For Oregon dune lakes, water clarity, measured as Secchi disk depth, varies from as low as 0.3 m at West Lake (Sanderson et al 1973) to >7.0 m in Clear, Edna, and Teal Lakes (Rinella 1979). Some dune ponds are only temporary, while permanent lakes range up to >33 m in depth (Rinella 1979) and over 300 ha in surface area (Saltzman 1962). With a Secchi disk depth of 4-4.5 m, maximum depth of 10 m, surface area of 12 ha, pH of 7.2-6.9, alkalinity of 13.43 mg $CaCO_3$ and conductivity of 133.65 mhos / cm, Carter Lake is in the median range of these parameters for Oregon dune lakes.

Secchi disk depth of dune lakes is correlated with maximum lake depth to some degree (R^2=.323) (Fig. 13). The Oregon dune lakes showed a stronger correlation (R^2=.425) than the other dune lakes (R^2= .290). The

Table 8a. Water Characteristics of 18 Oregon dune lakes.

Lake	Zmax (m)	S. Area (ha)	deltaT (C)	O2 dep.	Cond. (µS/cm)	Alk. (mg CaCO3/l)	pH surface	pH bottom	Secchi (m)	Date	Ref
Carter	8.5	-	2.1	no	133.65	13.43	7.2	6.9	4.5	6/86	A
Carter	>3.7	12	0.6	no	132-135	11	6.9	6.8	>3.7	10/77	B
Carter	>7.3	-	4.5	yes	-	-	6.7	6.2	-	9/48	C
N. Threemile	>6.1	12	0	no	157	14	7.3	7.3	3.4	10/77	B
S. Threemile	>9.1	14	0.1	no	149	11	7.6	6.4	4	10/77	B
Perkins	>9.5	1.6	8	yes	95-109	11	6.8	6.18	3.4	5/78	B
Munsel	22.9	41.71	14	yes	-	2.4-13	7.4	6.2	3-4.9		L
Clear	24.4	60.35	-	yes	-	12-21	7.6(c)	6.1(c)	3.7-8.8		L,O
Floras	11.3	90.32	small	no	-	10-16	7.2-7.6	-	turbid		L
Woahink	27(d), 21(e)	318.74	5(e)	yes(e)	-	7-8.5(1968) 9-15(1947(f))	7.8(f)	6.3(f)	3.66-7.32	47;8/60;68	D,E, F
Mercer	11.6	138.1	6.7	yes	-	8-34	7.5	6.5	3.7-4	summer/59,60	G
	12.5		10.5	yes	-	17sur-54bot	6.6	6.6	3	10,12/38;1/48;7/60	H
Sutton	10.4(h)	51.5(h)	10(i)	yes	-	8sur-54bot(i)	7.4(f)	6.4(f)	3.4(h),3.7(f)	38;48;60;73	H,I,F
Town	4.27	3.93	-	slight	-	26-27	7	6.9	1.5-1.8	summer/59,60	J
Daley	2.44	7	small	-	-	31	7.4	-	-	8/60	K
Collard	15.8	14.1	10	yes	64-75(f)	12sur-23bot	7.6	6.7	6.1		M,F
Cleawox	14.6	33.2	6.1(6/73)	slight	103-115	8-12	6.6	-	3.8-5.0		F
Buck	8-10(I)	1.62	9.2(Sept)	yes(Sept)	92-103	7.3-6.8	6.6	5.7	4.9	72;73	F,N
Alder	10.7	1.22	10.8(Jun)	yes(5,8,9)	95-108	7.7-12	6.2-7.5	5.8-6.5	3.0-4.6	4,5,6,8,9,11/72	F
Dune	10.4	1.22	12.5(Aug)	yes(5,8,9)	97-115	7.4-15.1	6.0-6.9	5.9-6.6	2.4-4.0	4,5,6,8,9,11/72	F
Coffenbury	>2.7	20.3	0.2	no	110	15	7.6	7.4	1.8	8/72	M
AVERAGE	**11.3**	**45.7**			**113.6**	**14.5**	**7.2**	**6.5**	**3.8**		

zmax= maximum depth
S. Area= surface area
delta T= maximum vertical temperature difference
O2 dep. = oxygen depletion
Cond. = conductivity
Alk. = alkalinity
Secchi = secchi disk depth
Ref= references

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Table 8b. Water Characteristics of 14 selected dune lakes worldwide.

Lake	Zmax (m)	S. Area (ha)	deltaT (C)	O2 dep.	Cond. (µS/cm)	pH Surface	pH Bottom	Secchi (m)	Date of sampling	Location	Ref
Whitney	2.3	182	5(March)	yes	-	4.5-6.0	3.5-5.9	0.5	1,3,5,7,9,11/77	Ga, USA	A
Minnie Water	10	52.1	-	-	-	6.1-6.3	-	3.27	1975-1979	NSW, Aus.	B
Hiawatha	11	315	-	-	-	6.3-6.5	-	5.11	1975-1979	NSW, Aus.	B
Elusive	21	22.2	10	slight	-	6.1-6.8	-	0.58-0.94	1/70; 8/71	Vic, Aus.	C
Barracoota	8	244	0	slight	-	7.3-5.9	-	0.82-1.8	12/69; 6/70	Vic, Aus.	C
Wabby	11.5	3.0	5(Oct,Dec)	yes	147	6	-	7.2	1984	Qnsl,Aus.	D
Ototoa	26	162.3	8.6	yes	-	7-8	6-7.5	6-9	1969-1970	N.Is. NZ	E
Waiparera	5.8	117.4	0	no	-	6.6	-	2.5	summer/49,50	N.Is. NZ	F
Ngatu	6.0	62.19	0	no	-	6.2	-	4.0	summer/49,50	N.Is. NZ	F
Swan	5.5	17.2	0	no	-	6.2	-	2.0	summer/49,50	N.Is. NZ	F
Pokoroa	4.5	28.09	0	no	-	6.6	-	1.0	summer/49,50	N.Is. NZ	F
Oturi	6.5	11.62	0	no	-	8.0	-	1.75	summer/49,50	N.Is. NZ	F
Kopurehereho	12	7.85	11	yes	-	-	-	0.75	1/77	N.Is. NZ	F
Sibaya	39		0.2	slight	-	-	-	-	-	S. Africa	G
AVERAGE	12.1	94.2				6.5		2.9			

Zmax = maximum depth
S. Area = surface area
delta T = maximum vertical temperature difference
O2 dep. = oxygen depletion
Cond. = conductivity
Secchi = secchi disk depth
Ref = references

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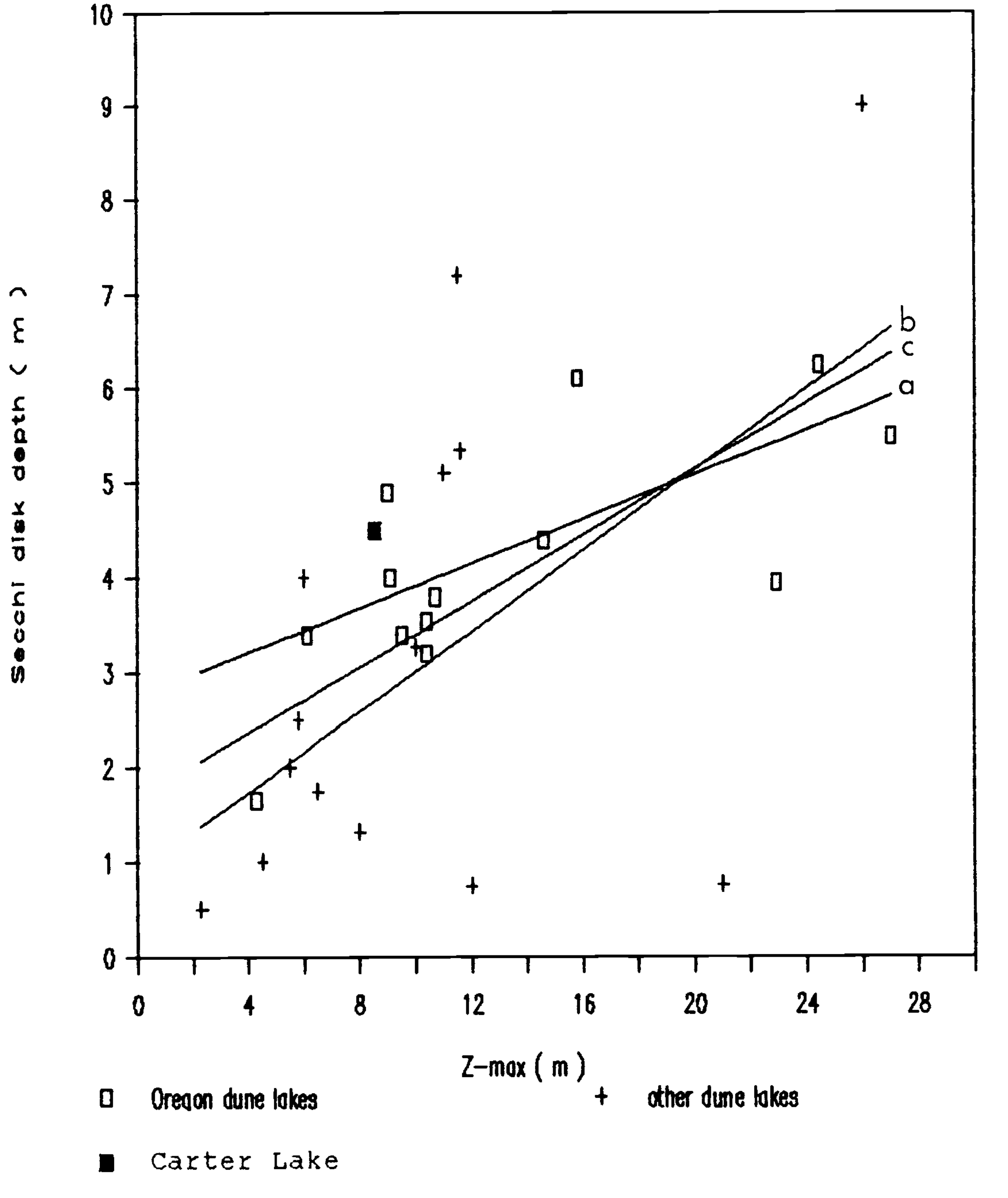

Figure 13. Secchi disk depth (Z_{sd}) VS maximum depth (Z-max) of dune lakes in Oregon and worldwide. a= linear regression of Z_{sd} on Z-max of Oregon dune lakes, R^2=0.425. b= linear regression of Z_{sd} on Z-max of other dune lakes, R^2=0.290. c= linear regression of Z_{sd} on Z-max of all dune lakes, R^2=0.323.

Secchi disk depth of Carter Lake (4-4.5 m) is deeper than average for its maximum depth (10 m).

Substrate Characteristics

The sediments of Carter Lake are fairly representative of Oregon dune lakes (Table 9) with sand in shallow areas grading into soft mud in deep areas. Mechanical sorting by wave action causes finer and less dense sediment to be removed from the shallows and to be deposited lower in the lake basin (Benson and Hudson 1975; Hunt and Jones 1972). Because the level of Carter Lake changes over 2 m during the year, the upper 2 m area is subject to wave action at some time during the year and has sediment with very little organic matter.

With 0-16% LOI, Carter lake sediments are fairly low in organic content as compared to other dune lakes (Table 9). However, sediment organic content is quite variable among dune lakes and among lakes in general (Table 9).

Substrate/ Benthos Relationships

Infilling of lakes with sand can significantly decrease the diversity and quantity of benthic macroinvertebrates (Arthington et al 1986). Griffiths and Yeoman (1938) found that low benthic invertebrate production was associated with sandy lake bottoms in their study of Oregon coastal lakes. Their benthic biomass values (fresh weight) ranged from 23.9 g/m^2 in Mercer Lake to

Table 9. Sediment Characteristics of selected lakes.

Lake	LOI, %of Dry Wt.	Depth (m)	sediment description	Reference
			Dune Lakes	
			(Oregon, USA)	
Carter	0-16	0-9	sand(shallows) to brown or dark brown mud (deep)	A.
South Threemile			Primarily sand	b.
North Threemile			Primarily sand	b.
Perkins			Primarily sand	b.
Munsel		.3-.6	sand	q.
		1.5-9	sand and muck	
		12.2-15.2	muck	
Clear		shores	sand on NW side, some bedrock on E side	r.
Woahink		shores	sand	d.,e.
		deeper water	silt, mostly muck some sand and clay at 6-9m	
Mercer		.3-4.6	sand or sandy muck	g.
		6-9	sandy muck or muck	
Sutton		shore	sand on part of W side	h.
		1.5-4.6	muck w/ up to 30%sand	i.
Town			muck w/ sand particles	j.
Daley		.3-.6	sand on W side	k.
		1.5-2.1	sandy muck or black muck	
Collard		shore	dune on W side, sandstone on E side	
		.3-4.6	sand	l.
		6.1-9.1	sand and muck	
Buck	12-48 (top 2cm)	9	brown, 45% sand	s.
Alder	35-45	10.7	dark brown, 28% sand	s.
Dune	20-40	10.4	brown, 62% sand	s.
			(Georgia, USA)	
Whitney	6.94-18.2(TOC)		black,organic "gyttja"	n.
			refractory "dy"	z.
			(New South Wales, Australia)	
Minnie Water	49.4	9.5	soft organic ooze	o.
Hiawatha	22.1	10.7	sandy	o.
			(Victoria, Australia)	
Elusive	20	20	sand<6m, fine black mud 6-8m	p.
Barracoota			sand, brown mud, organically bound sand	p.
			Other Lakes	
			(Connecticut and New York, USA)	
33 Connecticut and New York lakes	7.9-38.5			D.
			Poland	
various olig.	11-20			F.
various mes.	17-30			F.
various eut.	17-60			F.
various dys.	76-82			F.
oligotrophic	16-25			G.
mesotrophic	18-25			G.
eutrophic	23-69			G.
			Worldwide	
various olig.	12-85			E.
various mes.	8-30			E.
various eut.	8-61			E.

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2.37 g/m^2 in Woahink Lake. These values are equivalent to dry weight values of about 2.988 to 0.298 (estimated by dividing fresh weight values by 8 (Larson 1973)). While a large proportion of Carter Lake has sandy bottom, its overall biomass averages (dry weight) were 2.58 g/m^2 in May and 3.61 g/m^2 in October, relatively high in comparison to Griffiths and Yeoman's data. Insects were sparse in the sandy areas of Carter Lake, however _Corophium_, _Juga_, and Oligochaetes flourished in these areas of low sediment organic content (Figs. 8 and 11b). While _C_. _spinicorne_ do feed on particles at the sediment surface, they also filter particles from the water they circulate through their burrows (Miller 1984) and so they are not necessarily dependant on sediment for their food. Available organic matter in these areas may be of high nutritive quality to _Juga_ and oligochaetes.

Epipsammic production may be important to the benthos of Carter Lake, as it is in Lake Sibaya, South Africa. Epipsammic primary production in Lake Sibaya was found to be significant in the upper 1 cm of sand from 1 m to at least 3 m depth in the lake (Allanson, 1979a). When algae reproduce rapidly, a small standing stock can support a larger stock of herbivores (Minshall 1978; McIntire 1973), offering one explanation of the large macroinvertebrate biomass in sediment low in organic content in Carter Lake.

The distribution of the snail, _Juga_ _plicifera_ (Figs.

11a and 11c) implies that it may be a consumer of epipsammic algae in May and epiphytic algae in October. J. plicifera were found almost exclusively in shallow water (habitat A) in May, and almost exclusively at mid-depth (habitat C) in October. In October, little silt-free sand was available and the only submerged vegetation was Nitella in habitat C. All J. plicifera observed in this zone were on Nitella rather than the sediment. Nitella may become a more desirable grazing area in October due to an increase in epiphytic algae that would be expected with higher light intensity resulting from lower water level. Very few Juga were found on Nitella in May, when the water level was high, suggesting that Nitella itself is not desirable as food. Collection by sweeping indicated that submerged Carex also supported some Juga in May.

Large non-tubificid oligochaetes may also be consumers of epipsammic algae. These worms were generally found in shallow areas with sandy substrates. Their guts were often visible without dissection and usually contained sand grains. Smaller worms probably did not utilize epipsammic algae, as they were found mainly in deeper areas with silty substrates.

As the water level dropped from May to October, large areas occupied by Corophium (habitat zone A) dried up and the abundance and biomass of Corophium per unit area increased in habitat zones C and D, without changing significantly in zone B. The abundance of Corophium in habitat B was $7800/m^2$ to $14600/m^2$ in October; the latter is fairly high for a natural population (Aldrich 1961; Siegfried et al 1980; McCarthy 1973). When the lake level drops, competition for space may drive Corophium into less favorable habitats.

Large individuals of the mayfly, Hexagenia, were found in deeper areas (habitat zones C and D) with soft sediment high in organic matter. Hexagenia are burrowers (Merritt and Cummins, 1984), and are not able to construct burrows in sand (Lyman 1943). Small individuals, however, were most abundant in shallow sandy areas. Cowell and Hudson (1967) attributed higher densities of Hexagenia that they observed in the shallow areas Lewis and Clark Lake, Missouri, to the tendency of females to deposit eggs "close to shore." This may also be the case in Carter Lake, however, no point in Carter Lake is more than about 85 m from shore. As in Carter lake, small Hexagenia nymphs of Big Silver Lake, Michigan were found on sand shoals in late summer with an apparent migration to deeper areas with softer bottom as the nymphs matured (Hunt 1953).

Hexagenia were much more abundant in October than in May, probably because of their life cycle. Hunt (1953) found Hexagenia limbata populations emerging throughout the summer beginning in May and that eggs hatched about three weeks after fertilization (in the laboratory). As mortality claims members of a cohort, the Hexagenia population would be expected to shrink through the year to a low at the onset of emergence, before the young of the year have been added. Hexagenia exuviae were observed on the lake surface in June 1986 indicating emergence at that time. While the abundance of Hexagenia was significantly greater ($0.10 > P > 0.05$ in habitat D; $0.05 > P$ in habitats B and C) in October, biomass was only significantly greater ($0.10 > P > 0.05$) in habitat zone B where large numbers of small nymphs were found in October and virtually none was found in May.

In addition to the direct effects of providing food and habitat for BMI, the sediment type may affect the growth of submerged macrophytes (Barko and Smart 1986). The sediment density and % in the finest (<.125 mm) fraction in zone C (where Nitella, the only submerged plant that grows in any quantity in Carter Lake, was found) were intermediate between these values for zones B and D. However, the range of sediment organic content was rather broad (1.47% to 14.17% LOI), and the distribution of Nitella may be in response to wave action and light as well as sediment type.

Diversity

Diversity was highest in habitat C because more taxa were found at this elevation and no taxon overwhelmingly dominated the community. Because habitat C is mid-depth in the lake, it is intermediate in sediment characteristics (particle size distribution, density, and organic content) and light intensity. Enough light penetrates to habitat C to allow Nitella and probably epiphytic algae to grow and provide food and surfaces for animals to cling to. Nitella may also be important in offering cover from predacious fish and newts. Because habitat C is below the deepest point of surface wave influence, the sediment is muddy sand, which may appeal to a larger number of taxa than pure mud or sand. Sand is available for tube builders (Corophium and Tanytarsini), the sediment is probably more habitable to burrowers (Hexagenia, Orthocladiinae, Chironomini) than the clean sand of the shallows, and fine detritus is available for detritivores.

The intermediate depth of habitat C allows recruitment into this zone from deep or shallow water. Movement of Corophium and Juga from habitat A to habitat C appears to have occurred in 1986 with the drop in water level. At the same time, the number of Hexagenia nymphs in habitats C and D increased, probably due to their life cycle as described in the previous section. Thus, Habitat C may function as a refuge for mobile organisms from other habitat zones experiencing extensive environmental changes such as the desiccation of habitat A as the water level dropped from May to October. Furthermore, shifts in the distribution of mobile species from habitat D to C could occur in Carter Lake during periods of oxygen depletion (eg. Hexagenia will leave their burrows under conditions of oxygen stress;

Eriksen 1964, and are thought to migrate away from areas of low oxygen; Cowell and Hudson 1967; Hunt 1953) as reported by Saltzman (1961). How mobile organisms might migrate in response to fluctuating water levels and deep water oxygen concentrations is shown in Figure 14.

Decreasing lake level and low oxygen would be expected to occur during summer, although oxygen depletion may only occur occasionally. In fall, cool weather can break down stratification, raise the profundal oxygen level, and allow the migration of invertebrates from habitat C back to habitat D. The level of the lake rises in spring, and populations of *Corophium* and *Juga* can re-establish themselves in habitat A from habitats B and C.

Low diversity at both ends of the depth gradient in Carter Lake suggest that many taxa in the lake are affected by depth dependant variables.

The greatest single factor determining the relatively low diversity in habitats A and B is the dominance of *Corophium* in these zones. Because of the ephemeral nature of habitat A, only organisms that can migrate in and out of it are successful. *Corophium* have demonstrated their mobility in the San Joaquin River estuary where they have been found to inhabit temporary sand areas at different depths at different times of the year (Aldrich, 1961).

In habitat D, lower light intensity may limit benthic primary production. No macrophytes grew in habitat D and benthic algae may also be scarce. Low productivity limits

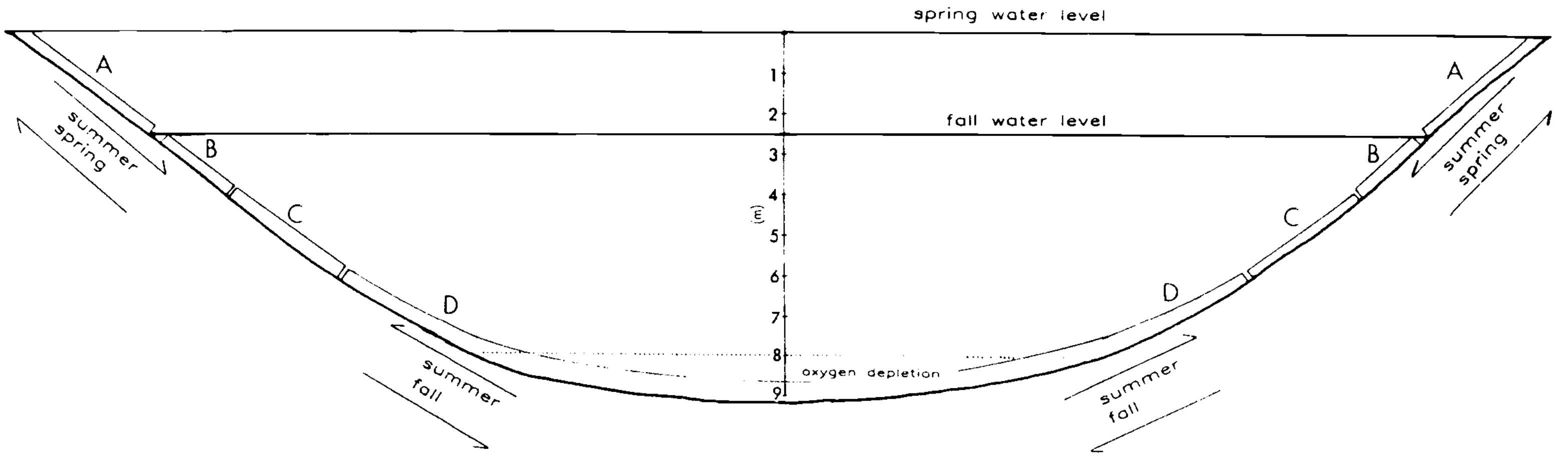

Figure 14. Conceptual diagram of benthic macroinvertebrate migration in Carter Lake. A, B, C, D = habitat zones. Arrows indicate direction of benthic macroinvertebrate migration.

the variety of food types available to macroinvertebrates and could lead to the lower diversity observed in this zone.

Diversity was higher in October than in May in zones B and D because of an increase in the abundance of many taxa, rather than the addition of many new taxa. This change was probably due, in large part, to the life cycles of the taxa that increased. Dropping water level also probably contributed to this change by displacing organisms from habitat A into the other zones, while Corophium abundance remained about the same in habitat B where it was most dominant.

Notes On Selected Taxa

Corophium spinicorne

Notes on C. spinicorne are given here because it was the most numerous species in Carter Lake and is not a typical lacustrine species. C. spinicorne have been found from Amchitka Island, Alaska (Shoemaker 1949) to Oso Flaco Lake, San Luis Obispo County, California (Eriksen 1968). It is the largest species of Corophium on the west coast of North America (males up to 8 mm from front of head to end of uropods, females up to 10 mm) (Shoemaker 1949). C. spinicorne is found in estuaries from fresh to sea water (Felice 1958) and has been collected from a few freshwater coastal lakes (Merced Lake, California (Shoemaker 1949); Oso Flaco Lake, California (Eriksen

1968); Cleawox Lake, Oregon (McCarthy 1973), and Carter Lake, Oregon (this study)). An unidentified species of Corophium has also been collected from Woahink Lake (Saltzman 1962).

C. spinicorne show a preference for sandy substrate (Felice 1958; Aldrich 1961; Eriksen 1968; McCarthy 1973) and an aversion to peat or mud substrate (Aldrich 1961; Eriksen 1968) in natural environments. Corophium spp. have also shown specific substrate preferences in laboratory studies (C. volutator and C. arenarium by Meadows 1964a,b,c; and C. salmonis and C. spinicorne by McCarthy 1973).

C. spinicorne reside in U-shaped burrows of mucous cemented sand (Eriksen 1968) or in tubes constructed on submerged surfaces (McCarthy 1973). Feeding is accomplished by filtering suspended particles from water circulated through their burrows via pleopodal current and by scraping particles into their burrows from the sediment surface with their second antennae. During suspension feeding the setae of the second gnathopods act as a filter for suspended particles (Miller 1984). Corophium spinicorne in Carter Lake are unusual functionally as filter feeding benthic arthropods.

Although C. spinicorne is the only species of Corophium found in freshwater on the west coast of North America, analogous euryhaline species C. curvispinum in Europe (Taylor and Harris 1984a,b) and C. triaenonyx in

South Africa (Hart 1979) have been found in freshwater.

Pacifastacus leniusculus

The crayfish *Pacifastacus leniusculus*, is highly mobile and probably not efficiently sampled by the Ekman grab sampler. However, *P. leniusculus* probably comprise a considerable part of the BMI biomass. Although the largest specimen collected was only about 3 cm long, adult crayfish over 10 cm in length (rostrum to telson) were seen in habitat zones B and C. Ten cm wide *Pacifastacus* burrows were also seen in these zones. Crayfish are omnivorous and eat "all kinds of succulent aquatic vegetation" (Pennak 1978). *P. leniusculus* may keep some types of aquatic vegetation grazed down in Carter Lake as *Orconectes causeyi* have been shown to do when introduced into a weedy lake (Pennak 1978). However, *Nitella* growth is quite dense in some areas of Carter Lake.

Margaritifera falcata and Corbicula fluminea

The bivalves *M. falcata* and *C. fluminea* may be important in the overall trophic dynamics of the lake biota in that they are able to filter considerable quantities of phytoplankton from the water (Cohen et al, 1984) and to make nutrients available to invertebrates in their immediate area through deposition of feces and pseudofeces, i.e. filtered but unused seston and mucus (Sephton et al, 1980). Unfortunately, not enough specimens of *M. falcata* or *C*. *fluminea* were collected to estimate their abundance or impact on neighboring bottom fauna. While *M*. *falcata* are reportedly found in sand or gravel substrates (Clarke, 1981), they were mainly seen in mud in Carter Lake. Visual observations indicated that some areas support ≥ 2 individuals of *Margaritifera* / m2. While bivalves are rare in comparison to other taxa in the lake, their biomass is considerable.

The asiatic clam *Corbicula* was introduced into the Columbia River system around 1938 (Felice 1958) and is currently spreading through most of the southern and central United States (Clarke 1981). The shells of *Corbicula* are variable in shape from ovate to triangular depending on any or all of the following: species, population, sediment, and age (Sinclair and Isom 1963). All of the specimens collected from Carter Lake (6 total) were ovate and found in sand (habitat B) or sand and mud (habitat C).

Vertebrate Predators

Several vertebrate species that prey on benthic macroinvertebrates (*Taricha granulosa*, Cottidae, *Perca flavescens*, and *Salmo gairdneri*) were observed in Carter Lake. What effects predators have on benthic community structure is a somewhat controversial topic (Post and Cucin 1984; Thorp 1986). However, Post and Cucin (1984) reported a decrease in biomass and mean weight per individual, and an increase in density of benthic macroinvertebrates in some depth zones of a lake after introduction of yellow perch, _Perca flavescens_.

In 1986, many successful anglers were seen at Carter Lake at the beginning of the trout season (April and May) and some in June. After this time few (and less successful) anglers were seen. I only caught a few yellow perch and no trout on hook and line after June. Because the trout population in Carter Lake was stocked and received heavy fishing pressure in the spring, any effects of trout on the benthos are not constant through the year, or even the summer.

BMI Community Comparisons

Because most studies of the benthos of Oregon dune lakes have been reported without detailed information on the methods used, true comparisons between studies cannot be made. In some lakes representative depths have been sampled on one or two transects, in others a stratified random sampling method was employed, and in some reports no information of the whereabouts of sampling locations is given. Some investigators picked organisms that they could see with the unaided eye from sediment grab samples while others strained samples through screens of unreported mesh size. Tables 10a and 10b compare the Carter Lake benthos to several other dune lakes (and the Sacramento River) that have been studied. Because of the inconsistency in methods,

Table 10a. Presence (+) of non-insect taxa identified from Carter Lake (1986) at; Carter Lake (1948), 16 other dune lakes, and the Sacramento River.

Lake	Carter	Cleawox	Munsel	Clear	Woahink		Mercer		Sutton		Town	Daley	Collard	Oso Flaco	Whitney	Minnie Water	Hiawatha	Elusive	Barracoota	Sibaya	Sacramento River
Turbellaria														g	s						
Pelecypoda	+	+				+	+		+											s	s
SPHAERIIDAE			+	+				+	+		+	+	+		g			g		s	
CORBICULIDAE																					
<u>Corbicula</u> <u>fluminea</u>																				s	s
Gastropoda		+				+	+					f		s	g				s	s	
<u>Physa</u>														+	+						
PLEUROCERIDAE			+	+	+			+		+	+		+								
Annelida	+					+			+										g	s	s
Oligochaeta			+	+	+			+		+	+	+	+							+	
TUBIFICIDAE														s	s		+				+
other Oligochaetes															s						+
Hirudinea														+	s						+
Acarina						+				+	+				+		+		+		
Crustacea																		s	s	g	s
Ostracoda									+					+						s	+
Malacostraca																				s	
Mysidacea								+		+		+	+								
MYSIDAE					+																
<u>Acanthomysis</u> <u>awatchensis</u>																					+
Isopoda	+						+												f	s	+
SPHAEROMIDAE										+		+							+		
<u>Gnorimosphaeroma</u> <u>oregonensis</u> <u>lutea</u>														+							s
ASELLIDAE								+		+		+									
<u>Asellus</u>																					+
Amphipoda	+					+															
TALITRIDAE					+			+		+	+									s	
<u>Hyalella</u> <u>azteca</u>														+							
GAMMARIDAE												+			g						
<u>Anisogammarus</u>																					
COROPHIOIDEA																				s	s
<u>Corophium</u> <u>spinicorne</u>						g								+						s	+
Decapoda								+		+	+		+							s	s
ASTACIDAE																					
	A	B	C	D	E	F	G	H	G	I	J	K	L	M	N	O	O	P	P	Q	R

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R. Siegfried et al 1980

The letters o, f, g, s, indicate the lowest level of taxonomic identification reported in the references cited, when different from Carter Lake benthos (e.g. Eriksen (1968) reported finding a turbellarian of the genus <u>Dugesia</u> from Oso Flaco Lake, so the letter "g" is found in the "Turbellaria" row and Oso Flaco Lake column. Smock et al reported finding <u>Dugesia</u> <u>tigrina</u> and <u>Cura</u> <u>foremani</u> so the letter "s" is found in the "Turbellaria" row and Whitney Lake column).

Table 10b. Presence (+) of insect taxa identified from Carter Lake (1986) at; Carter Lake (1948), 16 other dune lakes, and the Sacramento River.

Lake	Carter	Cleawox	Munsel	Clear	Woahink	Mercer	Sutton	Town	Daley	Collard	Oso Flaco	Whitney	Minnie Water	Hiawatha	Elusive	Barracoota	Sibaya	Sacramento River
Insecta					o	o	o											
Ephemeroptera	+	+			+	+				+		s			+	g	s	
BAETIDAE												s		g			g	
Baetis																		
EPHEMERIDAE			+		+	+	+											
Odonata						+									+	s		
Zygoptera							+		+	+								
COENAGRIONIDAE					+						+	g				s		
Anisoptera		+			+	f				+		s			s	s		
LIBELLULIDAE							+					s						
Libellula												s						
Hemiptera								f			g	s				g		
Gerris												s						
CORIXIDAE								+			+	s						
Callicorixa																		
Megaloptera																		
SIALIDAE	+				+	+	+	+		+								
Trichoptera			+		+	+	+	+	+	+		g		g	f	g	s	
LEPTOCERIDAE												g						s
Mystacides																		
Oecetis												g		+		+	s	
Lepidoptera												g				+		
Coleoptera		+						f		+		s		+		s		
Gyrinus																s		
DYTISCIDAE							+					s					s	
Uvarus																		
HALIPLIDAE							+	+				s						
Haliplus										+								
Diptera	+			f	++	f	f	f		f		s						
TIPULIDAE									+			g						
CHAOBORIDAE						+	+	+		+							+	
Chaoborus					+	+	+					s	+	+	+			
CERATOPOGONIDAE							+					s		+	+	+		+
CHIRONOMIDAE		+	+		+	+	+	+	+	+					+	+	+	
TANYPODINAE												s		s			g	
Larsia												+						
Procladius												s	+	+		+	+	
Psectrotanypus																		
ORTHOCLADIINAE												s					g	+
Heterotrissocladius																		
Hydrobaenus																		
Parametriocnemus																		
Psectrocladius												+						
CHIRONOMINI					g	g	g				s	s	g	g	s	s	g	g
Cryptochironomus																		
Demicryptochironomus																		
Dicrotendipes												+				+		
Endochironomus												+						
Paracladopelma																		
Phaenopsectra																		
Polypedilum												s		+				
TANYTARSINI												g				+	g	
Tanytarsus												+					+	+
TABANIDAE												g						+
Chrysops												+						
Silvius																		
References	A	B	C	D	EF	GH	GI	J	K	L	M	N	O	O	P	P	Q	R

References

A. Saltzman 1961a
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C. Oakley 1962e
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E. McGie and Brueser 1962
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H. Oakley 1962d
I. Oakley 1962c
J. Oakley 1962a
K. Oakley 1962b
L. Anonymous 1962
M. Eriksen 1968
N. Smock et al 1981
O. Timms 1982
P. Timms 1973
Q. Hart 1979
R. Siegfried et al 1980

The letters o, f, g, s, indicate the lowest level of taxonomic identification reported in the references cited, when different from Carter Lake benthos .

only presence / absence data are presented.

Strong numerical dominance of malacostracean crustaceans sets Carter Lake aside from most other sand dune lakes. Only Daley Lake, Oregon (Oakley 1962b), Lake Sibaya, South Africa (Hart 1979), and Oso Flaco Lake, California (Eriksen 1968) share this type of composition. Large numbers of asselid isopods were collected from Daley Lake. Burrowing malacostraceans Grandidierella (Amphipoda) 45% , Apseudes (Tanaidacea) 33%, and Corophium (Amphipoda) 14% dominate the Lake Sibaya benthos (Hart 1979), as Corophium does in Carter Lake. Like Carter Lake, Oso Flaco Lake is a coastal dune lake and its BMI community is dominated by C. spinicorne, especially in sandy areas. Corophium have been reported from some other Oregon dune lakes (Woahink Lake (Saltzman, 1962), Cleawox Lake (McCarthy, 1973)). However, they were not collected from these lakes or from Carter Lake during other studies (Woahink: (McGie and Brueser, 1962), Cleawox: (Saltzman, 1961b), Carter: (Saltzman, 1961a)). Either the presence of Corophium is variable over time, or these studies are not comparable in their collection methods.

The benthos of Australian dune lakes are generally lower in numbers and diversity than Carter Lake, with chironomids dominating their communities. While some of these lakes have taxa with marine or estuarine affinities (a polychaete and two isopods in L. Barracoota (Timms 1973), Macrobrachium in L. Wabby (Arthington et al

1986), nothing analogous to the burrowing crustaceans in Carter Lake or Lake Sibaya has been reported from the Australian dune lakes.

The benthos of Carter Lake shows some similarities to some stations studied in the San Francisco Bay Estuary, Sacramento River (Siegfried et al 1980). Fifteen of thirty four taxa identified from the Sacramento R. were ones found in Carter Lake, with *Corophium* dominating the abundance in some areas.

Concluding Remarks

Benthic studies of Oregon dune lakes are few and limited in detail. A better understanding of dune lake ecosystems will be useful in insuring wise management of these lakes and in determining any temporal changes, either natural or induced by human activities. The potential for such changes is perhaps greater than with lakes of other areas because of the presence of moving sand. Activities that disturb the vegetation of dunes that border lakes can result in sand movement into these lakes which can in turn alter their morphology and benthic communities (Arthington et al 1986). If we are to understand dune lakes as ecosystems, information on all components of their biota, as well as their physical and chemical properties, will be needed.

Domination of the Carter Lake benthos by an estuarine species (*Corophium spinicorne*) sets this lake aside as different from most lakes that have been studied. *C. spinicorne* are suspension feeders and are able to live in clean sand where deposit feeding detritivores (that typically dominate lacustrine benthic communities) might be limited by food availability. The high density of this species indicates a fairly productive benthos that is probably an important part of the diet of fish in Carter Lake. Further benthic studies of coastal dune lakes are needed in order to classify Carter Lake as typical or unique among them in its benthic faunal composition.

It is my recommendation that future studies of Coastal lake benthic communities include samples taken during two or more seasons, sieve organisms onto a fine mesh screen (0.250 mm aperture), and collect from depths representing as many habitats as possible. If such studies are conducted and carefully reported, a reliable base of information will then be available for future assessment of changes or stability in the benthos of these lakes.

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