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ABSTRACT

The benthos of the Ottawa River was sampled near Ottawa-Hull, Canada, throughout 1973 as part of the Ottawa River Project. Nineteen stations encompassing a variety of environmental types were chosen in the study area.

Six species of sphaeriid clams (*Pisidium casertanum*, *P. punctatum*, *P. ferrugineum*, *P. supinum*, *P. nitidum*, *P. lilljeborgi*) and one amphipod crustacean (*Gammarus fasciatus*) were chosen for detailed analysis of population dynamics, standing crop, production, and turnover ratio. For two species, *P. casertanum* and *G. fasciatus*, relations between production and environmental parameters were determined.

Production of *P. casertanum* was affected by current velocity and sediment grain size while that of *G. fasciatus* could be related only to the presence of aquatic plants. Production of both species was reduced in that area polluted by the Canadian International Paper Company mill in Gatineau, Quebec.

The turnover ratio (the ratio of annual production to mean annual standing crop biomass) was found to be a constant for a species, even under the differing environmental conditions found.

Species diversity of sphaeriids was calculated for each station and was found to be closely related to sediment organic matter content.

Data are reported on dry weight, ash-free dry weight, and mercury and pesticide content for various groups of benthic organisms.

RÉSUMÉ

Le benthos de la rivière des Outaouais fut échantillonné près de Ottawa-Hull, Canada, tout au long de l'année 1973 dans le cadre du "Ottawa River Project". Dix-neuf stations, représentant différents types d'environnements furent choisies dans la zone étudiée.

Six espèces de moules sphaeritidées (*Pisidium casertanum*, *P.punctatum*, *P.ferrugineum*, *P.supinum*, *P.nitidum*, *P.lilljeborgi*) et un crustacé amphipode (*Gammarus fasciatus*) furent particulièrement étudiées par rapport à la dynamique des populations, au "standing crop", à la production, et au "turnover ratio". Les relations entre la production et les facteurs environnants furent déterminées pour les deux espèces, *P.casertanum* et *G.fasciatus*.

La production de *P.casertanum* fut affectée par la vitesse du courant et la grosseur des grains du sédiment, tandis que la production de *G.fasciatus* ne put être reliée qu'à la présence des plantes aquatiques. La production des deux espèces fut trouvée réduite dans la zone polluée par le moulin de la Compagnie de Papier Canadienne Internationale situé à Gatineau, Québec.

Le "turnover ratio" (le rapport de la production annuelle à la moyenne de la biomasse annuelle du "standing crop") demeura constant pour chaque espèce, et ne fut pas affecté par les différentes conditions ambiantes rencontrées.

La diversité des espèces de sphaeritidées fut calculée à chaque station et fut trouvée étroitement liée au contenu en

matières organiques du sédiment.

Les données sont également reportées pour le poids sec, le poids sec de la matière organique, et le contenu en mercure et en pesticide de différents groupes d'organismes benthiques.

INTRODUCTION

The Ottawa River Project is a five-year research task initiated in September 1972 under the auspices of the National Research Council of Canada and the University of Ottawa. Its purpose is to examine the distribution and transport of certain trace contaminants in a four-kilometer section of the Ottawa River near Ottawa-Hull, Canada.

Report Number 2 (1974) of the Ottawa River Project lists the following ways in which this research effort differs from most studies of river pollution:

1. This is a total system study. We seek to describe how pollutants are transferred between and among all the biological and physical compartments of the river, as well as geographical distribution and transport.

2. The study is closely linked to a large-scale mathematical model of a small section of the river which is designed to represent the overall behaviour of the system and to allow such behaviour to be simulated or predicted under a variety of environmental conditions.

3. The study is designed to develop methodology whereby the dynamics of transport may be elucidated for pollutants in other locations, rather than being concerned solely with the particular system under study.

The study described in this thesis, as part of the overall Ottawa River Project, was initiated for the following reasons:

1. -- to gather information on the benthos of the Ottawa River study area, including standing crop, production, and mercury and pesticide content. These data will be used in the mathematical model developed by the Ottawa River Project.

2. -- to investigate the productivity of two specific groups of benthos, sphaeriids and amphipods.

3. -- to investigate the turnover ratio theory by calculating turnover ratios for various species in different habitats.

4. --to determine the effects of environmental conditions on production.

5. -- to test and improve research methods and materials, particularly those used in benthos work.

The benthos of the Ottawa River near Ottawa-Hull was extensively studied by Mackie (1971) during the period 1967 - 1969. He described species composition, horizontal, depth, and seasonal distribution patterns, standing crop biomass and numbers, and also physical and chemical water parameters. In a second study he investigated the biology and productivity of one specific organism, <u>Musculium</u> <u>securis</u> (Pelecypoda: Sphaeriidae)(Mackie 1973).

Secondary production, as defined by the International Biological Programme (Edmondson and Winberg 1971), is the net production of consumers above respiration and excretion. It is this amount of matter which is available to be passed on to other organisms, either predators such as fish, or decomposers. The theory of production was discussed by Clarke (1946) and Ivlev (1966) and the mathematical formulation provided by Clarke <u>et</u> <u>al</u>.(1946).

The estimation of benthic productivity is a necessity in any total-system study, as demonstrated by the works of Juday (1940), Lindeman (1941, 1942), Odum (1957), Teal (1957), Tilly (1968), and Berrie (1972). Because benthic invertebrates are used as food by fish, an investigation into benthic productivity is also a requirement for fish production studies (Surber 1936, Ricker 1946, Allen 1951, Gerking 1962). Finally, benthic productivity is an important characteristic of that community. Recent studies of this nature have been done by Crisp (1962), Negus (1966), Waters (1966), Kimerle and Anderson (1971), Sameoto (1971), and Burke and Mann (1974). No estimates of production are available for the species investigated in the present study, although work has been done on sphaeriids in general (Johnson and Brinkhurst 1971b) and on other species of amphipods (Green 1971, Mathias 1971, Nilsson 1974).

It has been suggested that the ratio of annual production to mean annual standing crop biomass (the turnover ratio) is a constant for each species, even under varying environmental conditions (Waters 1969, Winberg 1970). If this is so, then the process of estimating annual production would be greatly simplified. Allen (1971) examined in detail the nature of this ratio and expressed it mathematically for several models of mortality and growth.

Mercury and pesticides were chosen for study because of their effects on the environment. Mercury has been known for some time to be a toxic material and has caused birth defects and deaths in humans. It is taken up and concentrated by benthic organisms (Hannerz 1968, Huckabee _et al._ 1972, Hamilton 1973) and can be passed up through the food chain causing biological magnification (Yoshida et al. 1967, Jernelov and Lann 1971). It was used in the past as a slimicide in paper mills, but this use has been discontinued (Fimreite 1970). Nuorteva (1969) discussed the problem of mercury in food chains.

Contaminants chosen for the present study were DDT and PCB. DDT can be taken up and accumulated by benthic organisms (Johnson et al. 1971, Vaajakorpi and Salonen 1973) and passed through the food chain (Macek and Korn 1970). The action of PCB and the effects of both of these substances on organisms are not yet well understood.

Description of Study Area

The Ottawa River is one of the largest rivers in Canada, extending 1113 km from Lake Timiskaming to the St.Lawrence River and draining some 128,000 square km. It flows through sedimentary deposits of limestone, sandstone, and shale, all of which are superimposed on ancient Precambrian rock.

The study area is located on the Ottawa River downstream from Ottawa-Hull, as shown in Figure 1. This four-km section was chosen for the Ottawa River Project because of the diversity of habitat it presents (Fig.2). It contains mainland shores and island shores, deep channels and shallow channels, open river and protected bays, polluted water and relatively clean water. The main industry in the immediate vicinity is the Canadian International Paper Company mill in Gatineau, Quebec, which is located within the study area. Logs are moved to this mill by floating them down the river.

Figure 1. The Ottawa River through Ottawa-Hull showing location of the study area.

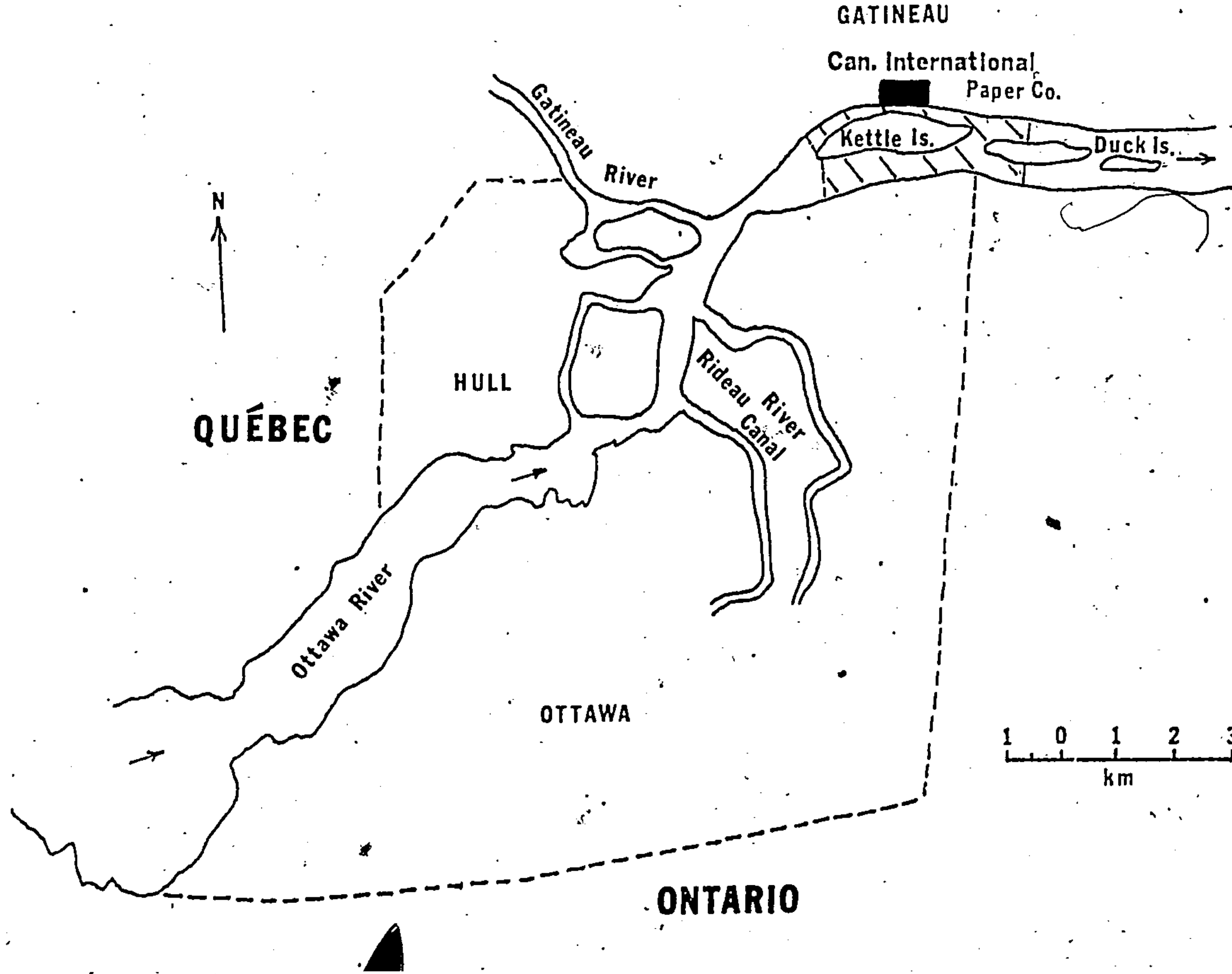

GATINEAU
Can. International Paper Co.
Kettle Is.
Duck Is.
Gatineau River
N
HULL
QUÉBEC
Rideau Canal
River
Ottawa River
OTTAWA
ONTARIO
1 0 1 2 3
km

Figure 2. The Ottawa River study area showing depth contours (depth in metres).

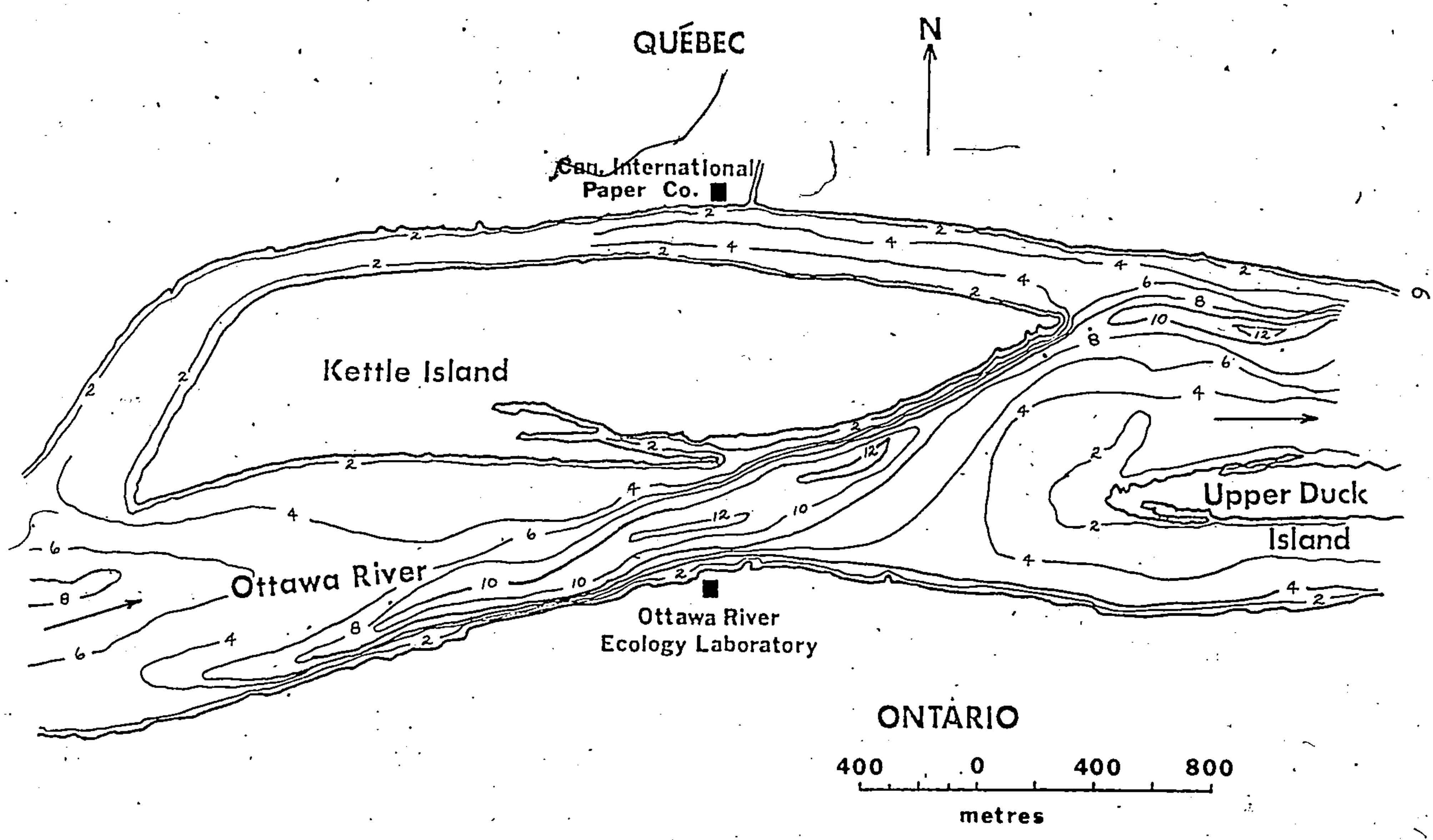

QUÉBEC
N
Can. International Paper Co.
Kettle Island
Upper Duck Island
Ottawa River
Ottawa River Ecology Laboratory
ONTARIO
400 0 400 800
metres

Table A1* gives some physicochemical characters of the Ottawa River in the study area as determined by Mackie in 1968 and 1969 (Mackie 1971, Mackie and Qadri 1971b). Additional data were collected during the present study but few differences were noted either with Mackie's 1971 results or among stations. One area where conditions were different was on the Quebec shore below the paper mill where there was higher BOD, hardness, phenols, sulfate, and turbidity and lower conductivity than in other areas (Mackie 1971, Mackie and Qadri 1973). None of the physicochemical values listed in Table A1 exceeds the pollution criteria recommended for fish and wildlife by the Ontario Water Resources Commission (1970).

Other characteristics of each station are given in Table 1. The main flow of water in the study area is through the deep channel on the south side of Kettle Island and the north side of Upper Duck Island. It can be seen from Table 1 that in these channels the bottom sediments are coarse sand with no detritus. Lower current flows in the shallower channels and along the shores permit the settling out of finer sediments and detritus. Kettle Island Bay is a backwater in which the substrate is silt overlain by very fine detritus particles. The river bottom below the paper mill is covered with wood chips and wood fiber. Particle size of sediments is expressed on a Phi scale which is explained in Table A2.

* see Appendix, page 82

Table 1. Some characteristics of each station in the Ottawa River study area.

Station[1]	Ottawa River Project map reference Old grid[2]	New grid[3]	Mean depth (m)	Depth-averaged velocity[4] (m/sec, summer)	Sediment type	Sediment mean grain size (Phi)[5,6]	Sediment organic matter content[7] (%dry wt)	Vegetation (aquatic macrophytes)[8]
Transect 1								
Ont.shore	32/01	1/1	2	0.15	clay(eroding)	9.46	0.97	EPSV[9]
Mid-south	32/04	1/2	8	0.32	coarse sand	1.2	0.53	none
Is.south	32/06	1/4	3	0.21	medium sand & detritus	2.27	0.46	ESV
Is.north	32/07	1/5	2	0.09	medium sand & detritus	2.31	0.34	ESV
Mid-north	32/08	1/6	4	0.10	medium sand & detritus	2.30	0.66	V
Que.shore	32/09	1/7	2	0.13	silt & detritus	5.1	---	ESV
Transect 2								
Ont.shore	52/01	23/1	2	0.07	very fine sand & detritus	4.0	0.0	EPSV
Mid-south	52/04	23/2	8	0.50	coarse sand	1.18	0.53	none
Is.south	52/05	23/4	2	0.08	fine sand & detritus	3.52	0.57	ESV
Is.north	52/08	23/5	2	0.17	fine sand & wood chips	3.67	1.5	Pr[10]
Mid-north	52/09	23/6	4	0.17	medium sand, chips, fiber	2.33	---	none
Que.shore	52/10	23/7	3	0.25	wood fiber	---	---	none

Table 1 (Continued)

Kettle Is. Bay	45/04	--	3	0.0	silt & fine detritus	---	---	none
Transect 3								
Ont. shore	62/01	34/1	2	0.01	silt(eroding)	6.22	0.0	EPSV
Mid-south	62/02	34/2	5	0.38	coarse sand & wood chips	1.81	0.12	none
Is. south	62/03	34/3	2	0.07	fine sand & detritus	3.11	0.11	ESV
Is. north	62/05	34/4	2	0.04	medium sand & detritus	2.77	8.0	ESV
Mid-north	62/06	34/5	8	0.41	coarse sand	1.37	0.12	none
Que. shore	62/09	34/7	3	0.08	fine sand, chips, fiber	3.86	0.40	Pr

1 see Fig.2
2 see Ottawa River Programme (1972): p.0 map
3 see Ottawa River Project (1974): p.2.32
4 from Warnock (1972, 1974)
5 from Rust (1972)
6 Phi (ϕ) = $-\log_2$ diameter mm (see Table A2)
7 from Norstrom and Brownstein (1974)
8 from Eriksson (1974)
9 E: *Elodea canadensis*, P: *Potamogeton* sp., S: *Sparganium angustifolium*, V: *Vallisneria americana*
10 Pr: *Potamogeton richardsonii*

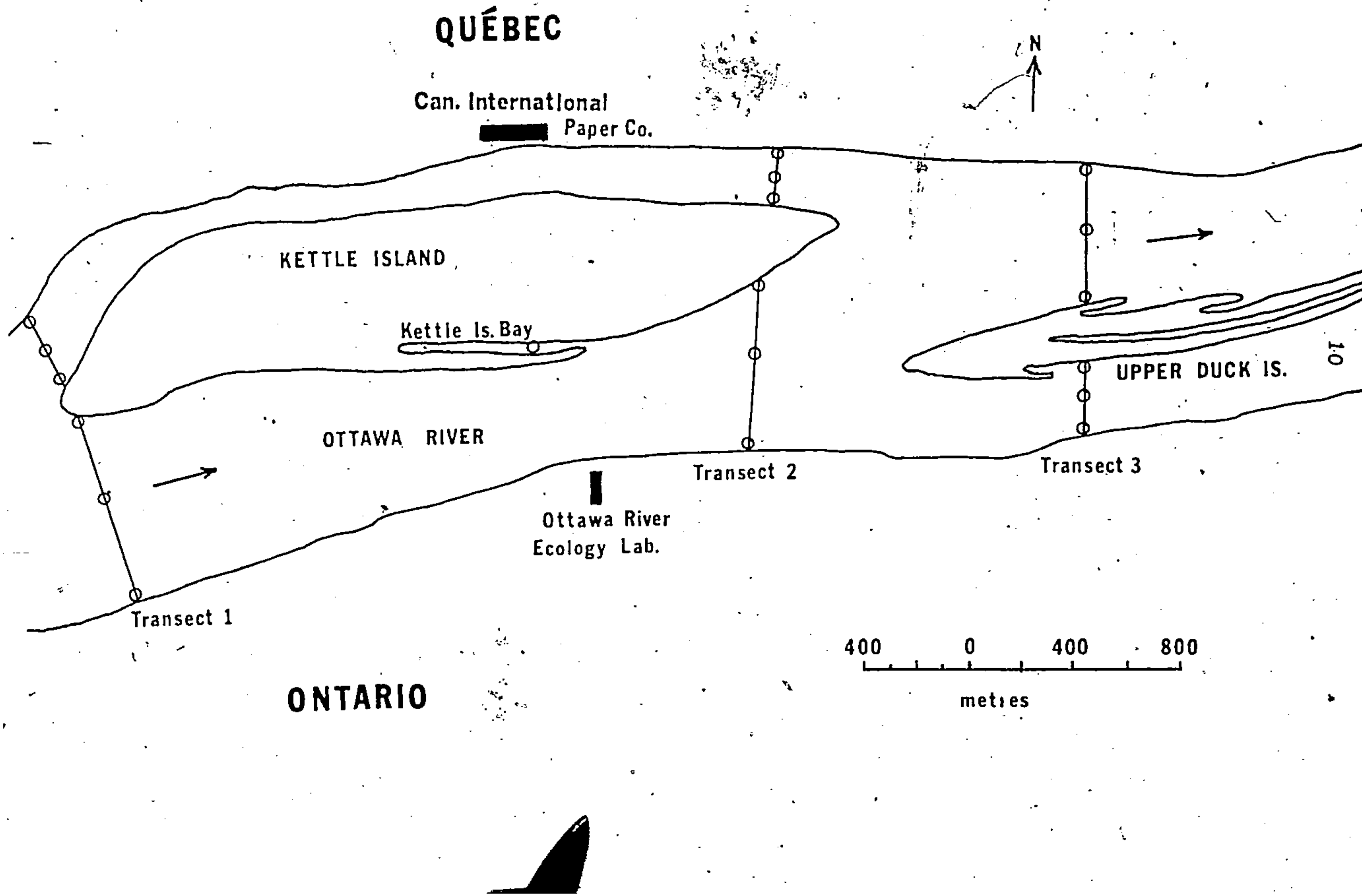
METHODS AND MATERIALS

Field and Laboratory

Three transects of the study area were chosen for the Ottawa River Project --- one at each end and one in the middle. Figure 3 shows the locations of these transects and the stations along them. In addition to the eighteen stations on the transects, one was chosen in Kettle Island Bay. This distribution of stations, using a stratified random sampling method, covers a wide range of contrasting types of habitat.

The sampling equipment to be used had to meet the following requirements: easy to operate, useable from a small boat, efficient, reliable, and operable at a variety of depths, sediment types, and temperatures. Several studies have been done recently comparing the efficiencies of bottom sampling devices (Flannagan et al.1969, Flannagan 1970, Hudson 1970, Howmiller 1971, Paterson and Fernando 1971a, Milbrink and Wiederholm 1973) and evaluating new instruments (Menzies and Rowe 1968, Maitland 1969, Hamilton et al.1970, Milbrink 1971, Burton and Flannagan 1973). The consensus of opinion appears to be that efficiencies of particular devices depend on the sediment type. Corers, although reducing the amount of material collected and the amount of time required for sorting, are not well suited for deep, fast-flowing waters as found in the Ottawa River mid-channels. The Ponar, Shipek, and Petersen grabs are heavy and awkward, if not impossible to use from a small boat. To meet the requirements stated above, a 15 x 15 cm standard Ekman grab with a screen on top was chosen.

Figure 3. The Ottawa River study area showing the locations of transects and sampling stations.



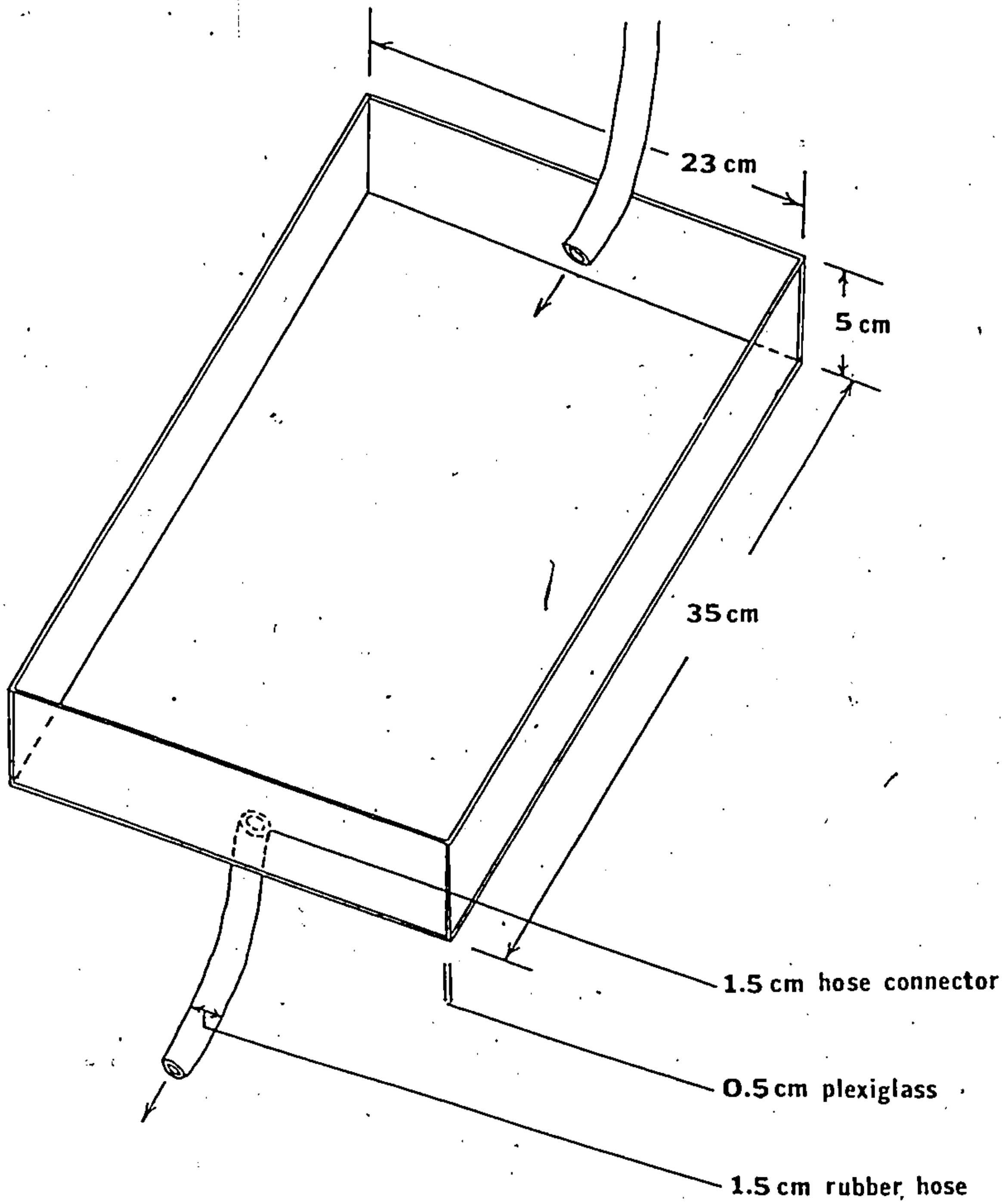
QUÉBEC
Can. International
Paper Co.
N
KETTLE ISLAND
Kettle Is. Bay
OTTAWA RIVER
UPPER DUCK IS.
Transect 1
Transect 2
Transect 3
Ottawa River
Ecology Lab.
ONTARIO
400 0 400 800
metres

Because of variation in spatial distribution of benthic invertebrates, the sample size must be large enough to reduce sampling error to an acceptable level. Paterson and Fernando (1971b) found that four Ekman grabs were usually required to obtain a population estimate of the total fauna within ±30% of the mean obtained with a larger number of samples. Wiederholm (1972) showed that to achieve a precision of 10% standard error when dealing with total fauna, a minimum of three Ekman grab samples must be taken per station. A greater number of samples increases the accuracy but at the same time increases the sorting time. It was decided that for the present study three grabs would be taken and combined at each station.

The grab was emptied directly into a 30cm x 30cm sieve of the design described by Mackie and Qadri (1971a). Jonasson (1955, 1958) gave an analysis of the effects of using different sieve mesh sizes. He compared mesh sizes of 0.20, 0.26, 0.51, and 0.62 mm and found that the smaller sizes increase the take but also increase the sorting time. According to him, the most commonly used mesh guage is 0.6 mm. For the present study a mesh size of 0.37 mm was chosen.

The samples were returned to the laboratory in 16-ounce jars and kept in a cold room at 5°C until sorted (for periods of up to two weeks). The material was hand-sorted in a clear, continuous-flow tray (Fig.4) on a light table as described by Hamill (in preparation). The sediment is placed at the inflow end of the tray. With a sweeping motion of the hand using forceps, the material is spread out over the tray,

Figure 4. Diagram of the clear, continuous-flow sorting tray designed by the author.



23 cm
5 cm
35 cm
1.5 cm hose connector
0.5 cm plexiglass
1.5 cm rubber hose

making individual particles readily visible. After removal of the organisms, the material is swept on down the tray with another sweeping motion, and the water flow carries it out the outlet hole. The flow of water can be adjusted to maintain the proper amount of water in the tray and the desired outflow rate. This invention greatly increased the efficiency of sorting and decreased sorting time by at least 50%. It works best with sand, but was used successfully with silt, clay, and even wood chips, if the larger chips are pulled to one side of the tray.

Various methods have been devised for sorting bottom fauna samples. Flotation has been described by Andersson (1959), Whitehouse and Lewis (1966), and Flannagan (1973); Mason and Yevich (1967), Hamilton (1969a), and Williams and Williams (1974) used staining techniques; Lauff <u>et al.</u> (1968) and Worswick and Barbour (1974) preferred elutriation, a process of suspending the organisms with bubbled air and separation through differential settling rates and sieving. All of these methods reduce the amount of time required for sorting but are selective for particular groups. Flotation and staining involve the addition of a chemical substance to the organisms. Howmiller (1972) showed that organisms kept in preservative tend to lose weight. Because individual dry weights were required in the present study, no preservatives were used. It was thought that the addition of chemicals for flotation or staining might also affect the weights of organisms and consequently the hand-sorting method was chosen.

Organisms were separated into major taxonomic groups with the aid of Pennak (1953). They were counted, weighed wet, dried for at least twelve hours at 80°C, and weighed dry. Samples of various groups were ashed at 600°C for two hours in a muffle furnace and ash-free dry weights were determined. The remainder of the specimens were stored dry in vials for future use. Equipment used in the above procedures included a Mettler Micro Gram-atic balance with six decimal place accuracy, a Thelco Model 27 drying oven, and a Temco Type 1500 muffle furnace.

Organisms chosen for intensive study in this project were sphaeriid clams and amphipod crustaceans. These animals are easy to work with in a dried condition, abundant in the study area, and important food for fish, particularly brown bullhead (Ictalurus nebulosus), yellow perch (Perca flavescens), and pumpkinseed sunfish (Lepomis gibbosus), in this section of the Ottawa River (J.M.Gunn, pers.comm.,1974). The sphaeriids were identified by Dr.G.L.Mackie while the author identified the amphipods following Bousfield (1958) and Holsinger (1972).

Six species of sphaeriids and one of amphipods were present in sufficient numbers to be studied. Individual measurements of length and weight of all specimens of these species were made using a Wild M5 dissecting microscope with an eyepiece micrometer and the balance described above. Total length of sphaeriids was measured, but for amphipods, because of curling of the body, head length was used. This practice of taking head length of amphipods as an indication of total size was also used by Mathias (1971).

In order to determine what proportion of the total weight of an individual can be attributed to its shell, a sample of sphaeriids taken once during the year was shelled. To determine whether dried specimens changed in weight while in storage a test was run on a random sample of sphaeriids stored for various lengths of time. After periods in storage of up to one year, sphaeriids gained 1% of their weight (N=41, correlation 1.00). This variation was considered to be negligible and was subsequently ignored.

Samples must be taken at sufficiently frequent intervals that reproductive peaks of different organisms are not missed, but not so often that the material collected cannot be sorted in time for the next sampling. In consideration of the large number of stations sampled (19), the method of sorting chosen (by hand), and the nature of the organisms of greatest importance to this study (non-emerging sphaeriids and amphipods), it was decided that samples would be taken monthly throughout the year 1973. Due to problems associated with winter sampling (uncertain ice conditions, cold temperatures, large amounts of time required at each station and in travelling between stations), a reduced complement of stations was visited during the period January to April. After August, several stations at which sphaeriids and amphipods occurred in very low numbers were dropped from the sampling program. No samples could be taken in December because of poor ice conditions and equipment breakdown. Table A3 indicates the date, location, and number of each sample. A total of 147 samples were taken in 1973.

During the summer samples were taken from a 16-foot outboard motorboat while in the winter, holes were cut through the ice.

A chain saw was initially used to cut these holes, however, a motorized ice auger eventually proved to be more practical and efficient. Four holes were drilled with the auger and the remaining ice broken out with an ice chisel. This created a hole large enough to allow the sieve to be immersed in the water.

Calculations and Statistics

As a test of sampling error, several duplicate samples were taken at various times during the year. These data were used to examine the relationship between number of Ekman grabs per sample and per cent standard error (Fig.5). From this diagram, each sample of sphaeriids, made up of three Ekman grabs, has a standard error of 27%. Using this value as a starting point, and with the aid of Elliott (1971), the error was carried through the method(A15,A16), and errors were calculated for other estimates (Table A4). Similarly, errors were calculated for amphipod estimates. Because of the grouping together of several species, the error for estimates of "other sphaeriids" is low. However, because amphipods seem to occur in clumps, the error for these animals is quite high.

The various methods for the calculation of benthic productivity have been summarized by Edmondson and Winberg (1971) and Winberg (1971). There are two approaches to this subject. The physiological approach involves measuring rates of metabolic processes within organisms. This method was used by Juday (1940), Lindeman (1941), Odum (1957), Konstantinov and Nechvalenko (1968), and Johnson and Brinkhurst (1971b). The second approach involves population dynamics and concerns such properties as rates of reproduction and death,

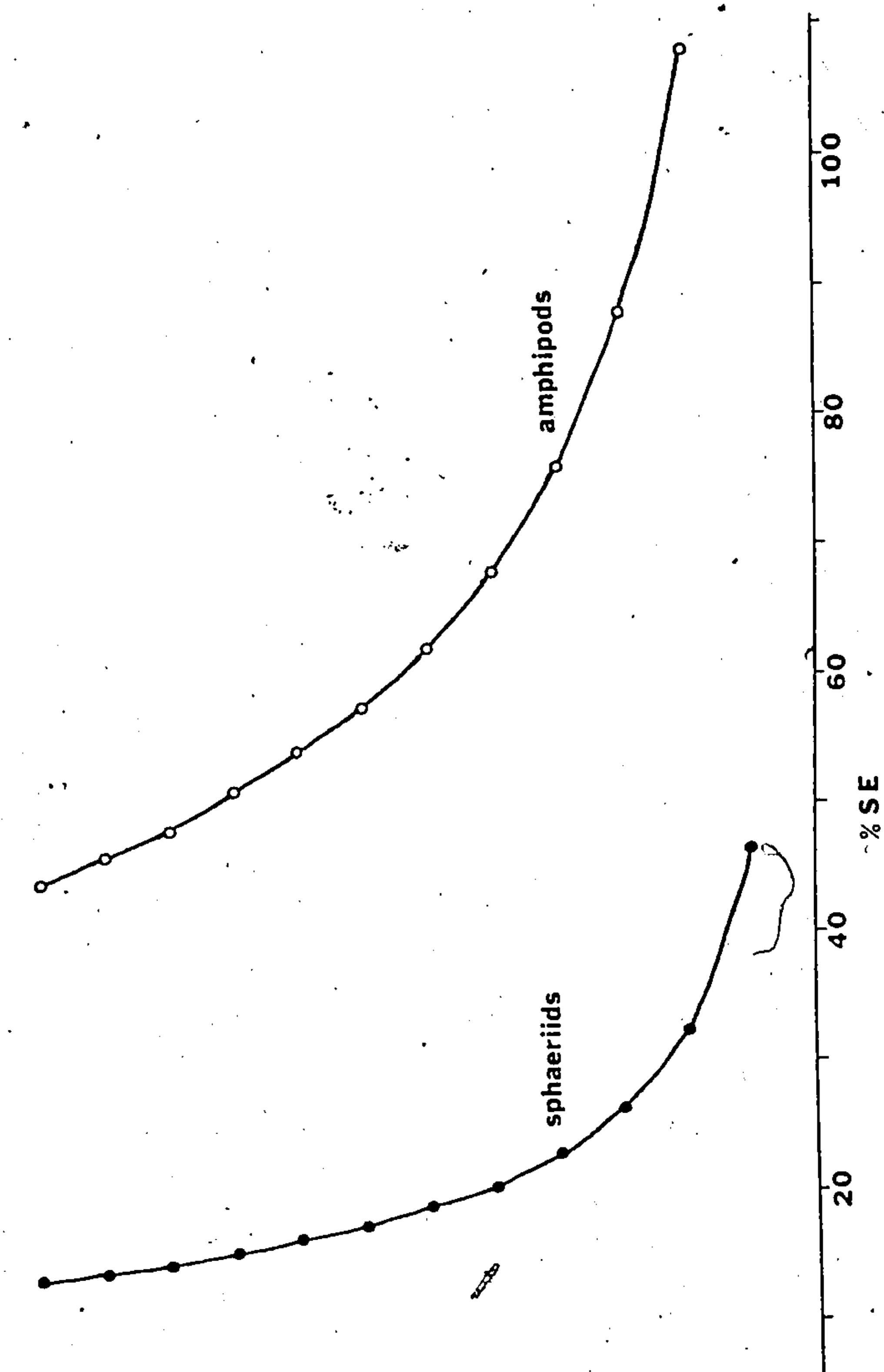
Figure 5. Relationship between number of Ekman grabs per sample (n) and per cent standard error (%SE) of that sample for sphaeriids and amphipods (fitted by eye).

standard deviation (s) = 2.35 (sphaeriids), 2.67 (amphipods),

standard error of the mean for sample of size "n" = $\frac{s}{\sqrt{n}}$,

% standard error = $\frac{s}{\sqrt{n}} \times \frac{100}{\text{best estimate of mean}}$,

best estimate of mean sphaeriids 5.08, amphipods 1.75.



amphipods
sphaeriids
% SE
n
20
40
60
80
100
2
4
6
8
10
12

and the structure of populations in terms of age and size.

For studies using the second approach, several specific methods are available: Neess and Dugdale (1959) described a method based on the relationship between mean larval weight and size of the larval population, which is essentially the same as the Allen curve used by Allen (1951) in his study of the Horokiwi Stream; Waters (1962a) suggested a method involving stream drift measurements; Hynes and Coleman (1968) proposed a method, which was subsequently modified by Fager (1969) and Hamilton (1969b), based on summing the losses between successive size classes; Speir and Anderson (1974) used emergence data for estimating production of aquatic insects. Some of these methods have been compared by Waters and Crawford (1973).

For the present study, the method of Hynes and Coleman (1968) as modified by Hamilton (1969b) was chosen (Table A15). This method was further modified for this study in that each dried specimen was measured and weighed individually and a mean dry weight for each size class calculated, rather than a mean dry weight calculated from a known length and estimated density of organism. The Hynes-Coleman-Hamilton method was used by Green (1971) to calculate production of the amphipod Pontoporeia affinis.

Analyses of total numbers and size class seasonal abundance, and length-weight relationships, and calculations of mean annual standing crop, annual production, and turnover ratio were made for six species of sphaeriids and one species of amphipod. Two species, Pisidium casertanum and Gammarus fasciatus, were sufficiently abundant that these calculations could be made at several individual stations. A correlation of mean annual standing crop biomass and annual production was made to determine if the turnover ratio is constant. For the less abundant sphaeriids, one production calculation was made for the total area.

Data and information on physical and chemical water conditions, bottom type, mean sediment grain size, organic matter content of substrate, water depth, and current strength were collected at each station. Where possible, values for annual production were related to environmental conditions to explain differences in production.

Species diversity of sphaeriids was calculated at all nineteen stations using the following formulae:

Shannon-Wiener $$D = -\sum_{1}^{m} \left(\frac{ni}{N} \log_2 \frac{ni}{N} \right)$$

Simpson $$D = 1 - \sum_{1}^{m} \left(\frac{ni}{N} \right)^2$$

Wilhm-Dorris (1966) $$D = \sum_{1}^{m} \left(ni \log \frac{ni}{N} \right)$$

where m = number of species,

N = total number of individuals,

ni = number of individuals per species.

The value for each station was calculated by averaging monthly species diversities at that station.

The results of these three methods were compared. Species diversity was correlated to various environmental parameters to determine if there were any relationships.

Tables labelled "A" can be found in the Appendix, page 82.

RESULTS AND DISCUSSION

Total Benthos

Standing Crop

Mean annual standing crop of total benthos for 1973 in the study area is given in Table 2. Very large values are caused by the inclusion of shell weights of large clams (Elliptio complanatus and Lampsilis radiata) and large snails (Campeloma decisum). Because of this effect, these large molluscs were separated from the remainder of the benthos. Their standing crop also appears in Table 2.

Benthic organisms are abundant throughout the study area except in the deep channels (Transect 1 mid-south, 2 mid-south, 3 mid-north) where there is high current velocity, coarse sand sediment, and no vegetation. Reduced numbers are also apparent in polluted areas (Transect 2 Quebec shore, 3 mid-south). The large molluscs occur only in certain areas and reach relatively high densities where conditions are favourable (Transect 1 Is. south, Is. north, mid-north).

Pollution

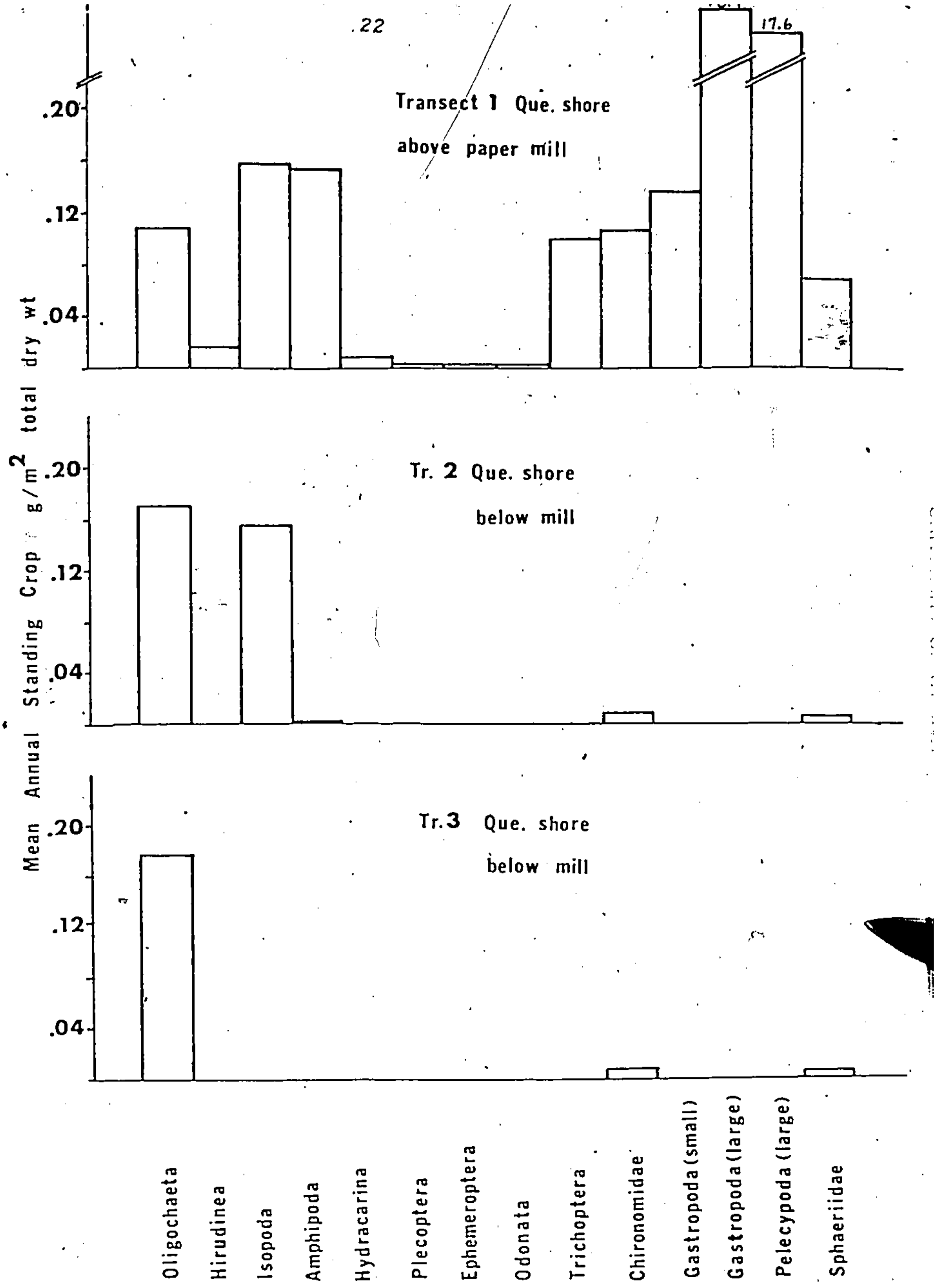
Figure 6 shows the effects of the Canadian International Paper Company mill on the benthos of the Ottawa River. Above the mill there is a relatively large diversity of benthic groups, with no group dominating in mean annual standing crop biomass. However, below the mill the situation is drastically changed. Diversity is greatly reduced, with only a few groups, in particular

Table 2. Standing crop of total benthos[1], large molluscs (*Elliptio complanatus*, *Lampsilis radiata*, and *Campeloma decisum*), and sphaerids in the study area in 1973.

Station	Total benthos no/m²	Total benthos g/m² total dry wt	Large molluscs no/m²	Large molluscs g/m² total dry wt	Sphaerids (SE=10%) no/m²	Sphaerids (SE=10%) g/m² total dry wt
Transect 1						
Ont.shore	1437	0.502	0	0	235	0.113
Mid-south	82	0.019	0	0	0	0
Is.south	1944	163.664	53	162.669	54	0.040
Is.north	4285	112.093	28	111.029	681	0.179
Mid-north	777	341.774	37	341.463	155	0.103
Que.shore	1640	36.897	9	36.036	104	0.068
Transect 2						
Ont.shore	2229	20.452	9	19.570	266	0.147
Mid-south	50	0.009	0	0	0	0
Is.south	2340	86.081	9	85.203	400	0.239
Is.north	964	15.081	4	14.594	270	0.222
Mid-north	1643	5.160	2	4.566	331	0.135
Que.shore	535	0.341	0	0	2	0.005
Kettle Is.Bay	728	0.292	0	0	38	0.026
Transect 3						
Ont.shore	892	47.767	4	46.672	155	0.092
Mid-south	304	274.645	11	274.483	42	0.027
Is.south	2590	49.809	9	48.488	263	0.214
Is.north	6872	5.073	5	3.425	365	0.290
Mid-north	9	0.003	0	0	0	0
Que.shore	1357	0.547	0	0	4	0.002

1 total benthos includes all benthic organisms collected

Figure 6. Mean annual standing crops of the benthic groups at the three Quebec shore stations above and below the Canadian International Paper Company mill in 1973.



.22
17.6
Transect 1 Que. shore
above paper mill
Tr. 2 Que. shore
below mill
Tr. 3 Que. shore
below mill
Mean Annual Standing Crop g/m2 total dry wt
.20
.12
.04
Oligochaeta
Hirudinea
Isopoda
Amphipoda
Hydracarina
Plecoptera
Ephemeroptera
Odonata
Trichoptera
Chironomidae
Gastropoda (small)
Gastropoda (large)
Pelecypoda (large)
Sphaeriidae

oligochaete worms, being able to tolerate the severe conditions. Clean water organisms such as ephemeropterans (mayfly larvae), plecopterans (stonefly larvae), trichopterans (caddisfly larvae), and snails are absent. This pattern of change from above to below the mill is a good indication of pollution (Howmiller and Beeton 1971, Goodnight 1973, Wiederholm 1973).

The pollution is probably due to a combination of effluents and the blanketing of the river bottom with wood fibre, covering food and habitat and causing an increase in oxygen demand. Visible indications of pollution are: turbid water due to suspended fibres, lumps of floating material, slicks on the river surface, and a substrate composed entirely of wood fibre which gives off bubbles of gas when disturbed with the Ekman grab.

At other locations in the study area, particularly Transect 3 mid-south channel, the bottom is covered with wood chips and bark, presumably having been carried down from upstream where logs are floated in booms to the mill.

The effects of these different pollutants are all basically the same: reduction in the standing crop of benthic organisms.

Sphaeriidae

The Family Sphaeriidae of the Order Pelecypoda is represented in North America by 38 species belonging to 4 genera: Pisidium, Musculium, Sphaerium, and Eupera. According to Burch (1972), this is one of the truly cosmopolitan families of freshwater molluscs: at least one of its many species can be found in almost *any body of fresh water. Under natural conditions their food consists of detritus, bacteria, algae, and probably protozoans (Monakov 1972). This material is filtered from water drawn through the mantle cavity. Members of the family are uniformly monoecious and ovoviviparous. Self-fertilization has been reported for one species (Thomas 1959). Heard (1965:381) describes reproduction among sphaeriids as follows: "Their fertilized eggs are retained and incubated within the body of the parent, and the subsequent development of the embryos ..... takes place in the marsupia or brood sacs formed by the inner (anterior) gills. Although these tiny bivalves are without external sexual characteristics and lack copulatory organs, the brood chambers in the gills ..... may be considered to function as accessory sexual organs."*

Mackie (1971) collected twenty species of sphaeriids belonging to three genera (Pisidium, Musculium, and Sphaerium) in the Ottawa River. In the present study, on a more restricted area, nine species of the genera Pisidium and Musculium were taken.

Standing Crop

Mean annual standing crop values for sphaeriids at the various stations in the study area in 1973 are given in Table 2. These organisms reach their highest density in unpolluted shore areas with a maximum of 0.290 g/m^2 total dry weight (365 individuals/m^2) on Transect 3 at the north island shore station. For the three stations at which Mackie (1971) also sampled, the values reported here are similar to his.

Sphaeriids were rarely found in the deeper channels, in Kettle Island Bay, nor at the polluted Quebec shore stations. Reasons for this will be discussed in the following section.

Pisidium casertanum (Poli)

Pisidium casertanum has succeeded in adapting itself to a wide variety of habitats and is by far the most common species of Pisidium (Herrington 1962). Clarke (1973) gives a range map showing this sphaeriid distributed over almost the whole of Canada. Being a member of the subgenus Rivulina, it lives only one year and reproduces just once (Heard 1965).

Standing Crop

This species was found to be the most common sphaeriid in the study area: over 1000 specimens were collected, weighed, and measured. Mean annual standing crop values at the various stations in 1973 are given in Table 3. P. casertanum is most abundant at the island shore north station of Transect 2 (0.217 g/m^2 total dry weight, 234 individuals/m^2). It is common throughout the study area except in the deeper channels, along the polluted Quebec shores, and in Kettle Island Bay.

Population Dynamics

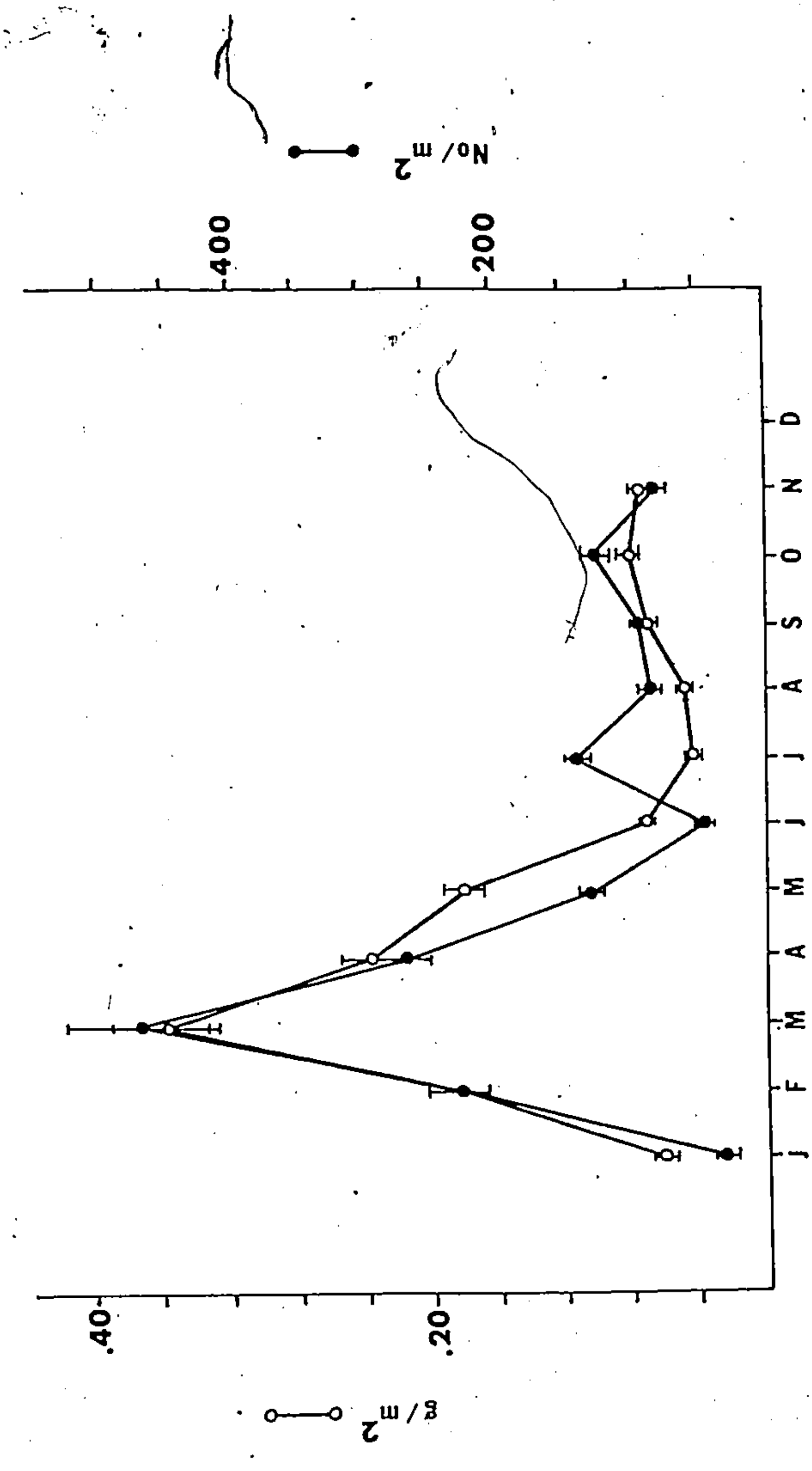
Seasonal abundance over the study area is shown in Fig.7. The largest monthly collection was made in March. Low values for January and February may be a function of the few samples taken

Table 3. Standing crop, production, and turnover ratio of <u>Pisidium</u> <u>casertanum</u> in the study area in 1973.

Station	Mean annual standing crop (SE=10%) no/m²	g/m² total dry wt	Production (SE=30%) g/m²/yr total dry wt	Turnover ratio (SE=57%)
Transect 1				
Ont.shore	120	0.055	0.196	3.56
Mid-south	0	0	0*	---
Is.south	36	0.033	0.086	2.61
Is.north	169	0.119	0.386	3.26
Mid-north	90	0.061	0.189	3.09
Que.shore	46	0.043	0.200	4.66
Transect 2				
Ont.shore	141	0.103	0.506	4.89
Mid-south	0	0	0*	---
Is.south	231	0.196	0.712	3.64
Is.north	234	0.217	0.827	3.81
Mid-north	208	0.108	0.346	3.21
Que.shore	1	0.004	0.015*	---
Kettle Is.Bay	30	0.024	0.091*	---
Transect 3				
Ont.shore	82	0.063	0.209	3.31
Mid-south	15	0.010	0.038*	---
Is.south	187	0.163	0.635	3.90
Is.north	158	0.154	0.560	3.63
Mid-north	0	0	0*	---
Que.shore	1	0.002	0.008*	---
Mean	92	0.071	0.263	---

* estimated using the turnover ratio 3.8 (see Fig.12)

Figure 7. Seasonal abundance of Pisidium casertanum in the study area in 1973. Open circles: g/m^2 total dry weight monthly standing crop; closed circles: no/m^2 monthly standing crop. Range given is ± per cent standard error (10%).


No/m²
400
200
J F M A M J J A S O N D
.40
.20
g/m²

during those months. The population declined in numbers and total biomass from March until July, when newborns appeared. The July collection shows an increase in numbers but a continued decrease in biomass from that of June, indicating an introduction of very small individuals to the population.

A more detailed look at growth and recruitment is given by seasonal size class distribution in Fig.8. The mean size increases from March until June, then in July there is an increase in the numbers of smaller individuals. This also shows that birth of young occurred in late June or early July. Further evidence of time of reproduction was noted while measuring specimens: dried individuals of P.casertanum are translucent; if young are present within the adult they can be seen through the shell. The first adult bearing young was noted in the May 31 collection. On June 26 eleven individuals carrying young were seen, one was found in the July 25 collection, two on August 23, and one on September 24. Most young, then, are born in June-July.

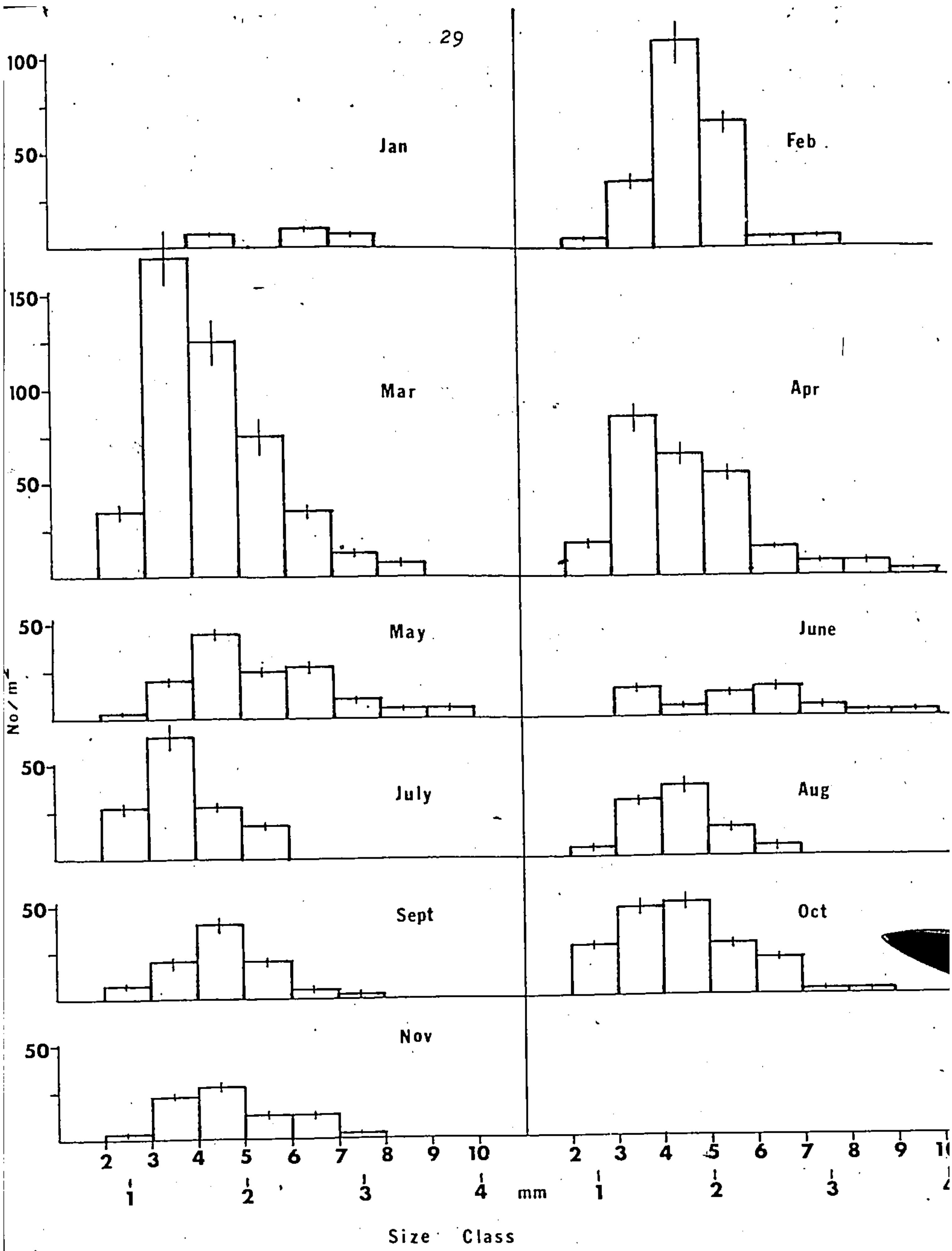
Young inside adults were measured at 2 micrometer units (0.8 mm) which is considerably larger than the sieve mesh size used (0.37 mm). It is not known at what size the average individual is born, but the 2-3 unit size class is well represented in the collections. However, the fact that the 3-4 unit size class was consistently collected in larger numbers than the 2-3 unit class indicates that more may be born at the larger size.

Fig.7 seems to show that either the 1972 year class (those collected from January to June) was a particularly strong one or

Figure 8. Seasonal size class distribution of Pisidium casertanum in the study area in 1973.

Range given is ± per cent standard error (10%),

$y = no/m^2$, x = total length size class in micrometer units and corresponding metric scale.


Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
No / m²
Size Class
mm

that the 1973 year class (those collected after June) was a weak one. Values for the latter part of 1973 (50-100 individuals/m^2) are more comparable to those given for P.casertanum by Mackie (1971), indicating that the estmates for the 1973 year class may be closer to normal.

The typical length-weight relationship of P.casertanum is shown in Fig.9. The equation of this relationship is:

$\log_{10}y = -1.66 + 0.30x$, $N = 916$, correlation ($\log_{10}y$ and x) 0.96, where y = total dry weight in milligrams and x = total length in micrometer units (1 unit = 0.4 mm).

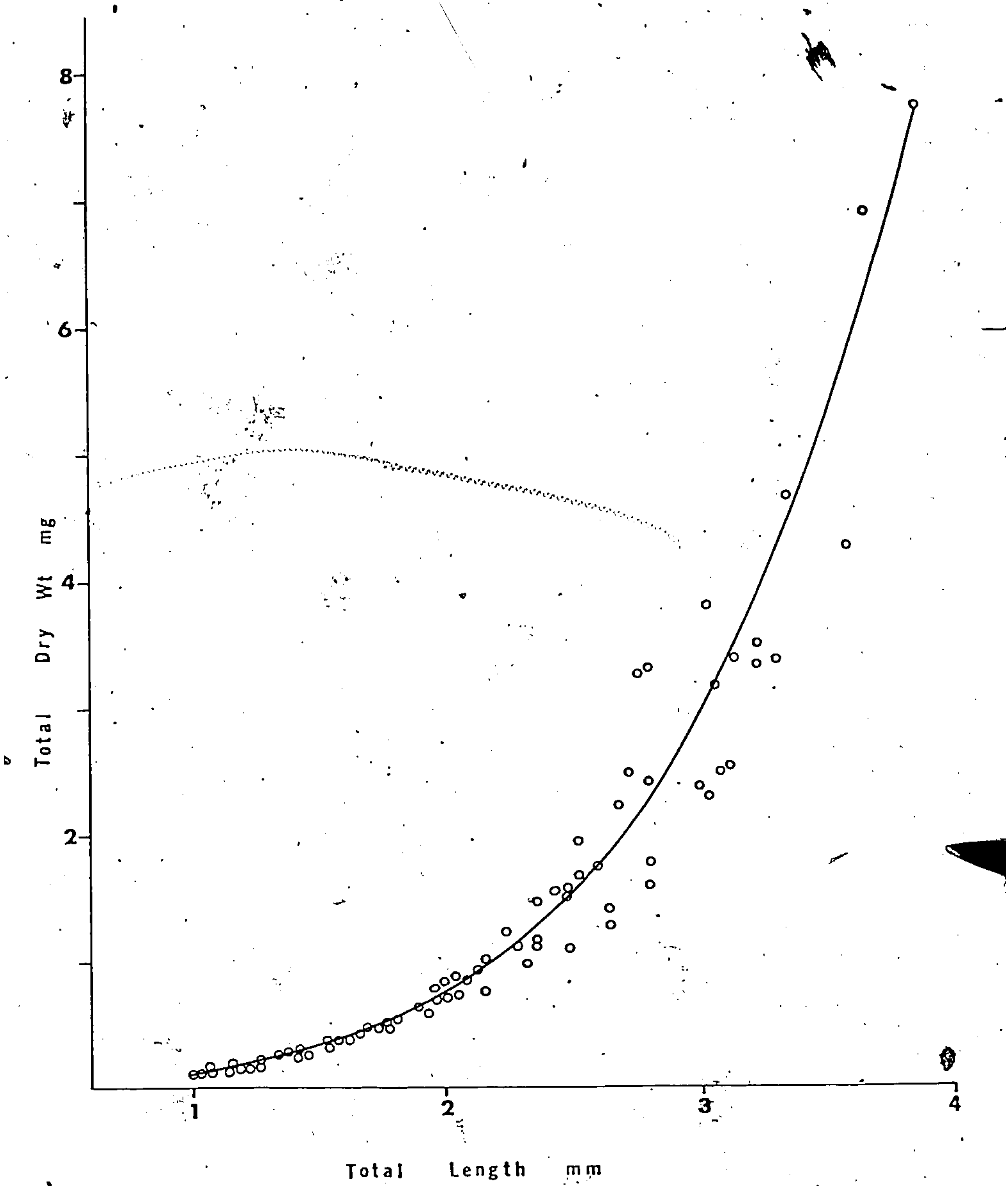
Equations of this relationship at the various stations are given in Table A5. These equations were used to calculate mean dry weights of size classes in the production calculations. The range of total lengths observed for P.casertanum was 0.96 mm to 3.88 mm.

Production

Production values for P.casertanum at each station are summarized in Table 3. Production ranges from a high of 0.83 g/m^2/yr total dry weight at Transect 2 island north shore to 0 g/m^2/yr where the species is absent.

The sphaeriid body is about 88% shell dry weight (N =32), the dry weight of a whole sphaeriid is 42% of the live weight (N = 56, correlation 0.99), and the energy content of the soft parts of the body is 4321 cal/g dry weight or 4759 cal/g ash-free dry weight (Cummins and Wuycheck 1971). From these conversion factors the production of P.casertanum can be expressed as total live weight, dry weight of soft parts, and calories, as well as

Figure 9. Length-weight relationship of <u>Pisidium</u> <u>casertanum</u> in the study area in 1973.
$\log_{10}y = -1.66 = 0.30x$, N=916, correlation ($\log_{10}y$ and x) 0.96, y = total dry weight in mg, x = total length in micrometer units (1 unit = 0.4mm).


8
6
4
2
Total Dry Wt mg
1
2
3
4
Total Length mm

total dry weight (Table A6).

Few estimates of sphaeriid productivity have appeared in the literature. Gillespie (1969) reported average net production of Pisidium compressum in the Madison River as 2.815 $g/m^2/yr$ soft parts dry weight or 11998 $gcal/m^2/yr$. This is much higher than any values calculated here for P. casertanum. Mackie (in Qadri et al. 1974) calculated the production of Musculium securis to be 300 $mg/m^2/yr$ in Britannia Bay (Ottawa River) and a maximum of 37.5 $mg/m^2/yr$ in the study area of the Ottawa River.

Effects of Some Environmental Parameters on Production

While sampling it was noted that sphaeriids were more abundant where the substrate was composed of fine sediments and detritus. The production calculations agree with these observations.

Murray and Harmon (1969) discussed the following factors affecting the productivity of Newfoundland streams: (1) morphometry (size, shape, runoff), (2) climate (temperature, precipitation), (3) edaphic factors (surface geology, water chemistry), and (4) biotic factors (competition, predation, fecundity, disease, migration). Pennak and Van Gerpen (1947) investigated the effect of substrate on benthic productivity and found decreasing production through the following substrate series: silt, rubble, bedrock, clay, gravel, sand. Hayne and Ball (1956) found that in the presence of fish, standing crops of benthos were lower but production was higher than in the absence of these predators. Egglishaw (1964) reported that the distribution of bottom fauna in a riffle was significantly correlated with the distribution of plant detritus.

Hall et al. (1970), experimenting with different nutrient and predation levels, found that for Caenis (Insecta:Ephemeroptera) highest production occurred under conditions of low nutrients and high predation while for Chironomus (Insecta:Diptera) these factors had no effect. Johnson and Brinkhurst (1971a) concluded that macroinvertebrate production decreased at very low and very high levels of energy import. Mackie (1971) noted that the standing crop of sphaeriids was inversely related to the sediment organic matter content. Benthos production, then, appears to be affected by a variety of factors.

Of these factors, climate is a large-scale phenomenon and not likely to cause changes in productivity within such a small area as in this study. No information was collected for biotic factors. Efford (pers.comm. 1975) found that competition among sphaeriids became evident only at densities above $1000/m^2$. The maximum observed density for P. casertanum in the present study was just over $200/m^2$; therefore it is unlikely that intraspecific competition was having a large influence on production. Morphometry is of some importance in the study area but it is primarily manifested in substrate differences (for example, the deeper channels have higher current velocities and coarser sediments) and therefore was not considered per se. The other parameters which can affect production are the edaphic factors. The data collected show that water chemistry is relatively constant throughout the study area except along the polluted Quebec shore. Low production in this area may be the result of toxic chemicals, high BOD, and/or the blanketing effect of paper fiber described by Stobo (1971).

From personal observations it was hypothesized that substrate organic matter content and sediment mean grain size were the most important factors affecting production. However, regression analysis indicated that there was no relationship between substrate organic matter content and production of P.casertanum in the study area (correlation 0.06). This result does not agree with either Egglishaw (1964) or Mackie (1971). There is a relationship between mean sediment grain size and production (Fig.10). Production appears to be greatest in fine to very fine sand substrates and decreases in coarser and finer sediments, reaching zero in coarse sand and a constant low value in silt and clay. This is comparable to the conclusions of Pennak and Van Gerpen (1947).

The effect of current velocity on production was investigated and a relationship with a correlation of -0.36 was found (Fig.11). Production appears to increase from zero exponentially as current velocity decreases from mid-channel values.

Current velocity and sediment grain size are closely correlated (Fig.12). Multiple linear regression showed that production has a slightly stronger relationship with sediment grain size (correlation 0.68) than with current velocity (correlation -0.62) and that grain size and velocity are closely correlated (correlation -0.74). Partial correlation between production and velocity adjusting for grain size gave a non-significant result, ie, there is no additional effect of current velocity over and above the effect of grain size. However, these two factors are so closely related that it would be necessary to investigate a situation where velocity and grain size were not so highly correlated in order to determine which is the more important controlling factor on production.

Figure 10. Relationship between mean sediment grain size and annual production of <u>Pisidium</u> <u>casertanum</u> in the study area in 1973.

Rising straight line between closed circles:
$y = -0.65 + 0.40x$, $N=9$, standard error of estimate 0.10, correlation 0.95;
remainder fitted by eye,
y = annual production in $g/m^2/yr$,
x = mean sediment grain size in Phi (ϕ) units (see Table A2).

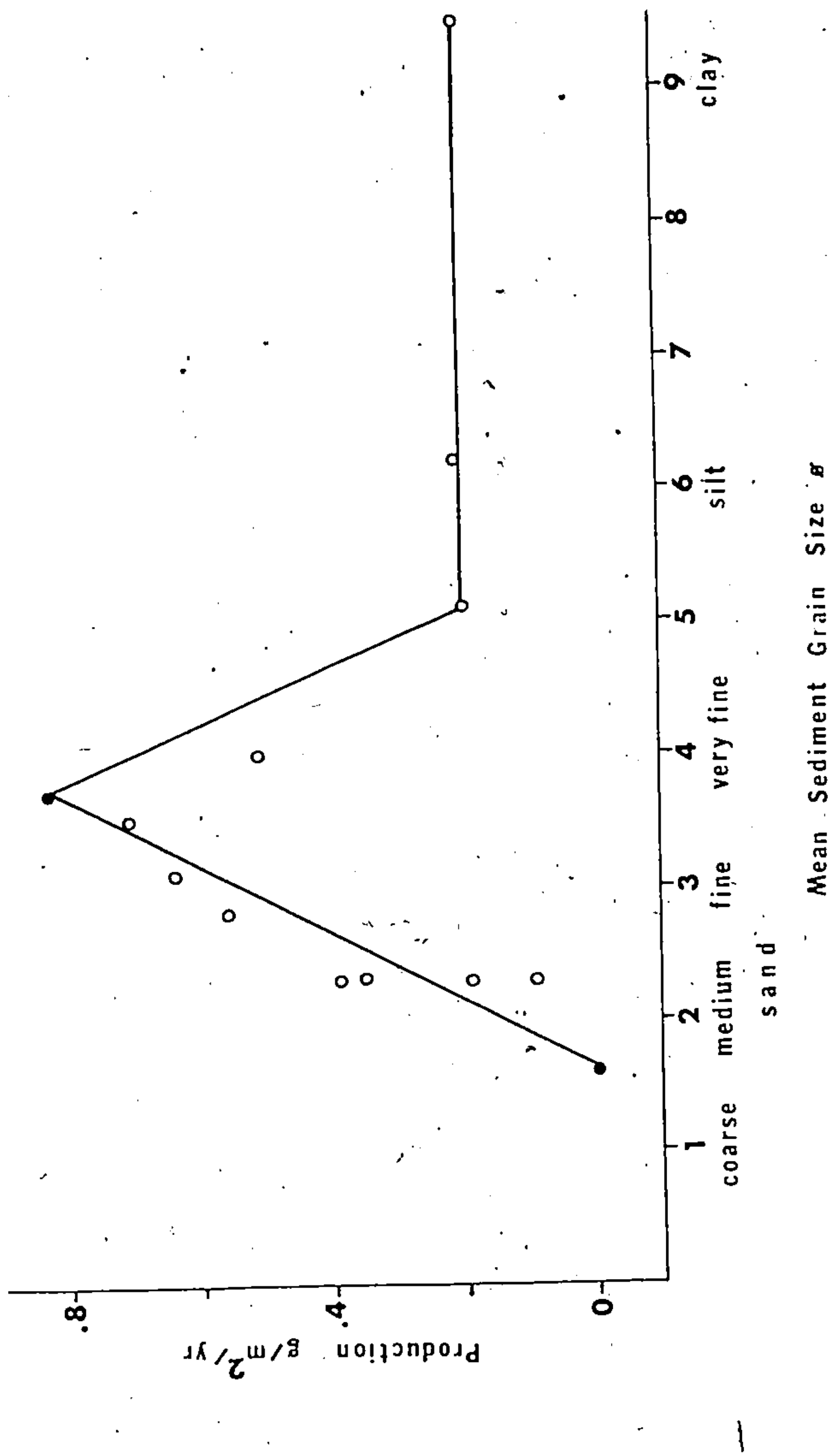

Production g/m²/yr
0
.4
.8
Mean Sediment Grain Size ø
1
2
3
4
5
6
7
8
9
coarse
medium
sand
fine
very fine
silt
clay

Figure 11. Relationship between depth-averaged current velocity and annual production of Pisidium casertanum in the study area in 1973.
$\log_{10}y = -0.08 - 3.26x$, N=12, standard error of estimate 0.27, correlation ($\log_{10}y$ and x) -0.57, y = annual production in $g/m^2/yr$, x = depth-averaged current velocity in m/sec.

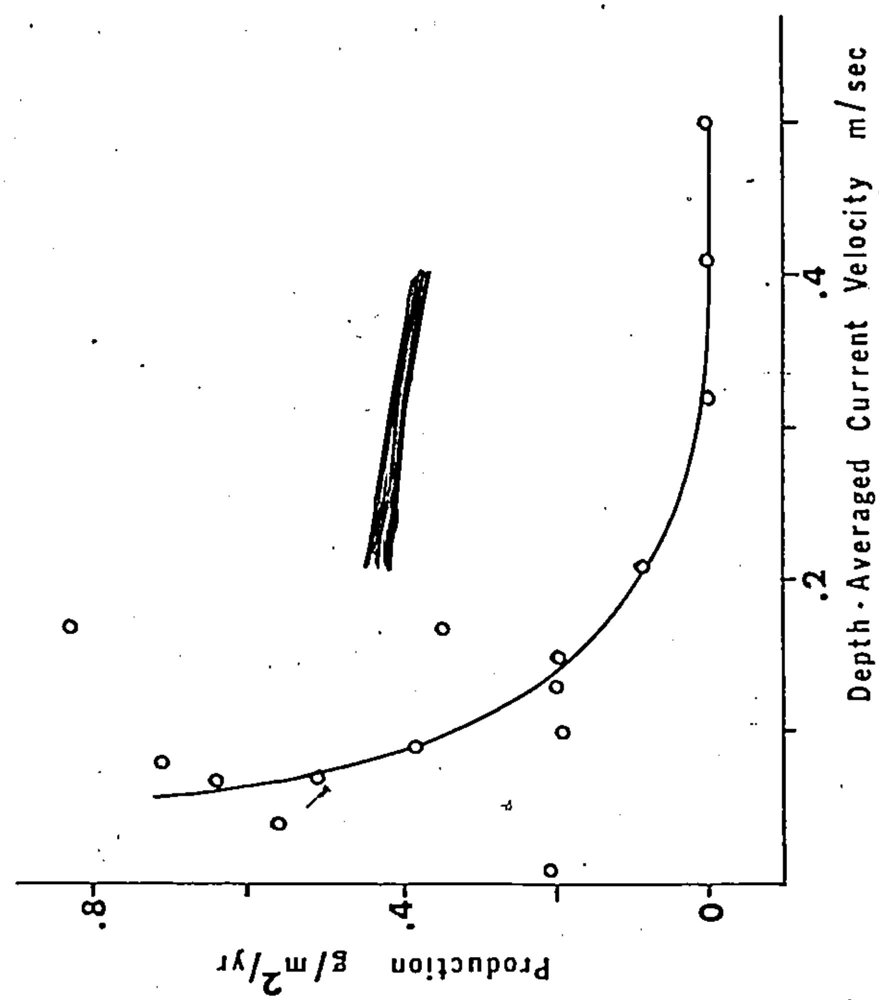
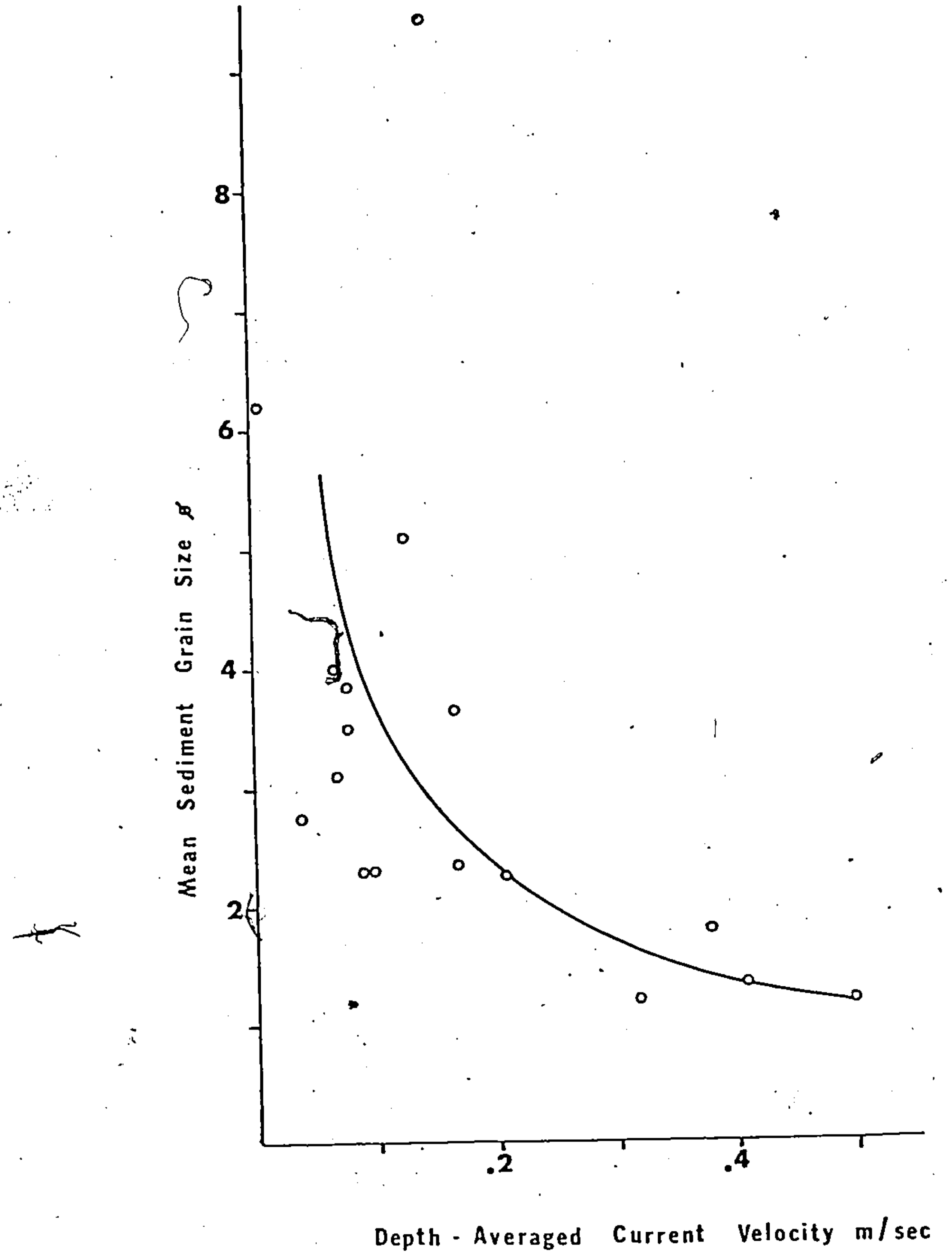

Production g/m^2/yr
.8
.4
0
.2
.4
Depth-Averaged Current Velocity m/sec

Figure 12. Relationship between depth-averaged current velocity and mean sediment grain size in the study area in 1973.

$\log_{10}y = 0.67 - 1.23x$, $N=17$, standard error of estimate 0.18, correlation ($\log_{10}y$ and x) -0.71,

y = mean sediment grain size in Phi (ϕ) units (see Table A2),

x = depth-averaged current velocity in m/sec.



8
6
4
2
Mean Sediment Grain Size ø
.2
.4
Depth - Averaged Current Velocity m/sec

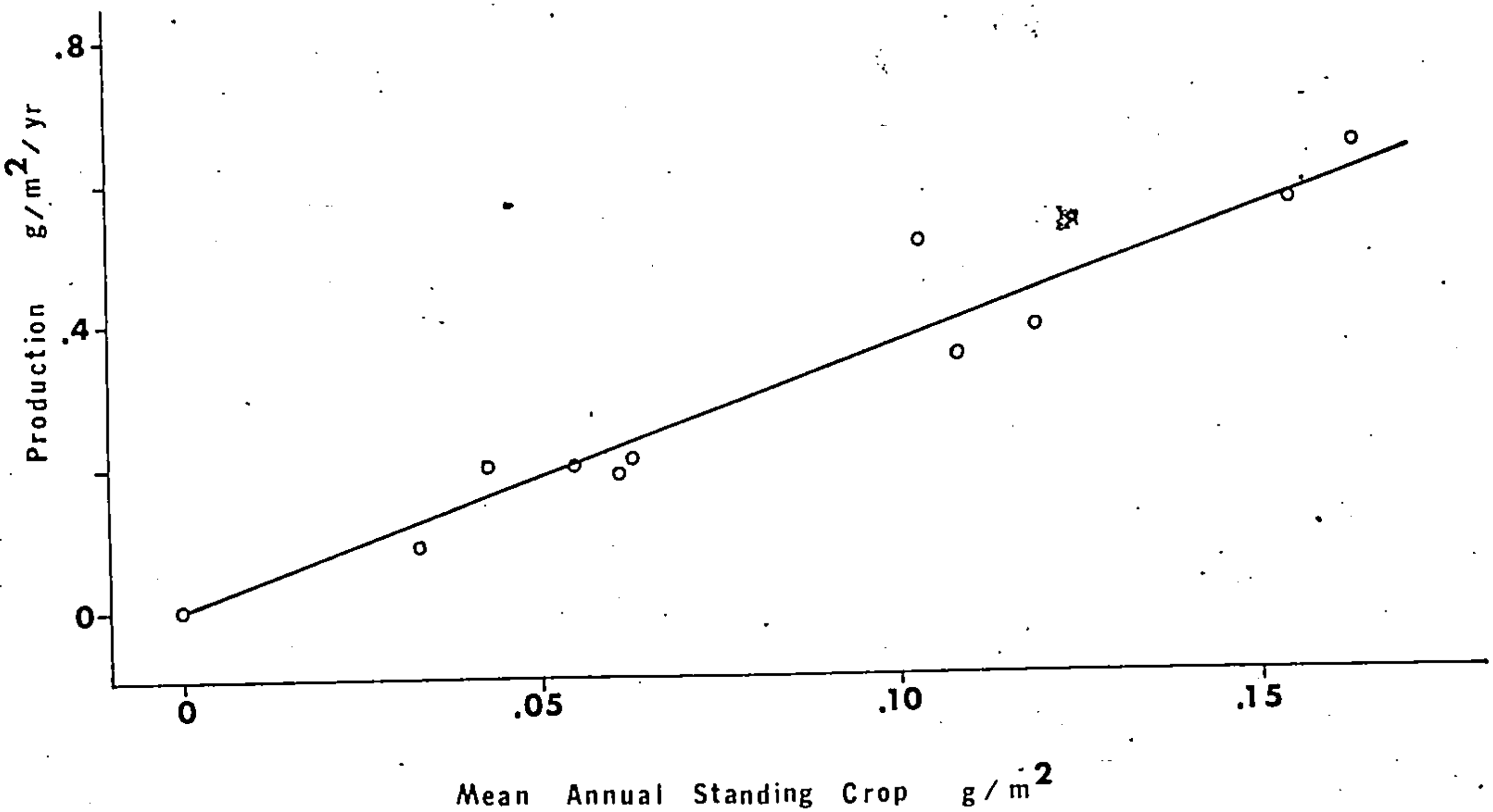
Turnover Ratio (TR)

Turnover ratios were calculated for P.casertanum at various stations and these are summarized in Table 3. The relationship between annual production and mean annual standing crop, shown in Fig.13, indicates that the turnover ratio is a constant and has the value 3.8 ± 0.5 (95% confidence). This compares favourably with Waters'.(1969) TR of 3.5 for univoltine species which spend a negligible portion of the year in the egg or adult stage, and with Winberg's (1970) value of 3.07 for non-predacious benthos. Johnson and Brinkhurst (1971b), however, reported TR's between 1.2 and 1.5 for sphaeriids in the Bay of Quinte and Lake Ontario. They also found that turnover ratios of macroinvertebrates were closely related to annual mean temperature due to the effect of temperature on respiration and growth. This could explain their low TR, since the temperature of the water where they collected sphaeriids, a constant 6-8^{o}C, is lower than that of the Ottawa River (range 0-25^{o}C, annual mean 9^{o}C).

Other Sphaeriids

Eight other species of sphaeriids, besides Pisidium casertanum, were collected in the study area. Of these, three, Pisidium equilaterale Prime, Musculium securis (Prime), and Musculium transversum (Say), occur in such low numbers as to make population analysis impossible. The other five are not sufficiently abundant to permit individual station analysis and so are described on a total area basis. Of these, P.ferrugineum Prime, P.supinum Schmidt, P.nitidum Jenyns, and P.lilljeborgi Clessin

Figure 13. Relationship between annual production and mean annual standing crop (the turnover ratio) of <u>Pisidium</u> <u>casertanum</u> in the study area in 1973. $y = -0.01 + 3.76x$, $N=15$, correlation 0.99, turnover ratio = 3.8 ± 0.5 (95% confidence interval), y = annual production in $g/m^2/yr$, x = mean annual standing crop in g/m^2.


.8
.4
0
Production g/m2/yr
0
.05
.10
.15
Mean Annual Standing Crop g/m2

belong to the subgenus Rivulina, live one year, and reproduce only once. The remaining species, P.punctatum Sterki, is a member of the subgenus Neopisidium and has two small litters per year for several years (Heard 1965).

Standing Crop

Mean annual standing crop estimates for these species at the various stations in the study area in 1973 are given in Table 4. Geographical distribution of these species is similar to that of P.casertanum: they are common or abundant in most littoral areas, but rare or absent in the deep channels, along the polluted Quebec shore, and in Kettle Island Bay. These species, however, are less widely distributed than P.casertanum, being absent from some shore areas and having a tendency to occur in isolated populations.

Each species seems to have a preferential habitat where it reaches its greatest population density, as shown in Table 5. The only overlap is that of P.ferrugineum and P.lilljeborgi and the latter is at a very low density. P.casertanum is dominant in numbers at all stations where sphaeriids occur except one (Transect 3 mid-north channel), where P.punctatum was the only species collected. P.punctatum is second in abundance in most areas with P.ferrugineum taking second place at a few stations. P.punctatum is second to P.casertanum in abundance over the total study area and the other species are much less common.(Table 5).

Population Dynamics

Seasonal abundance of four sphaeriid species is given in

Table 4. Mean annual standing crop of sphaeriids other than *Pisidium casertanum* in the study area in 1973 (standard error 10%).*

Station	*Pisidium punctatum*		*Pisidium ferrugineum*		*Pisidium supinum*		*Pisidium nitidum*		*Pisidium lilljeborgi*	
	g/m^2	no/m^2	g/m^2	no/m^2	g/m^2	no/m^2	g/m^2	no/m^2	g/m^2	no/m^2
Transect 1										
Ont.shore	0.015	81	0.009	7	0.015	11	0.003	2	0.002	7
Mid-south	0	0	0	0	0	0	0	0	0	0
Is.south	0.002	13	0.005	5	0	0	0	0	0	0
Is.north	0.050	303	0.008	13	0	0		0	0	0
Mid-north	0.007	41	0	0	0.033	20	0	0	0.001	2
Que.shore	0.009	43	0.006	3	0.002	1	0.0004	1	0	0
Transect 2										
Ont.shore	0.020	105	0	0	0.008	4	0.006	11	0	0
Mid-south	0	0	0	0	0	0	0	0	0	0
Is.south	0.034	137	0.014	26	0	0	0	0	0	0
Is.north	0.004	28	0	0	0	0	0	0	0	0
Mid-north	0.019	74	0	0	0.004	6	0.004	13	0.001	2
Que.shore	0	0	0	0	0	0	0	0	0	0
Kettle Is.Bay	0	0	0.003	3	0	0	0	0	0	0
Transect 3										
Ont.shore	0.010	39	0	0	0.009	17	0.0004	2	0.001	4
Mid-south	0.001	4	0.007	8	0	0	0.006	6	0	0
Is.south	0.009	17	0.042	50	0.001	2	0	0	0	0
Is.north	0.011	59	0.053	94	0.004	10	0.001	8	0.018	16
Mid-north	0.007	41	0	0	0	0	0	0	0	0
Que.shore	0	0	0.001	2	0	0	0	0	0	0
Total area[1]	0.012	58	0.010	13	0.005	4	0.001	2	0.002	2

* biomass values in g/m^2 total dry weight
1 from production calculations (standard error 2%)

Table 5. Abundance of sphaeriids in the study area in 1973.

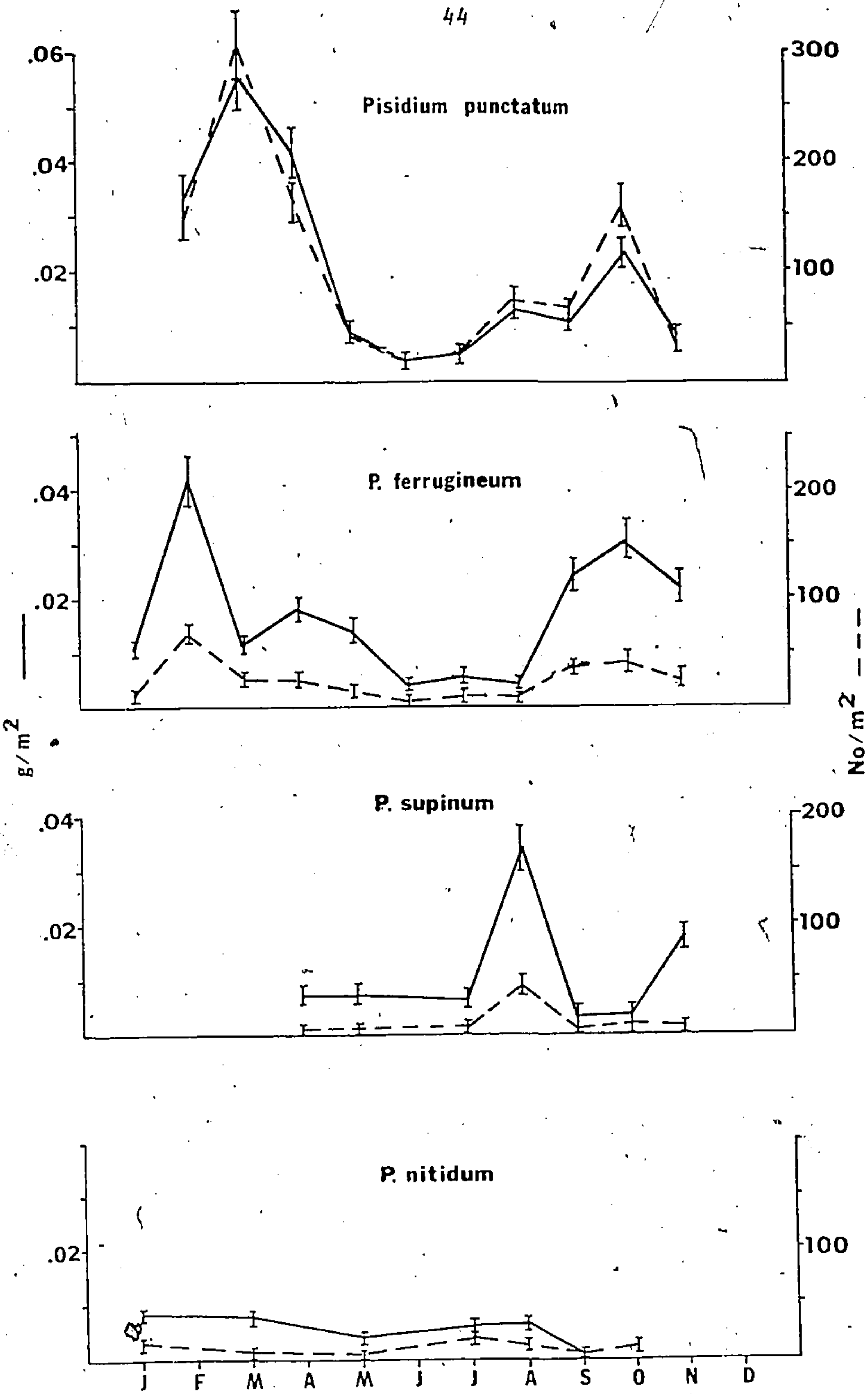
Species	Total no. collected	Max. biomass (g/m^2 total dry wt)	Max. density (no/m^2)	Location of maximum
Pisidium casertanum	1012	0.216	237	2 Is. north
P. punctatum	575	0.050	303	1 Is, north
P. ferrugineum	126	0.053	94	3 Is. north
P. supinum	40	0.033	20	1 Mid-north
P. nitidum	24	0.006 0.006	11 6	2 Ont. shore 3 Mid-south.
P. lilljeborgi	18	0.018	16	3 Is. north
P. equilaterale	2	---	---	---
Musculium transversum	7	---	---	---
M. securis	1	---	---	---

Fig.14. P.lilljeborgi was found only in three samples which was not sufficiently frequent to establish a pattern of seasonal abundance. The trends of P.punctatum, P.ferrugineum, and P.supinum are similar to that of P.casertanum: high numbers early in the year decreasing to a low in mid-summer, then increasing in late summer due to recruitment. P.nitidum was not abundant enough to show a pattern.

Seasonal size class distributions of these species give evidence as to times of reproduction. Recruitment times for P. punctatum appear to be March and October. Increases in numbers of P.ferrugineum were first noted in the September samples and adults carrying young were noticed in the June and July collections. Reproduction in this species may occur throughout the summer. No young-bearing adults of the other species discussed here were seen because of small size and thick shells. P.supinum appears to reproduce in mid-summer with the young being taken first in August. Reproduction is probably earlier for P.nitidum: young were collected first in July. All of the findings here agree with Heard (1965) in his discussion of number of breeding times per year. In summary, the main reproduction times appear to be: P.punctatum -- March and October, P.ferrugineum -- mid-summer, P.supinum -- July-August, P.nitidum -- June-July.

Equations of the length-weight relationships and maximum lengths observed for the five species of sphaeriids are summarized in Table A7. These equations were used to calculate mean dry weights of size classes in the production calculations. P.punctatum, which reproduces twice per year, has the smallest total length. P.casertanum and P.supinum, the two largest, have slower weight-

Figure 14. Seasonal abundance of four sphaeriid species in the study area in ~~1973~~. Solid line: g/m^2 total dry weight monthly standing crop; broken line: no/m^2 monthly standing crop. Range given is ± per cent standard error (10%).


Pisidium punctatum
.06
.04
.02
300
200
100
P. ferrugineum
.04
.02
200
100
g/m^2 ———
No/m^2 – – –
P. supinum
.04
.02
200
100
P. nitidum
.02
100
J
F
M
A
M
J
J
A
S
O
N
D

length growth rates than the other smaller species, all of which have similar rates.

Production and Turnover Ratio (TR)

Annual production values and turnover ratios for all sphaeriids are summarized in Table 6. The TR of P.punctatum is more than twice that of any of the other sphaeriids because it reproduces twice per year. P.ferrugineum, P.supinum, P.nitidum, and P.lilljeborgi have TR's similar to each other but slightly lower than that of P.casertanum.

Johnson and Brinkhurst (1971b) postulated that the turnover ratio is closely related to annual mean temperature and can be predicted by the equation

$$TR = \frac{T^2}{10}$$

where T is annual mean temperature in degrees Celsius. This formula appears to be rather simplistic and applicable only in a general way to large groups of benthos. In Johnson and Brinkhurst's study (their Fig.11) the TR's predicted by the equation are considerably higher than the observed values. In the present study, P.casertanum and P.punctatum, living at the same temperature, had TR's of 3.8 and 8.3 respectively. Using Johnson and Brinkhurst's formula the predicted TR's would be the same for both, 8.1 (Ottawa River annual mean temperature 9°C). It is possible that the turnover ratio is closely related to annual mean temperature, however, when calculating the TR for an individual species, some factor related to the number of reproductive cycles per year of the species

Table 6. Standing crop, production, and turnover ratio of sphaeriids over the entire study area in 1973.

Species	Mean annual standing crop (SE=2%) no/m^2	g/m^2 total dry wt	Production (SE=5%) (g/m^2/yr total dry weight)	Turnover ratio (SE=7%)
Pisidium casertanum	92	0.071	0.263	3.8
P. punctatum	58.2	0.012	0.099	8.3
P. ferrugineum	12.8	0.010	0.027	2.8
P. supinum	4.0	0.005	0.013	2.5
P. nitidum	2.4	0.001	0.003	2.2
P. lilljeborgi	1.8	0.002	0.004	2.3
Total sphaeriids	171.2	0.101	0.409	---

should be added. For example, in this study the TR's of species which have one cycle per year are more closely predicted by the formula

$$TR = \frac{T^2}{10} \times \frac{1}{2} .$$

However, the original equation is accurate for the species which have two cycles per year.

In the present study five species of sphaeriids were not sufficiently abundant to permit individual station analysis, though sampling effort for each was the same. For these species the TR was calculated on the basis of the total collection over the entire study area. The calculated TR was then used to estimate production at the individual stations from the mean annual standing crop biomass figures. These values are presented in Table A8. The same conversion factors as used for P.casertanum may be used here to convert values from total dry weight to total live weight, soft parts dry weight, or soft parts energy content.

The production estimates reflect the importance of each sphaeriid species in the community. P.ferrugineum, P.supinum, P.nitidum, and P.lilljeborgi comprise a small fraction (12.3%) of the sphaeriid fauna and , although annual production for each differs, the similar turnover ratios (2.3-2.8) show that they are producing equally in proportion to their standing crop. P.casertanum, at 53.7% the dominant species and probably the best adapted to the Ottawa River environment, appears to be more efficient at production as indicated by its higher turnover ratio (3.8). P.punctatum, although second in importance in the sphaeriid fauna (34.1%) and in production to P.casertanum, produces much more in relation to its standing crop (TR 8.3). This high efficiency can probably be attributed to its smaller size and more frequent reproduction. It apparently devotes less energy to growth and more to reproduction than does P.casertanum.

Effects of Some Environmental Parameters on Production

The five less abundant sphaeriids show relationships between annual production and sediment grain size, current velocity, and sediment organic matter content similar to those of P.casertanum, ie, production is related to grain size and to current velocity but not to organic matter content. However, since production of these species is at a lower level and occurrence is less consistent than for P.casertanum, the relationships are less easy to analyze.

Species Diversity of Sphaeriids

The Shannon-Wiener and Simpson methods produced similar results; the Wilhm-Dorris calculations were less comparable to these (Table A9). The Shannon-Wiener values for species diversity at each station were used in the linear regressions with environmental parameters. Current velocity and sediment grain size appear to have no effect on species diversity; however, there is a relationship between sediment organic matter content and diversity of sphaeriids (N=10, correlation 0.53) as shown in Fig.15.

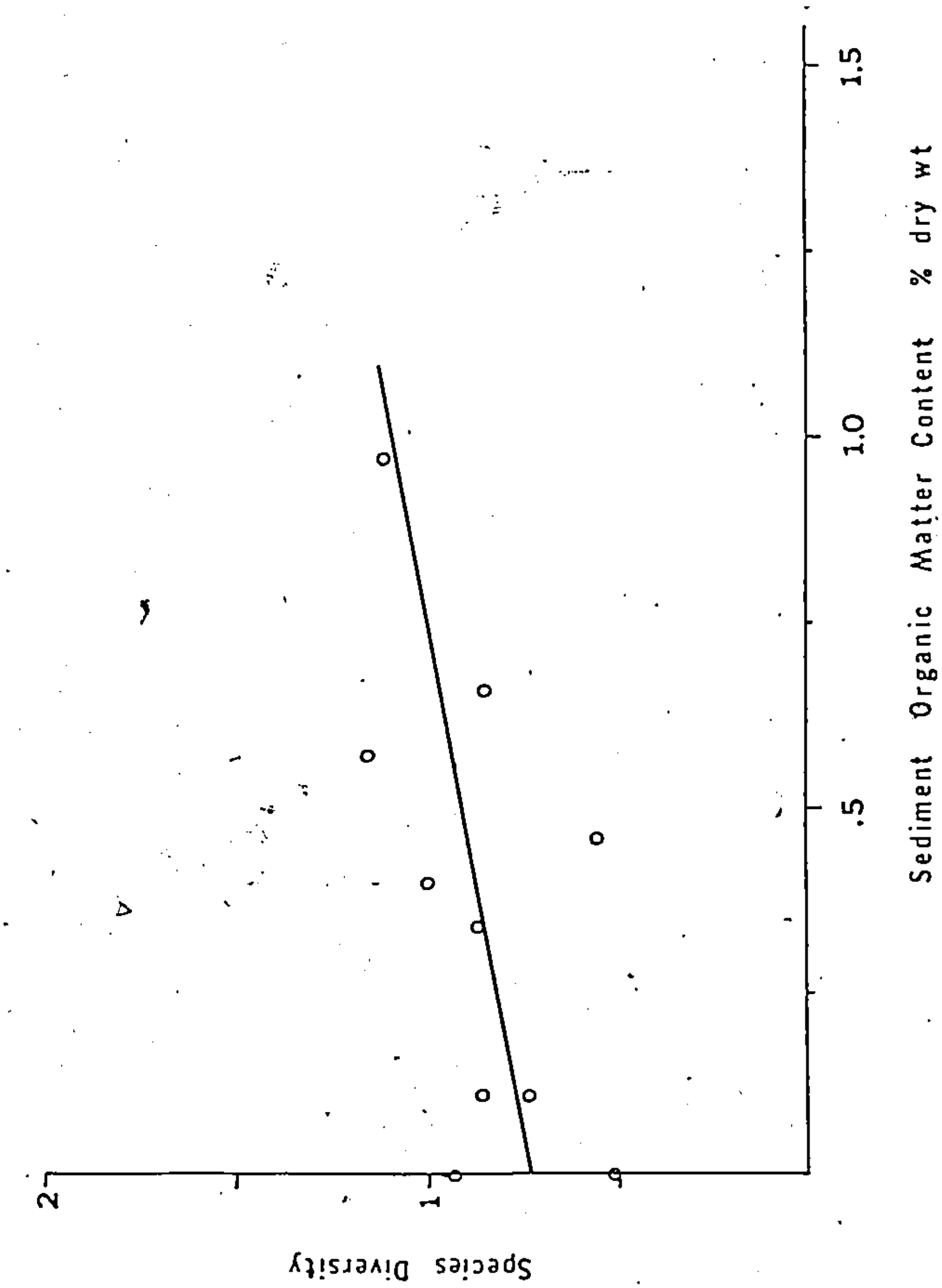
The species diversity index is a combination of number of species and number of individuals. There is a low correlation between number of sphaeriid individuals and organic matter content (N=10,

Figure 15. Relationship between sediment organic matter content and species diversity of sphaeriids in the study area in 1973.

$y = 0.73 + 0.35x$, $N=10$, standard error of estimate 0.19, correlation 0.53,

y = species diversity,

x = sediment organic matter content in % dry weight.


Species Diversity
2
1
.5
1.0
1.5
Sediment Organic Matter Content % dry wt

correlation 0.09) but a stronger relationship between number of sphaeriid species and organic matter content (N=10, correlation 0.17). It would appear then that the relationship between species diversity and organic matter content is a result of the increasing number of species of sphaeriids to be found as sediment organic matter content increases. This indicates that a sphaeriid species requires a certain level of organic matter in sediments in order to exist. Different species probably have different requirements; as organic matter content increases more species have their requirements met. However, as previously shown, organic matter content of sediment is not important in determining production of a sphaeriid species in a habitat.

Amphipoda

Amphipod crustaceans are one of the largest and most prominent groups of freshwater invertebrates (Holsinger 1972). Five families (Corophiidae, Haustoriidae, Hyalellidae, Pontogeneiidae, and Gammaridae) belonging to the suborder Gammaridea are represented in the freshwater environment of North America. Of these, the family Gammaridae, with nine genera and numerous species, is the most prominent.

Amphipods, being peracaridan crustaceans, have only one true thoracic segment fused to the head, have eggs borne in a thoracic brood pouch, and hatch into a juvenile rather than a true larval stage. They occur in virtually all marine habitats and many freshwater habitats. In the freshwater environment the majority of species are found in smaller bodies of water, such as streams, swamps, ponds, ditches, springs, and cave streams and pools. Few species inhabit large rivers or the open water of larger lakes and most species are associated with the substrate.

Amphipods can swim, walk, jump, and burrow and may be carnivores or detritovores. Additional information on amphipods can be found in Bousfield(1958, 1973) and Holsinger (1972).

Two species of amphipods were collected in the Ottawa River in 1973: Gammarus fasciatus Say of the family Gammaridae and Hyalella azteca (Saussure) of the family Hyalellidae. The latter was not present in sufficient numbers to allow detailed analysis.

Gammarus fasciatus Say

According to Bousfield (1958), G.fasciatus occurs mainly in lakes and large rivers that are slow-flowing, relatively turbid, and warm in summer. It ranges from the upper Mississippi River drainage eastward throughout the Great Lakes area and south along the Atlantic coastal plain to southern North Carolina (Holsinger 1972).

Sexes are separate and the male is larger than the female. Ovigerous females have been observed from February to September, there are two generations per year, and the life cycle is of less than one year's duration. Fertilization is achieved by copulation and the eggs are carried in a brood pouch or marsupium by the female. Young are released from the pouch shortly after hatching and they reach adulthood after about seven moults.

Clemens (1950) cites G.fasciatus as being omniverous, having observed it feeding on both living and dead plant and animal matter.

Standing Crop

G.fasciatus is the most abundant amphipod in the study area: over 550 specimens were collected during the study. Mean annual standing crop values for the various stations in the study area in 1973 are given in Table 7. This amphipod is most abundant in littoral areas, particularly at Transect 1 island south shore, but rare or absent in the deeper channels, in polluted areas, and in Kettle Island Bay. *G.fasciatus* appears to be more sensitive to pollution than sphaeriids, as indicated by the low standing crop in the north channel on Transect 2 below the paper mill; but less restricted by the sediment type, as shown by the number present in the silt at Transect 3 Ontario shore.

Population Dynamics

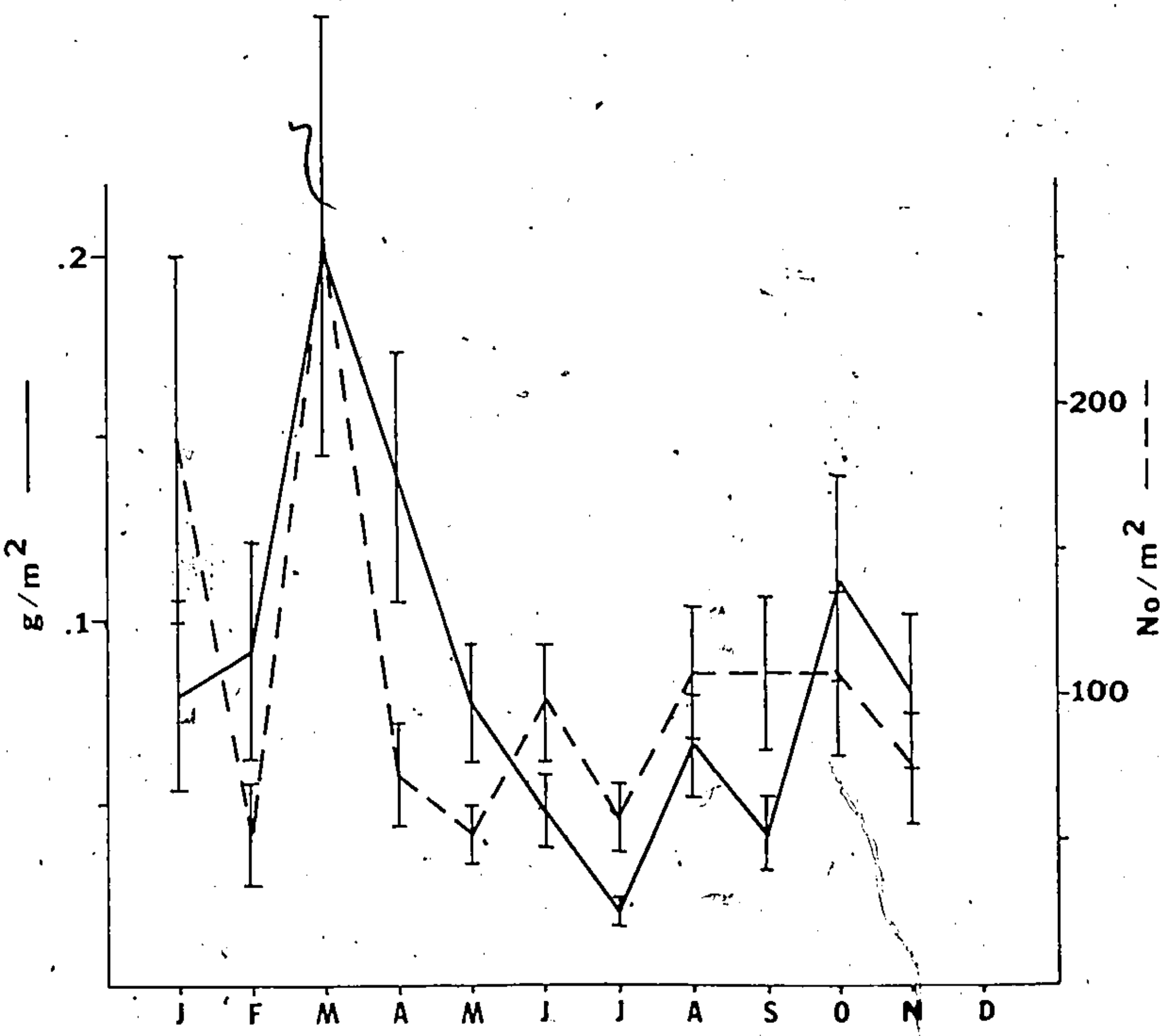
Seasonal abundance in the study area in 1973 is given in Fig.16. The largest monthly collection was made in March; however, low values for January and February may be a function of the few samples taken during those months. The population declined in numbers until May and in biomass until July, after which it began to increase again to a maximum in October. Subsequently it began to decrease again. Clemens (1950)found that the *G.fasciatus* population he was studying increased from a low winter level in February and March to a maximum in September and October, after which it declined. Mackie (1971:79) shows two peaks in numbers for his *G.fasciatus* population: a low peak in June and a higher one in September. The present study agrees with these two reports except for the high values in the spring of 1973. This appears

Table 7. Standing crop, production, and turnover ratio of *Gammarus fasciatus* in the study area in 1973.

Station	Mean annual standing crop (SE=30%) no/m²	g/m² total dry wt	Production (SE=70%) g/m²/yr total dry wt	Turnover ratio (SE=143%)
Transect 1				
Ont.shore	34	0.018	0.108	6.18
Mid-south	9	0.015	0.108*	---
Is.south	215	0.211	1.489	7.06
Is.north	173	0.107	1.013	9.43
Mid-north	15	0.020	0.123	6.18
Que.shore	148	0.155	1.019	6.58
Transect 2				
Ont.shore	33	0.053	0.287	5.40
Mid-south	0	0	0*	---
Is.south	32	0.025	0.146	5.81
Is.north	2	0.003	0.022*	---
Mid-north	7	0.011	0.079*	---
Que.shore	2	0.001	0.007*	---
Kettle Is.Bay	0	0	0*	---
Transect 3				
Ont.shore	48	0.096	0.478	4.97
Mid-south	49	0.023	0.120	5.22
Is.south	69	0.074	0.673	9.15
Is.north	79	0.041	0.247	6.10
Mid-north	0	0	0*	---
Que.shore	0	0	0*	---
Mean	48	0.045	0.312	---

* estimated using the turnover ratio 7.2 (from Fig.18)

Figure 16. Seasonal abundance of Gammarus fasciatus in the study area in 1973. Solid line: g/m^2 total dry weight monthly standing crop; broken line: no/m^2 monthly standing crop. Range given is ± per cent standard error (20-33%).


.2
.1
g/m2
200
100
No/m2
J
F
M
A
M
J
J
A
S
O
N
D

to indicate that either the 1972 year classes of G.fasciatus were particularly strong or that the 1973 year classes were weak. A comparison with the data of Mackie (1971), as with P.casertanum, shows that the 1973 crop is probably closer to normal than that of 1972. Mackie's work (1971:73) indicates a doubling of the population from 1968 to 1969 at his Station 5 (Transect 1 north half). Perhaps due to the mobility of this species high variation in population numbers is a common occurrence.

Recruitment can best be demonstrated by seasonal size class distribution (Fig.17). This indicates that there were two major increases in numbers of small (young) amphipods: in June and in September. Thus the two broods in 1973 appear to have been produced mainly at these two times of the year. Seasonal abundance (Fig.16) shows the same pattern: increase in numbers in June and again in August.

The typical head length-weight relationship of G.fasciatus is given in Fig.18. The equation of this relationship is: $\log_{10}y = -1.73 + 0.44x$, $N = 518$, correlation ($\log_{10}y$ and x) 0.88, where y = total dry weight in milligrams and x = head length in micrometer units (1 unit = 0.2mm). Equations of this relationship at the various stations are given in Table A10. These formulae were used to calculate mean dry weights of size classes in the production calculations. The range of head lengths observed for G.fasciatus was 0.30mm to 1.20mm.

Production

Production values for G.fasciatus at each station are

Figure 17. Seasonal size class distribution of <u>Gammarus fasciatus</u> in the study area in 1973. Range given is ± per cent standard error (20-33%), $y = no/m^2$, x = head length size class in micrometer units and corresponding metric scale.

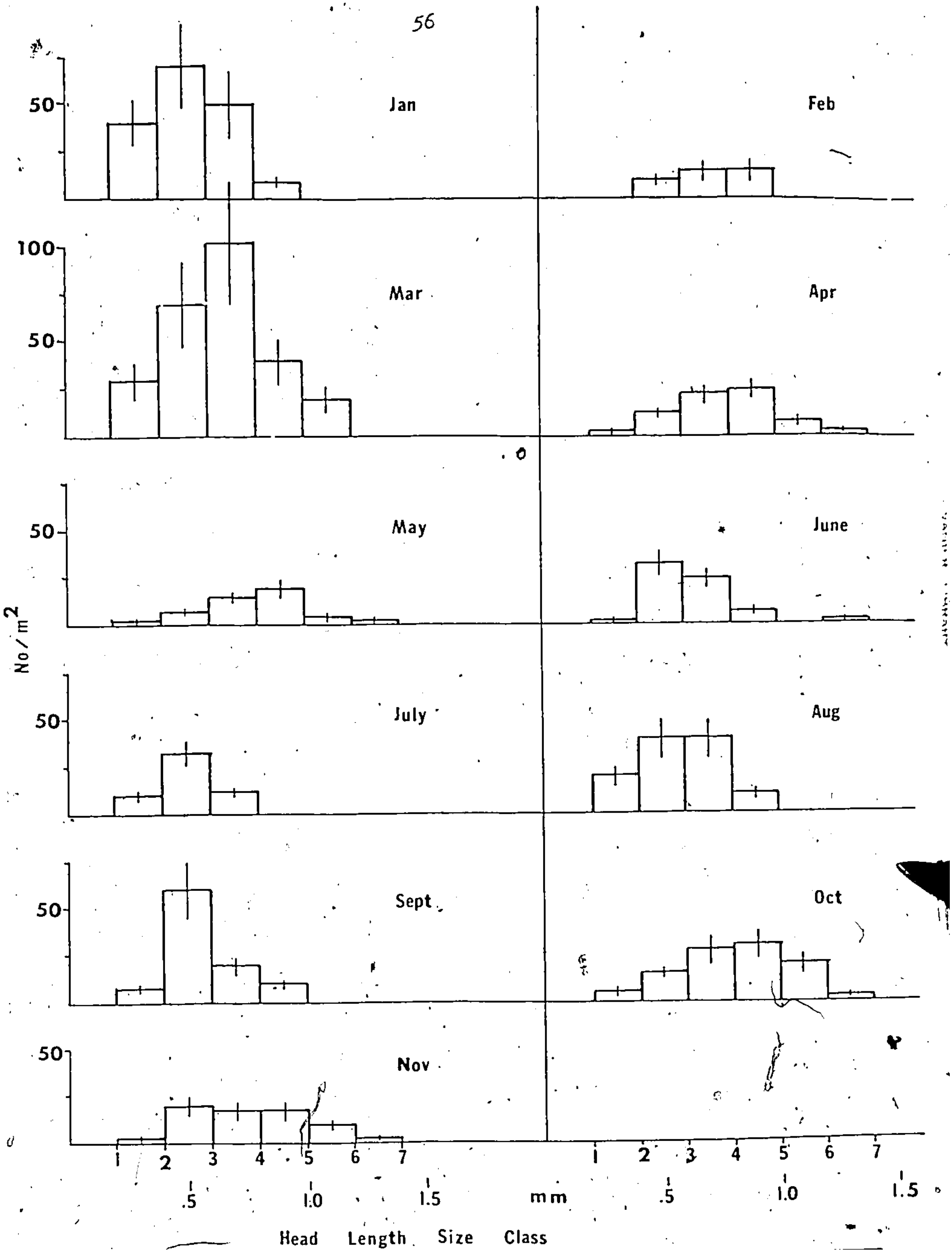
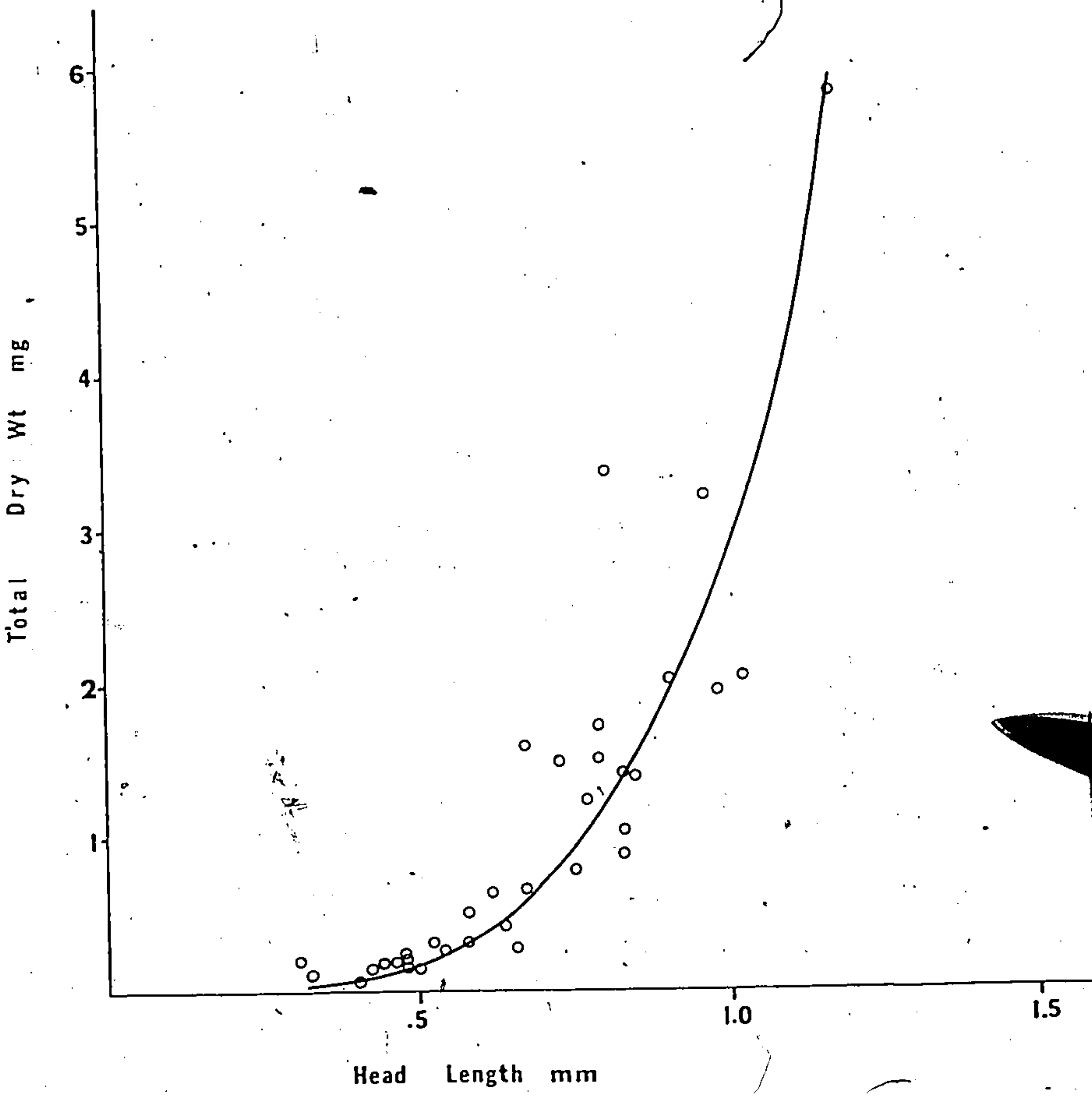

Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
50
100
No / m2
1
2
3
4
5
6
7
.5
1.0
1.5
mm
Head Length Size Class

Figure 18. Head length-weight relationship of <u>Gammarus fasciatus</u> in the study area in 1973.
$\log_{10} y = -1.73 + 0.44x$, $N=518$, correlation ($\log_{10} y$ and x) 0.88, y = total dry weight in mg,
x = head length in micrometer units (1 unit = 0.2mm).


Total Dry Wt mg
6
5
4
3
2
1
.5
1.0
1.5
Head Length mm

summarized in Table 7. Production ranges from a high of 1.49 $g/m^2/yr$ total dry weight at Transect 1 island south shore to 0 $g/m^2/yr$ where the species is absent.

The dry weight of an individual G. fasciatus is about 20% of the live weight (N=18) and the energy content of the body is 4.34 kcal/g dry weight or 5.63 kcal/g ash-free dry weight (D.W. Rodgers pers.comm.1974). Cummins and Wuycheck (1971) reported the energy content of gammarids to be 4050 cal/g dry weight and 5362 cal/g ash-free dry weight. From these conversion factors the production of G. fasciatus can be expressed as total live weight and as calories, as well as total dry weight (Table A11). The value of 4.34 kcal/g dry weight was used in the energy calculation.

Few estimates of amphipod production have appeared in the literature, and none could be found for G. fasciatus. The following values have been reported:

Hyalella azteca	0.3 kg/ha/day	(Gerking 1962)
H. azteca	0.129 kg/ha/day	(Cooper 1965)
Gammarus pseudolimnaeus	183 $kc/m^2/yr$	(Tilly 1968)
Pontoporeia affinis	1537504 $mm^3/m^2/yr$	(Green 1971)
H. azteca	4.535 $kcal/m^2/yr$	(Mathias 1971)
Crangonyx richmondensis	1.363 $kcal/m^2/yr$	(Mathias 1971)
Gammarus pulex	75 cal/g/day	(Nilsson 1974)

Comparisons are difficult because of differences in species, units, and environments.

Effects of Some Environmental Parameters on Production

Factors affecting the distribution and abundance of amphipods have been investigated by several researchers. Titcomb (1927) found the distribution of *G.fasciatus* and *G.limnaeus* in New England to be dependent upon the degree of hardness of the water. Pentland (1930) reported that in Ontario it was not the chemical composition of the water but temperature, vegetation, and presence of predators which controlled distribution and abundance of these amphipods. He found that they preferred cool waters where either living or dead vegetation was readily available and that their numbers could be reduced by trout predation. Creaser (1935) noted that *G.fasciatus* seemed to prefer cooler water temperatures ($48^{o}F$). The distribution of *G.duebeni* in Ireland appears to be restricted to fresh waters of high salt content (Sutcliffe 1967). Several researchers have found that amphipods, particularly *Hyalella azteca*, are attracted to submerged aquatic macrophytes (Krecker 1939, Rosine 1955, Gerking 1957, Mackie 1971). The preferred plants appear to be those with highly dissected leaves, such as *Myriophyllum* spp., while *Vallisneria americana*, with non-dissected leaves, harbours few amphipods. Mackie (1971) reported that in the Ottawa River, *H.azteca* was the numerically dominant amphipod on *Myriophyllum* spp. and *Elodea canadensis*, while *G.fasciatus* was dominant on *Potamogeton* sp. and in the sediment. He also concluded that sediment type has little influence on the distribution of amphipods. Wilder (1940) attributed the higher abundance of *H.azteca* in shallower waters of Marion Lake, B.C., to the presence of epibenthic bacteria and algae which the amphipod feeds upon. He found that increased growth of *H.azteca* was independent of temperature but closely correlated with increased rates of epibenthic primary production.

In laboratory experiments Nilsson (1974) calculated that production increased with increasing temperature.

In the present study temperature was relatively constant throughout the study area and does not explain different levels of production of G.fasciatus. No information was collected on sediment microflora, competition, nor fish predation. Water chemistry may have significant effects on production, but in this study it is important only in those areas below the paper mill. Low production here may be due to toxic chemicals, high BOD, the blanketing effect of paper fibre, and/or the absence of submerged aquatic plants. There appears to be no relation between level of production and mean sediment grain size, substrate organic matter content, nor current velocity. Table 8 lists the various stations in order of decreasing production of G.fasciatus along with aquatic vegetation present at each station. It is obvious that in order to achieve a high level of production vegetation must be present. However, it is not clear whether production is higher because vegetation is present or production is higher and vegetation is present because of some other factor(s).

Mackie (1971) postulated that amphipods might inhabit aquatic vegetation to obtain photosynthetic oxygen, but this would be necessary only in waters of low oxygen content. Hyalella azteca has been reported to browse on epiphytes of aquatic plants (Lindeman 1941), however, G.fasciatus appears to be more associated with the sediment than with the plants (Mackie 1971).

Several researchers have noted that drift is an important characteristic of amphipod populations, particularly those of

Table 8. Stations in order of decreasing production of *Gammarus fasciatus* along with aquatic vegetation present.

Transect and station	Production ($g/m^2/yr$ total dry wt)	Vegetation present* (from Table 1)
1 Is.south	1.489	ESV
1 Que.shore	1.019	ESV
1 Is.north	1.013	ESV
3 Is.south	0.673	ESV
3 Ont.shore	0.478	EPSV
2 Ont.shore	0.287	EPSV
3 Is.north	0.247	ESV
2 Is.south	0.146	ESV
1 Mid-north	0.123	V
3 Mid-south	0.120	none
1 Ont.shore	0.108	EPSV
1 Mid-south	0.108	none
2 Mid-north	0.079	none
2 Is.north	0.022	Pr
2 Que.shore	0.007	none
2 Mid-south	0	none
Kettle Is.Bay	0	none
3 Mid-north	0	none
3 Que.shore	0	Pr

* E: *Elodea canadensis*, S: *Sparganium angustifolium*, V: *Vallisneria americana*, P: *Potamogeton* sp., Pr: *Potamogeton richardsonii*

Gammarus limnaeus, G.pseudolimnaeus, and G.pulex (Waters 1961, 1965, Müller 1963). Amphipods also tend to move upstream against the current flow (Minckley 1964, Hughes 1970). Factors which have been found to affect drift are light intensity, current velocity, water depth, population density, and temperature (Müller 1963, Holt and Waters 1967, Minshall and Winger 1968, Pearson and Franklin 1968, Hughes 1970). All of these factors suggest that drift should be greater in littoral areas with shallow, slow water shaded by vegetation. There is no clear indication as to how this would affect production. The solution may simply be that G.fasciatus requires physical structures (the plants) in its environment to provide hiding places, food traps, and/or holdfasts.

These results show that variation in production of G.fasciatus can be explained by two factors: the presence or absence of aquatic macrophytes and pollution.

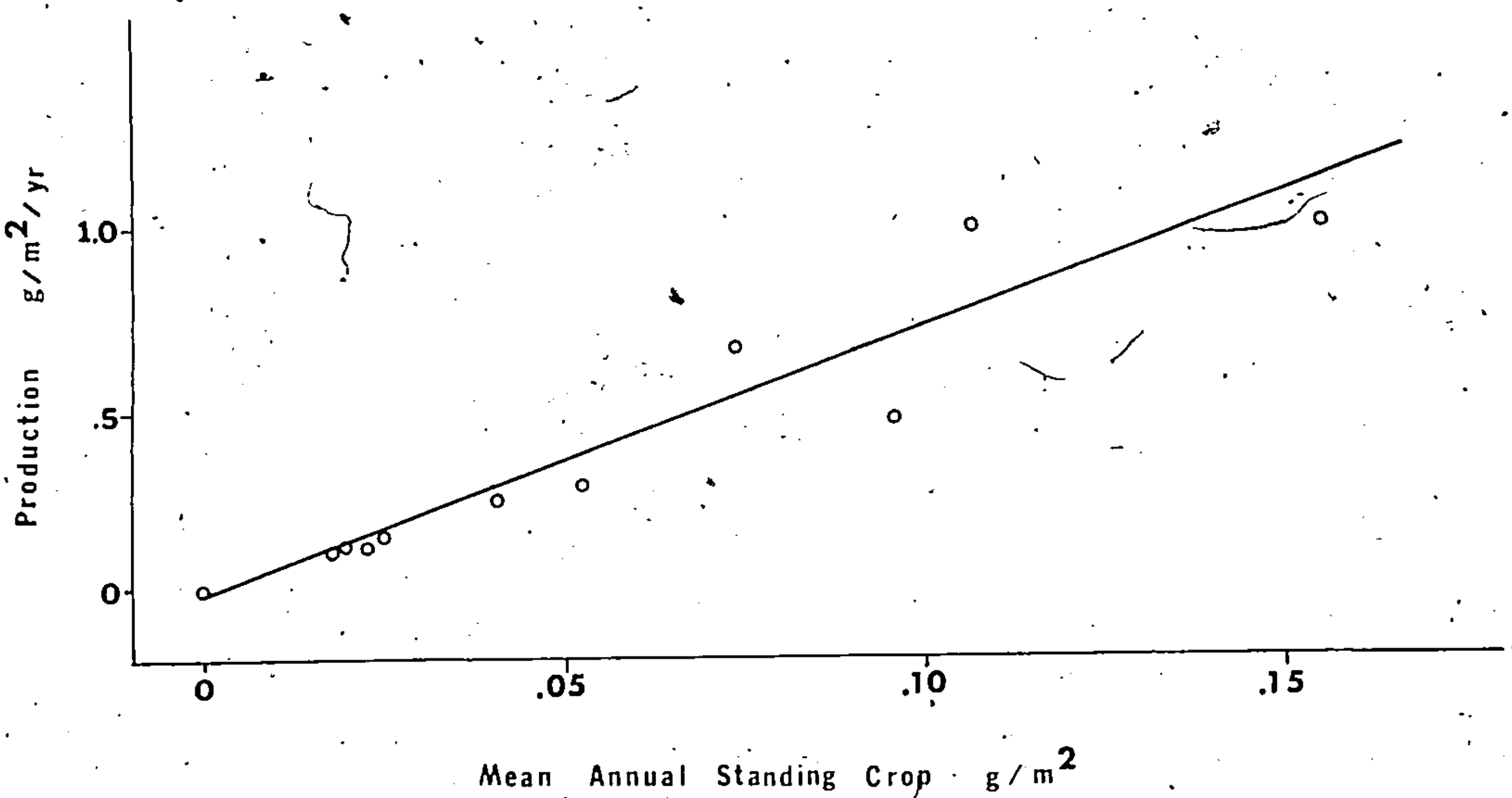
Turnover Ratio (TR)

Turnover ratios were calculated for G.fasciatus at the various stations and these are summarized in Table 7. The relationship between annual production and mean annual standing crop biomass, shown in Fig.19, indicates that the turnover ratio for this species is a constant and has the value of 7.2 ± 2.6 (95% confidence). Green (1971) reports a TR of 4.23 for Pontoporeia affinis, an amphipod with a one-year life cycle. G.fasciatus reproduces twice per year and would be expected to have a higher turnover ratio.

Figure 19. Relationship between annual production and mean annual standing crop (the turnover ratio) of Gammarus fasciatus in the study area in 1973. $y = -0.01 + 7.15x$, $N = 11$, correlation 0.98, turnover ratio = 7.2 ± 2.6 (95% confidence interval),

y = annual production in $g/m^2/yr$,

x = mean annual standing crop in g/m^2.


Production g/m2/yr
1.0
.5
0
.05
.10
.15
Mean Annual Standing Crop g/m2

Kettle Island Bay

The Kettle Island Bay station is obviously very different from any of the others. It was included because of its contrasting conditions: low flow, warmer temperature, very fine sediments. Few benthic organisms were found in this environment and production was low. The cause of this may be the light, almost fluffy organic material particles which make up the substrate. This may not provide a solid footing for the existence of benthos.

Dry Weight and Ash-free Dry Weight of Benthos

Dry weights and ash-free dry weights of various groups of benthos are given in Table A12. Most shell-less benthic organisms are about 90 to 95% combustible organic matter. However, the isopods (Crustacea: Isopoda), containing a greater amount of hard material are only 76% combustible. The shelled molluscs are made up of a much lower proportion of combustible matter (20-30%) because of the shell.

Mercury and Pesticide Content of Benthos.

Mercury and pesticide contents of all samples of benthos analyzed during 1972-1973 are given in Table A13. There are no apparent trends showing that mercury or pesticide concentrations are higher in specific locations in the study area.

Mean values for some benthic groups are given in Table A14. Mercury levels are similar among the various groups except for molluscs, especially Campeloma decisum. This large snail contains considerably more mercury than any other organism analyzed and has the only level over 0.5 ppm, the value often accepted as being safe for human consumption.

Johnels et al.(1967) analyzed the mercury content of benthic organisms above and below a paper mill in Sweden. Their values ranged from 0.05 to 0.07 ppm above the mill and from 1.9 to 17.0 ppm below the mill. From a study of the Fraser River mudflats, Parsons et al.(1973) reported mercury content values of 0.12 and 0.33 ppm for molluscs. Levels of mercury contamination in the Ottawa River are generally higher than the Swedish above-mill values but much lower than those from below the mill, indicating moderate pollution. The concentrations reported in the present study are similar to those of the Fraser River mudflats.

No trends are apparent in the levels of DDT and PCB contamination of Ottawa River benthos (Table A14).

Woodwell et al.(1967) reported levels of DDT in benthic organisms from a salt marsh in New York of from 0.16 to 0.42 ppm. Jensen et al.(1969), working with marine invertebrates from Swedish waters, recorded values of 0.007 ppm DDT and 0.084 ppm PCB. Sodergren et al.(1972), also working in Sweden, found levels of DDT up to 0.045 ppm and PCB up to 0.017 ppm in stream benthos. In Tokyo Bay, Shimmo et al. (1973) measured a concentration of 0.01 ppm PCB in a marine clam. In uptake experiments benthic organisms have been known to accumulate up to 2 ppm DDT (Johnson et al. 1971) and 3 ppm DDT (Vaajakorpi and Salonen 1973).

The levels of DDT measured in benthos of the Ottawa River in the present study are much lower than most of those others mentioned here, but the values for PCB are similar.

SUMMARY AND CONCLUSIONS

As part of the Ottawa River Project, benthos was sampled at nineteen stations in a four-kilometer study section of the Ottawa River near Ottawa-Hull, Canada. Three transects, each having six stations, were chosen such that each transect contained two mainland shore stations, two island shore stations, a deep channel station, and a shallow channel station. In addition, one station in the sheltered Kettle Island Bay was sampled. Samples were taken monthly throughout 1973 with a standard 15x15 cm Ekman grab with a screen on top. The material was sieved and hand-sorted in a sorting tray designed by the author. Information was collected and gathered from other sources on environmental parameters at each station.

Pollution from the Canadian International Paper Company mill in Gatineau, Quebec, was evident in the study area. Diversity of benthic groups was greatly reduced below the mill and pollutants were clearly visible in the form of turbidity, lumps and slicks on the surface, and woodfibre in the sediment.

Water chemistry did not differ greatly among stations, except for some less favourable conditions below the mill. None of the average chemical characters of the water in the study area exceeded the values recommended by the Ontario Water Resources Commission. Differences among stations were noted for current velocity, sediment grain size, and sediment organic matter content.

Six species of sphaeriid clams and one amphipod crustacean were chosen for intensive study. The following analyses were carried out on these species: total numbers and size class seasonal abundance, length-weight relationship, mean annual standing crop, annual production, and turnover ratio.

One species of sphaeriid, Pisidium casertanum, and the amphipod Gammarus fasciatus, were sufficiently abundant that these analyses could be made at individual stations. For these two species a correlation of mean annual standing crop biomass and annual production was made to determine if the turnover ratio is constant. Annual production of these two species was related to environmental conditions at individual stations to explain differences in production.

Species diversity of sphaeriids was calculated at all nineteen stations using three different methods and the results were compared.

Samples of benthic organisms were ashed to provide ash-free dry weights and other samples were analyzed for mercury, DDT, DDD, DDE, and PCB content.

Benthic organisms were abundant throughout the study area except in the deep channels where there is high current velocity, coarse sand sediment, and no rooted vegetation. Reduced numbers were also apparent in areas polluted by the paper mill and in Kettle Island Bay.

Pisidium casertanum reproduced in late June or early July. Production varied from a high of 0.83 $g/m^2/yr$ to 0 $g/m^2/yr$ total dry weight. Variations in production were attributed to differences in sediment grain size and in current velocity. Production increased as grain size and current velocity decreased. However, because sediment grain size and current velocity are closely correlated, it could not be determined which of these was the more important controlling factor. No relationship was found between production of P. casertanum and sediment organic matter content. The turnover ratio of P. casertanum was 3.8 and was constant even under varying environmental conditions.

Geographical distribution of other sphaeriids in the study area was similar to that of P. casertanum: common or abundant in most littoral areas but rare or absent in the deep channels, along the polluted Quebec shore, and in Kettle Island Bay. Each species seemed to have a preferential habitat where it reached its greatest population density.

Pisidium punctatum was second to P. casertanum in abundance in the study area. It reproduces twice a year, in the present study in March and October. Three lesser abundant sphaeriids, P. ferrugineum, P. supinum, and P. nitidum, were found to reproduce once a year, in mid-summer, July-August, and June-July, respectively.

P. punctatum, the only sphaeriid in this study reproducing twice a year, was the smallest in total length. The two largest species, P. casertanum and P. supinum, had slower weight:length growth rates than the other sphaeriids.

The turnover ratio of P. punctatum, at 8.3, was more than twice that of any of the other sphaeriids because it reproduces twice a year. P. ferrugineum, P. supinum, P. nitidum, and P. lilljeborgi had turnover ratios of 2.8, 2.5, 2.2, and 2.3 respectively.

Species diversity of sphaeriids was calculated using the Shannon-Wiener, Simpson, and Wilhm-Dorris methods. The Shannon-Wiener and Simpson values were similar but the Wilhm-Dorris calculations were less comparable to these. Current velocity and sediment grain size were not related to species diversity, but diversity increased as sediment organic matter content increased.

Gammarus fasciatus was the most abundant amphipod in the study area. It was most commonly found in littoral areas, but was rare or absent in the deeper channels, in polluted areas along the Quebec shore, and in Kettle Island Bay. This species reproduced in June and in September.

Production of G. fasciatus ranged from 1.49 $g/m^2/yr$ to 0 $g/m^2/yr$ total dry weight. No relationship was found between level of production and sediment grain size, sediment organic matter content, nor current velocity. However, it was noted that production was higher where aquatic vegetation was present. The turnover ratio of G. fasciatus was a constant 7.2.

Most shell-less benthic organisms were about 90-95% combustible organic matter. However, the isopods, containing a greater amount of hard material, were only 76% combustible. The shelled molluscs were made up of a much lower proportion of combustible material (20-30%) because of the shell.

There were no apparent trends showing that mercury or pesticide concentrations are higher in specific locations of the study area. Mercury levels were similar among the various groups of benthos except for molluscs, especially Campeloma decisum. This large snail contained considerably more mercury than any other organism analyzed and had the only level over 0.5 ppm. No trends were apparent in the levels of DDT and PCB contamination of Ottawa River benthos. Benthic organisms in the Ottawa River were found to carry a moderate level of mercury and PCB contamination and low concentrations of DDT.

SUGGESTIONS FOR FUTURE RESEARCH

During the course of this study questions have arisen which would require more detailed research to be answered. The research in this study was restricted to accomplishing the objectives laid down at the outset. However, if future research in this field were contemplated, the following lines appear promising:

(1) Pisidium casertanum and P.punctatum are very similar organisms. However, P.punctatum breeds twice a year and has a much higher turnover ratio than P.casertanum, which breeds only once a year. Does P.punctatum's smaller size allow it to devote more energy to reproduction and less to growth? Or is it more efficient in some other way? Similarly, P.casertanum has a higher turnover ratio than the other sphaeriids, which also breed once per year. Because P.casertanum is very adaptive (Herrington 1962) is it more efficient than the other sphaeriids? Or is it just better suited to this particular environment?

(2) Production of P.casertanum is closely related to both sediment grain size and current velocity. Because no area of high current velocity and small grain size exists in the study area it was impossible in this study to determine which is more important in affecting production. De March (pers.comm.1975) postulated that sphaeriids choose sediment grains of the size which are carried in a current at the same rate at which they themselves are carried. However, Gale (1973) found that the sphaeriid Sphaerium striatinum had no preference among a choice of substrates. Which does control distribution and production of sphaeriids, sediment grain size or current velocity?

(3) Johnson and Brinkhurst (1971b) postulated that the turnover ratio is closely related to annual mean temperature and can be predicted by the equation

$$TR = \frac{T^2}{10}$$

where T is annual mean temperature in degrees Celsius. However, in the present study this formula was not consistently applicable. Because temperatures were constant throughout the study area the relationship between temperature and turnover ratio could not be investigated in this study. Is the turnover ratio closely related to annual mean temperature and can it be predicted from this parameter?

(4) Production of Gammarus fasciatus appears to be closely related to the distribution of aquatic plants. Is this because the amphipods are attracted to the plants or because both are reacting to some other factor? What is the attractant or other factor?

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APPENDIX

Table A1. Average values of some physicochemical characters of the Ottawa River study area.
All values are in ppm unless otherwise indicated. An average of eleven samples was used in each determination (from Mackie and Qadri 1971).

		Pollution criteria*
Alkalinity	24.1	> 20
BOD	1.6	< 4
Calcium	9.8	---
Carbon dioxide	10.2	< 25
Conductivity (micromhos/cm)	64.3	no increase > $\frac{1}{3}$ normal
Chlorides	2.8	< 250
Dissolved oxygen	8.4	> 5
Hardness	27.7	should not
Iron	0.28	cause
Manganese	0.006	nuisance
Nitrate	0.09	plant
Nitrite	0.013	growths
pH	6.9	6.5-8.5
Phenols	5.6	should not taint fish
Phosphate	0.14	should not cause nuisance plant growths
Secchi disc (m)	1.6	---
Sulfate	15.1	should not cause nuisance plant growths
Temperature (^{0}C)	0-25	---
Turbidity (JTU)	18.6	---
Velocity (m/sec)	0-2.9	---

* as recommended by the Ontario Water Resources Commission (1970)

Table A2. Terminology of particle sizes and the Phi (ϕ) scale classification (from Mackie 1971).

Substrate type	Particle size (mm diameter)	Phi scale
Gravel	2.0-16.0	-3,-2,-1
Very coarse sand	1.0-2.0	0
Coarse sand	0.5-1.0	1
Medium sand	0.25-0.50	2
Fine sand	0.125-0.250	3
Very fine sand	0.0625-0.1250	4
Silt	0.0039-0.0625	5,6,7,8
Clay	less than 0.0039	9

Table A3. Sample number, date, and location for all samples taken in 1973.

	Ont.shore	Mid-south	Is-south	Is-north	Mid-north	Que.shore	Kettle Is.Bay
Transect 1							
Jan.17		2	1			3	
Feb.19		12		9		8	
Mar.28		23		16		17	
Apr.24	32	36	34	30	31		
May 23	54	55	48	46	52	50	
June 25	68	73	72	71	70	69	
July 24	79	93	77	85	84	80	
Aug. 22	103		96	97	99	95	
Sept.24	115		113	114	112	111	
Oct.23	130		126	127	124	129	
Nov.23	140		139	138	137	136	
Dec.							
Transect 2							
Jan.21		5				7	
Feb.21						13	
Mar.28		24		21		22	
Apr.24	27		26	37	25		33
May 31	56	43	41	42	45	47	44
June 26	62	75	63	60	65	64	57
July 25	86	91	78	83	89	90	76
Aug.23	98		101	108	109	110	102
Sept.25	118		116	123	121		
Oct.23	125		131	134	135		
Nov.23	142		143	144	145		
Dec.							

Table A3 (Continued)

Transect 3

Jan.22		4				6
Feb.22		11		10		14
Mar.29		19		18		20
Apr.30	28		35		29	
May 31	49	51	53	38	39	40
June 26	67	66	58	59	74	61
July 30	88	94	81	82	92	87
Aug.23	105	100	104	106		107
Sept.25	117		119	122		120
Oct.23	128		133	132		
Nov. 23	141		147	146		
Dec.						

Table A4. Sampling error and error of estimates.

	% standard error
Sphaeriidae	
Each sample (3 grabs) for each species[1]	27
Mean annual standing crop estimates for each species at individual stations[2]	10
Pisidium casertanum production estimates at individual stations[3]	30
Other sphaeriids standing crop estimates for total area[2]	2
Other sphaeriids production estimates for total area[3]	5
Amphipoda	
Each sample (3 grabs)[1]	88
Mean annual standing crop estimates at individual stations[4]	30
Gammarus fasciatus production estimates at individual stations[3]	70

1 see Fig.5

2 $= \frac{27\%}{\sqrt{\text{number of combined samples}}}$

3 see Table A16

4 $= \frac{88\%}{\sqrt{\text{number of combined samples}}}$

Table A5. Length-weight relationships for Pisidium casertanum in the study area in 1973.

Station	Equation of the relationship*	N	Correlation coefficient[1]
Transect 1			
Ont.shore	$\log y = -1.81 + 0.32x$	64	0.93
Is.south	$\log y = -1.79 + 0.32x$	21	0.98
Is.north	$\log y = -1.85 + 0.34x$	101	0.97
Mid-north	$\log y = -1.83 + 0.34x$	43	0.96
Que.shore	$\log y = -1.52 + 0.28x$	30	0.95
Transect 2			
Ont.shore	$\log y = -1.54 + 0.27x$	76	0.97
Is.south	$\log y = -1.58 + 0.29x$	122	0.96
Is.north	$\log y = -1.65 + 0.28x$	117	0.98
Mid-north	$\log y = -1.86 + 0.34x$	111	0.97
Transect 3			
Ont.shore	$\log y = -1.36 + 0.23x$	42	0.91
Is.south	$\log y = -1.47 + 0.26x$	99	0.96
Is.north	$\log y = -1.55 + 0.28x$	90	0.95
Total area	$\log y = -1.66 + 0.30x$	916	0.96

* y = total dry weight in mg
x = total length in micrometer units (1 unit = 0.4mm)
$\log = \log_{10}$

1 correlation of $\log_{10} y$ and x

Table A6. Production of Pisidium caserfanum in the study area in 1973 (standard error 30%).

Station	Total dry weight ($g/m^2/yr$)	Total live weight ($g/m^2/yr$)	Soft parts dry weight ($g/m^2/yr$)	Soft parts energy content ($kcal/m^2/yr$)
Transect 1				
Ont.shore	0.196	0.47	0.02	0.09
Mid-south	0*	0	0	0
Is.south	0.086	0.21	0.01	0.04
Is.north	0.386	0.92	0.05	0.22
Mid-north	0.189	0.45	0.02	0.09
Que.shore	0.200	0.48	0.02	0.09
Transect 2				
Ont.shore	0.506	1.21	0.06	0.26
Mid-south	0*	0	0	0
Is.south	0.712	1.70	0.09	0.39
Is.north	0.827	1.97	0.10	0.43
Mid-north	0.346	0.82	0.04	0.17
Que.shore	0.015*	0.04	0.002	0.01
Kettle Is.Bay	0.091*	0.22	0.01	0.04
Transect 3				
Ont.shore	0.209	0.50	0.03	0.13
Mid-south	0.038*	0.09	0.01	0.04
Is.south	0.635	1.51	0.08	0.35
Is.north	0.560	1.33	0.07	0.30
Mid-north	0*	0	0	0
Que.shore	0.008*	0.02	0.001	0.004
Mean	0.263	0.63	0.03	0.14

* estimated using the turnover ratio 3.8 (from Fig.12)

Table A7. Length-weight relationships for sphaerids in the study area in 1973.

Species	Equation of the relationship *	N	Correlation coefficient ($\log_{10} y$ & x)	Max. total length observed (mm)
Pisidium casertanum	$\log y = -1.66+0.30x$	916	0,96	3.9
P. punctatum	$\log y = -2.38+0.52x$	568	0.91	2.1
P. ferrugineum	$\log y = -1.67+0.32x$	112	0.96	2.5
P. supinum	$\log y = -1.48+0.24x$	36	0.92	3.5
P. nitidum	$\log y = -2.14+0.41x$	20	0.97	2.4
P. lilljeborgi	$\log y = -1.90+0.36x$	15	0.99	2.5

* y = total dry weight in mg
x = total length in micrometer units (1unit = 0.4mm)
$\log = \log_{10}$

Table A8. Production of sphaeriids other than Pisidium casertanum in the study area in 1973, estimated using turnover ratios (standard error 18%).

Station	Production ($g/m^2/yr$ total dry weight)				
	Pisidium punctatum	Pisidium ferrugineum	Pisidium supinum	Pisidium nitidum	Pisidium lilljeborgi
Transect 1					
Ont.shore	0.123	0.026	0.037	0.007	0.004
Mid-south	0	0	0	0	0
Is.south	0.013	0.015	0	0	0
Is.north	0.418	0.022	0	0	0
Mid-north	0.465	0	0.082	0	0.002
Que.shore	0.074	0.015	0.005	0.001	0
Transect 2					
Ont.shore	0.169	0	0.021	0.012	0
Mid-south	0	0	0	0	0
Is.south	0.278	0.040	0	0	0
Is.north	0.032	0	0	0	0
Mid-north	0.157	0	0.009	0.009	0.002
Que.shore	0	0	0	0	0
Kettle Is.Bay	0	0.008	0	0	0
Transect 3					
Ont.shore	0.081	0	0.023	0.001	0.002
Mid-south	0.007	0.020	0	0.013	0
Is.south	0.076	0.117	0.003	0	0
Is.north	0.094	0.149	0.009	0.001	0.046
Mid-north	0.056	0	0	0	0
Que.shore	0	0.003	0	0	0
Total area*	0.099	0.027	0.013	0.003	0.004

* from production calculations (standard error 5%)

Table A9. Species diversity of sphaeriids in the study area in 1973.

Station	Shannon-Wiener	Simpson	Wilhm-Dorris
Transect 1			
Ont.shore	1.11	0.43	-14.16
Mid-south	---	---	---
Is.south	0.56	0.31	- 1.16
Is.north	0.87	0.38	-11.43
Mid-north	0.85	0.38	- 4.59
Que.shore	0.22	0.11	- 4.31
Transect 2			
Ont.shore	0.51	0.22	- 4.97
Mid-south	---	---	---
Is.south	1.16	0.50	- 9.32
Is.north	0.22	0.09	- 2.56
Mid-north	0.73	0.40	- 7.60
Que.shore	0	0	0
Kettle is.Bay	0.21	0.08	- 0.75
Transect 3			
Ont.shore	0.93	0.38	- 3.16
Mid-south	0.74	0.31	- 1.55
Is.south	0.86	0.31	- 3.25
Is.north	1.66	0.67	-10.01
Mid-north	---	---	---
Que.shore	1.00	0.50	- 0.60

Table A10. Length-weight relationships for Gammarus fasciatus in the study area in 1973.

Station	Equation of the relationship *	N	Correlation coefficient[1]
Transect 1			
Ont.shore	$\log y = -2.11 + 0.57x$	16	0.94
Is.south	$\log y = -1.49 + 0.36x$	127	0.84
Is.north	$\log y = -1.93 + 0.48x$	112	0.86
Mid-north	$\log y = -1.43 + 0.35x$	6	0.75
Que.shore	$\log y = -1.75 + 0.47x$	97	0.92
Transect 2			
Ont.shore	$\log y = -1.62 + 0.42x$	18	0.91
Is.south	$\log y = -2.06 + 0.55x$	17	0.93
Transect 3			
Ont.shore	$\log y = -1.28 + 0.36x$	19	0.94
Mid-south	$\log y = -1.64 + 0.38x$	23	0.94
Is.south	$\log y = -1.70 + 0.43x$	37	0.93
Is.north	$\log y = -1.96 + 0.51x$	46	0.88
Total area	$\log y = -1.73 + 0.44x$	518	0.88

* y = total dry weight in mg
x = head length in micrometer units (1 unit = 0.2mm)
$\log = \log_{10}$

1 correlation of $\log_{10} y$ and x

Table A11. Production of Gammarus fasciatus in the study area in 1973 (standard error 70%).

Station	Total dry weight ($g/m^2/yr$)	Total live weight ($g/m^2/yr$)	Energy content ($kcal/m^2/yr$)
Transect 1			
Ont.shore	0.108	0.54	2.34
Mid-south	0.108*	0.54	2.34
Is.south	1.489	7.45	32.33
Is.north	1.013	5.07	22.00
Mid-north	0.123	0.62	2.69
Que.shore	1.019	5.10	22.13
Transect 2			
Ont.shore	0.287	1.44	6.25
Mid-south	0*	0	0
Is.south	0.146	0.73	3.17
Is.north	0.022*	0.11	0.48
Mid-north	0.079*	0.40	1.74
Que.shore	0.007*	0.04	0.17
Kettle Is.Bay	0*	0	0
Transect 3			
Ont.shore	0.478	2.39	10.37
Mid-south	0.120	0.60	2.60
Is.south	0.673	3.37	14.63
Is.north	0.247	1.34	5.38
Mid-north	0*	0	0
Que.shore	0*	0	0
Mean	0.312	1.56	6.77

* estimated using the turnover ratio 7.2 (from Fig.18)

Table A12. Dry weight and ash-free dry weight of benthos in the study area in 1973.

Group	No of organisms in sample	Dry wt as % wet wt	Ash-free dry wt as % wet wt	Ash-free dry wt as % dry wt
Oligochaeta	1028	18.3	16.7	91.3
Hirudinea	17	15.9	15.7	98.5
Isopoda	31	19.7	15.0	76.3
Amphipoda				
Hyalella azteca	24	16.9	16.2	97.4
Hydracarina	53	25.7	23.3	90.5
Plecoptera	3	11.8	10.8	91.3
Ephemeroptera				
Hexagenia sp	6	14.9	13.6	91.0
Caenis sp	17	17.9	15.4	86.1
Trichoptera	71	19.9	18.9	94.9
Diptera				
Chironomidae	1284	18.9	17.6	93.1
Ceratopogonidae	71	19.4	18.2	93.8
Gastropoda*				
Ferrissia paralella	7	23.8	4.8	20.3
Physa gyrina	7	24.6	20.3	83.0
Gyraulus sp	18	26.2	8.6	32.9
Amnicola sp	7	49.2	8.4	17.0
Campeloma decisum	15	41.1	11.9	28.9
C. decisum (soft parts)	9	21.3	14.9	69.7
C. decisum (shell)	9	93.0	0.1	0.1
Pelecypoda*				
Elliptio complanatus	14	41.7	7.2	17.3

* shell included unless otherwise indicated

Table A13. Results of mercury and pesticide analysis of benthic samples taken in the study area in 1972 and 1973.

Date collected	Site[1]	Map reference[2]	Sample number	Sample composition	Mercury (ppm) total	Mercury (ppm) organic	Remarks
24/7/72	A	32-06S	MB-001	121 composite	0.090	0.050	
28/8/72		random	MB-002	91 composite	0.092	0.092	
24/7/72		43-01	MB-003	61 composite	0.427	0.427	includes 1 _C. decisum_[3]
24/7/72	J	53-09	MB-004	123 composite	0.240	0.116	includes 3 _C. decisum_
24/7/72	B	32-07	MB-005	38 composite	0.313	0.079	includes 4 _C. decisum_
26/7/72	K	62-01	MB-006	64 composite	0.200	0.022	includes 1 _C. decisum_
26/7/72	G	61-03	MB-007	217 composite	0.120	0.100	includes 1 Hirudinea
24/7/72	L	31-09	MB-008	146 composite	0.088	0.070	
24/7/72	F	53-08	MB-009	151 composite	0.050	0	includes 2 _C. decisum_
24/7/72		43-04	MB-010	42 composite	0.133	0.004	includes 2 _C. decisum_
26/7/72	N	62-07	MB-011	3 composite	0.235	0.036	includes 2 _C. decisum_
24/7/72	M	32-08	MB-018	33 composite	0.416	0.416	
24/7/72	B	32-07	MB-019	34 composite	0.333	0.333	
28/8/72	D	52-01	MB-020	31 composite	0.227	0.227	
28/8/72	G	62-03	MB-021	----------	0.175	---	
28/8/72	A	32-06S	MB-022	15 composite	0.346	0.044	includes 1 _C. decisum_
28/8/72	B	32-06N	MB-023	12 composite	0.223	0	includes 1 _C. decisum_
28/8/72	M	32-08	MB-024	9 composite	0.302	0.014	includes 1 _C. decisum_
28/9/72	L	30-09	MB-026	25 Amphipoda	0.250	---	
28/9/72	L	30-09	MB-027	31 Isopoda[1]	0.085	---	
28/9/72	D	52-01	MB-035	1 _C. decisum_	0.581	---	
28/9/72	B	32-06N	MB-036	5 _C. decisum_	0.308	0.013	
28/9/72	A	32-06S	MB-037	2 _C. decisum_	0.344	---	
28/9/72	B	32-07	MB-038	6 _C. decisum_	0.371	0	
28/9/72	A	32-06S	MB-039	2 _E. complanatus_[4]	0.188	---	
28/9/72	A	32-06S	MB-040	2 _E. complanatus_	0.139	0.027	

Table A13 (Continued)

								DDE	DDD (ppb)	DDT	PCB
3/3/73	A	32-06S	MB-041	342	composite	2.420	0.240	19.0	17.9	19.2	509
3&6/73	B	32-07	MB-042	4	C.decisum	1.230	0.564	1.6	2.5	3.8	41
10/3/73	G	62-03	MB-043	1	C.decisum	0.777	0.112	3.2	3.6	3.7	182
3,6&7/73	D	52-01	MB-044	3	C.decisum	0.713	0.217	20.8	56.4	14.3	621
10/3/73	E	52-05	MB-045	2	C.decisum	0.705	0.066	3.5	5.5	2.6	117
18/6/73	H	62-09	MB-046	39	Oligochaeta	0.330	0.122	6.7	16.2	13.8	272
6&7/73	BCFD	various	MB-047	63	Pisidium spp	9.0	---	4.6	11.1	14.8	162
6&7/73	C	45-04	MB-048	64	Chironomidae	0.153	-0.024	19.0	23.9	9.3	143
20/6/73	D	52-01	MB-049		composite	0.172	0.054	18.0	25.3	10.0	559
30/7/73	E	52-05	MB-050	76	Amphipoda	0.138	0.019	7.5	8.4	11.1	172
30/7/73	D,E	52-01,-05	MB-051	176	Chironomidae	0.211	0.050	7.6	13.2	18.6	207
30/7/73	D	52-01	MB-052	25	Trichoptera*	0.063	0.010	8.6	7.7	11.4	335
30/7/73	C	45-04	MB-054	61	Oligochaeta	(inorg.	0.175)	12.8	15.9	16.7	56
10/3/73	D	52-01	MB-055	1	E.complanatus	0.798	0.119	1.3	5.5	1.1	28
10/3/73	D	52-01	MB-056	1	E.complanatus	0.431	0.151	0.4	14.3	0.4	41
10/3/73	E	52-05	MB-057	1	E.complanatus	0.300	0.014	1.8	6.6	0.4	20
20/6/73	E	52-05	MB-058	1	E.complanatus	0.101	0.014	0.9	1.9	0	18
20/6/73	E	52-05	MB-059	8	C.decisum	0.940	0.428	5.4	7.3	7.2	139
30/7/73	A	32-05	MB-060	16	C.decisum	0.857	0.555	2.9	3.4	1.6	58
30/7/73	A	32-05	MB-061	4	E.complanatus	0.193	0.138	1.5	2.5	0.9	31
---8/73	A	32-06	MB-062		Gastropoda*	(inorg.	0.063)	2.0	0.4	2.4	15
---8/73	E	52-05	MB-063		Amphipoda*	(inorg.	0.341)	0.4	0.6	1.1	4
---8/73	E	52-05	MB-064		Trichoptera*	0.214	0.021	12.6	17.0	7.2	50
-----73	E	52-05	MB-065		Coleoptera*	0.073	0.018	4.1	2.4	11.3	28
-----73	G	62-03	MB-066		Gastropoda*	(inorg.	0.040)	1.4	1.4	2.3	10
-----73	G	62-03	MB-067		Odonata*	0.031	0.018	0.8	0.6	3.5	12
-----73	H	62-09	MB-068		Amphipoda*	0.027	0.018	7.1	6.3	2.5	26

* collected by L.Leung from submerged aquatic plants (The remainder were collected from sediments.)

1 A: 1 Is.south, B: 1 Is.north, C: Kettle Is.Bay, D: 2 Ont.shore, E: 2 Is.south, F: 2 Is.north, G: 3 Is.south, H: 3 Que.shore, J: 2 Que.shore, K: 3 Ont.shore, L: 1 Que.shore, M: 1 Mid-north, N: 3 Mid-north

2 see Ottawa River Programme (1972): p.0 map

3 Campeloma decisum

4 Elliptio complanatus

Table A14. Mean mercury and pesticide content of benthic groups in the study area in 1972 and 1973.*

Group	No of samples	Total mercury (ppm)	Organic mercury (ppm)	DDT (ppb)	PCB (ppb)
Oligochaeta	2	---	0.15±.03	15.3±1.5	164±108
Isopoda	1	0.09	---	---	---
Amphipoda	2	0.19±.06	---	---	---
Amphipoda[1]	2	---	0.18±.16	1.8±0.7	15±11.1
Odonata[1]	1	0.03	0.02	3.5	12
Trichoptera[1]	2	0.14±.08	0.02±.01	9.3±2.1	193±143
Coleoptera[1]	1	0.07	0.02	11.3	28
Diptera					
Chironomidae	2	0.18±.03	0.04±.01	14.0±4.7	175±32
Gastropoda					
<u>Campeloma decisum</u>	10	0.68±.09	0.24±.08 (N=8)	5.5±1.9 (N=6)	193±88 (N=6)
Pelecypoda					
<u>Elliptio complanatus</u>	7	0.31±.09	0.09±.03 (N=5)	0.6±0.2 (N=5)	28±4 (N=5)
<u>Pisidium</u> spp	1	9.0	---	14.8	162

* error given is standard error of the mean

1 collected by L.Leung from submerged aquatic plants (The remainder were collected from sediments.)

Table A15. Sample production calculation table : <u>Pisidium</u> <u>casertanum</u> Transect 1 Ont. shore.

Size class length (micrometer units)*	No/m^2	Mean wt (mg)	Standing crop (mg/m^2)	No loss/m^2	Wt at loss (mg)	Wt loss (mg/m^2)	x6 = production (mg/m^2)
2.1 - 3.0	20.4	0.11	2.24	- 5.5	0.10	- 0.55	- 3.30
3.1 - 4.0	25.9	0.22	5.70	-25.9	0.20	- 5.18	-31.08
4.1 - 5.0	51.8	0.48	24.86	37.0	0.43	15.91	95.46
5.1 - 6.0	14.8	0.98	14.50	9.2	0.89	8.19	49.14
6.1 - 7.0	5.6	0.88	4.93	3.7	1.86	6.88	41.28
7.1 - 8.0	1.9	1.48	2.81	1.9	3.89	7.39	44.34
	120.4/m^2		55.04 mg/m^2				195.84 mg/m^2

Mean annual standing crop	120.4 individuals/m^2 , 55.04 mg/m^2 (B)
Annual production	195.84 mg/m^2 (P)
Turnover ratio (P/B)	3.56

* one micrometer unit = 0.4 mm

Table A16. Sample error calculation table: <u>Pisidium</u> <u>casertanum</u> Transect 1 Ont. shore[1]

No/m² (n)	SE* $= \frac{10\%}{\sqrt{\frac{n}{N}}}$	Mean wt (error assumed negligible) (mg)	No loss/m²	SE	Wt at loss (error assumed negligible) (mg)	Wt loss SE	x6 = production SE
20.4	24.27%=4.96	0.11	- 5.5	$\sqrt{4.96^2+5.59^2}=7.47$	0.10	0.75	4.50
25.9	21.56%=5.59	0.22	-25.9	9.70	0.20	1.94	11.64
51.8	15.25%=7.93	0.48	37.0	8.98	0.43	3.86	23.16
14.8	28.52%=4.22	0.98	9.2	4.96	0.89	4.41	26.46
5.6	46.37%=2.60	0.88	3.7	3.01	1.86	5.60	33.60
1.9	79.60%=1.51	1.48	1.9	1.51	3.89	5.87	35.22

$120.4/m^2 = N$
SE≅10% (from Table A4)

Mean annual standing crop $120.4/m^2$, $55.04\ mg/m^2$ (B) SE≅10%

Annual production $195.84\ mg/m^2$ (P) $SE=\sqrt{4.50^2+11.64^2+23.16^2+26.46^2+33.60^2+35.22^2}$

$= 61.33 = 31.32\% \cong 30\%$

Turnover ratio (P/B) 3.56 SE≅57%

* SE = standard error
1 based on production calculation shown in Table A15