A SURVEY OF MACROPHYTES, BENTHIC INVERTEBRATES, AND PERIPHYTON IN PETER, PAUL, AND LONG LAKES(UNDERC)

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ABSTRACT

Three lakes, Paul, Peter, and Long (sampled as if it were two lakes, namely Long West and Long East), were sampled for macrophytes, benthic invertebrates, and periphyton. Macrophytes were qualitatively mapped, benthic invertebrates were sampled with an Ekman grab, and periphyton was sampled from frosted glass slides after a four week incubation.

For all responses, Paul and Peter, at one time the same lake, were similar to one another, as were the two basins of Long Lake. *Nuphar* and *Isoetes braunii* were the only two macrophytes common to all four basins. *Calla palustris, Typha latifolia,* and *Nuphar* were the dominant plants in terms of biomass in Paul, Peter, and Long Lakes respectively. In all lakes, chironomids, dominating the hypolimnion, comprised the majority of benthic invertebrates. The epilimnion supported the greatest diversity of macroinvertebrates of the three thermal levels; it harbored Gastropods, two genera of Ephemeroptera, seven Trichopteran genera, and two Odonate genera in addition to two Dipteran families and an annelid, *Naidium breviseta.* Periphyton was analyzed in terms of dry weight, ash free dry weight, chlorophyll a, and pheophyton. The lakes could not be differentiated from one another in terms of the first three categories, but Long Lake differed significantly from Paul and Peter in terms of pheophyton. Across all four categories, Long Lake values exceeded those of Paul and Peter.

INTRODUCTION

The study of lakes demands a holistic approach in order integrate the interactions of numerous components, such as macrophytes, benthic invertebrates, periphyton, as well as fish and abiotic factors. These variables do not exist in isolation from one another but interact dynamically. For example, periphyton confers both beneficial and detrimental effects upon macrophytes(Lodge et. al. 1988). Positively, grazers feed upon the periphyton instead of the plant tissue, but the periphyton may also shade the plant from vital solar energy and thus limit the plant's growth. Bronmark(1988) has shown that predation upon grazers, such as snails, in turn causes changes in the periphyton community. Macrophytes not only respond to various external pressures, such as grazing, but also exert their own effect upon the physical, chemical, and biotic aquatic environment(Carpenter and Lodge 1986). Benthic organisms also have complex roles as they function as either sinks or sources for nutrients resulting from predation, herbivory, or consumption of detritus.

The data collected can also serve as a crude data baseline for a whole-lake experiment to be conducted in the near future. This future experiment will determine the importance of the benthos in terms of nutrient cycling within a lake. Macrophytes, fish, bioturbation, insect emergences, and vertical migration of organisms are some of the factors that influence the level and distribution of nutrients in a lake(Lodge et al. 1988). Fish may feed in the open pelagic zone, thereby decreasing nutrients in that area, but then these fish may deposit nutrients, via feces, in the littoral zone, thus netting a transfer of nutrients. Macrophytes also play a crucial role in the cycling of nutrients as they act as a sink for nutrients during growth and as a source for organic material during senescence.

My research project examines macrophytes, benthic invertebrates, and periphyton in Paul, Peter, and Long Lakes. At a reductionistic level, each component of the tripartite provides faunistic or floristic information about the lakes' content. The research will determine the distribution, relative density, and species composition of macrophytes in the littoral zone. Benthic samples will provide a broad indication of what type of species of invertebrates inhabit the bottom of the lakes in different thermal strata. Lastly, the periphyton study will provide information about the level of algae, bacteria, and organic matter which covers macrophytes and other submersed substrates.

MATERIALS AND METHODS

Study Sites

Paul and Peter Lakes, once a single lake, are now separated by a narrow culvert. Long Lake is a single dumbbell-shaped lake, but plans exist to construct a curtain across the narrow channel which will effectively isolate the two basins. Maps of the three lakes are shown in Figure 1.

Paul Lake covers three acres and is close to Long East in size. The shallow littoral zone consists of many islands covered with *Chamnedaphne* , moss and other small terrestrial plants. No inlets were observed. Peter Lake is twice the size of Paul and has a maximum depth of 14.3 m compared to 12.2m for Paul. The western bank is lined with *Chamnedaphne* , which also dominates the northern sector of the lake. Long Lake lacks the island structures of Paul, but the same heath plant lines the shoreline of both basins. The two ends of the lake reach depths around 14.0m.

Based on the data provided by Dr. Carpenter's lab(Appendix 1), temperature, light, and oxygen profiles of each lake were graphed in order to determine sample placement(Figure 2).

Macrophytes

For each lake, I recorded the macrophyte distribution and species composition on a map as I rowed around the lake perimeters. No quantitative measurements were taken. I mapped the lakes on 10 July(Paul), 11 July(Peter), and 12 July(both basins of Long Lake). I used the keys in Fassett(1957) to identify any unknown macrophytes.

Invertebrates

I took six Ekman grab(.003m^3) samples from each of the four basins. Because of an ongoing study, the samples could only be taken from pre-existing transect lines so future researchers will know where the benthic sediments have been disturbed. Samples were taken from the midpoints of the epi, meta, and hypolimnion in each lake, one from each end of pre-existing transect lines (Figure 1). Thus, six samples from each lake, with two samples from each of the three thermal regions, were taken. All hypolimnion samples were from a depth of 9.0m. Metalimnion samples for Paul, Peter, and Long Lakes were 4.2m, 4.25m, 5.0m, and 4.0m respectively. Paul and Peter epilimnion samples were in water .75m deep, while Long East and Long West samples were from depths of 1.25m and 1.0m respectively. One exception is that, due to the steep shoreline of Peter lake, the northern epilimnetic sample could not be taken at .75m. Instead, I took a grab sample from 2.0m.

I took two samples from Long West on June 12 and took the remaining twenty-two samples the following day. Ekman contents were emptied into large plastic garbage bags and then placed in coolers for transport back to the lab where they were kept refrigerated until processing. Sediments were rinsed through a .5ml sieve. Except for the two Long West hypolimnion samples, all the organisms were collected using sucrose flotation(300g/L). These two hypolimnion samples were processed by picking through the sediments on a white enamel pan with a probe and forceps. The organisms were preserved in 70% ethanol and all, except most of the Dipterans, were identified to genus level. Except for the Chaoboridae, the diptera were identified only to the level of family. I identified the insects using the dichotomous keys of Hilsenhoff(undated), while I used Pennak(1953) for the non-insect invertebrates.

Periphyton

Frosted glass microscope slides, suspended horizontally in each lake at an appropriate level where they would receive 50% of the incident light intensity(see Figure 2), acted as artificial substrates for the periphyton to colonize. Two glass slides, 7.5 cm by 2.5 cm, were inserted into slots on opposing sides of a wooden dowel rod(frosted side up) and secured with ordinary bathroom caulk(Figure 3). A brick, tied with tarred nylon cord to an eye hook connected to the bottom of the dowel, anchored the apparatus in the sediments. A bobber, tied to an anterior eye hook provided the buoyancy needed to keep the slides at the appropriate depth and light intensity. A total of ten dowels, each with two slides, were evenly(approximately) distributed around the perimeters of the lakes(Figure 1). One slide from each float was used for the chlorophyll analysis and the other for the dry weight and ash-free dry weight measurements.

The colonization period lasted approximately thirty-two days, beginning on May 31 and terminating on July 2. As the slides were removed from the lakes, they were kept in coolers to shield the slides from the degradative radiation from the sun during transport.

Chlorophyll a

In the laboratory, each slide was wrapped in Kimwipe, broken in half, placed in a film canister, and subsequently frozen. The slides remained frozen for twenty days until processing. Standard procedures, as outlined by Soranno(1989), were followed except for the filtering step which was disregarded. Five canisters with just Kimwipes were treated in the same manner in case the chlorophyll values would have to be adjusted for Kimwipe fluorescence.

Dry Weight and Ash-Free Dry Weight

Slides were dried at 60°C for 24 hours immediately following the slides' retrieval. The periphyton was then scraped off the slides with a razor blade into dried, pre-weighed crucibles and periphyton dry weight determined by difference. The crucibles were then heated for 14 hours in a muffle furnace at 550°C. The AFDW was then calculated.

RESULTS

Macrophytes

Comparatively, Long Lake, both east and west basins, supported similar macrophyte species, while it differed from both Peter and Paul lakes. The latter two lakes showed some similarities but also differed from one another in species abundance and composition. Figure 4 illustrates the location and relative abundance of the macrophytes in each of the lakes as well as the channel connecting the two basins in Long Lake. Based on my observations of the lake, and for the lack of quantitative data, I qualitatively ranked the major species in each lake in terms of biomass(Table 1).

In Long Lake, only *Nuphar* is present continuously, for the most part, along the entire perimeter of the whole western basin. Only in the northwest corner is this water lily noticeably absent. The three other dominant species, *Sparganium*, *Sagittaria*, and *Isoetes*, do not show such consistency. Along the west bank, from just north of the transect line to the southern tip, only *Nuphar* exists at any significant levels. *Sparganium* can be found in greatest number at the mouth of the basin on the north and south banks, and to a lesser degree in the northwestern area and at the southern tip. The *Sparganium* at the mouth were all floating-leaved plants, but the plants at the southern tip were both floating and emergent. The emergent plants were *Sparganium eurycarpum*, but the others, without fruits could not be identified to species. *Sagittaria* inhabits the southern tip and extends sporadically halfway up the eastern shore. The northern bank harbors about half the *Isoetes* population while the eastern bank, one-third of the distance up from the southern tip, contains the remainder of this submersed macrophyte. The entire western bank lacked any *Isoetes*..

Other species exist, though only in sparse number. A patch of *Equisetum fluviatile* exists in the central northern area; traces of *Dulichium arundinaceum* appear on the central banks of the north, east, and west banks; *Utricularia minor*, at the time of the sampling inhabited the northern bank near the mouth and could be found sparingly along the east bank. *Eleocharis acicularis* runs on and off along the east edge, mainly on the shore and not in the water.

The southern tip supports the greatest diversity of macrophytes in the whole west basin. *Sparganium*, emergent and floating types, *Sagittaria*, *Carex comosa*, *Glyceria grandis*, and *Dulichium arundinaceum* all grow in this small gulf.

The east basin, like Long West, contains the same four major macrophytes. *Sagittaria* dominates the northern bank while *Sparganium* and *Isoetes* line the southern bank. *Nuphar* stretches along both these banks. The southeast corner of the lake supports a scarce *Nuphar* population while the eastern and northeastern shore lacks *Nuphar* as well as any other macrophytes. Heath plants solely line the bank in this area. Traces of *Utricularia* and *Iris versicolor* can be found along the southern bank. Scattered sedges grow amongst the *Chamnedaphne* on the southern shore.

Paul and Peter Lakes differ markedly from the composition of Long Lake. *Chamnedaphne*, which lines all of the lakes, is particularly abundant in Peter Lake. The northern and western areas have land which extends far from the water, and heath plants dominate this area. Small rivulets infiltrate the heath filled plains. Compared to

Long Lake, Paul supports a paucity of *Nuphar* ; perhaps less than fifty individual plants inhabit Paul Lake. In terms of biomass, *Calla palustris* and *Eleocharis acicularis* outweigh the rest of the macrophytes combined. These two species primarily inhabit the western side of the lake, especially in the northern and southern corners. Besides on the western bank, *Calla* also grows in patches along the south and east side, interspersed with the heaths. *Sparganium* extends along the southern shore, with the largest patch occurring toward the southeast corner. *Isoetes* also occupies this same general region. *Dulichium* traces can be found around the area of the southern transect line and in the northern corner. The southeastern corner also supports a small population of *Juncus effuses.* Between the islands of heath plants and the western shore, freshwater sponges with symbiotic algae inhabit the shallow water of the littoral zone.

The entire northern bank is nearly depauperate of macrophytes. A few sponges and *Isoetes* grow along the edge. Only close to the dock can patches of *Sparganium, Dulichium,* and *Isoetes* be seen.

Finally, Peter Lake shares some of the same species as Paul but in quite different number. *Calla* can be found around the perimeter but the majority is located on the south and east sides. No dense patches, as in Paul, can be found. This holds true for *Eleocharis* as well, which only appears in any significant amount near the south transect. The south shore holds quite a diversity of macrophyte when compared to the rest of the lake. *Eleocharis, Dulichium, Calla, Glyceria, Isoetes,* and *Sparganium* all grow on the shore or amongst the fallen trees.

In terms of biomass *Typha latifolia* grabs the number one ranking. This species is not very abundant(it only grows in three main areas) but their size compensates for their dearth. *Calla* is second behind the cattail in biomass abundance. Although not very abundant, its size, like cattail compensates. *Nuphar*, *Isoetes*, and *Chara* are close to one another in weight. No more than thirty *Nuphar* comprise the entire water lily population, concentrated on the eastern side of the lake. *Isoetes* grows in small patches on the east side, but the majority grows in the area around the dock. The whole floor of the lake in the dock gulf supports *Isoetes*. *Chara* also thrives in this area and grows just along the edge of the dock and extends along the sides of the adjacent shore. The only patch of *Equisetum fluviatile* in the lake grows along the western shore in the dock region. Other macrophytes which make candid appearances are *Dulichium* and *Juncus effuses*. A patch of *Sparganium* with floating leaves grows near the south inlet while emergent forms, *Sparganium eurycarpum*, occur sporadically along the eastern shore.

Invertebrates

Figure 5 correlates the total number of organisms collected in each Ekman sample to the thermal level in each lake from which the invertebrates were removed. The figure demonstrates the wide variability between lakes and among the thermal levels.

All lakes shared four benthic groups: Odonates, Chironomids, Trichopterans, and Chaoborids. Of all the orders found, chironomids outnumbered all other taxa combined. This was the only family to occur at every thermal strata in all of the lakes, dominating the epilimnion and hypolimnion(Appendix 2). The metalimnion contained fewer chironomids overall, compared to the other two areas. With few exceptions, all of the chironomids collected from the hypolimnion contained hemoglobin and therefore belong to the sub-family Chironominae(McCafferty 1981).

The dipteran larvae *Chaoborus* also occurred across the four lakes, but unlike chironomids, *Chaoborus* did not extend into the epilimnion. While the *Chaoborus* did not exist in the epilimnion, the odonates found, did not extend outside the epilimnion. Only one dragonfly was found in each of the lakes, except for Long East which harbored three such predators. Libellulidae *Ladona* was common to all four lakes while Corduliidae *Epitheca* was unique to the epilimnion of East Lake.

Epilimnetic, and to a lesser degree, metalimnetic waters harbored the trichopterans, which numbered 144, 337, 240, 337 per square meter in Paul, Peter, Long West, and Long East Lakes respectively. Although four different families and seven genera were collected, a genus common to all four lakes could not be found. Paul Lake contained Leptoceridae *Nectopsyche* and Polycentropodidae *Polycentropus*, while Peter harbored Limnephilidae *Limnephilus* , Molannidae *Molanna* and *Polycentropus*. Long West possessed Limnephilidae *Limnephilus* and the Leptocerids *Mystacides* and *Molanna*.. *Nemotaulis* and *Ocetis* inhabited the epilimnion of Long East. Several of the latter caddis flies were early instars, spanning less than 5 mm.

In addition to these four categories, other organisms were recovered which were not common to all four lakes. Ceratopogonids were found in Paul and Long Lake. *Naidium breviseta* was present in all the lakes except for Peter, and while Paul harbored thirty-eight worms, the two basins of Long Lake accounted for only twelve annelids. A total of four mayflies were recovered, three Caenidae *Caenis* from Peter and one Ephemeridae *Hexagenia* from Long West. The mite *Diplodontus despiciens* occurred singularly in all but Peter lake. A single gastropod, *Gyraulus parvus*, and a sole amphipod, belonging to the Gammaridae family, inhabited Peter and Long West Lakes respectively.

Species composition is important but more informative is the function of the organisms, especially their trophic status. The four pie graphs(Figure 6) compare the relative abundance, within each lake, of the different types of feeding habits of the invertebrates from the epilimnion and metalimnion. I classified the organisms, accordingto what the sources indicated as the primary nutritional components of the invertebrates' diet, as herbivore/detrivore, detrivore alone, predator, and other, which comprises omnivores and parasites(Table 2). Based on the literature, I excluded the hypolimnion since, except for *Chaoborus*, the only other organisms found here were chironomids which, being detrivores, would not interact directly, as the epilimnion and, to a lesser extent, the metalimnion organisms do, with macrophytes. Herbivore-detrivore and detrivore were inversely related. In Paul and Long West, detrivores accounted for about half of the feeding type while herbivore-detrivores hovered in the 30% range. The opposite distribution was seen in Peter and Long East. Detrivores did not surpass 15% whereas the herbivore-detrivore category reached 75% and 62% respectively in the two lakes.

Predaceous organisms did not rise above the 20% level; the values were 11.6% in Paul, 9.09% in peter, 15.2% in Long West, and 18.26% in Long East.

Periphyton

I analyzed the periphyton quantitatively for dry weight, ash-free dry weight(AFDW), chlorophyll a, and pheophyton. I did not have to correct the values for Kimwipes because their fluorescence was insignificant. The values for each category are compared between the four lakes(Figure 7). In all categories, Long Lake values were greater then those of Peter and Paul, but only in terms of pheophyton does a significant difference arise.

Chlorophyll a, pheophyton, and the ratio of pheophyton to chlorophyll a were plotted against the number of potential grazers(per square meter) found in the epilimnion of the three lakes in order to deduce the interactions between periphyton and potential grazers(Figure 8). I determined the grazer abundance per epilimnion sample by averaging the sum of the herbivore/detrivore organisms and the omnivore animals found in the two epilimnion samples from each lake. No obvious relation exists between the grazers and the three dependent variables.

DISCUSSION

The lack of quantitative data constrains the ability to explain the species composition, distribution, and density of macrophytes except in qualitative terms. These three factors depend greatly on the time of season, trophic status of the lake, the lake topography, periphyton, and grazing among other factors which cannot be discussed for lack of data.

First, the abundance of these species corresponds to the time period in which I sampled the lakes. Abundance varies seasonally and since time allowed only one sampling period, the mapping I constructed illustrates the macrophyte assemblage at that second week in July and thus cannot be necessarily extrapolated to other time periods.

Peter and Paul's macrophyte population could be best described as barren compared to that of Long Lake. One reason for the lower macrophyte biomass may be a difference in nutrient availability. Reasoning circularly, the lower biomass indicates a decreased availability of nutrients necessary for plant growth. The periphyton data also supports the claim of Peter and Paul's more oligotrophic status. Dry weight, AFDW, as well as chlorophyll abundance in Long Lake, exceed the levels in Peter and Paul. Thus, Long Lake appears to possess a higher nutrient level to support not only a greater macrophyte abundance but also a greater periphyton population as well.

Shading, either by floating leaves or by periphyton, grazing and the physical structure of the lake place limits upon macrophyte growth and distribution. Paul and Peter's major plant species emerged from the water while Long Lake's major species consisted of the floating-leaved *Nuphar*. A plant such as *Nuphar* could limit the growth of plants underneath its floating canopy due to the obstruction of incident sunlight. The low number of submersed plants, such as *Isoetes* in Long West, probably results from this lack of solar energy. Just the opposite condition occurs in Paul Lake, where *Isoetes* and *Sparganium* cover the southern littoral zone, an area where *Nuphar* is absent as it is in most of the lake.

One way to test this hypothesis would be to determine how the two plant species change in relation to one another. Holding all else constant, *Sparganium*, which is a perennial arising from rhizomes or from seed(Crow and Hellquist 1981), may appear first early in the season, but as soon as *Nuphar* extends its leaves to the water surface, the floating-leaves may exclude *Sparganium* from those regions.

Besides canopy cover, periphyton may also shade the macrophyte tissue, thereby reducing photosynthetic efficiency. Periphyton interacts intimately with macrophytes, too much reducing valuable sunlight and too little indirectly promoting invertebrate grazing of plant tissue instead of periphyton material(Lodge et al. 1988). Based on this interactive process, I believe the smaller, submersed macrophytes would experience greater loss of photosynthetic capacity compared to the larger plants, emergent or floating. Periphyton would cover a greater percentage of the photosynthetic surface area of the small, submersed plants.

Periphyton may cover almost 100% of a plant such as *Isoetes*, but will only cover a much lower fraction of the critical light absorbing tissue of a macrophyte such as *Nuphar*. *Nuphar* has an advantage over submersed plants in that, while periphyton may cover the stem, its leaves will be free of periphyton, yet its large leaf surface area will be vulnerable to grazers. Based on periphyton abundance, especially in terms of chlorophyll a, the smaller plants, like *Sparganium* and *Isoetes*, in Long Lake should be less populous(relatively speaking) than in other lakes. This is seen in the lakes, for Paul Lake, which has a lower chlorophyll a abundance, also contains a greater percentage of *Isoetes* and *Sparganium* than does Long Lake.

Another important factor for distribution of macrophytes is the physical topography of the lake bottom. Paul's littoral zone consists of a shallow(<1.0m) plain which extends for several meters from shore before it drops off steeply. This contrasts with the consistent slope of Long Lake's littoral zone. Plants such as *Isoetes* growing in Long Lake would receive less sunlight, for the sediments are rooted deeper in the water. Associated with this is the clarity of the water. Long Lake water appears to block or absorb more sunlight than Paul or Peter lakes, based on the depths for 50% light intensity. The level for half of the incident light in Long East is .25m, while fifty percent of the light penetrates to a full meter in Peter. Thus, the submersed plants in Long receive stress not only from a deeper littoral zone but also from the turbidity of the water.

Along with the physical geography of the lake is the fetch, which can account for the high density and diversity of plants on the southern tip of Long West. This small gulf, has a low fetch, and lies isolated from the wind, thus allowing plants to populate the area without being stressed by wind and wave energy. The fetch may also account for the paucity of macrophytes along the eastern shore of Long East. Here the fetch would be at its greatest level in the lake, assuming west to east winds, and would thus prohibit the colonization of the shore.

Macrophyte distribution results from the integration of several factors, such as those just mentioned. One factor not mentioned but which has a substantial effect is grazing. Insects, snails, as well as mammals can severely restrict if not determine species composition. Some researchers have indicated that snail abundance directly affects species composition(Lodge 1989). Unfortunately for this project, I did not sample organisms grazing on the various macrophytes(that is a separate project), so data do not exist for macrophyte grazers. Grazers may have favored the growth of emergent plants in Paul Lake. A recent work indicates that emergent plants escape most of the invertebrate herbivory damage common to submersed forms(Lodge 1989). Perhaps grazers have reduced the abundance of present macrophytes and even eliminated other submersed or floating types which are no longer present, thus giving emergent plants an advantage.

Grazer-macrophyte interplay also hinges upon periphyton communities. The relation between periphyton and potential grazers does not reveal much of significance, most likely due to the small number of invertebrate samples taken. Only six Ekman samples were taken from the entire lake, only two from the epilimnion areas. The variability between the opposite ends of the same thermal strata was quite high in some instances. The sucrose flotation method would not force shelled organisms, like snails, to rise, thereby reducing the number of such organisms collected. Further research should involve a greater number of samples from different transects to treat more than one linear area of the lake.

Putting these limitations aside, two opposing predictions can be formulated concerning what type of distribution grazers would have in relation to chlorophyll and pheophyton. First, grazer abundance could be directly related to periphyton abundance, in that the greater amount of periphyton would support a larger grazer population. Or, as the second hypothesis predicts, grazer population could be inversely proportional to periphyton abundance. A large population of grazers would consume the periphyton, reduce its abundance, and when this area was sampled a large population of grazers would be associated with a low periphyton level. Accordingly, a small grazer population would consume less periphyton, thereby resulting in a low grazer-high periphyton association.

Other problems with this comparison arise from the determination of what organisms are herbivorous and which are not. I only identified to the genus level so I had to generalize feeding habits since literature on these organisms were species specific. Various sources indicate that some insects may consume both detritus and periphyton, preferring one over the other, but consuming both nonetheless. *Hexagenia(limbata)*, in one study, ingested 90% detritus and algae comprised the remaining fraction(Wissing and Zimmerman, 1979). Likewise, the caddis fly *Limnephilus* showed gut contents consisting of 14% plant, 9% diatoms, and 77% detritus(Hilsenhoff and

Shapas 1976). The point is that both of these animals were classified as grazers but the extent to which they graze was not factored into the analysis. The chironomids presented the greatest problem in terms of feeding habits, for different species have different feeding strategies. Based on the data from P.D. Armitage(1968) and Kajak(1968), I assumed that the majority of the chironomids are herbivore/detrivores. Since the midges from the hypolimnion are below the light compensation level, I assumed that they, as well as the midges from the metalimnion were all detrivores. For the epilimnion midges, I counted 10% of the chironomids as predaceous, following the procedure set up by Cummins and Wilzbach(1985). Clearly the odonates are predaceous and can severely restrict invertebrate populations in the littoral zone. Benke has even predicted that were it not for refuges provided by macrophytes and other objects, the dragonflies would practically eliminate their prey altogether(Benke 1976). Too few organisms were retrieved to see if this hypothesis has any validity in the lakes I sampled.

Some of the chironomids can also be predaceous and therefore limit the number of grazers of periphyton and macrophytes. In the epilimnion, other organisms besides insects, prey upon grazers, one example being fish. Substantial populations of both small and largemouth bass live in Long Lake(UNDERC manual), and if they feed upon snails, they could indirectly increase periphyton abundance. Bronmark's study supports this theory(Bronmark 1989). During my mapping I noticed a small school of eight bass or so, swimming about in the littoral zone of Paul Lake, but the total population for Paul, as well as Peter's fish composition is unknown.

Periphyton obviously plays a major role in lake ecosystems, and thus a measure of its abundance and composition is critical. Although the periphyton section of my project was the most quantitative, several limitations are apparent. One limitation is the time period used for colonization. The sampling period was not structured to quantify seasonal fluctuations in periphyton composition. Another problem involves the physical set-up of the slides. All the slides floated horizontally at the fifty percent level of light intensity, but slides suspended vertically may mimic macrophytes more closely. The periphyton measurements also face certain limitations. The chlorophyll was determined per square centimeter of slide, not taking into account the difference between the amount of chlorophyll on the top and bottom of the slide. The top of the slide had a thicker coating of periphyton than the bottom, but the values were averaged over the entire area regardless of the different amounts. Also, when I removed the periphyton from the slides, a small amount remained on the slides. Thus, the values obtained are underestimations of the periphyton weight.

As one might expect, Paul and Peter Lakes shared many characteristics, as did the two basins of Long Lake. The two lakes, from within each of these two groups, mirrored one another in terms of abiotic factors, periphyton and macrophyte species, but no similarities existed concerning benthic invertebrate number. The number of potential grazers, however, from each set of lakes were similar in abundance, yet no general statement could be made concerning the relationship between grazer and periphyton abundance. Further research, on a more quantitative and intensive level, would clarify this ambiguity, as well as provide less subjective data, concerning macrophyte populations, and less variable information concerning benthic invertebrate populations.

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TABLE LEGEND

TABLE 1

The numbers indicate the ranking of the macrophytes in terms of their relative biomass within each lake. The plus signs represent those macrophytes which were present but not in great quantity. Plants absent to a particular lake are indicated by the darkened area.

TABLE 2

This table lists all the types of invertebrates found, their primary feeding habits, and the literature which provided this information. Within each grouping, all of the literature pertaining to any of those organisms is listed.

Abbreviation	MACROPHYTE	PAUL LAKE	PETER LAKE	LONG WEST	LONG EAST
A	Calla palustris	1	2		
B	Eleocharis acicularis	2		+	
C	Juncus effuses	+			
C'	Sparganium eurycarpum		+		
D	Sparganium sp.	4		2	3
E	(Freshwater Sponge)	+			
F	Dulichium arundinaceum	+	+		
I	Isoetes braunii	5	3	4	4
N	Nuphar	3	4	1	1
Y	Glyceria grandis		+		
U	Utricularia minor			+	+
Iris	Iris versicolor			+	+
Alis	Sagittaria latifolia			3	2
Cattail	Typha latifolia		1		
	Chara		5		
Horse-tail	Equisetum fluviatile		+	+	

TABLE 1

TAXON	FUNCTIONAL GROUP	LITERATURE SOURCE
ODONATA		
Libellulidae *Ladona*	PREDACEOUS	Benke 70, 75, 76
Corduliidae *Epitheca*	PREDACEOUS	
EPHEMEROPTERA		
Caenidae *Caenis*	HERB/DET	Brittain, 82; Cummins, 73;
Ephemeridae *Hexagenia*	HERB/DET	Wissing and Zimmerman, 79;
		Wissing and Zimmerman, 78;
TRICHOPTERA		
Leptoceridae Nectopsyche	OMNIVORE	Shapas and Hilsenhoff, 76;
Oecetis	PREDACEOUS	Winterbourn, 71;
Mystacides	OMNIVORE	Hodkinson, 75;
Polycentropodidae Polycentropus	PREDACEOUS	Cummins and Merritt, 84;
Limnephilidae Limnephilus	HERB/DET	Wiggins, 77.
Nemotaulius	HERB/DET	
Molannidae Molanna	OMNIVORE	
DIPTERA		
Chironomidae	PREDACEOUS	Armitage, 68; Johnson, 87;
	HERB/DET	Kajak and Warda, 68;
	DETRIVORE	Thut, 69.
Ceratopogonidae	PREDACEOUS	McAlpine, 81;
Chaoboridae *Chaoborus*	PREDACEOUS	Cummins and Merritt, 84.
HYDRACARINA		
Diplodontus despiciens	PRED/PARASITIC	
GASTROPODA		
Gyraulus parvus	HERB/DET	PENNAK, 89
AMPHIPODA		
Gammaridae	OMNI/DET	
ANNELIDIA		
Naidium breviseta	DETRIVORE	

TABLE 2

FIGURE LEGEND

FIGURE 1

Paul, Peter, and Long Lakes are shown with depth contours. The circled numbers mark the sites where the periphyton colonizers were placed at 50% light intensity, which were at depths of .75m(Paul), 1.0m(Peter), .25m(Long West), and .50m(Long East). These values were determined from the graphs in Figure 2. The X's on the lines, which represent pre-existing transect lines, drawn across the lakes indicate the six Ekman sample sites from the three thermal strata. The first letter of the two letter abbreviation(N and S) corresponds to the two different samples from the each of the three levels, which are indicated by the second letter; "E", "M", and "H" stand for epilimnion, metalimnion and hypolimnion respectively. These sample sites were determined by the graphs from Figure 2 as well; Ekman samples were taken from the midpoints of each of the strata. The depths for the epi, meta, and hypolimnion are the following: .75m, 4.2m and 9.0m(Paul); .75m(N) and2.0m(S), 4.25m, and 9.0m(Peter);1.0m, 4.0m, 9.0m(Long West); 1.25m, 5.0m, 9.0m(Long East). Due to the steep shoreline in Peter Lake, the S sample had to be taken at 2.0m instead of .75m.

FIGURE 2

These three graphs plot depth against temperature, dissolved oxygen, and light intensity for the four lake basins, namely Paul(blue), Peter(red), Long West(green), and Long East(black). The color-coded arrows, in the thermocline graph, indicate the depths at which the Ekman samples were taken(see Figure 1 for values). The circles, all at 50% incident light, in the light intensity graph mark the sites where the frosted slides were placed in the lakes(see Figure 1 for depths). Dr. Carpenter's lab provided the data(see Appendix 1), collected on days 142(Paul), 143(Peter), 146(Long West), and 147(Long West), used to construct the graphs.

FIGURE 3

This is a schematic illustration of the periphyton colonizer. Two frosted slides, plain side facing down, insert into the side of the dowel and is kept in place with bathroom caulk. A bobber and brick were tied to eye hooks on either end of the dowel with tarred-nylon cord.

FIGURE 4

These maps indicate the relative position and abundance of macrophytes, indicated by letters, in the three lakes. The letters represent the following: A-*Calla palustris*, B-*Eleocharis acicularis*, C-*Juncus effuses*, C'- *Sparganium eurycarpum*, D-*Sparganium sp.*, E-

Freshwater sponge with symbiotic algae, F-*Dulichium arundinaceum*, I-*Isoetes braunii*, N- *Nuphar*, Y-*Glyceria grandis*, U- *Utricularia minor*, Iris-*Iris versicolor*, Alis-*Sagittaria latifolia*, Cattail-*Typha latifolia*, Horsetail- *Equisetum fluviatile*. The open circles represent stands of *Nuphar*, and the associated number indicates the abundance, with one unit equal to 4-5 leaves. The numbers next to D are the number of individual plants. The boxed-numbers represent sample numbers for a separate project.

FIGURE 5

The mean number and range of invertebrates collected in each lake are compared on the basis of thermal levels. The abundance of organisms are expressed in terms of number per square meter. The bars represent the mean number of invertebrates from each level. The thin lines designate the range of invertebrates from the two different samples from within each strata.

FIGURE 6

The invertebrates are grouped according to their trophic status. These categories are Herbivore-detrivore, detrivore alone, predator, omnivore, or parasite. The last two groups are combined in the charts into one category. The omnivore/parasite group is consistently the smallest group, while predaceous invertebrates are the next lowest, except in Long East. Herbivore-detrivore and detrivore rank first in two of the lakes.

FIGURE 7

The four basins are compared on the basis of Dry Weight, Ash-Free Dry Weight, chlorophyll a, and pheophyton. While Long Lake consistently had higher values than Peter and Paul across all four categories, Long only differs significantly from both Peter and Paul on the basis of pheophyton. The error bars represent the 95% confidence levels.

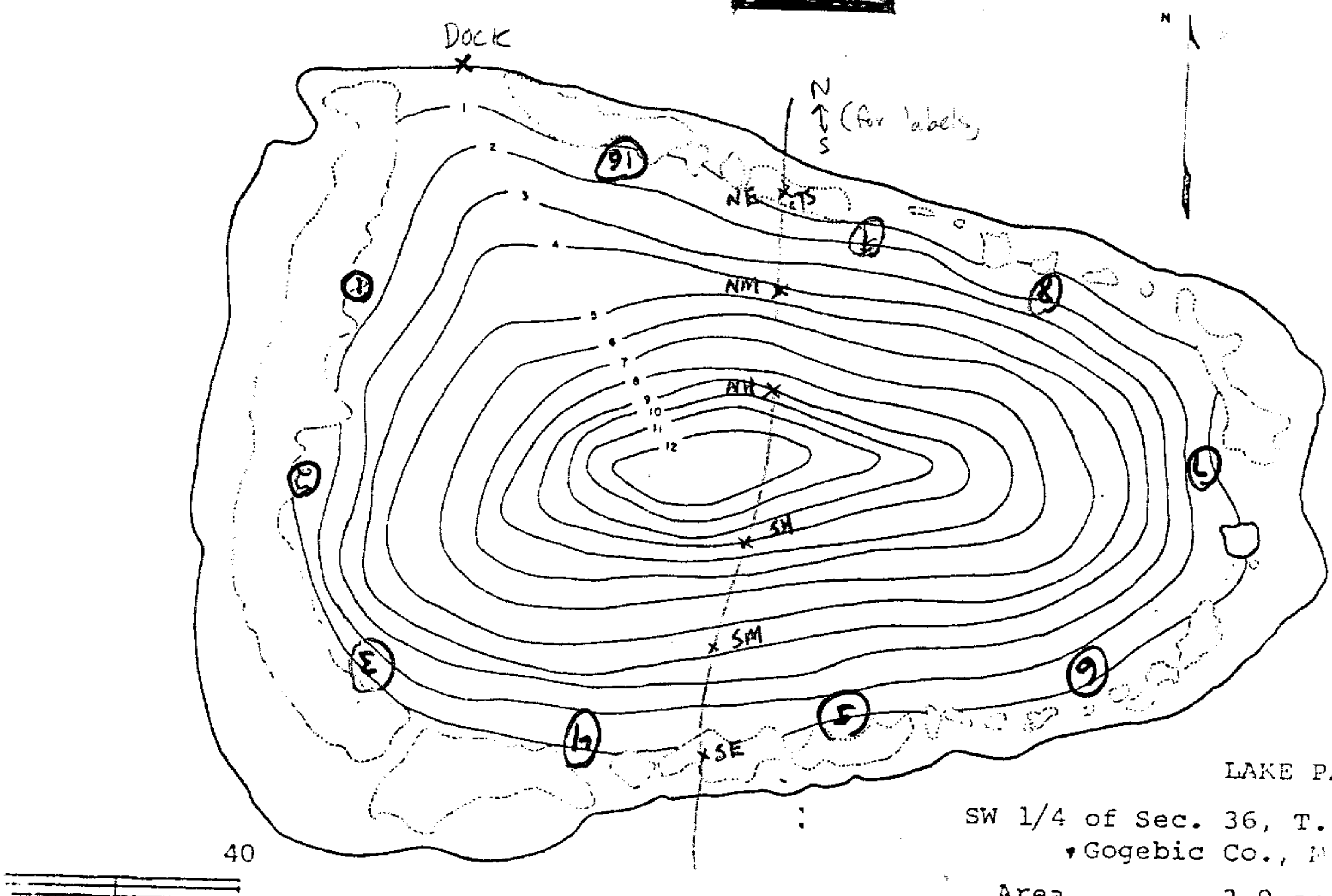
FIGURE 8

The mean number of potential epilimnion grazers are correlated to chlorophyll a, pheophyton, and pheophyton/chlorophyll a. No pattern emerges from this relationship. The number of grazers in each lake was calculated by averaging the sum of the number of omnivores and herbivore-detrivores from the epilimnion.

FIGURE 1
PAUL LAKE

Figure 3.

[redacted]



Scale in meters

Survey by U. of Wis. Dept. of Zoology

LAKE PAUL(L) Green

SW 1/4 of Sec. 36, T. 45 N., R. 42 W.
Gogebic Co., Michigan

Area	3.0 acres
Max. depth	12.2 m.
Volume	134 $m^3 \times 10^3$

Depth contour interval = 1 meter

FIGURE 1

PETER LAKE

LAKE PETER (R) Pink

SW 1/4 of Sec. 36, T. 45 N., R. 42 W. [redacted]
Gogebic Co., Michigan

Area 6.0 acres

Max. depth 19.3 m.

Volume 436 $m^3 \times 10^3$

Depth contour interval = 1 meter.

0 40

Scale in meters

S ↕ N (for labels)

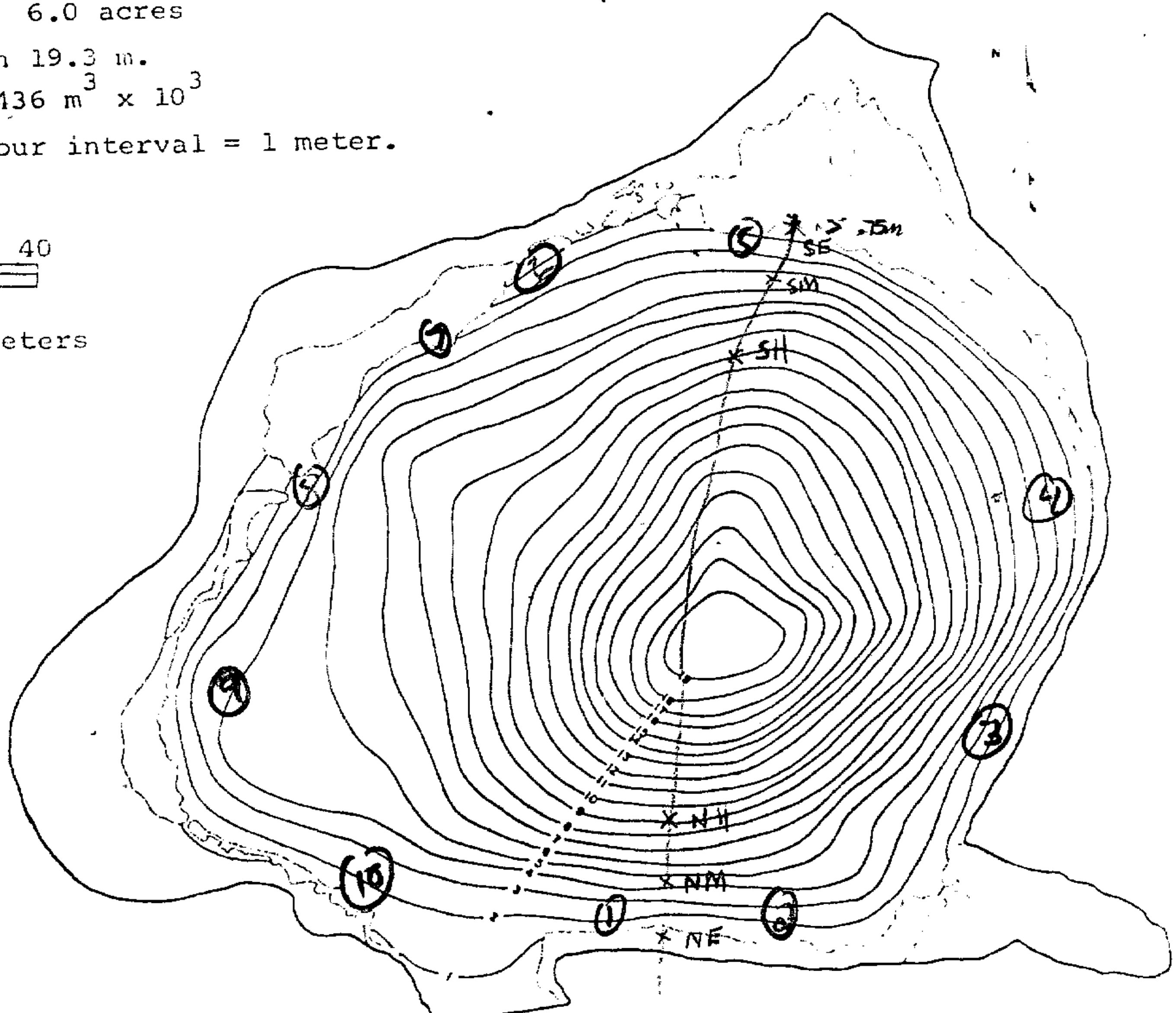


Figure 4. Survey by U. of Wis. Dept. of Zoology

FIGURE 1 7-2

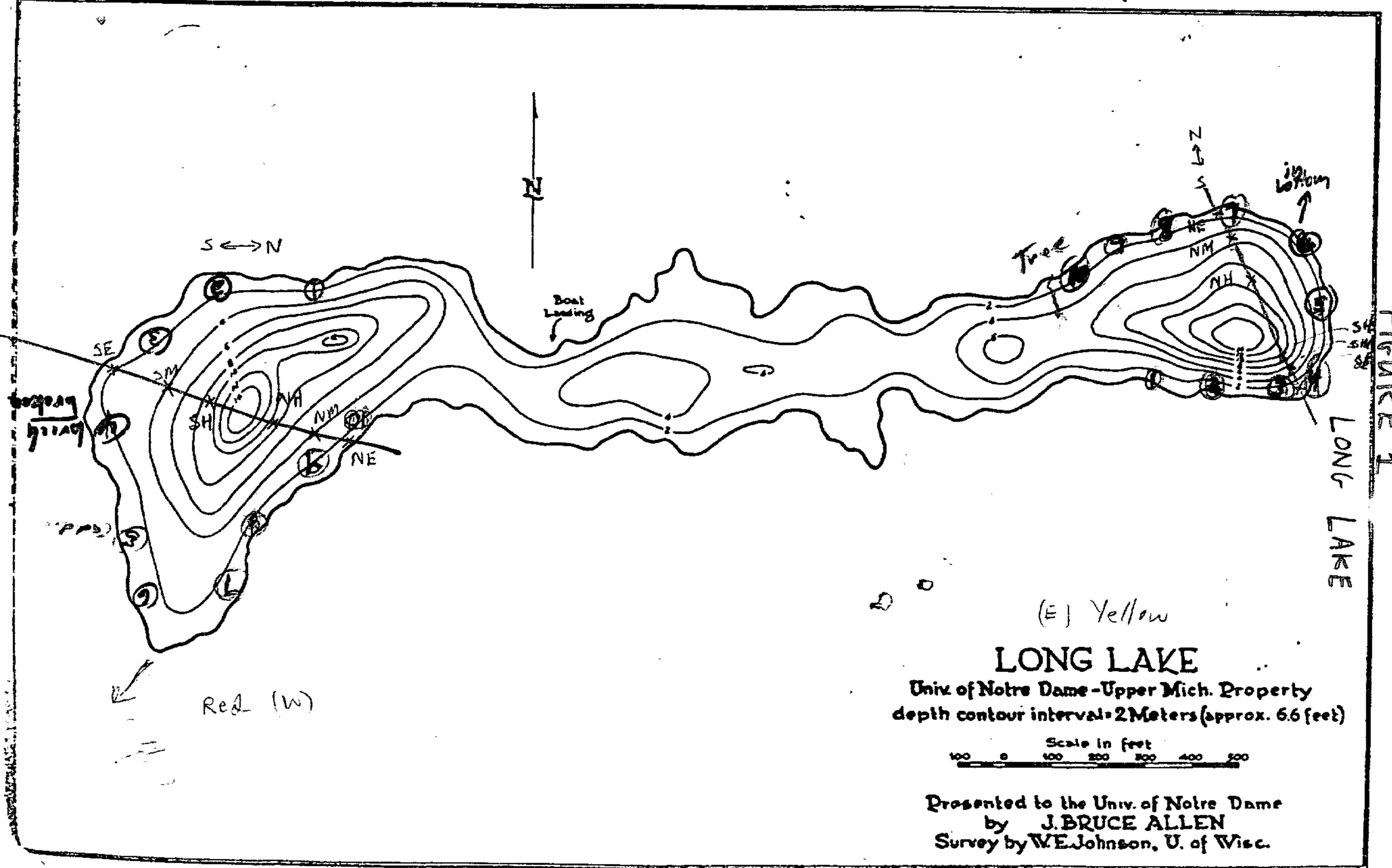
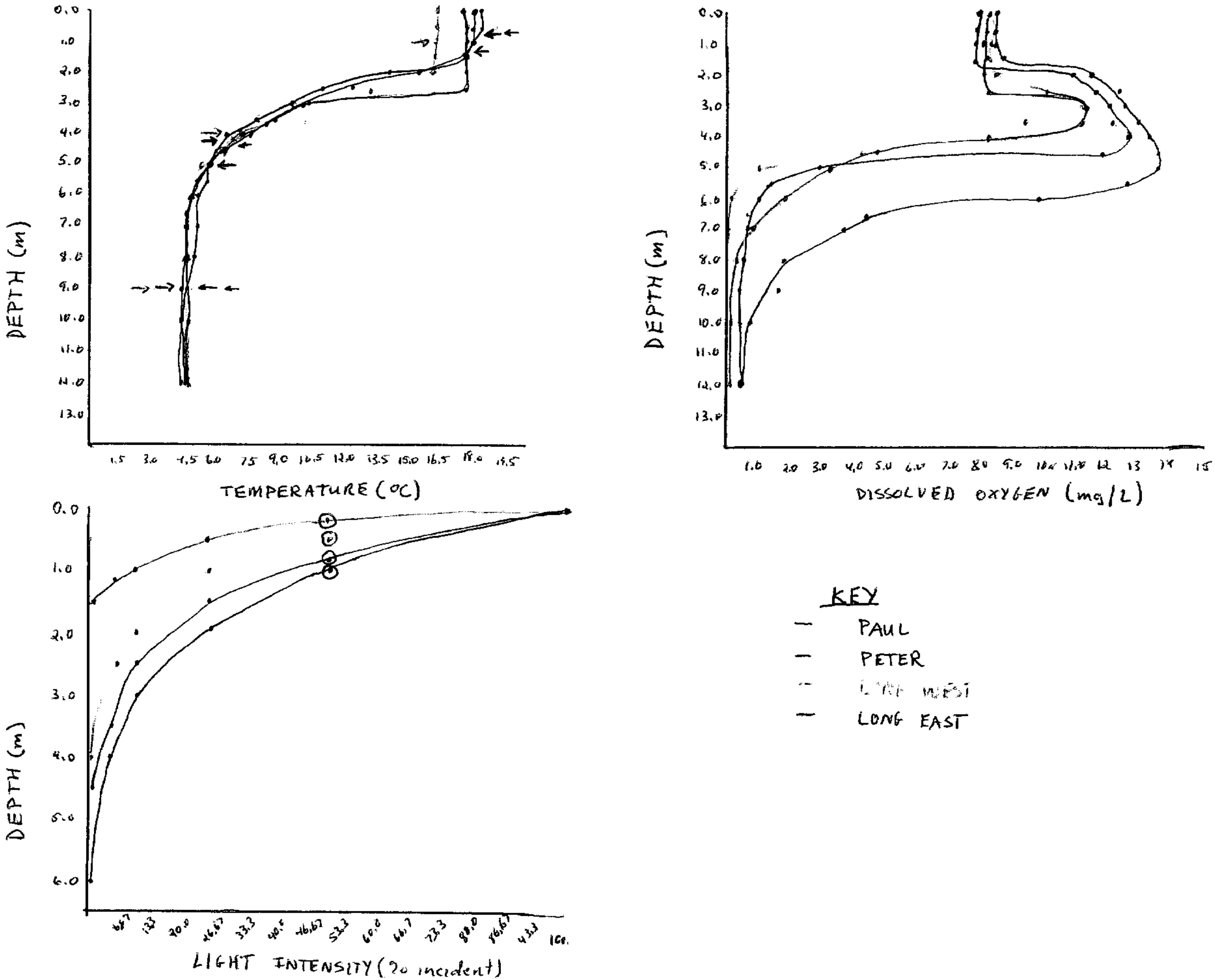


FIGURE 1
LONG LAKE
N
S ⟷ N
Boat Landing
Tree
in bottom
SE
SM
SH
NH
NM
NE
Red (W)
(E) Yellow
LONG LAKE
Univ. of Notre Dame-Upper Mich. Property
depth contour interval: 2 Meters (approx. 6.6 feet)
Scale in feet
100 0 100 200 300 400 500
Presented to the Univ. of Notre Dame
by J. BRUCE ALLEN
Survey by W.E. Johnson, U. of Wisc.

FIGURE 2



DEPTH (m)
TEMPERATURE (°C)
DEPTH (m)
DISSOLVED OXYGEN (mg/L)
DEPTH (m)
LIGHT INTENSITY (% incident)
KEY
PAUL
PETER
LONG EAST

FIGURE ?

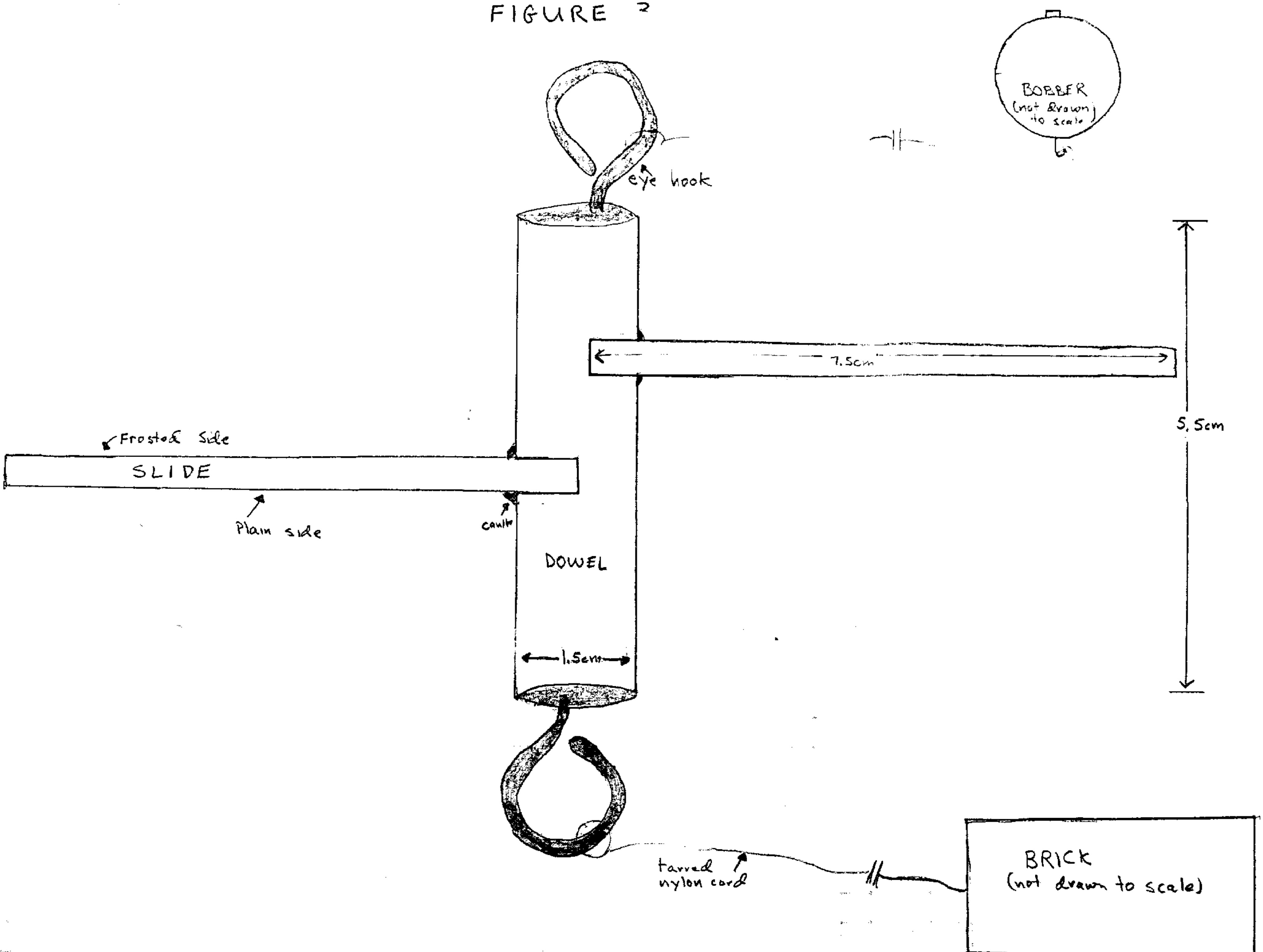

BOBBER
(not drawn to scale)
eye hook
7.5cm
5.5cm
Frosted Side
SLIDE
Plain side
caulk
DOWEL
1.5cm
tarred nylon cord
BRICK
(not drawn to scale)

FIGURE 4

PAUL LAKE

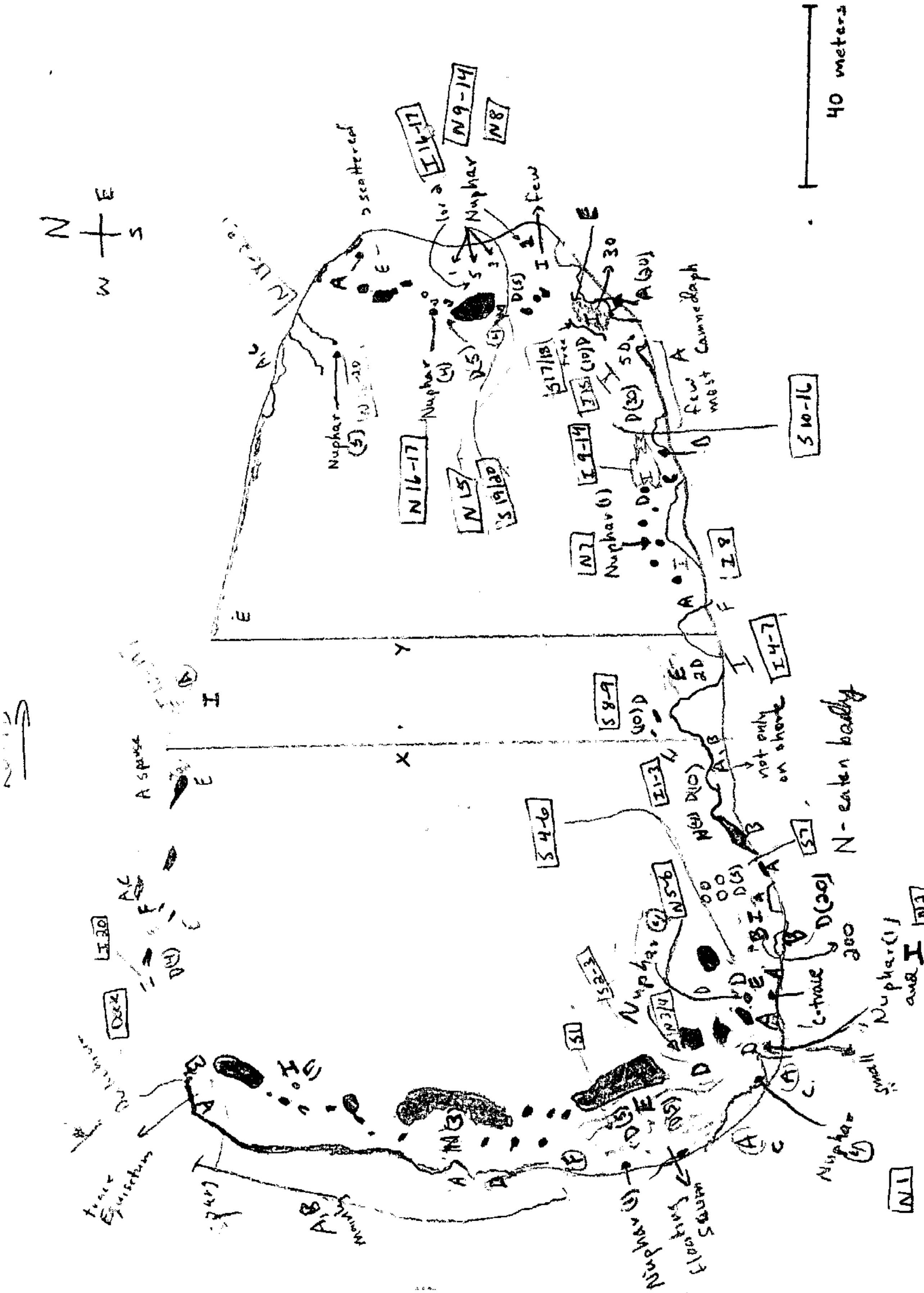


FIGURE 4
PETER LAKE

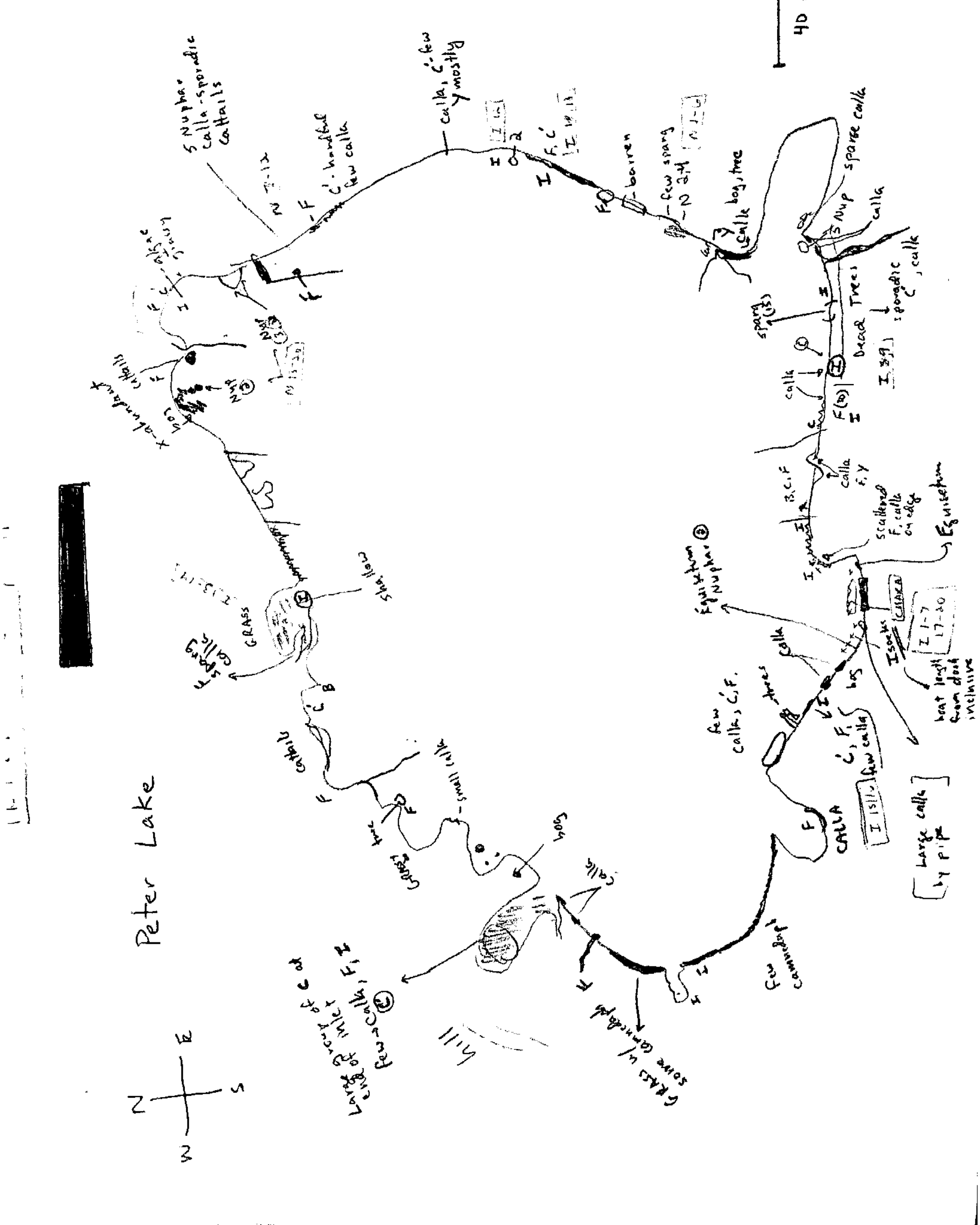


FIGURE 4
LONG WEST

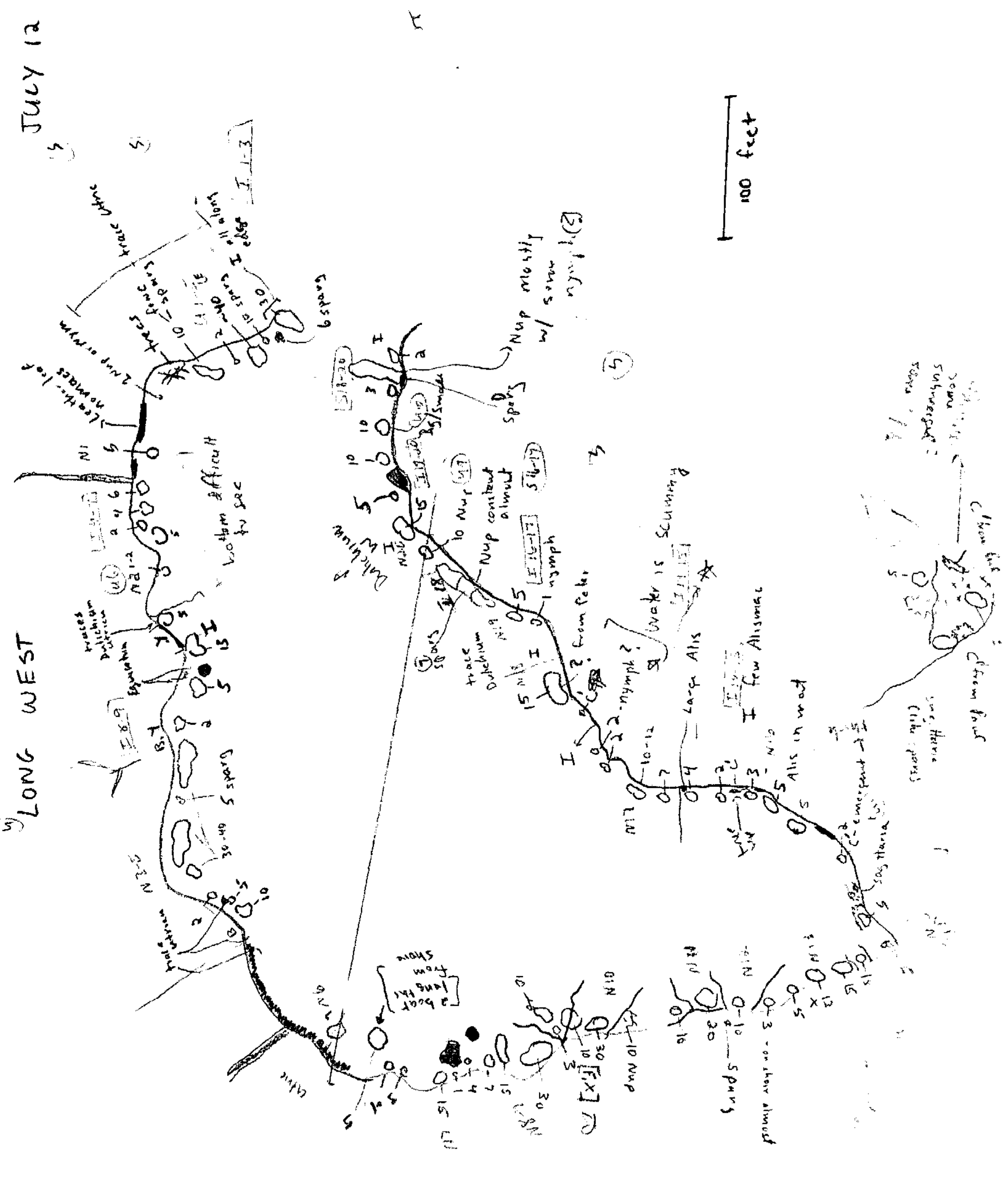


FIGURE 4
LONG EAST

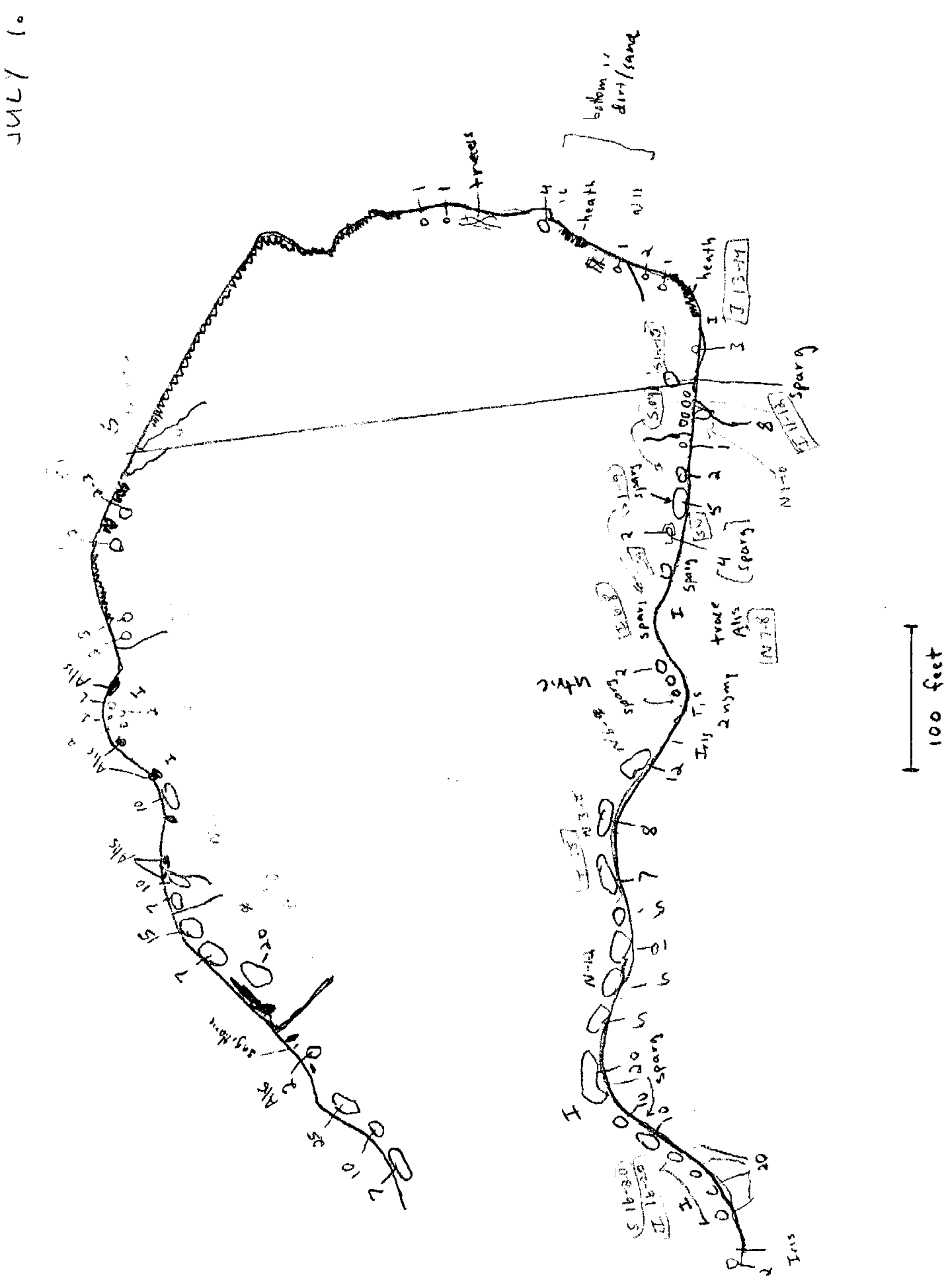


FIGURE 4
LONG LAKE

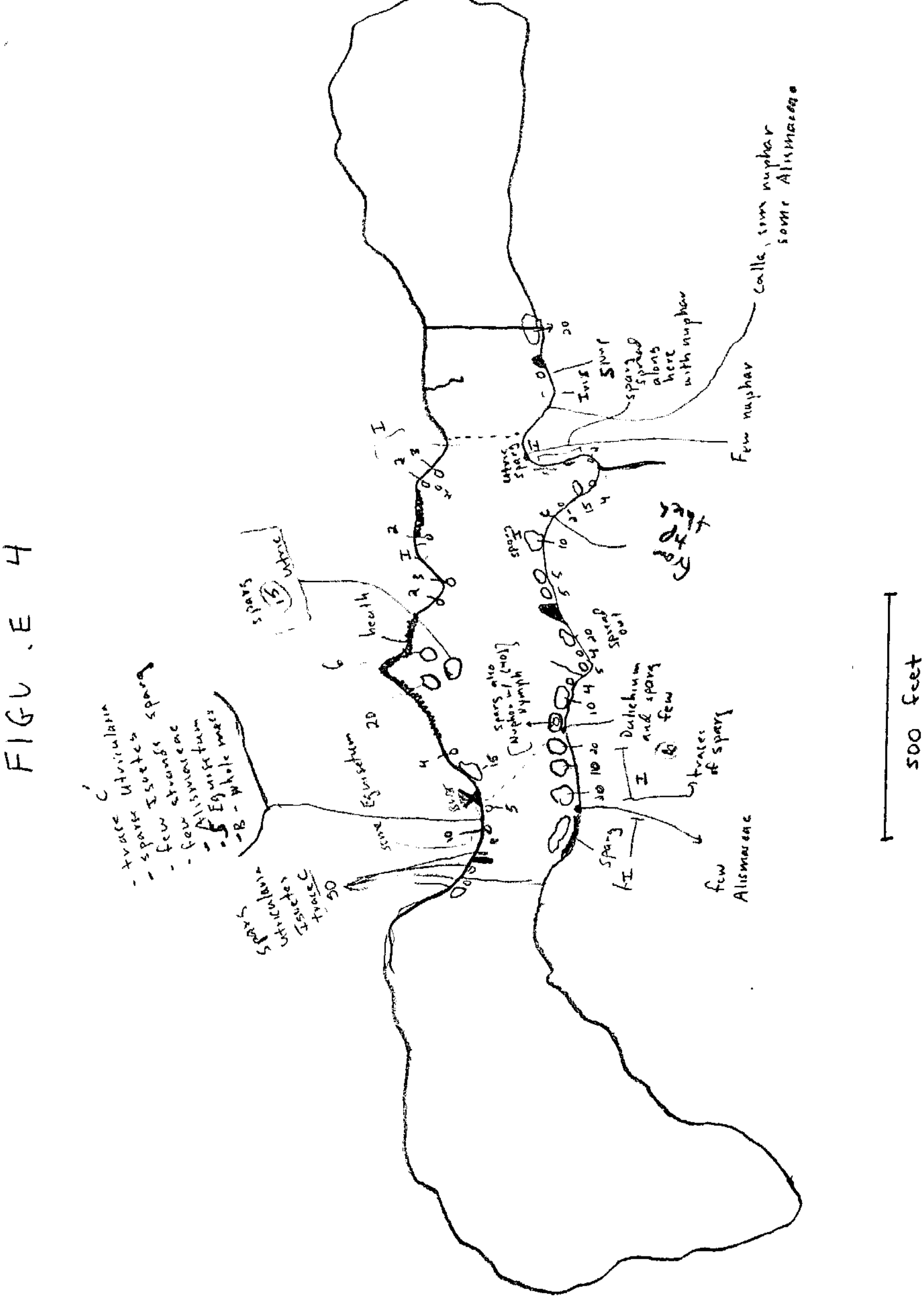


FIGURE 5

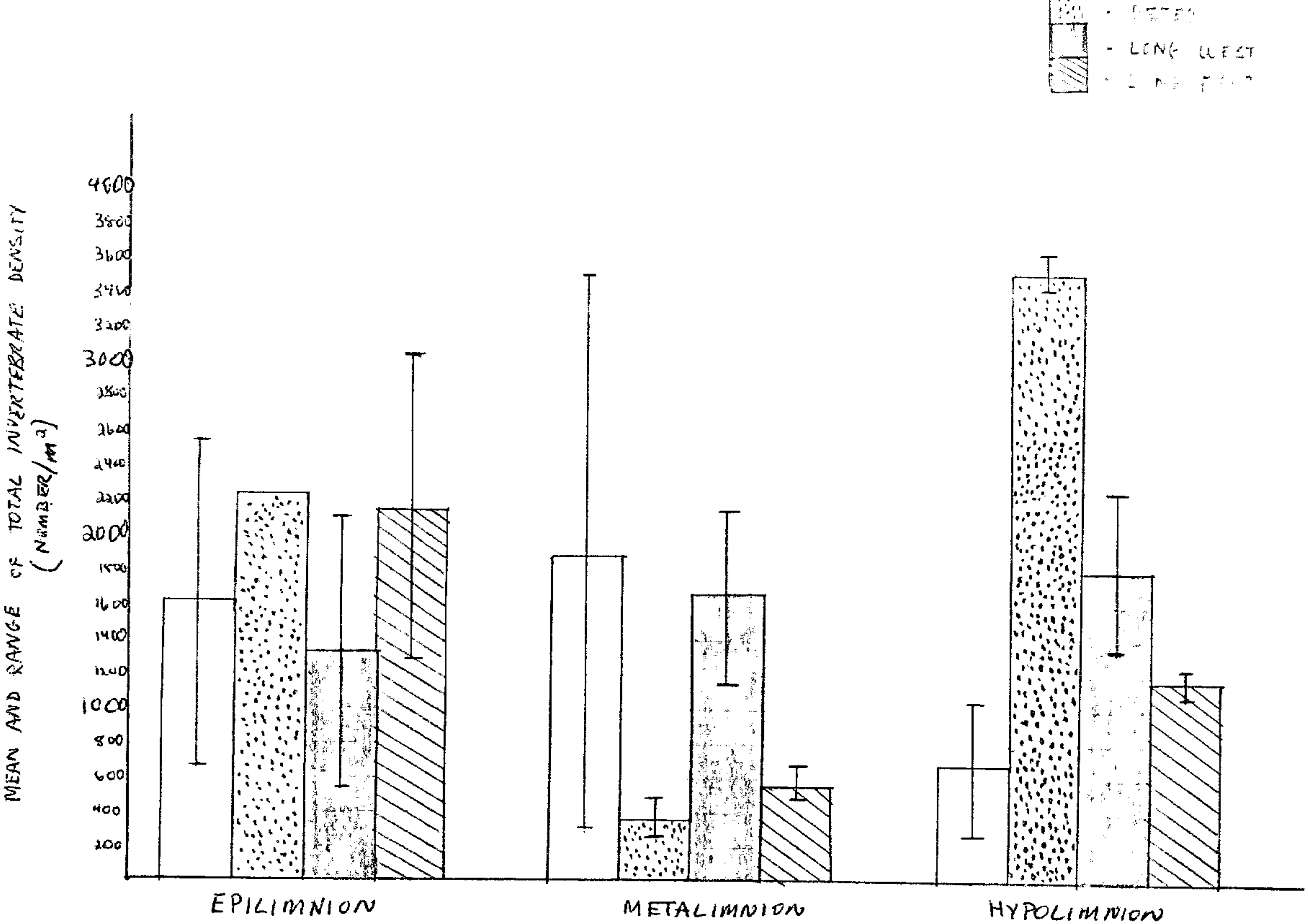

PAUL
LONG WEST
MEAN AND RANGE OF TOTAL INVERTEBRATE DENSITY
(NUMBER/M²)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
EPILIMNION
METALIMNION
HYPOLIMNION

FIGURE 6

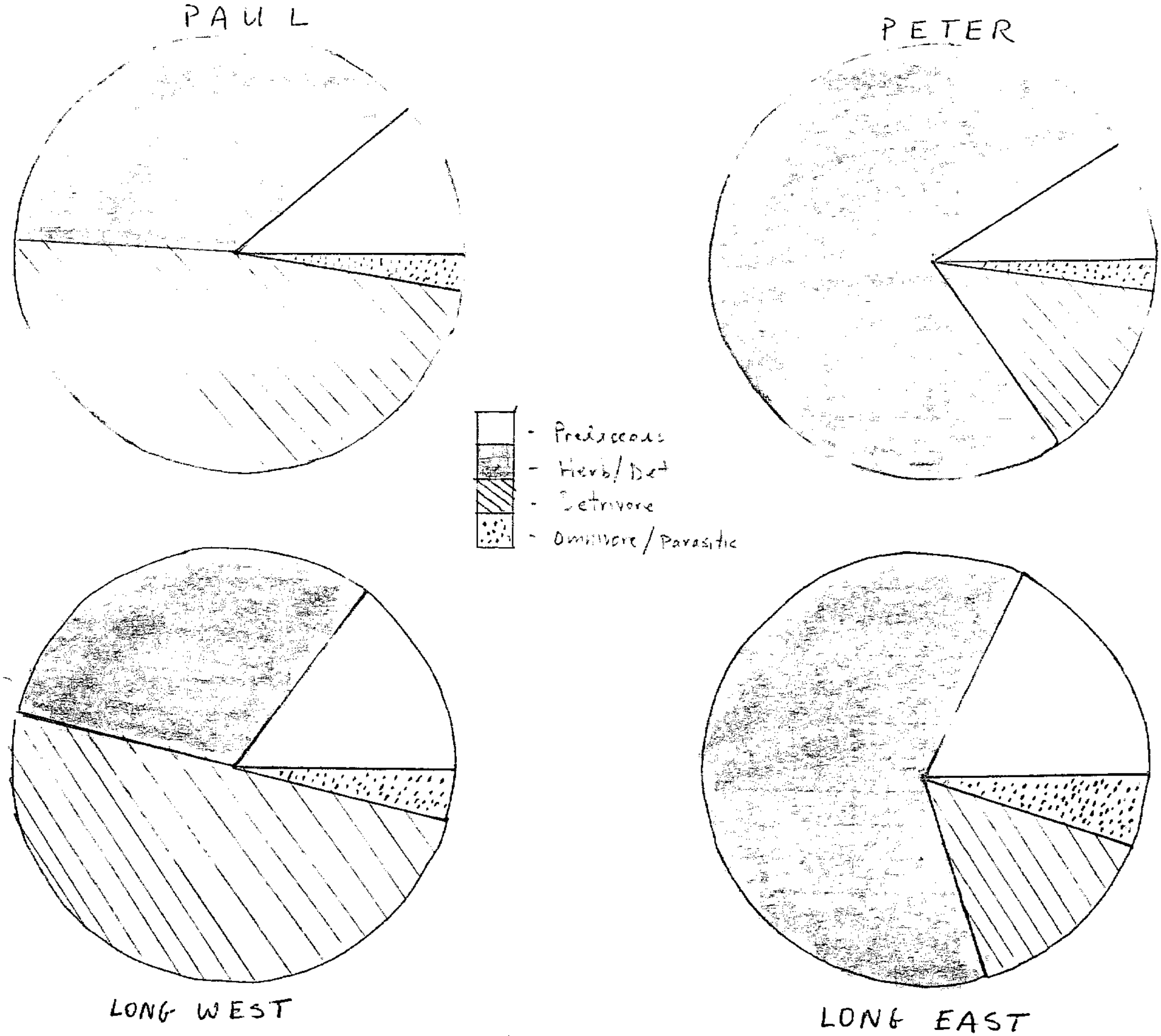

PAUL
PETER
Predaceous
Herb/Det
Detrivore
Omnivore/Parasitic
LONG WEST
LONG EAST

FIGURE 7

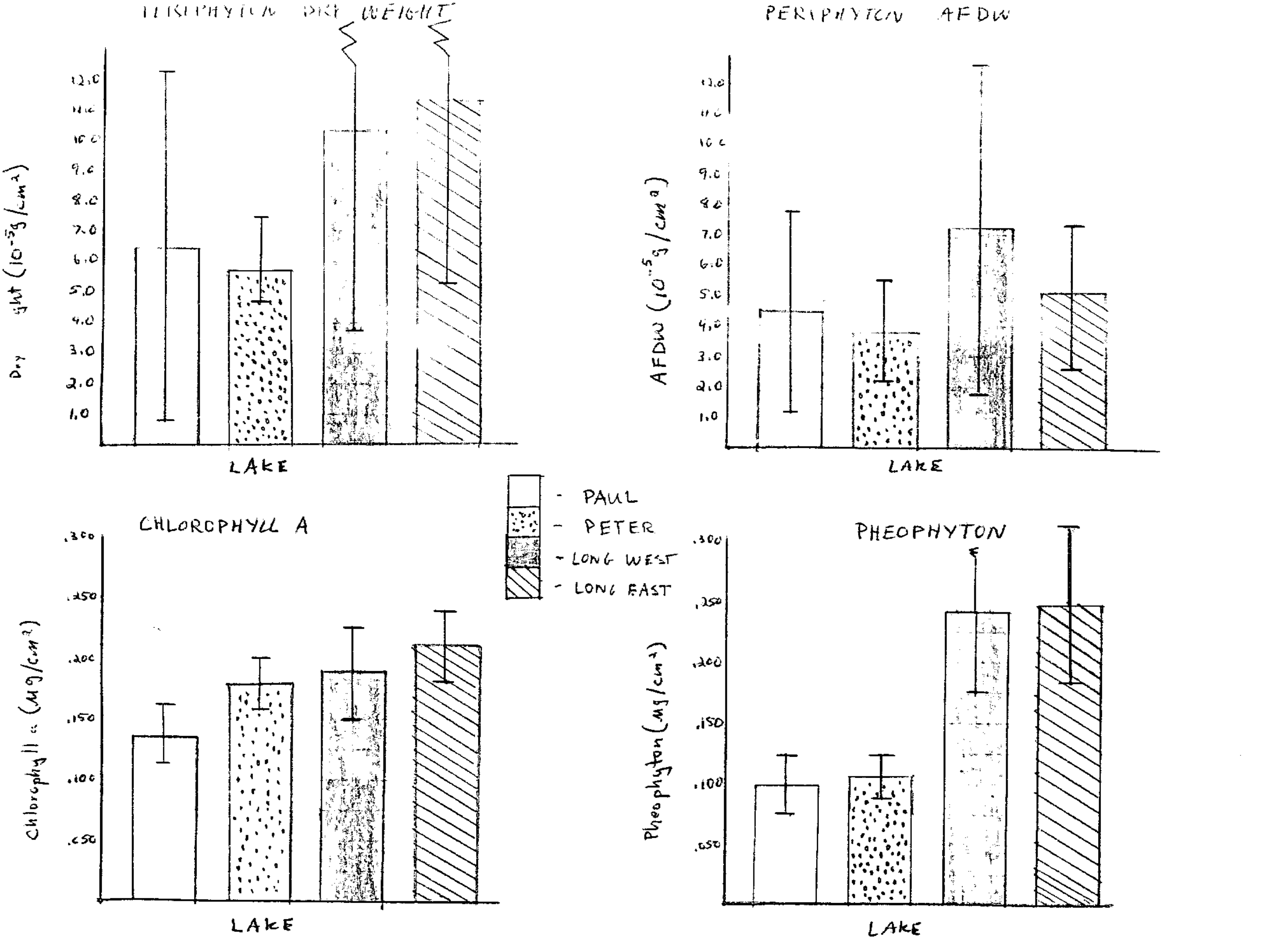
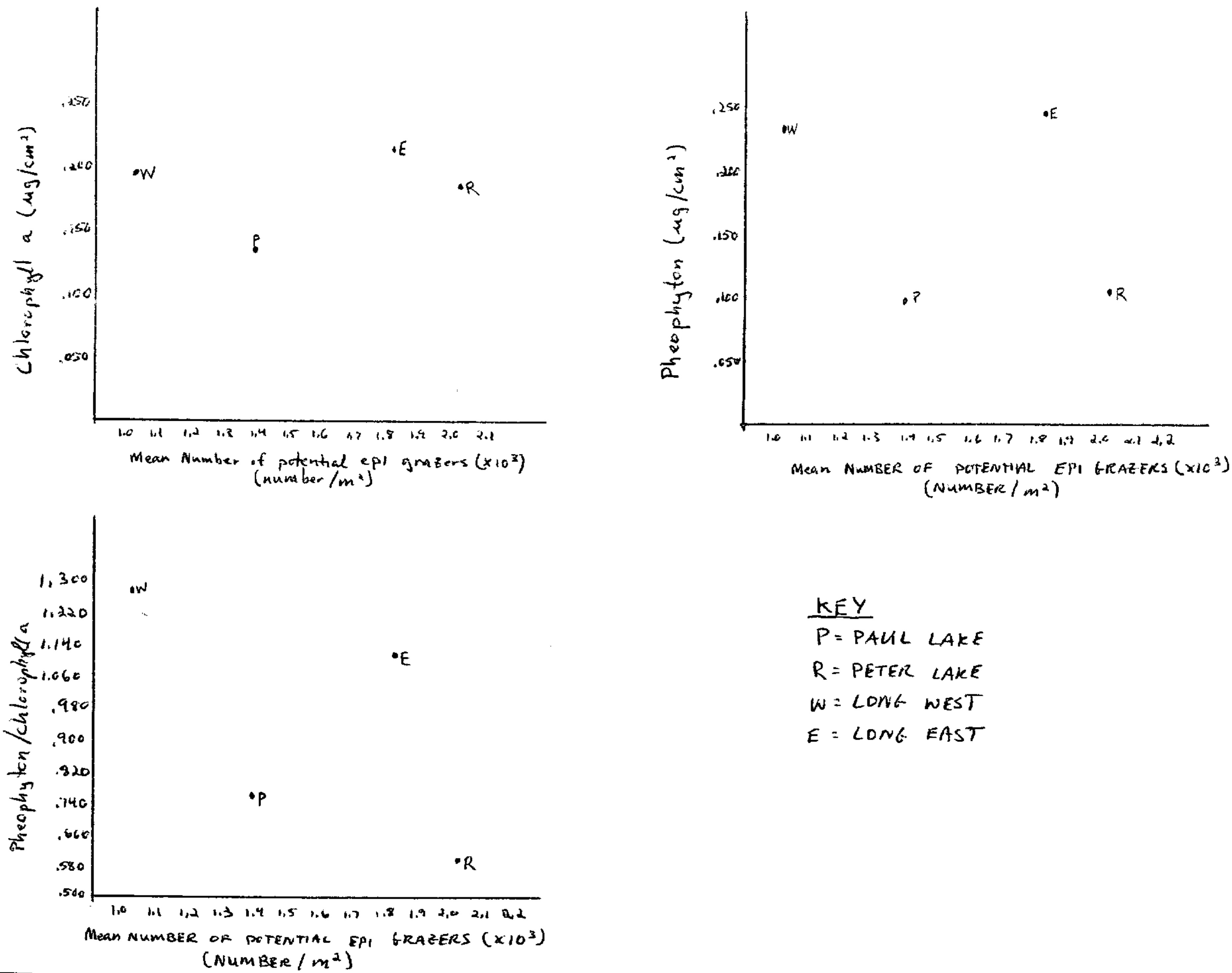

PERIPHYTON DRY WEIGHT
Dry wght (10⁻⁵g/cm²)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
LAKE
PERIPHYTON AFDW
AFDW (10⁻⁵g/cm²)
LAKE
PAUL
PETER
LONG WEST
LONG EAST
CHLOROPHYLL A
Chlorophyll a (Mg/cm²)
.300
.250
.200
.150
.100
.050
LAKE
PHEOPHYTON
Pheophyton (Mg/cm²)
LAKE

FIGURE 8


Chlorophyll a (ug/cm²)
.250
.200
.150
.100
.050
W
P
E
R
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1
Mean Number of potential epi grazers (x10³)
(number/m²)
Pheophyton (ug/cm²)
.250
.200
.150
.100
.050
W
P
E
R
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2
Mean NUMBER OF POTENTIAL EPI GRAZERS (x10³)
(NUMBER/m²)
Pheophyton/chlorophyll a
1,300
1.220
1.140
1.060
.980
.900
.820
.740
.660
.580
.500
W
P
E
R
1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2
Mean NUMBER OF POTENTIAL EPI GRAZERS (x10³)
(NUMBER/m²)
KEY
P = PAUL LAKE
R = PETER LAKE
W = LONG WEST
E = LONG EAST

APPENDIX 1

[redacted]

Lake: Paul   Date: 142 ≈ 22 May 1988   Time: 9:11

Secchi Z (m): 3.5 m   Conditions: Sunny breezy

	Z (m)	Temp (C)	D.O. (mg/L)	Conduct. (umhos)	Light water	scale	deck	scale
100%	0.0	18.3	7.9		1.52	3000	1.42	3000
	.25	—	—		1.27			
	.50	18.3	7.8		.95	1000		
50%	.75	—	—		.79		1.42	
	1.0	18.0	7.7		.65			
	1.5	17.7	7.7		.44			
25% 1.75	2.0	14.0	10.8		2.95	300		
	2.5	10.9	11.5		2.05			
10% 2.7	3.0	9.4	11.9		1.33 1.45		1.55	
5%	3.5	7.7	12.0		.75 .82	100	1.55	
	4.0	6.5	12.5		.15 .46		1.47	
1%	4.5	5.9	11.7		1.60 1.65	30		
	5.0	5.3	2.9		.46 .47	10		
	5.5	5.2	1.4					
	6.0	5.0	1.0					
	7.0	4.9	.6					
	8.0	4.6	.5					
(HYPO)	9.0	4.5	.4					
	10.0	4.4	.4					
	12.0	4.5	.4					

* SEDIMENT TRAPS   4 ?? Conochilus colonies

FIELD PROFILES [redacted]

Lake: Peter Date: 143 Time: 8:18

Secchi Z (m): 3.75m Conditions: Sunny

	Z (m)	Temp (C)	D.O. (mg/L)	Conduct. (umhos)	Light water	Light scale	Light deck	Light scale
100%	0.0	18.0	8.4		1.2	3000	1.05	3000
	.25	—	—		1.05			
	.50	18.0	8.4		.83	1000		
	.75	—	—		.68			
50%	1.0	18.0	8.4		.56			
	1.5	17.8	8.6		.40			
5% 1.9	2.0	15.3	11.4		2.75	300		
	2.5	12.3	12.1		1.95			
% 3.25	3.0	10.3	12.4		1.35			
	3.5	8.1	12.9		1.05			
% 4.25	4.0	7.0	13.1		.69	100		
	4.5	6.2	13.4		.48			
	5.0	5.6	13.4		.32		1.00	3000
	5.5	5.1	12.5		1.65	30		
1%	6.0	4.8	9.7		1.15			
	6.5	4.5	4.4		.59	10		
	7.0	4.5	3.6					
PDI	8.0	4.4	1.8					
	9.0	4.3	1.6					
	10.0	4.3	0.8					
	12.0	4.2	0.4					

FIELD PROFILES

[redacted]c

Lake: LONG, WEST Date: 147 Time: 8:15

Secchi Z (m): 3.0 m Conditions: [illegible] - [illegible], no bugs

	Z (m)	Temp (C)	D.O. (mg/L)	Conduct. (umhos)	Light water	scale	deck	scale
100%	0.0	16.0	8.2		1.2	3000	1.1	3000
	.25	—	—		.82	1000		
50%	.50	16.0	8.4		.57			
25%	.75	—	—		.42			
	1.0	16.0	8.3		.31			
	1.5	15.9	8.2		1.7	300		
10%	2.0	15.9	8.3		1.1			
5%	2.5	13.1	9.9		.6	100		
	3.0	9.3	11.1		.37			
	3.5	7.7	9.4		2.1	30		
1%	4.0	6.9	8.1		1.5	30		
	4.5	6.1	4.3		.67	10		
	5.0	5.2	1.0					
	6.0	5.0	0.2					
	7.0	4.8	0.1					
[illegible]	8.0	4.7	0.0					
	10.0	4.6	0.0					
	12.0	4.6	0.0					

FIELD PROFILES [redacted]

Lake: LONG-EAST   Date: 146   9.50   Time: 8:45

Secchi Z (m): 2.25   Conditions: Shitty - rainy, cloudy WIND

	Z (m)	Temp (C)	D.O. (mg/L)	Conduct. (umhos)	Light water	scale	deck	scale
100%	0.0	17.4	8.2		.50	1000	.37	1000
50%	.25	—	—		1.7	300	.39	
25%	.50	17.6	8.1		1.1 .97	300	.42 .88	
	.75	—	—		.95 .89	300	.42	
10%	1.0	17.6	8.0		.52 .46	100	.42	
5% 1.2	1.5	17.6	8.1		1.5 .63	30	.42	
1% 1.6	2.0	17.6	8.0	1.75m →	1.0	3	.43	
	2.5	17.6	8.1					
	3.0	10.1	11.4					
	3.5	8.2	11.2					
	4.0	7.0	8.1					
	4.5	6.2	4.6					
	5.0	5.6	3.1					
	6.0	4.8	1.9 AM					
	7.0	4.5	.8					
	8.0	4.4	.4 AMD					
	10.0	4.4	.2					
	12.0	4.5	.1					

APPENDIX 2

PAUL LAKE

LOC	DEPTH	COL	SEP	ODONATA Anisoptera Libellulidae *Ladona*	DIPTERA CHIRONOMIDAE	DIPTERA CHAOBORIDAE	DIPTERA CERATOPOGONIDAE	TRICHOPTERA	
N	EPI 0.75m	6-13	6-15	1	13			case	
S	EPI 0.75m	6-13	6-15		49		1	2	TRI- Leptoceridae Nectopsyche WORM - 1
N	META 4.2m	6-13	6-16		6		1 Serromyia	2 unique cases	
S	META 4.2	6-13	6-16		27	1	6	1	Polycentropodidae Polycentropus WORMS - 37 Mite - 1
N	HYPO 9.0	6-13	6-15		1	5 Chaoborus			
S	HYPO 9.0	6-13	6-16		17	5			

nnak 1953

WORMS - Pleisiopora NAIDIDAE *Naidium breviseta*
MITE - HYDRACARINA Diplodontidae *Diplodontus despiciens*

LOC	PETER LAKE DEPTH	COL	SEP	ODANATA ANISOPTERA Libellulidae Ladona	CHIRONOMIDAE	CHAOBORIDAE	CERATOPOGONIDAE	TRICHOPTERA	
N	EPI .75m	6-13	6-16	1	38			case 2 - Limnephilidae Limnephilus 2 - Molannidae	1 - Gastropod Gyraulus parvus 3 - Ephemerop Caenidae/Caenis
S	EPI 2.0m	6-13	6-15		45			2 - Limni Limn	
N	META 4.25m	6-13	6-15		5			① case ① Polycentropodidae Phylocentropus	
S	META 4.25m	6-13	6-16		10			3 cases	
N	HYPO 9.0m	6-13	6-16		63	13 Chaoborus			
S	HYPO 9.0m	6-13	6-15		70	2 Chaoborus			

N - EPI Ephemeroptera 3 - Caenidae *Caenis*
Gastropoda 1 - *Gyraulus parvus*

LUNG WEST

LOC	DEPTH	CCL	SFP	ODONATA	CHIRONOMIDAE	CHAOBORIDAE	TRICHOPTERA	
N	EPI 1.00m	6-12	6-13		36		2 - Lm	1/1 - Ceratopogonidae 2/2 - Worms
S	EPI 1.00m	6-13	6-14	1 Ll	5		1 - Ll 1 - Lp	mik - 1 1 - Ephe worm - 1 1 - Amphipoda Gammarid
N	META 4.0m	6-13	6-14		36	8 Chaoborus	1 - Mm	
S	META 4.0m	6-13	6-13		19	3 Chaoborus		2 - Worms
N	HYPO 9.0m	6-12	6-12		44	3 Chaoborus		
S	HYPO 9.0m	6-12	6-12		25	3 Chaoborus		

TRICHOP LM - Leptoceridae *Mystacides*
Ll - Limnephilidae *Limnephilus / Asynarchus*
Mm - Molannidae *Molanna*

odonata Ll - Libellulidae *Ladona*

Ephem - Ephemeridae *Hexagenia*

Arthropod - Amphipoda Gammaridae

LONG EAST

LOC	DEPTH	COL	SEP	ODONATA	CHIRONOMIDAE	CHAOBORIDAE	TRICHOPTERA	
N	EPI 1.25	6-13	6-14	1 Ce	55		2 Ln 5 Lo	
S	EPI 1.25	6-13	6-14	1 - Ce 1 - Ll	21			2 - Ceratopogonidae 2 - Worms
N	META 5.0	6-13	6-14	1	7	4 chaoborus		
S	META 5.0	6-13	6-13		5	5 Chaoborus		Worms - 3
N	HYPO 9.0m	6-13	6-13		20	5 Chaoborus		Mite - 1
S	HYPO 9.0m	6-13	6-14		21	1 Chaoborus		

Odonata Ce - Corduliidae *Epitheca*
Ll - Libellulidae *Ladona*

Trichop. Ln - Limnephilidae *Nemotaulius*
Lo - Leptoceridae *Oecetis*